Application-layer Protocols

Based on Notes by D. Hollinger

Based on UNIX Network Programming, Stevens, Chapter 9

Also Java Network Programming and Distributed Computing, Chapter 3,8

Also Online Java Tutorial, Sun.

Topics

- Issues in Protocol Design

- Sample Application-layer Protocols
  - TELNET
  - FTP
  - DNS

Application Protocol Design

- Think of different people/teams, working on the client and server programs.
  - Different programming languages.
  - Diverse hardware, operating systems.
- Be unambiguous, precise.
  - Consider potential error conditions.
- Allow for future extensions.
  - Leave room for additional data, meta-data.
- Do not replicate services provided by lower-layer protocols
  - e.g., checksum

In Summary

Strive for:

- Interoperability
- Precision
- Extensibility
- Efficiency
- Minimality

Learn by Example

- Many existing protocols are the result of long term collaborations.
- Look at existing Request for Comments (RFC) documents, specifying protocols:

  See http://www.rfc-editor.org/rfc.html

Knock-Knock Protocol

Server: “Knock knock!”

Client: “Who's there?”

Server: “Dexter.”

Client: “Dexter who?”

Server: “Dexter halls with boughs of holly.”

Client: “Groan.”

Java Implementation

- Client class
  - – KnockKnockClient.java
- Server class
  - – KnockKnockServer.java
- Protocol class
  - – KnockKnockProtocol.java

Supporting multiple clients

- Main listener code
  - – KKMultiServer.java
- Protocol service thread code
  - – KKMultiServerThread.java

The TELNET Protocol

Reference: RFC 854

TELNET vs. `telnet`

- TELNET is a *protocol* that provides “a general, bi-directional, eight-bit byte oriented communications facility”.
- **`telnet`** is a *program* that supports the TELNET protocol over TCP.
- Many application protocols are built upon the TELNET protocol.

