Network Applications: Network Programming: UDP, TCP

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https://sngroup.org.cn/courses/cnns-xmuf23/index.shtml

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This deck of slides are heavily based on CPSC 433/533 at Yale University, by courtesy of Dr. Y. Richard Yang.

Outline

- Admin. and recap
- Basic network applications
  - Email
  - DNS
- Java in a Nutshell
- Network application programming

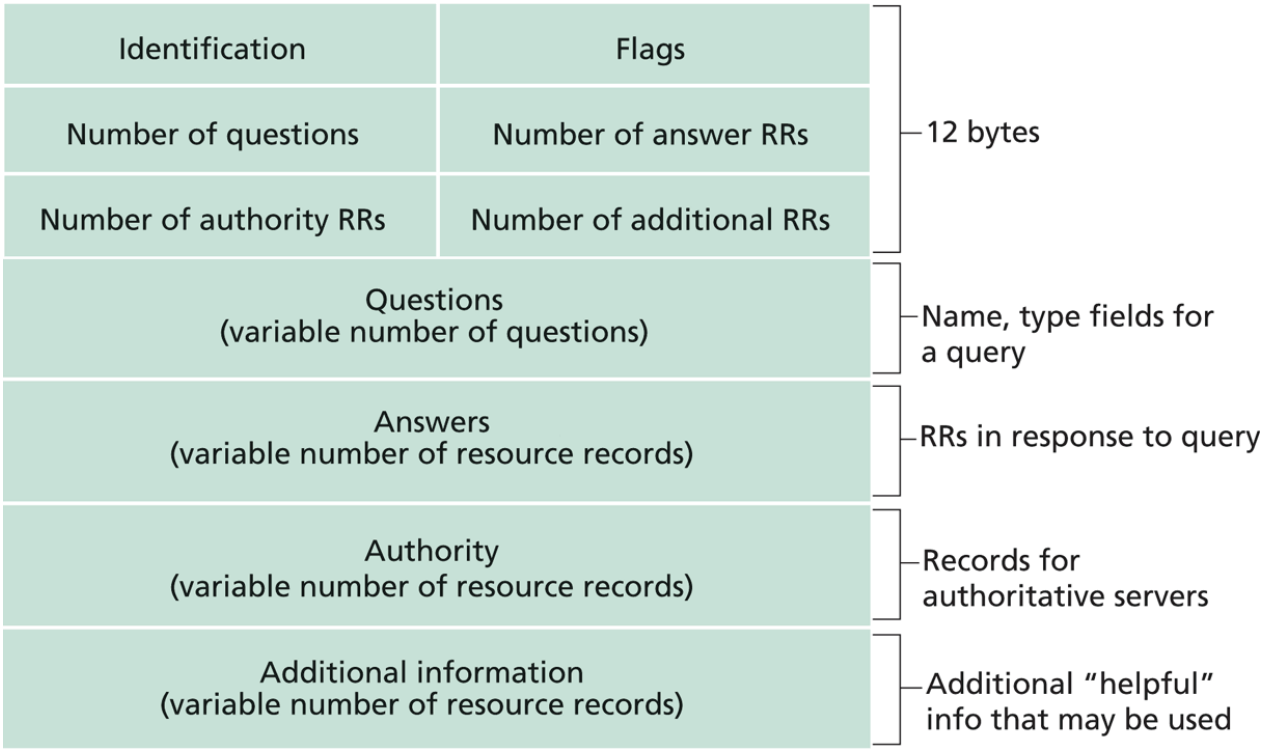
Admin

- Assignment One due today
- Assignment Two linked on the schedule page
  - Oct. 19, in class or by email to the instructor
- A list of potential project topics to be linked on the schedule page next week
  - 2~4 persons per team
  - Talk to the instructor for more details
  - More topics to post soon

https://www.ietf.org/rfc/rfc1035.txt

Recap: DNS Protocol, Messages

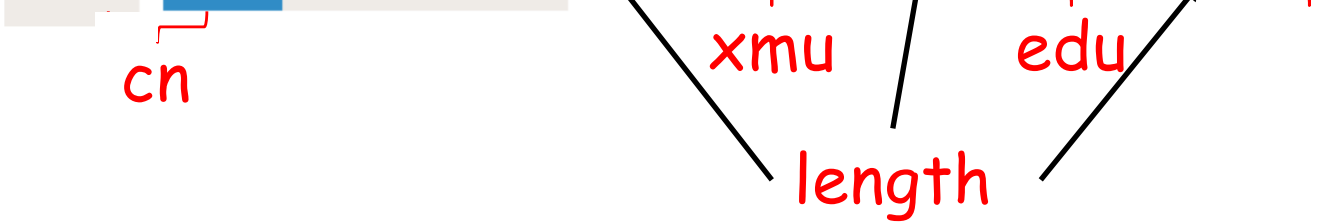
Many features: typically over UDP (can use TCP); *query* and *reply* messages with the same *message format; length/content encoding of names; simple compression; additional info as server push*



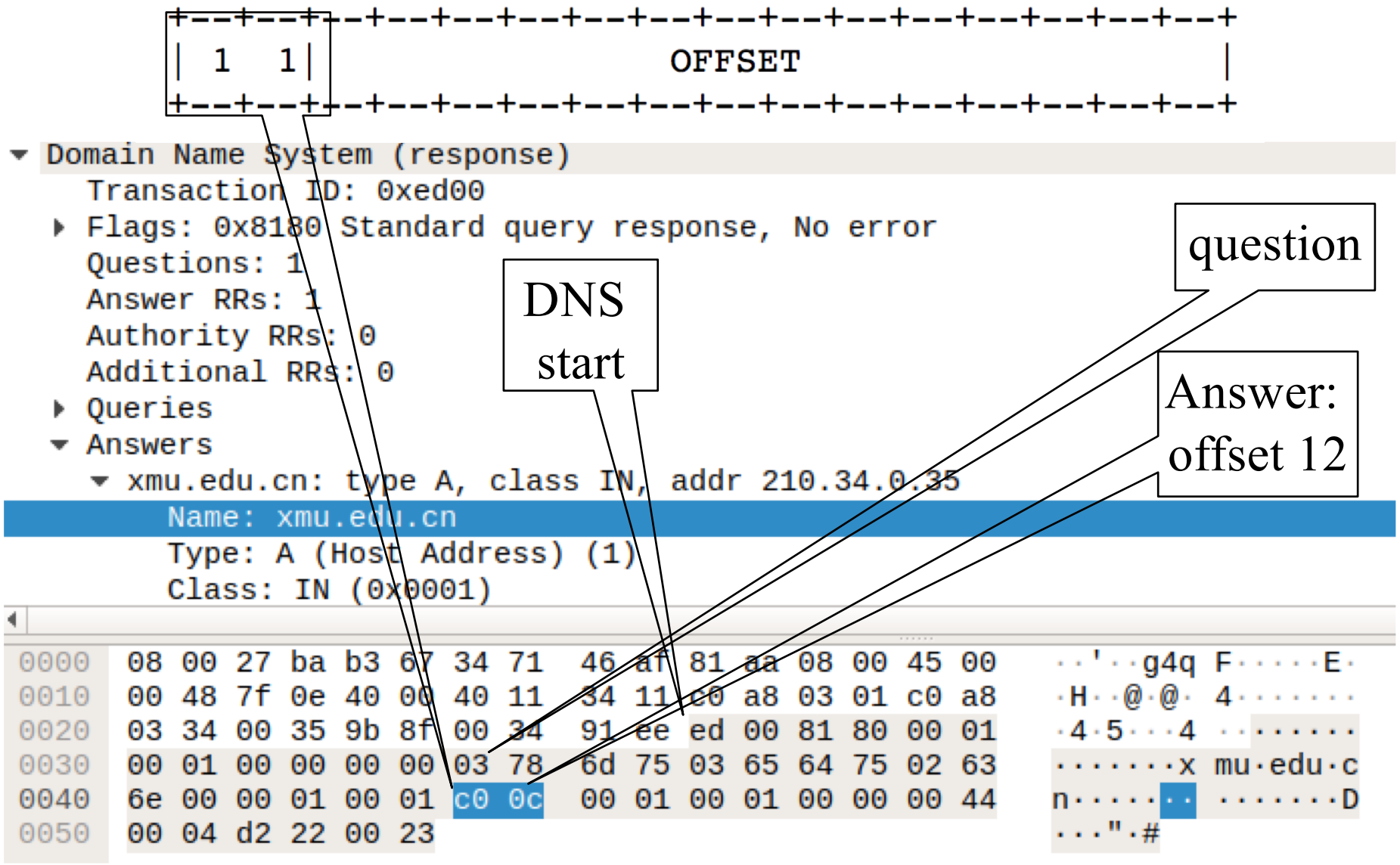
Name Encoding

```
▼ Queries
  ▼ xmu.edu.cn: type A, class IN
      Name: xmu.edu.cn
      [Name Length: 10]
      [Label Count: 3]
      Type: A (Host Address) (1)
      Class: IN (0x0001)
    [Response In: 3]
```

```
0000  34 71 46 af 81 aa 08 00  27 ba b3 67 08 00 45 00   4qF····· '··g··E·
0010  00 38 02 d4 40 00 40 11  b0 5b c0 a8 03 34 c0 a8   ·8··@·@· ·[···4··
0020  03 01 9b 8f 00 35 00 24  87 bb ed 00 01 00 00 01   ·····5·$ ·· ·····
0030  00 00 00 00 00 00 03 78  6d 75 03 65 64 75 02 63   ·····x mu·edu·c
0040  6e 00 00 01 00 01                                 n·····
```



Message Compression (Label Pointer)



What DNS did Right?