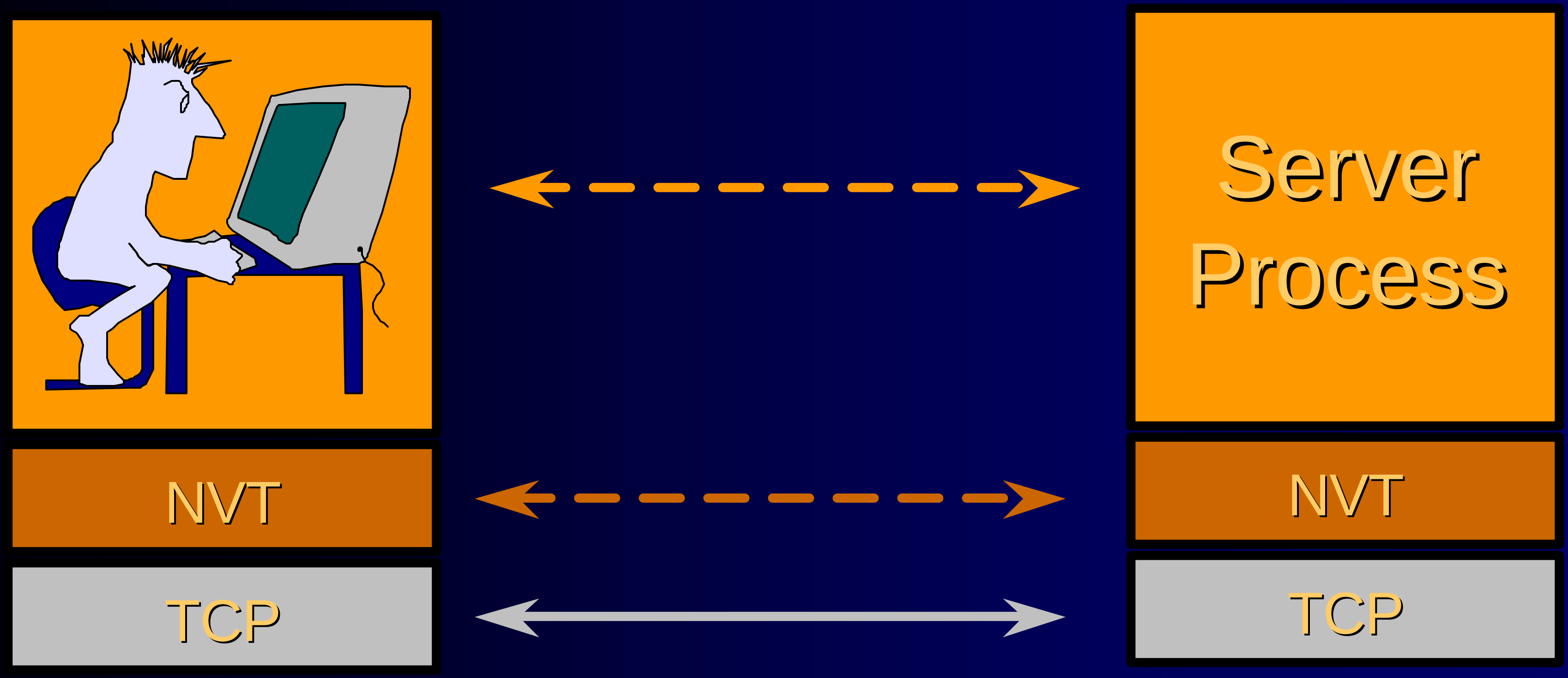
The TELNET Protocol

- TCP connection
- data and control over the same connection.
- Network Virtual Terminal
- negotiated options

Network Virtual Terminal

- intermediate representation of a generic terminal.
- provides a standard language for communication of terminal control functions.

Network Virtual Terminal



Server Process

NVT

TCP

NVT

TCP

Negotiated Options

- All NVTs support a minimal set of capabilities.
- Some terminals have more capabilities than the minimal set.
- The 2 endpoints negotiate a set of mutually acceptable options (character set, echo mode, etc).

Negotiated Options

- The protocol for requesting optional features is well defined and includes rules for eliminating possible negotiation “loops”.
- The set of options is not part of the TELNET protocol, so that new terminal features can be incorporated without changing the TELNET protocol.

Option examples

- Line mode vs. character mode
- echo modes
- character set (EBCDIC vs. ASCII)

Control Functions

- TELNET includes support for a series of control functions commonly supported by servers.

- This provides a uniform mechanism for communication of (the supported) control functions.

Control Functions

- Interrupt Process (IP)
  - suspend/abort process.
- Abort Output (AO)
  - process can complete, but send no more output to user’s terminal.
- Are You There (AYT)
  - check to see if system is still running.

More Control Functions

- Erase Character (EC)
  - – delete last character sent
  - – typically used to edit keyboard input.
- Erase Line (EL)
  - – delete all input in current line.

Command Structure

- All TELNET commands and data flow through the same TCP connection.
- Commands start with a special character called the Interpret as Command *escape* character (IAC).
- The IAC code is 255.
- If a 255 is sent as data - it must be followed by another 255.

Looking for Commands

- Each receiver must look at each byte that arrives and look for IAC.
- If IAC is found and the next byte is IAC - a single byte is presented to the application/terminal (a 255).
- If IAC is followed by any other code - the TELNET layer interprets this as a command.

Command Codes

IP	243
AO	244
AYT	245
EC	246
EL	247

WILL	251
WON’T	252
DO	253
DON’T	254
IAC	255

Playing with TELNET

- You can use the **`telnet`** program to play with the TELNET protocol.
- **`telnet`** is a *generic* TCP client.
  - Sends whatever you type to the TCP socket.
  - Prints whatever comes back through the TCP socket.
  - Useful for testing TCP servers (ASCII based protocols).

Some TCP Servers you can play with

- Many Unix systems have these servers running (by default):
  - **echo** port 7
  - **discard** port 9
  - **daytime** port 13
  - **chargen** port 19

telnet hostname port

```
> telnet rcs.rpi.edu 7
Trying 128.113.113.33...
Connected to cortez.sss.rpi.edu
  (128.113.113.33).
Escape character is '^]'.
Hi dave
Hi dave
stop it
stop it
^]
telnet> quit
Connection closed.
```

`telnet` vs. TCP

- Not all TCP servers talk TELNET (most don't)

- You can use the **`telnet`** program to play with these servers, but the fancy commands won't do anything.
  - type ^], then "help" for a list of fancy TELNET stuff you can do in **`telnet`**.