- Hierarchical delegation avoids central control, improving manageability and scalability
- Redundant servers improve robustness
  - see http://www.internetnews.com/dev-news/article.php/1486981 for DDoS attack on root servers in Oct. 2002 (9 of the 13 root servers were crippled, but only slowed the network)
- Caching reduces workload and improves robustness
- Proactive answers reduce # queries on server and latency on client

Problems of DNS

- Simple query model, relatively static resource values and types make it harder to implement generic service discovery
  - e.g., service discovery of all printers
  - Although theoretically you can update the values of the records, it is rarely enabled
- Early binding (separation of DNS query from application query) does not work well in mobile, dynamic environments
  - e.g., load balancing, locate the nearest printer
- Each local domain needs servers, but an ad hoc domain may not have a DNS server

Outline

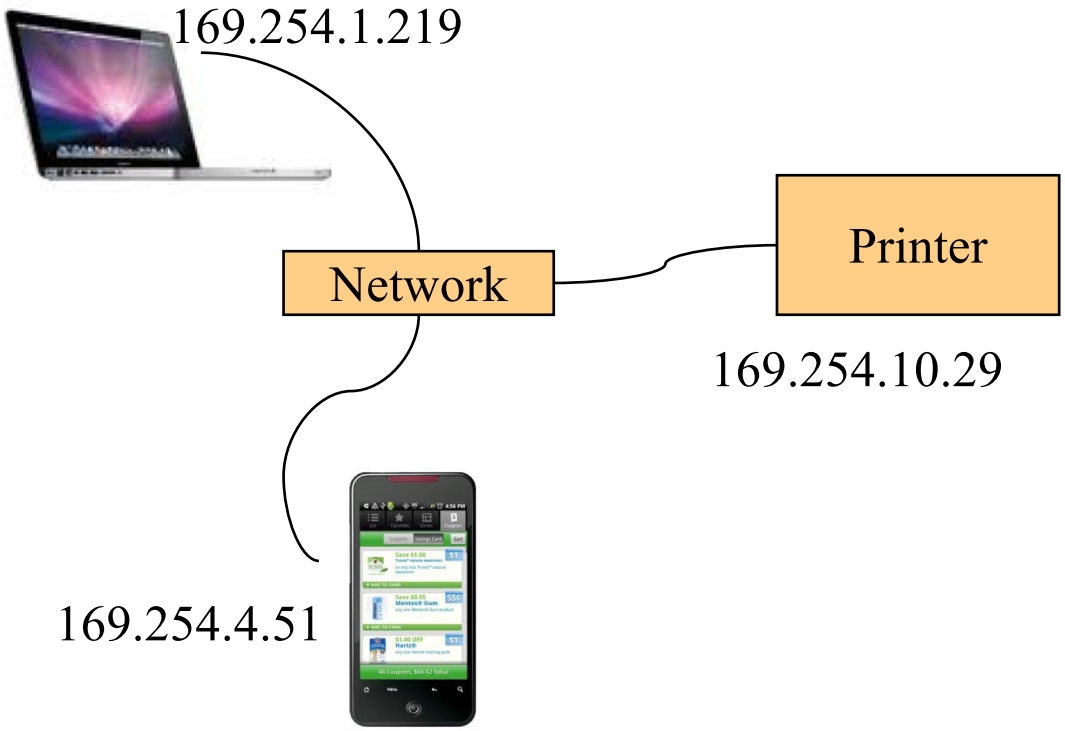
- Admin. and recap
- DNS
  - High-level design
  - Details
  - *Extensions/alternatives*

Discussions

- What extension(s) to standard DNS operations do we need to allow service discovery, say to implement Bonjour (discover all local printers)?
  - each printer needs to provide the following info: host, port, printer info (e.g., support postscript)

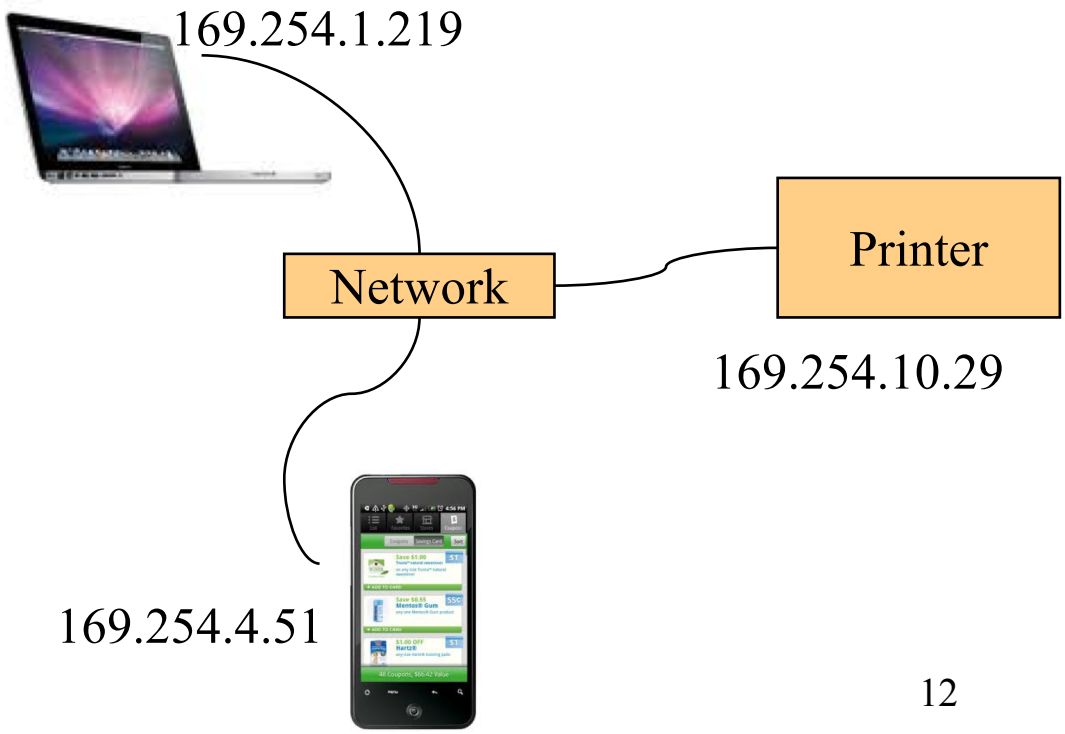
DNS-Service Discovery

- Leverage DNS message format, but each node can announce its own services



Realizing DNS-SD without Central DNS Server: mDNS

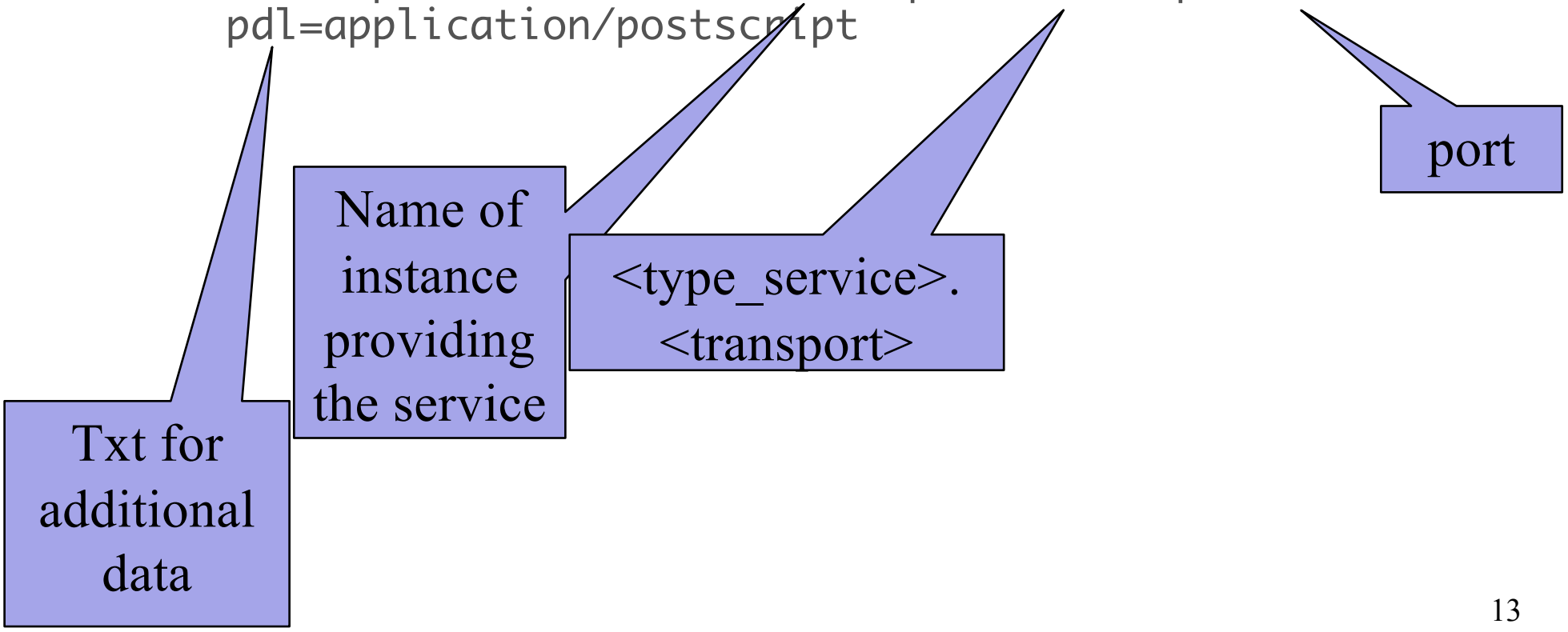
- Multicast in a small world
  - no central address server
    - each node is a responder
  - link-local addressing
    - send to multicast address: 224.0.0.251