- See GenericClient.java

FTP
File Transfer Protocol

Reference:

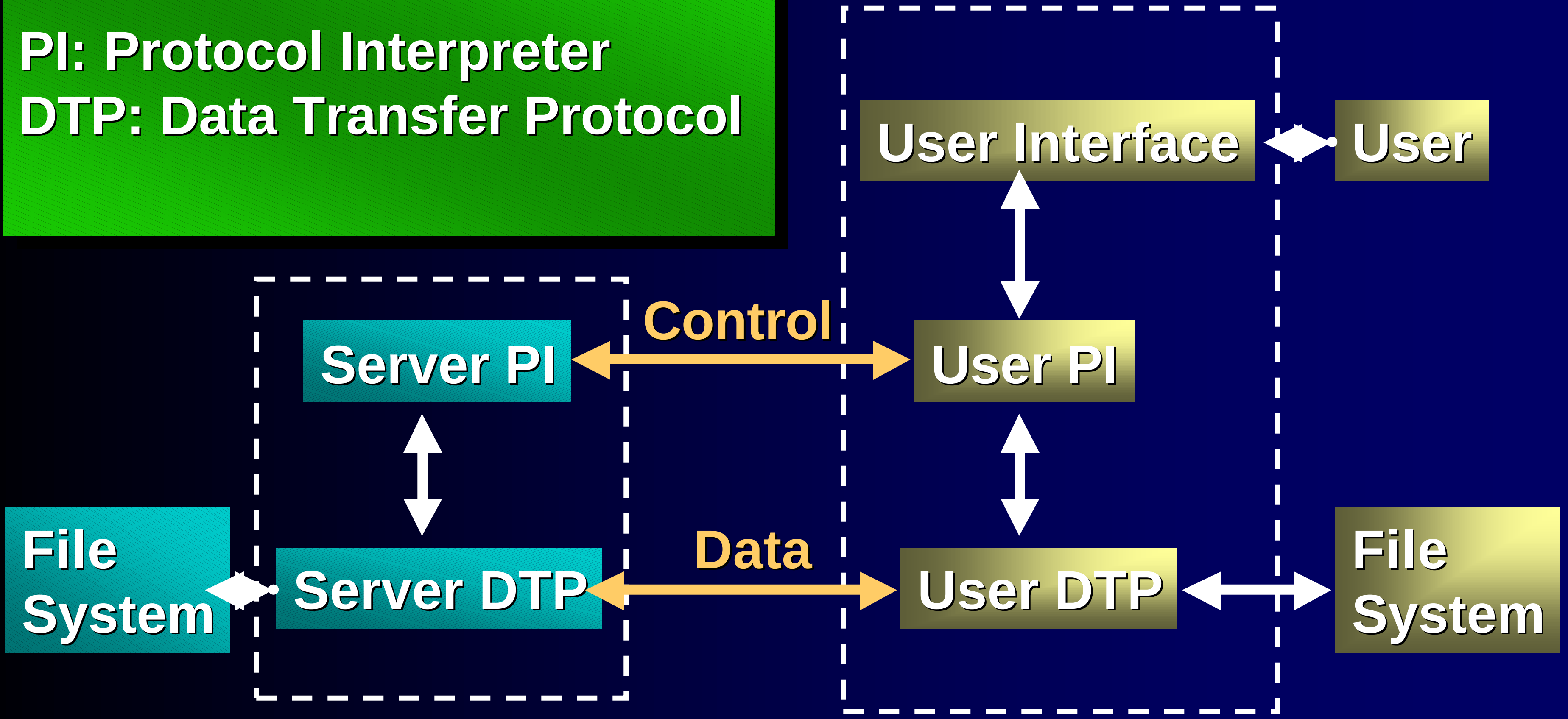
RFC 959

FTP Objectives (from RFC 959)

- promote sharing of files
- encourage indirect use of remote computers
- shield user from variations in file storage
- transfer data reliably and efficiently
- “FTP, although usable directly by a user at a terminal, is designed mainly for use by programs”