Example

- Use the avahi-publish-service command on Ubuntu as example
  - Advertise (register) an LPR printer on port 515

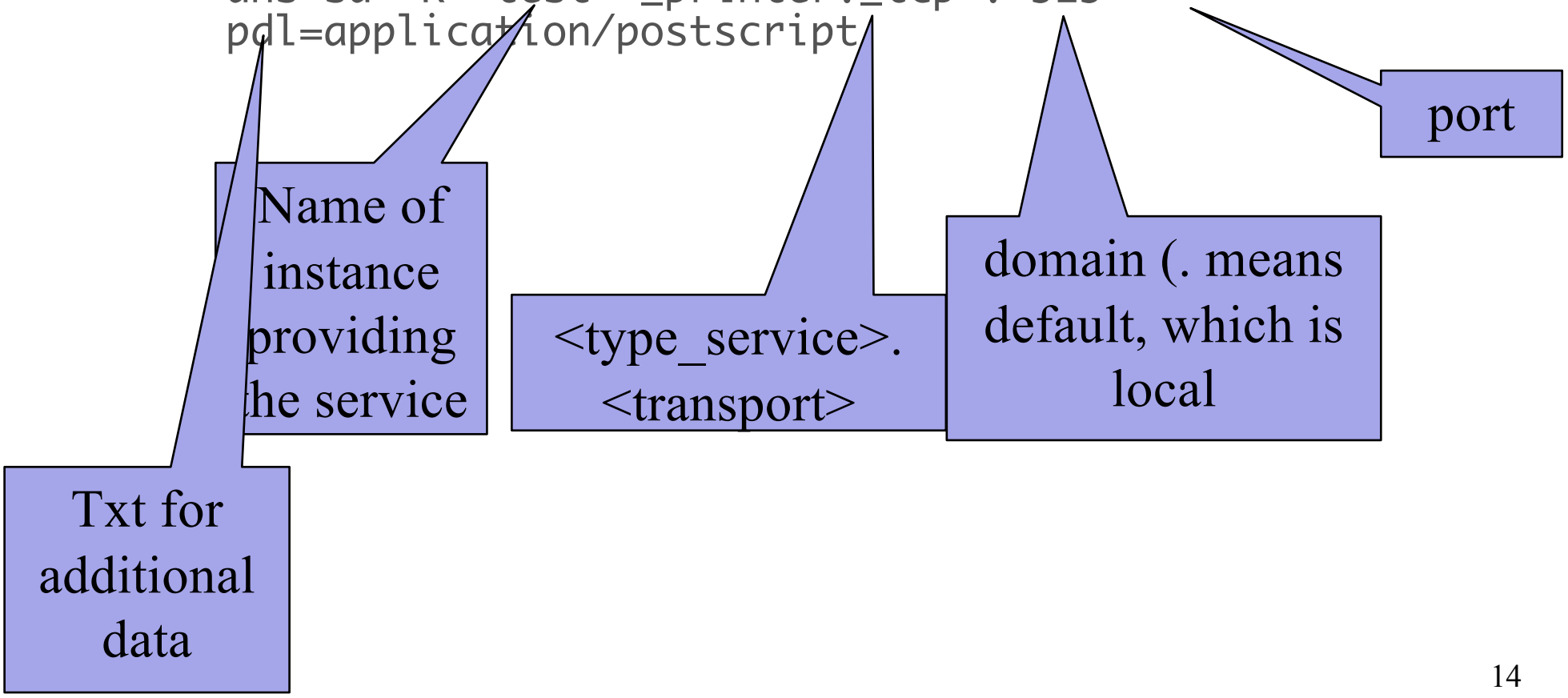
```
avahi-publish-service test _printer._tcp . 515
pdl=application/postscript
```

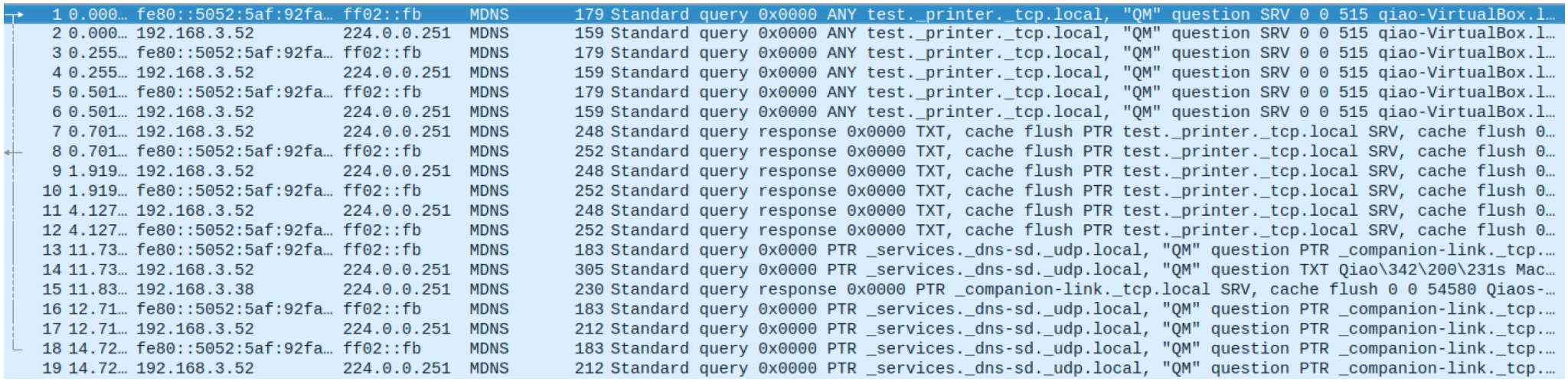


Example

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

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





1	0.000…	fe80::5052:5af:92fa…	ff02::fb	MDNS	179	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
2	0.000…	192.168.3.52	224.0.0.251	MDNS	159	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
3	0.255…	fe80::5052:5af:92fa…	ff02::fb	MDNS	179	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
4	0.255…	192.168.3.52	224.0.0.251	MDNS	159	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
5	0.501…	fe80::5052:5af:92fa…	ff02::fb	MDNS	179	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
6	0.501…	192.168.3.52	224.0.0.251	MDNS	159	Standard query 0x0000 ANY test._printer._tcp.local, "QM" question SRV 0 0 515 qiao-VirtualBox.l…
7	0.701…	192.168.3.52	224.0.0.251	MDNS	248	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
8	0.701…	fe80::5052:5af:92fa…	ff02::fb	MDNS	252	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
9	1.919…	192.168.3.52	224.0.0.251	MDNS	248	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
10	1.919…	fe80::5052:5af:92fa…	ff02::fb	MDNS	252	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
11	4.127…	192.168.3.52	224.0.0.251	MDNS	248	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
12	4.127…	fe80::5052:5af:92fa…	ff02::fb	MDNS	252	Standard query response 0x0000 TXT, cache flush PTR test._printer._tcp.local SRV, cache flush 0…
13	11.73…	fe80::5052:5af:92fa…	ff02::fb	MDNS	183	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question PTR _companion-link._tcp.…
14	11.73…	192.168.3.52	224.0.0.251	MDNS	305	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question TXT Qiao\342\200\231s Mac…
15	11.83…	192.168.3.38	224.0.0.251	MDNS	230	Standard query response 0x0000 PTR _companion-link._tcp.local SRV, cache flush 0 0 54580 Qiaos-…
16	12.71…	fe80::5052:5af:92fa…	ff02::fb	MDNS	183	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question PTR _companion-link._tcp.…
17	12.71…	192.168.3.52	224.0.0.251	MDNS	212	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question PTR _companion-link._tcp.…
18	14.72…	fe80::5052:5af:92fa…	ff02::fb	MDNS	183	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question PTR _companion-link._tcp.…
19	14.72…	192.168.3.52	224.0.0.251	MDNS	212	Standard query 0x0000 PTR _services._dns-sd._udp.local, "QM" question PTR _companion-link._tcp.…

Offline Exercise

- Use the dns-sd /avahi-publish-service command as example
  - Advertise (register) a web page on local machine

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

Issue: How to Query

- Query needs a back pointer, PTR records
- Exercise: Use the dns-sd / avahi-service-publish command as example

  - Browse web pages on local machines

```
dns-sd -B _http._tcp
avahi-browse –rt _http._tcp
```

Network Service Discovery in Android

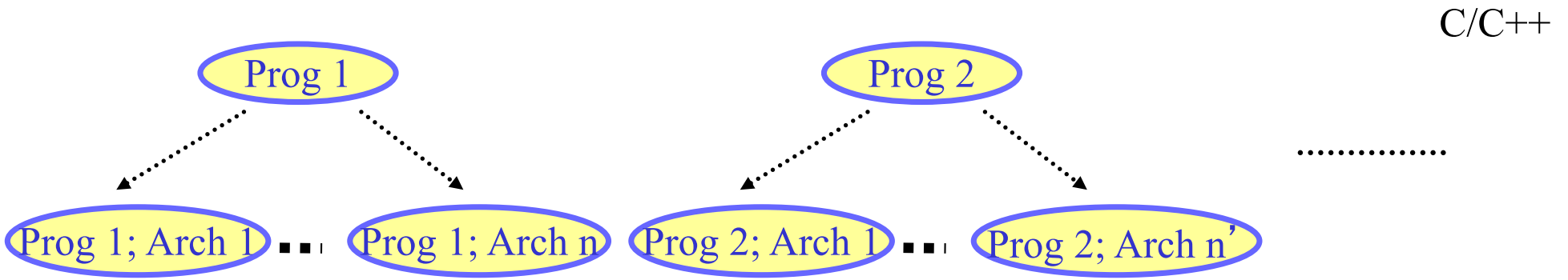
- Based on DNS-SD/mDNS
- Foundation for peer-to-peer/Wi-Fi Direct in Android

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

Outline

- Admin. and recap
- Basic network applications
  - Email
  - DNS
- *Java in a Nutshell*

High-level Picture



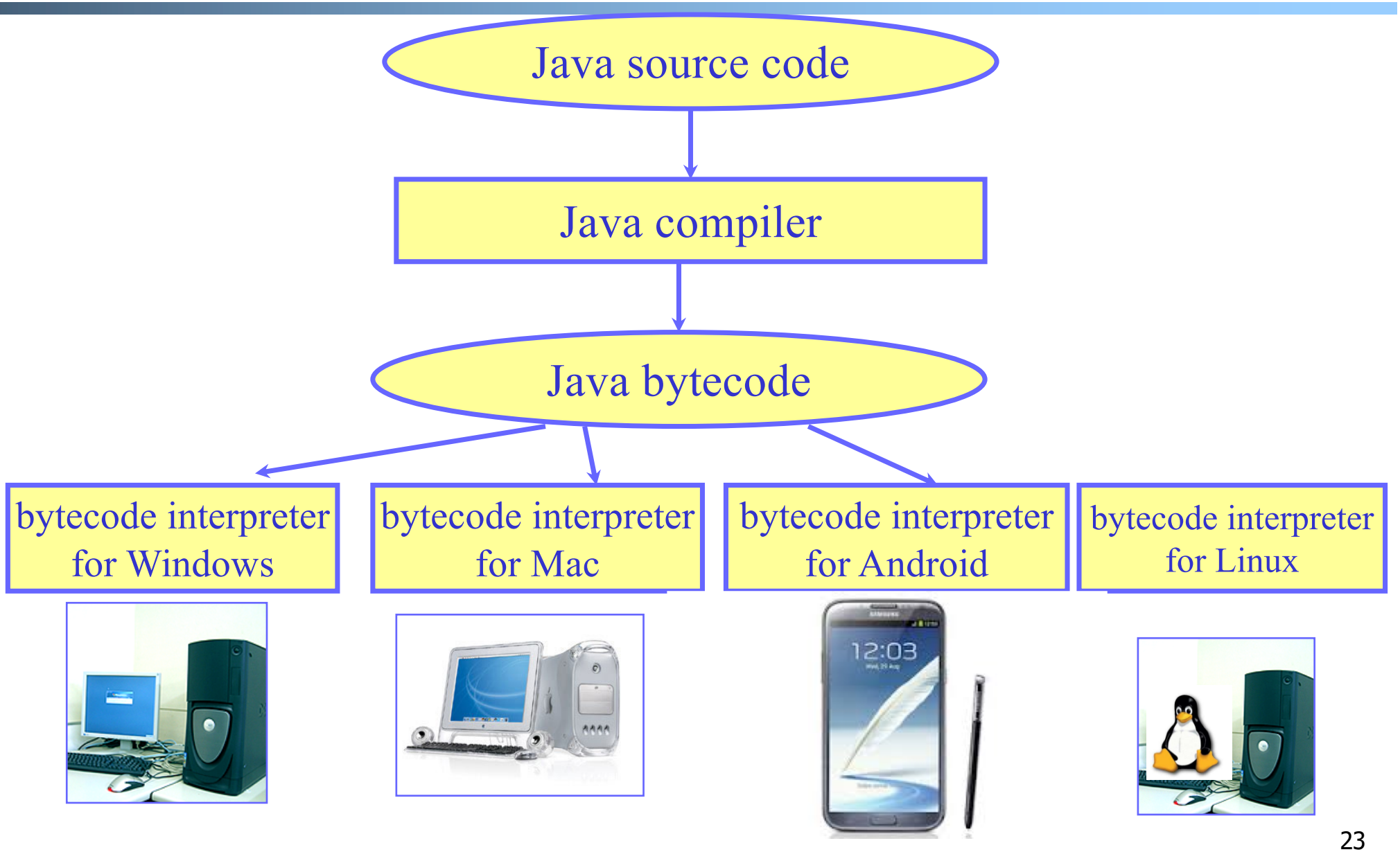
Java Virtual Machine

- To be platform independent, Java designers introduced Java Virtual Machine (JVM), a machine different from any physical platform, but a *virtual machine*
  - The language of the virtual machine is referred to as *bytecode*
  - Thus Java actually has two programming languages
- A Java compiler translates Java source code (.java files) into *bytecode* (in .class files)
  - Each Java software program needs to be compiled only once: from the Java source code to bytecode
- Other languages (e.g., Jruby, Jython, Scala) may also compile to bytecode

Java Execution

- To execute a Java program, another piece of software called an *interpreter*, translates between bytecode and the actual machine
  - an interpreter is specific to a specific platform
  - the interpreter understands java bytecode, and then issues instructions in the specific platform for which it is written
  - we also say that an interpreter provides a java virtual machine (JVM)

Java Translation and Execution



Comparing Traditional (e.g., C/C++) and Java Software Development

Traditional, e.g., C/C++

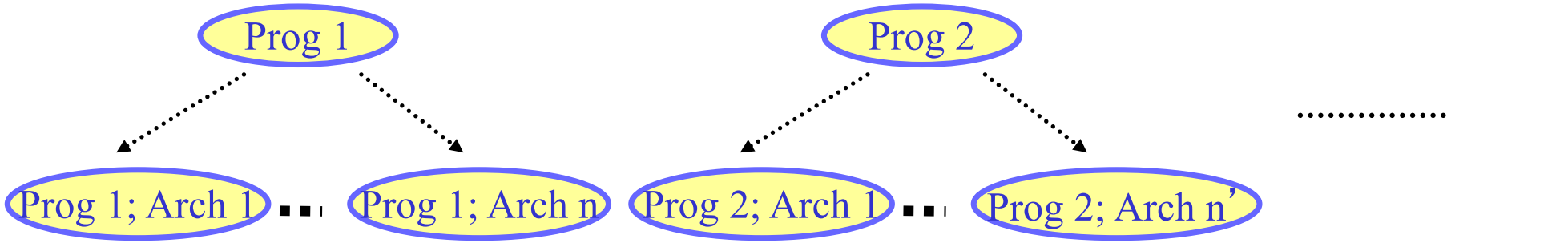
- A developer writes a program in C/C++
- The C/C++ source code is generally considered proprietary, and not released
- The developer compiles the C/C++ program for each platform it intends to support, and distributes one version for each platform
  - thus each program has multiple compiled versions
  - each compiled version can run by itself
- Platform dependency handled by each software developer

Java

- A developer writes a program in Java
- The Java source code is generally considered proprietary, and not released
- The developer compiles the Java program to bytecode, and distributes the bytecode version
  - thus each program has only one compiled version
  - the compiled bytecode needs an interpreter for each platform
- Platform dependency handled by platform vendor

High-level Picture

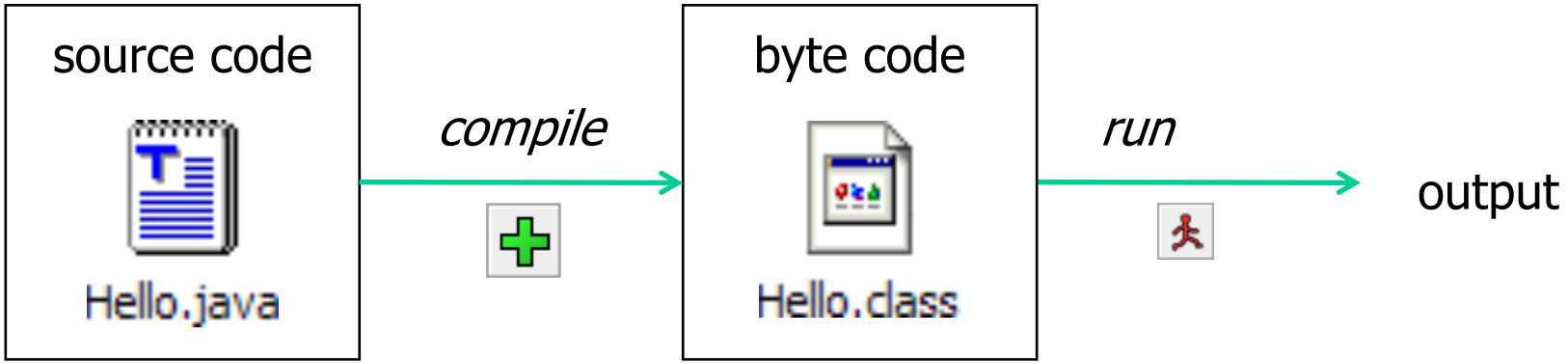
C/C++



Java

Recall: Java Programming Steps

- Programming in Java consists of 3 simple steps
  - Create and edit "Java source code" (.java files)
  - Compile into "Java bytecode" (.class files)
  - Execute bytecode with a "Java interpreter"



Programming in Java (Step 1): Create/Edit

- The basic way is to use a text editor
  - Example editors: vim, sublime, Notepad, TextEdit (Format/Make Plain Text) etc.
    - Note: MS Word is **NOT** a text editor
  - The key is that your .java file ***cannot*** include any markup or stylistic formatting; just text.
  - You enter your Java code following Java Language syntax (more soon).