The FTP Model

PI: Protocol Interpreter
DTP: Data Transfer Protocol



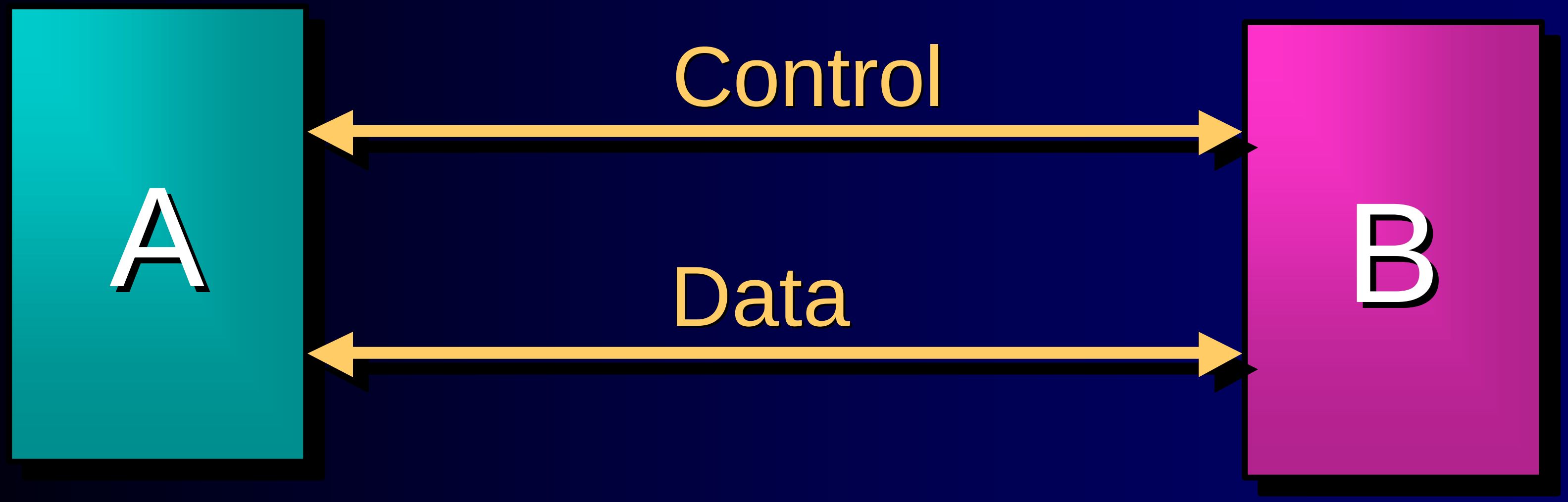
Control and Data Connections

- Control functions (commands) and reply codes are transferred over the control connection.
- All data transfer takes place over the data connection.
- The control connection must be “up” while data transfer takes place.