Programming in Java (Step 2): Compile

- Compile a Java program
  $ javac HelloWorld.java

- Take a look to see that HelloWorld.class is generated
  $ ls
  HelloWorld.java HelloWorld.class

Programming in Java (Step 3): Execute

- Run Java interpreter

  $ java HelloWorld

First Java Program

```
/**************************************
 * Prints "Hello World"
 * Everyone's first Java program.
 **************************************/
public class Hello {
    public static void main(String[] args) {
        System.out.println("Hello, world!");
    }
}
```

Another Java Program

```
public class Hello2 {
    public static void main(String[] args) {
        System.out.println("Hello, world!");
        System.out.println();
        System.out.println("This program produces");
        System.out.println("four lines of output");
    }
}
```

Programming in Java: Method 2

- Another way is to use an Integrated Development Environment (IDE)
  - Example IDEs: Eclipse, IDEA, DrJava, etc.
  - An IDE usually presents the user with a space for text (like an editor) but layers *additional features* on top of the text for the user's benefit.
    - Note: The underlying file contains pure text, just like a text editor.
  - These features can be very useful and save time.
    - Example features are GUI compile, GUI execution, code completion, and syntax highlighting.
  - IDEs take more time to get started than a simple text editor, e.g.,
    - set up where to find the "java" and "javac" programs
    - find out where does the IDE save my file

Java Syntax Structure: A Top-Down View

A class:
- has a name, defined in a file with same name

Convention we follow: capitalize each English word
- starts with {, and ends with }
- includes a group of methods

```
public class <class name> {
    public static void main(String[] args) {
        <statement>;
        <statement>;
        …
        <statement>;
    }
}
```

A method:
- has a name

Convention we follow: lowercase first word, capital following
- starts with {, and ends with }
- includes a group of statements

statement:
- a command to be executed
- end with ;

The `System.out.println` statement

- A statement that prints a line of output on the console.
  - pronounced "print-linn"

- Two ways to use `System.out.println`:
  - `System.out.println(<string>);`

    Prints the given message <string> as output.

  - `System.out.println();`

    Prints a blank line of output.

Java program structure

- A top-down view
- A bottom-up view

Java Syntax: A Bottom-Up View

```
// Comment 1: A Java program
/* Comment 2: a long comment
 ********************************/
public class Hello {
    public static void main(String[] args) {
        System.out.println("Hello, world!");
        System.out.println();
        System.out.println("This program produces");
        System.out.println("four lines of output");
    }
}
```

Java Syntax: A Bottom-Up View

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        System.out.println();
        System.out.println("This program produces");
        System.out.println("four lines of output");
    }
}
```

- Basic Java syntax units
  - white space and comments
  - identifiers (words)
  - symbols: { } " ( ) < > [ ] ; = …
  - strings
  - numbers

Syntax: White Space

- White space
  - includes spaces, new line characters, tabs
  - white space is used to separate other entities
  - extra white space is ignored

- White space allows a Java program to be formatted in many ways, and should be formatted to enhance readability
  - the usage of white space forms part of programming style

Syntax: Comments

- **comment**: A note written in source code by the programmer to describe or clarify the code.
  - Comments are ignored by the compiler
  - Useful for other people (and yourself!) to understand your code

- Two types of comments in Java
  - single-line comments use `//…`

```
// this comment runs to the end of the line
```

  - multi-lines comments use `/* … */`

```
/*  this is a very long
    multi-line comment */
```

Syntax: Identifier

- **Identifier**: A name given to an item in a program.

- Syntax requirement on identifier:
  - must start with a letter or _ or $
  - subsequent characters can be any of those or a number
  - Important: Java is case sensitive:
    - Hello and hello are different identifiers

Three Types of Identifiers

1. Identifiers chosen by ourselves when writing a program (such as `HelloWorld`)

2. Identifiers chosen by another programmer, so we use the identifiers that they chose (e.g., `System`, `out`, `println`, `main`)

```
public class HelloWorld
{
    public static void main(String[] args)
    {
        System.out.println("Hello World!");
    }
}
```

Three Types of Identifiers

3. Special identifiers called *keywords* or *reserved words:*
   A keyword has a special meaning in Java.

abstract	default	if	private	this
boolean	do	implements	protected	throw
break	double	import	**public**	throws
byte	else	instanceof	return	transient
case	extends	int	short	try
catch	final	interface	**static**	**void**
char	finally	long	strictfp	volatile
class	float	native	super	while
const	for	new	switch	
continue	goto	package	synchronized	

Java reserved words: they are all **lowercase!**

Syntax: Strings

- **string**: A sequence of characters that starts and ends with a " (quotation mark character).
  - The quotes do not appear in the output.
  - Examples:

```
"hello"
"This is a string.  It is very long!”
```

- Restrictions:
  - May not span multiple lines

```
"This is not
a legal String."
```

Examples

- Which of the following are legal strings in Java?
  - `"This is a string.  It's very long!"`
  - `"This cool string spans`
    `two lines. "`
  - `"It is a great thing when children cry, "I want my mommy"! "`

Escape Sequences

- **escape sequence**: A special sequence of characters used to represent certain special characters in a string.

`\b`	backspace
`\t`	tab character
`\n`	new line character
`\"`	quotation mark character
`\\`	backslash character

  - Example:
```
System.out.println("\\hello\nhow\tare \"you\"?\\\\");
```
  - Output:
```
\hello
how     are "you"?\\
```

Comment on syntax errors

- **A syntax/compile error**: A problem in the structure of a program that causes the compiler to fail, e.g.,
  - Missing semicolon
  - Too many or too few { } braces
  - Class and file names do not match
  - …
- Compilers can't (DO not) read minds.
- Compilers don't make mistakes.
- If the program is not doing what you want, do NOT blame the computer---it's **YOU** who made a mistake.

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- Java in a Nutshell
- *Network application programming*

Socket Programming

Socket API

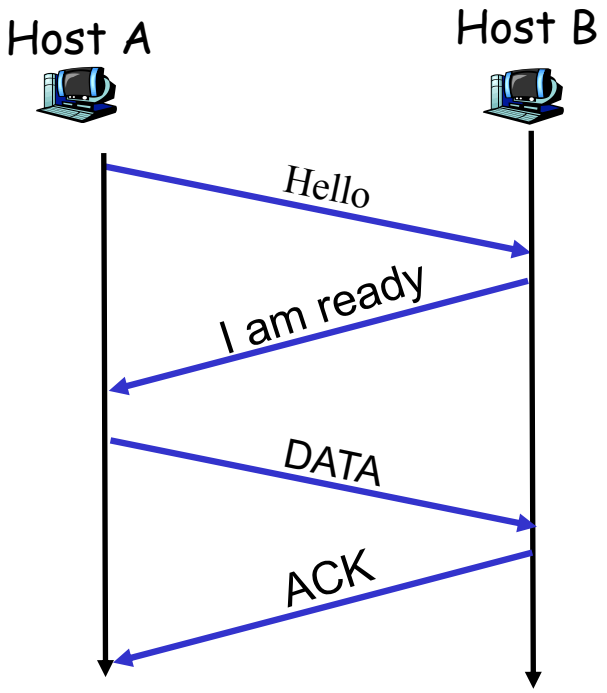
- introduced in BSD4.1 UNIX, 1981
- Two types of sockets
  - connectionless (UDP)
  - connection-oriented (TCP)

socket

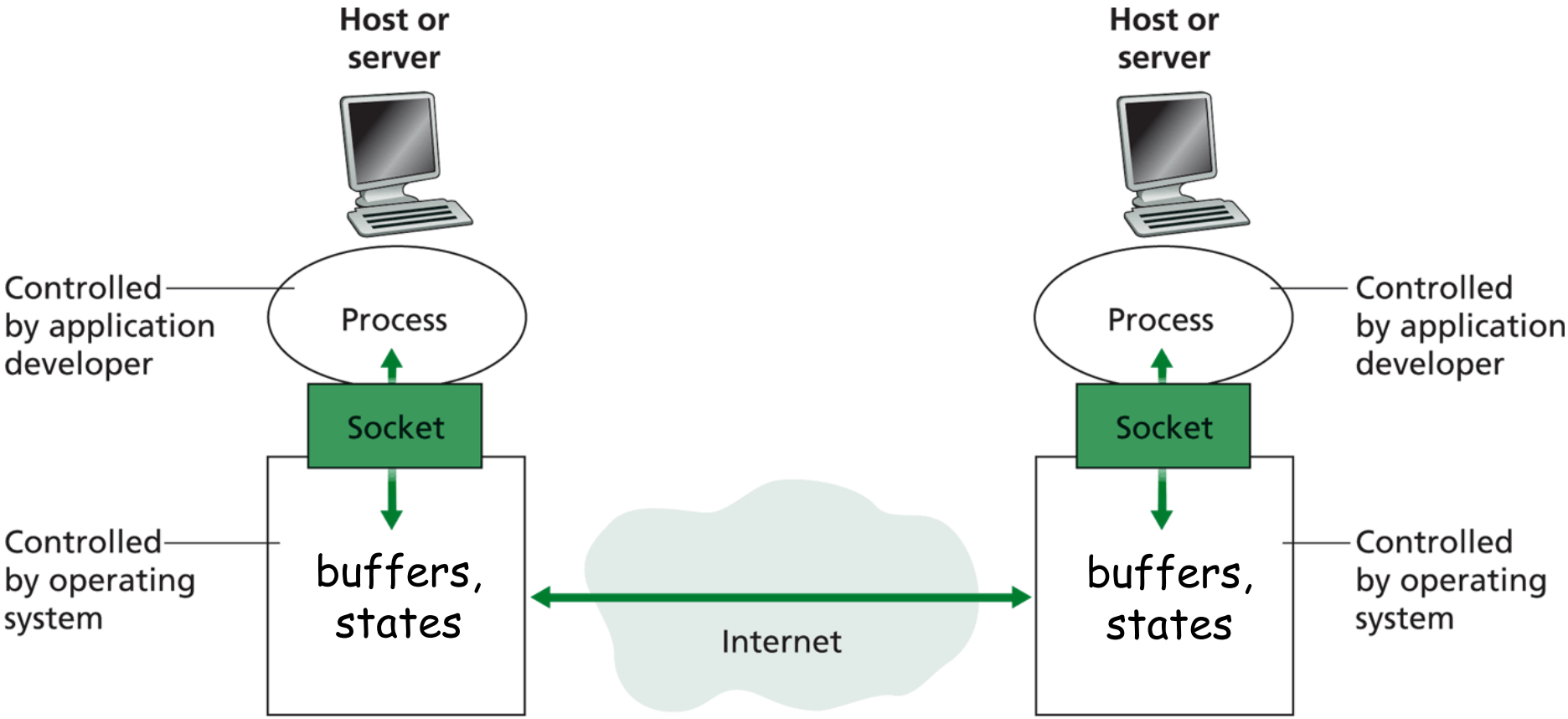
an interface (a "door") into which one application process can both send and receive messages to/from another (remote or local) application process

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
- Basic network application programming
  - Overview
  - *UDP (Datagram Socket)*

DatagramSocket(Java) (Basic)

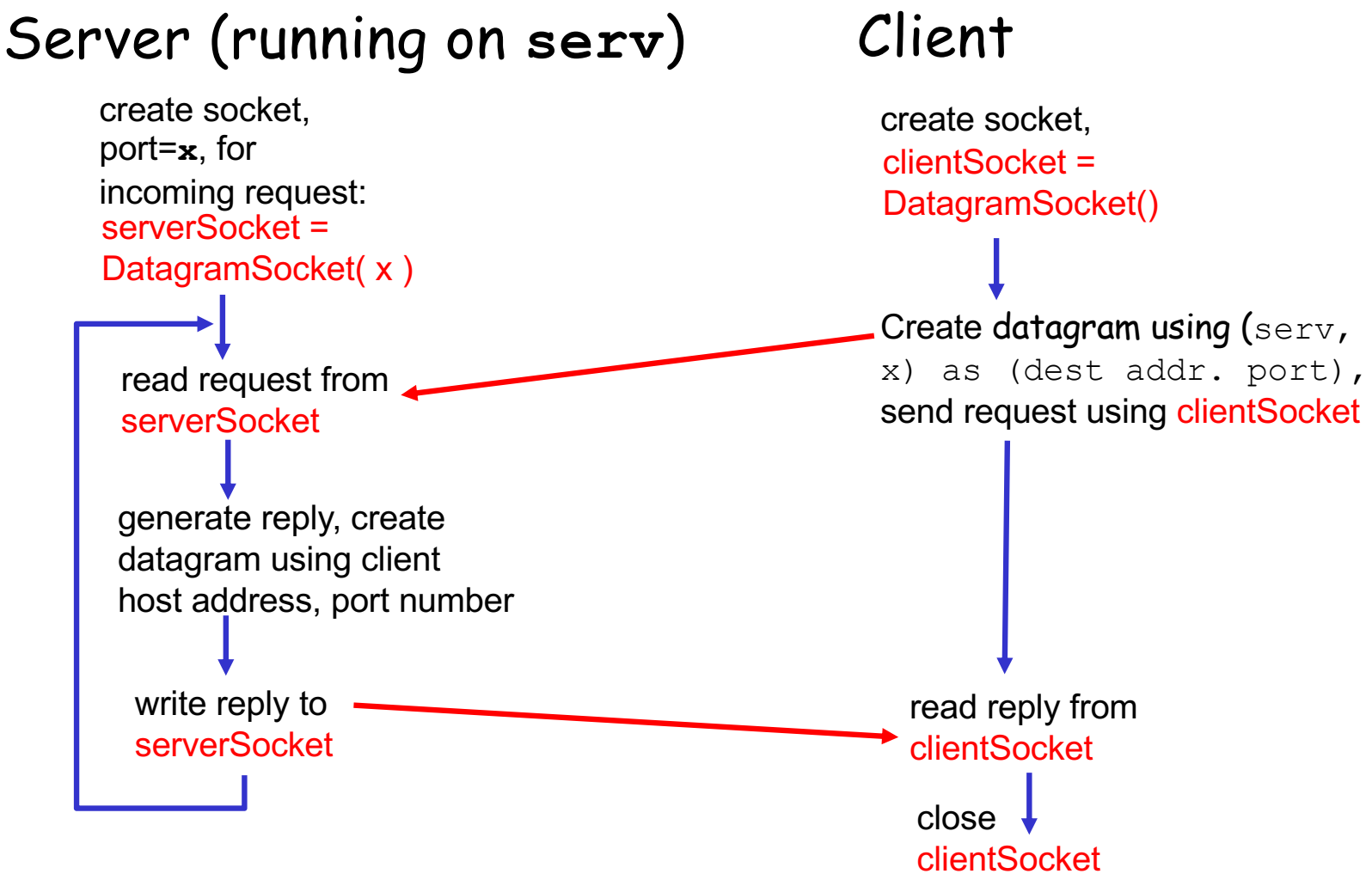
- **DatagramSocket**()
  constructs a datagram socket and binds it to any available port on the local host
- **DatagramSocket**(int lport)
  constructs a datagram socket and binds it to the specified port on the local host machine.

- **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.

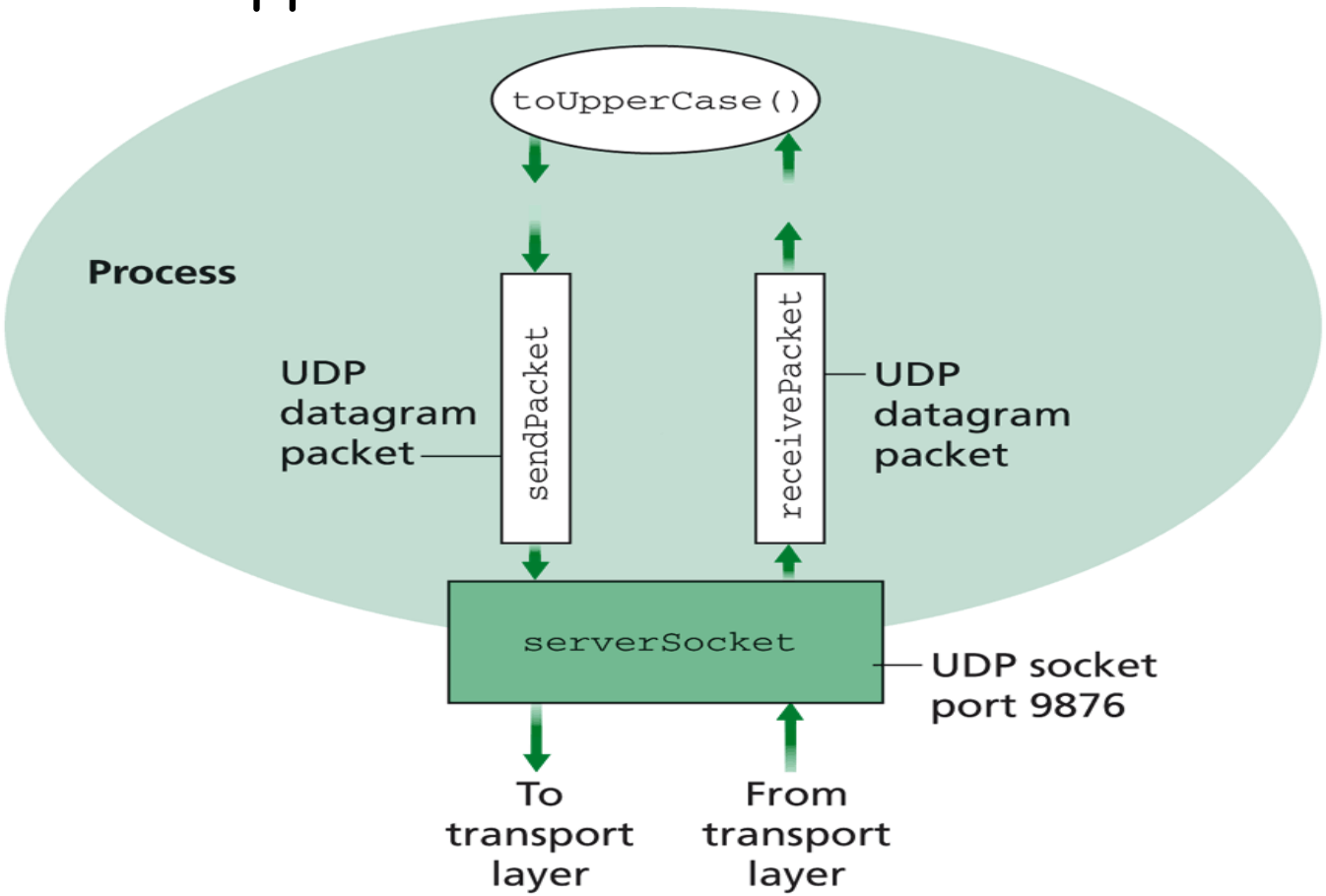
- **close**()
  closes this datagram socket.

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.*;

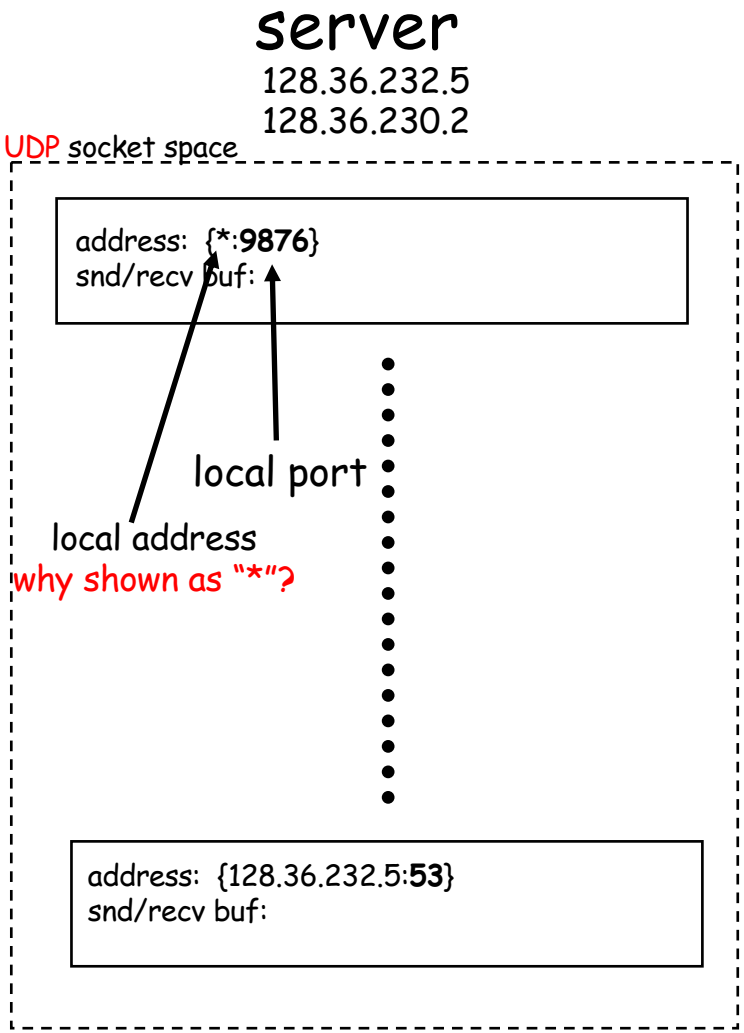
class UDPServer {
  public static void main(String args[]) throws Exception
   {

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

Create datagram socket bind at port 9876

Check socket state:
Ubuntu: %netstat –a –u –n
Mac: %netstat –a –p tcp/udp –n

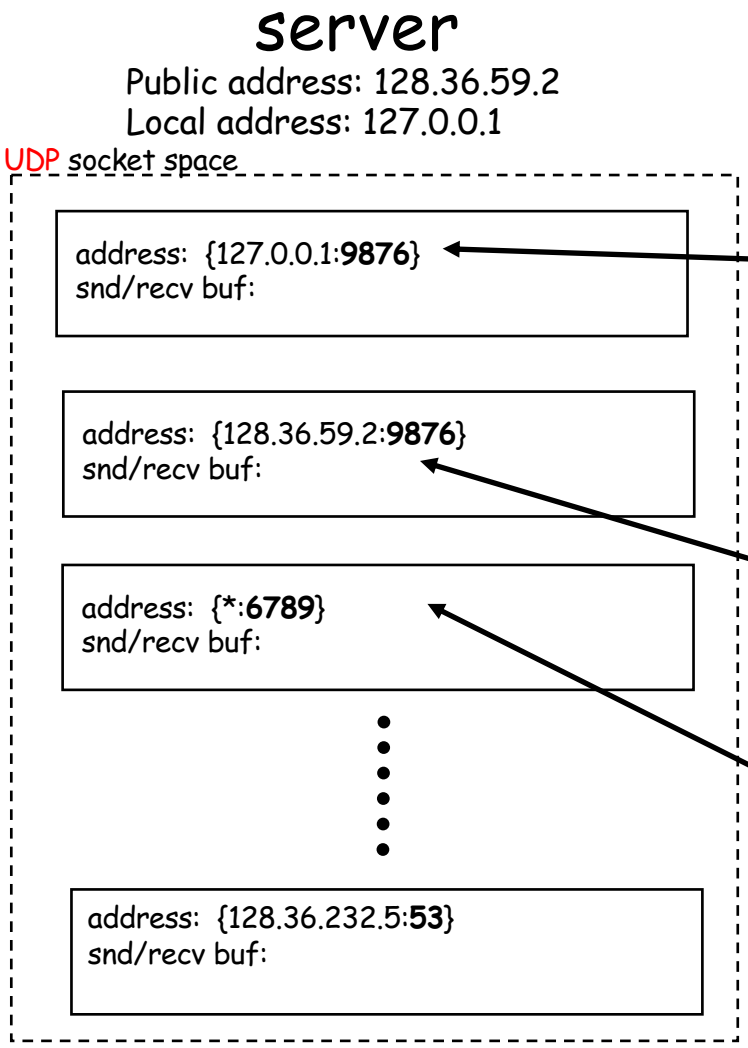
System State after the Call



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