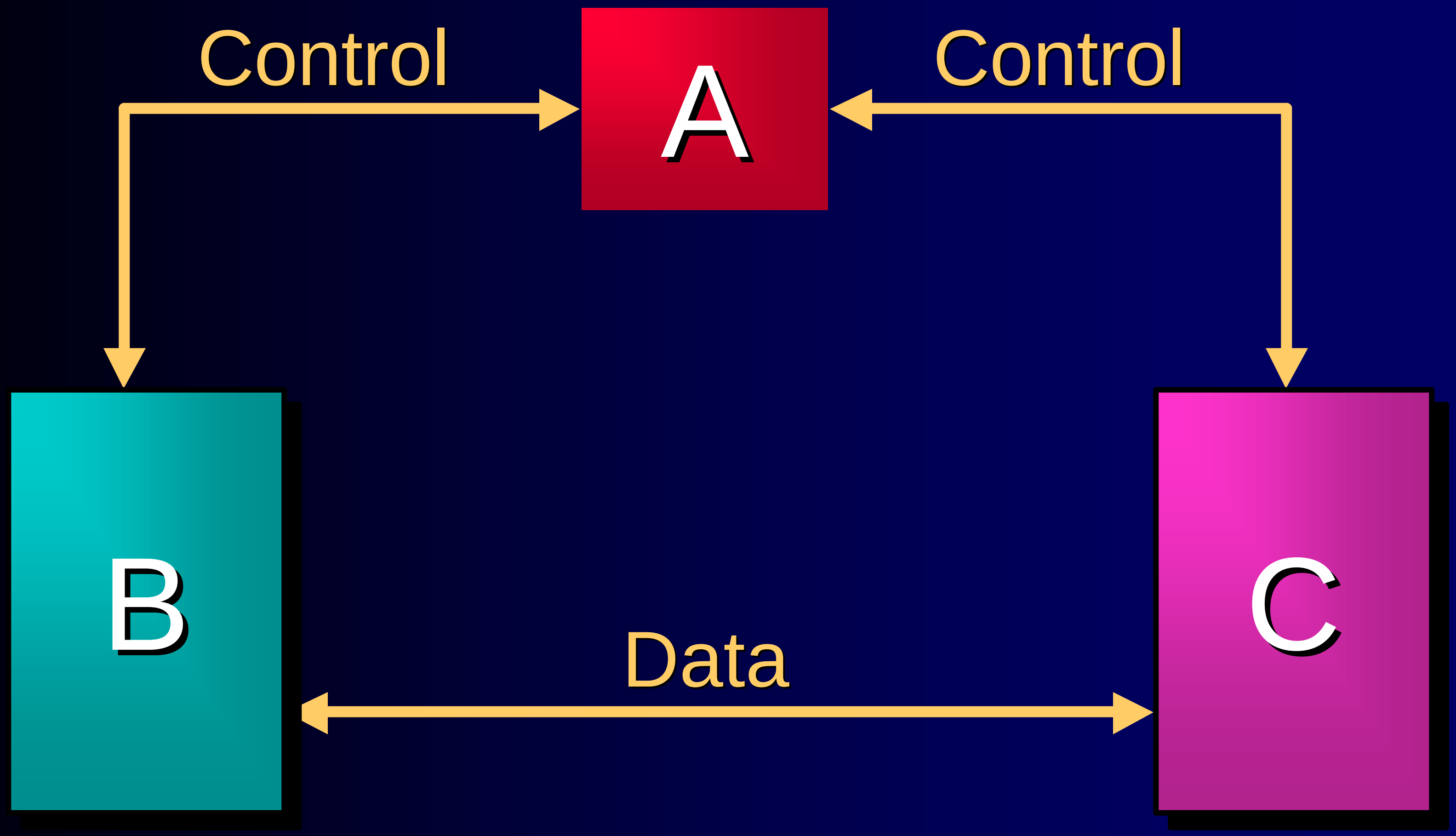
Control Connection

- The control connection is the “well known” service.
- The control connection uses the TELNET protocol.
- Commands and replies are all line oriented text (default is ASCII).

Standard Connection Model



Alternative Connection Model



Access Control Commands

USER	*specify user*
PASS	*specify password*
CWD	*change directory*
CDUP	*change directory to parent*
QUIT	*logout*

Transfer Parameter Commands

PORT	*publish local data port*
PASV	*server should listen*
TYPE	*establish data representation*
MODE	*establish transfer mode*
STRU	*establish file structure*

Service Commands

RETR	*retrieve file*
STOR	*send file*
STOU	*send file and save as unique*
APPE	*send file and append*
ABOR	*abort prev. service command*
PWD	*print working directory*
LIST	*transfer list of files over data link*

FTP Replies

- All replies are sent over control connection.
- Replies are a single line containing
  - 3 digit status code (sent as 3 numeric chars).
  - text message.
- The FTP spec. includes support for multiline text replies.

FTP Reply Status Code

First digit of status code indicates type of reply:

‘1’: Positive Preliminary Reply (got it, but wait).

‘2’: Positive Completion Reply (success).

‘3’: Positive Intermediate Reply (waiting for more information).

‘4’: Transient Negative Completion (error - try again).

‘5’: Permanent Negative Reply (error - can’t do).

FTP Reply Status Code

- 2nd digit indicates function groupings.

  ‘0’: Syntax (problem with command syntax).

  ‘1’: Information (reply to help or status cmds).

  ‘2’: Connections (problem with a connection).

  ‘3’: Authentication (problem with login).

  ‘4’: Unspecified.

  ‘5’: File system (related to file system).
- 3rd digit indicates specific problem within function group.

Data Transfer Modes

- STREAM: file is transmitted as a stream of bytes.
- BLOCK: file is transmitted as a series of blocks preceded by headers containing count and descriptor code (EOF, EOR, restart marker).
- COMPRESSED: uses a simple compression scheme - compressed blocks are transmitted.