```
% ifconfig -a
```

Binding to Specific IP Addresses

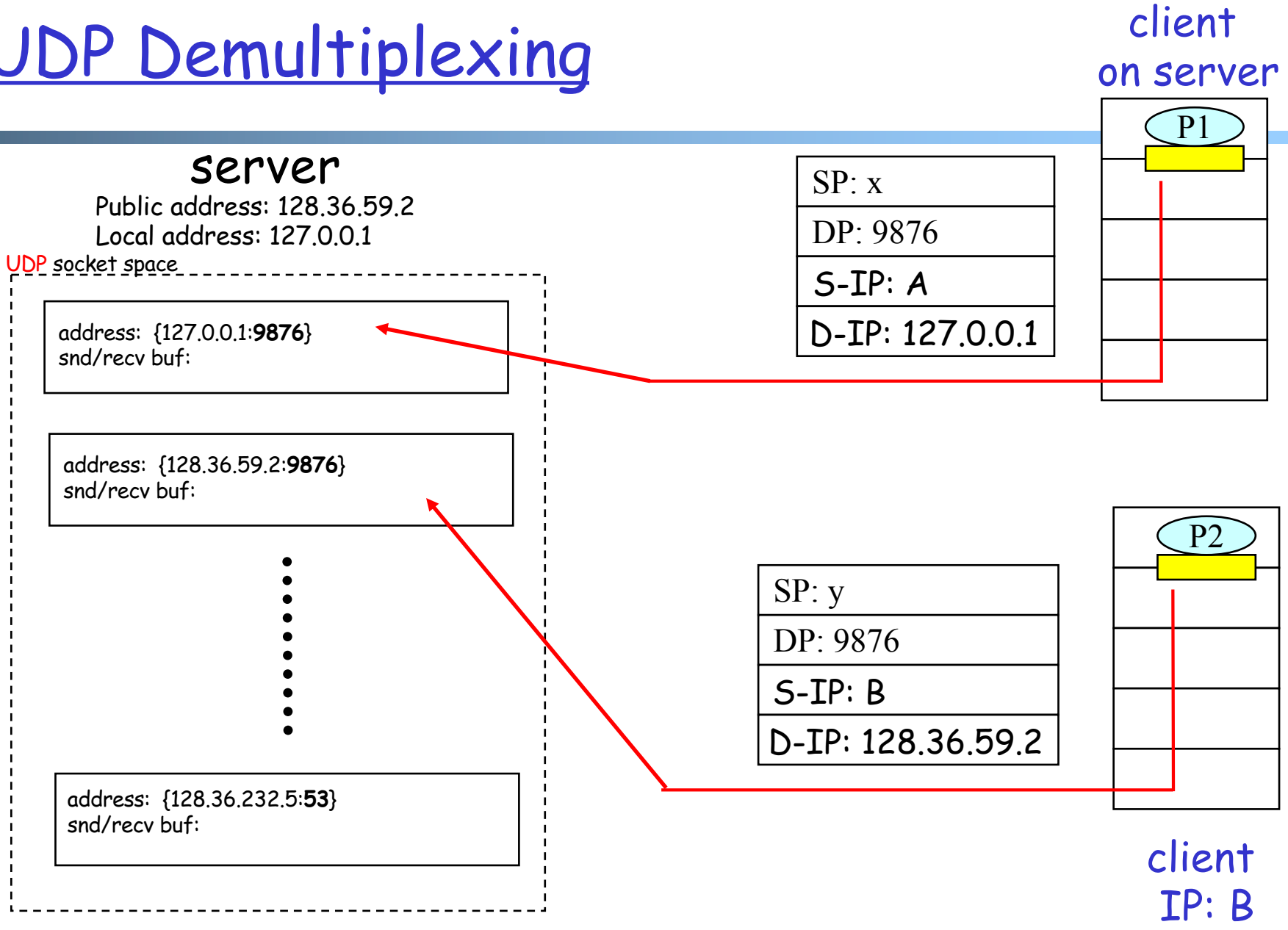



```
InetAddress sIP1 =
   InetAddress.getByName("localhost");
DatagramSocket ssock1 = new
       DatagramSocket(9876, sIP1);

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

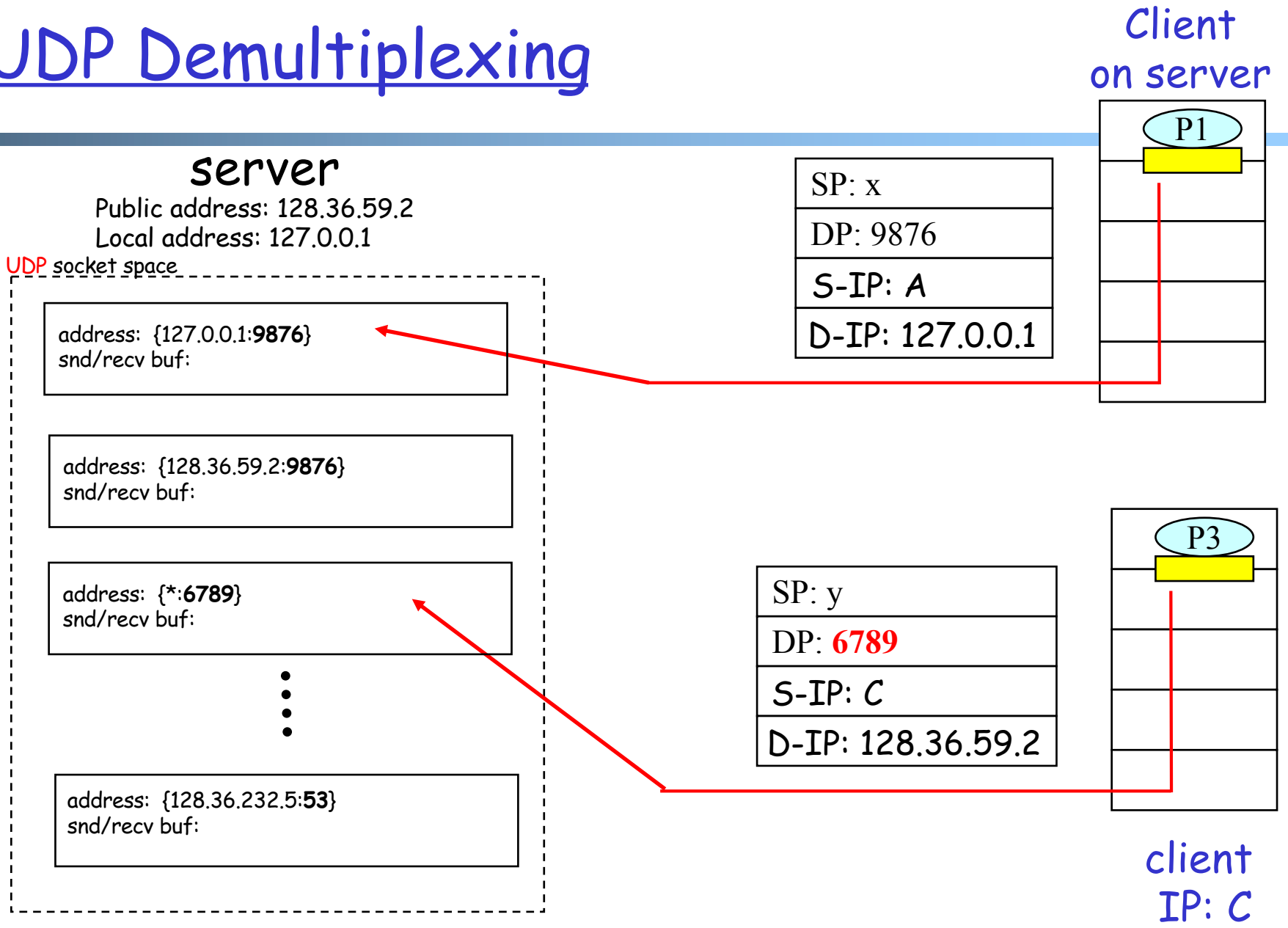
DatagramSocket serverSocket = new
DatagramSocket(6789);
```

UDP Demultiplexing



UDP demutiplexing is based on matching (dst address, dst port)

UDP Demultiplexing



UDP demutiplexing is based on matching (dst address, dst port)

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

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 {

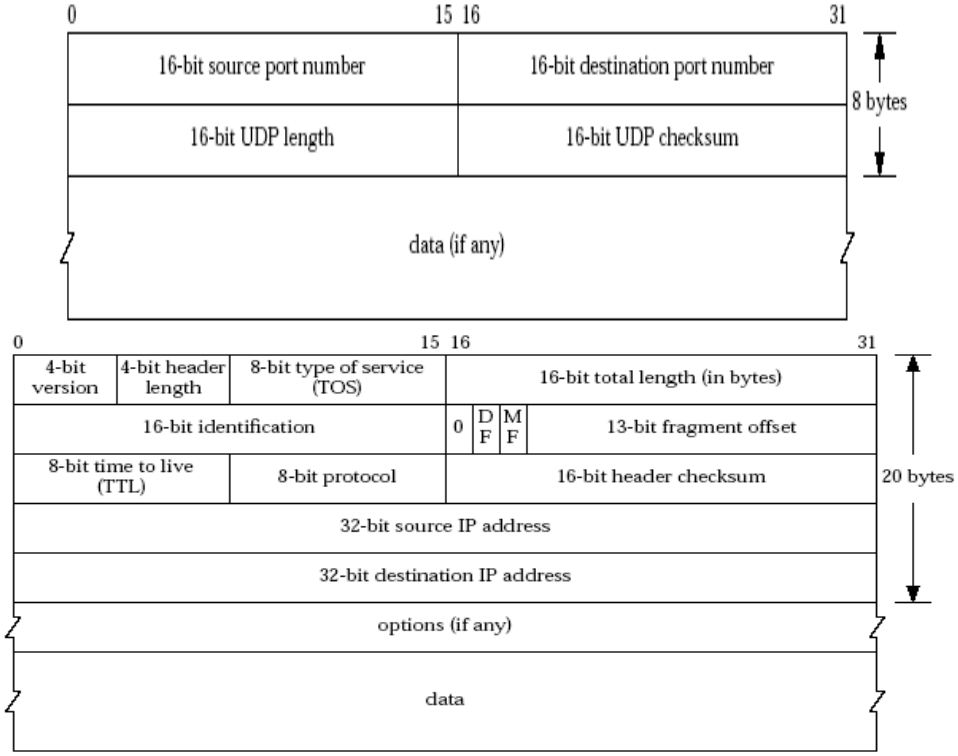
…
// process data
String sentence = new String(receivePacket.getData(),
                             0, receivePacket.getLength());
String capitalizedSentence = sentence.toUpperCase();
sendData = capitalizedSentence.getBytes();
```

getData() returns a pointer to an underlying buffer array; for efficiency, don't assume receive() will reset the rest of the 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);
```

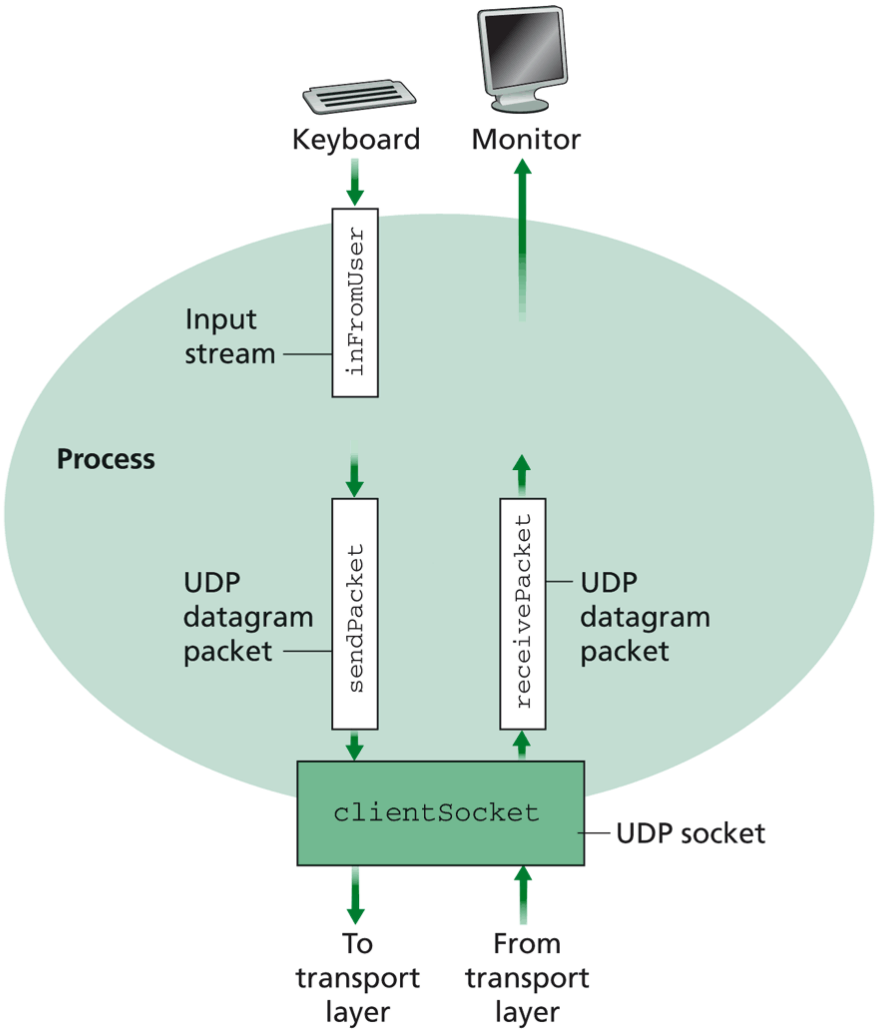
Write out datagram to socket

```
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();
}

}
```

Demo

%ubuntu: java UDPServer

%netstat to see buffer

%ubuntu: java UDPClient <server>

%wireshark to capture traffic