RFC 959

- The RFC includes lots more information and many details including:
  - – parameters for commands
  - – lists of reply status codes
  - – protocol state diagrams
  - – support for a variety of file structures
  - – sample sessions

Address Conversion Functions and The Domain Name System

Based on Notes by D. Hollinger

Refs: UNIX Network Programming, Stevens, Chapter 9

RFC 1034

RFC 1035

Also based on Java Network Programming and Distributed Computing, Chapter 3

Hostnames

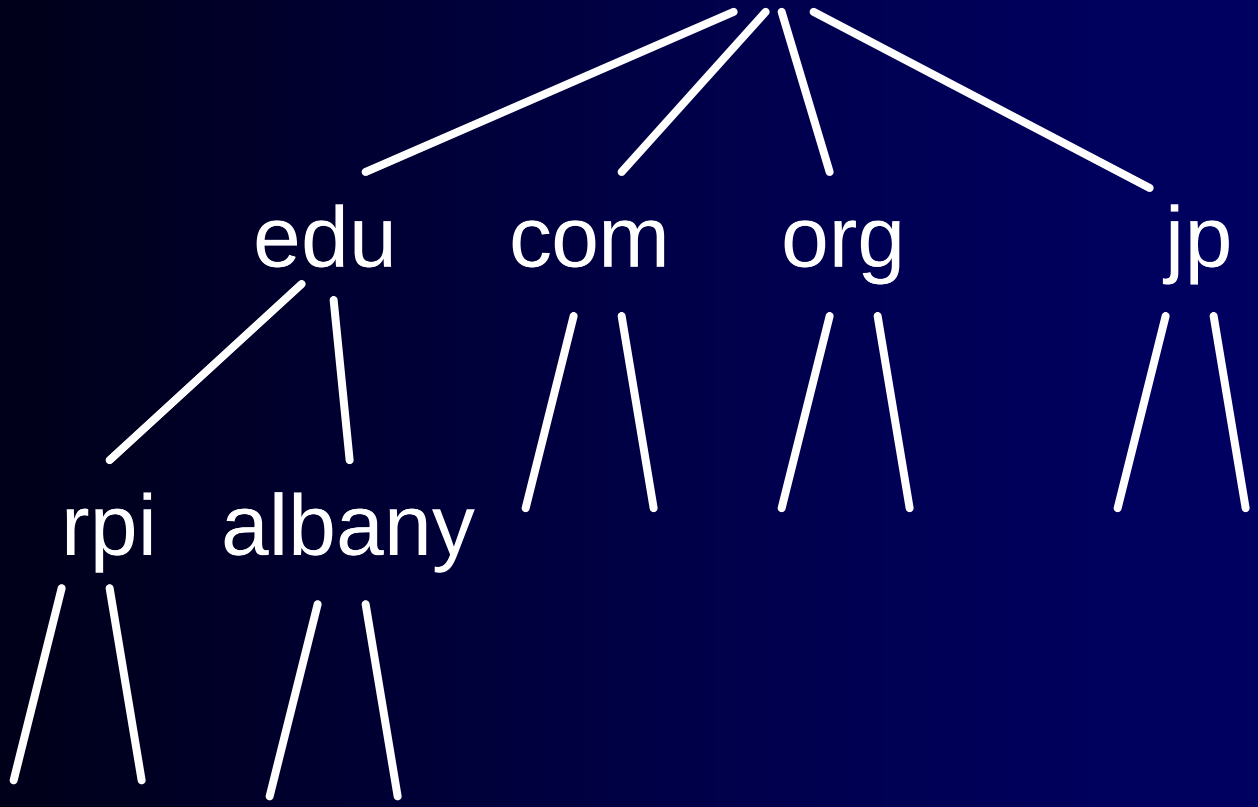
- IP Addresses are great for computers
  - IP address includes information used for routing.
- IP addresses are tough for humans to remember.
- IP addresses are impossible to guess.
  - ever guessed at the name of a WWW site?

The Domain Name System

- The *domain name system* is usually used to translate a host name into an IP address .

- Domain names comprise a hierarchy so that names are unique, yet easy to remember.

DNS Hierarchy



Host name structure

- Each host name is made up of a sequence of *labels* separated by periods.
  - Each label can be up to 63 characters
  - The total name can be at most 255 characters.
- Examples:
  - whitehouse.gov
  - barney.the.purple.dinosaur.com
  - monica.cs.rpi.edu

Domain Name

- The domain name for a host is the sequence of labels that lead from the host (leaf node in the naming tree) to the top of the worldwide naming tree.

- A domain is a subtree of the worldwide naming tree.

Top level domains

- **`edu, gov, com, net, org, mil`**, …
- Countries each have a top level domain (2 letter domain name).
- New top level domains include:

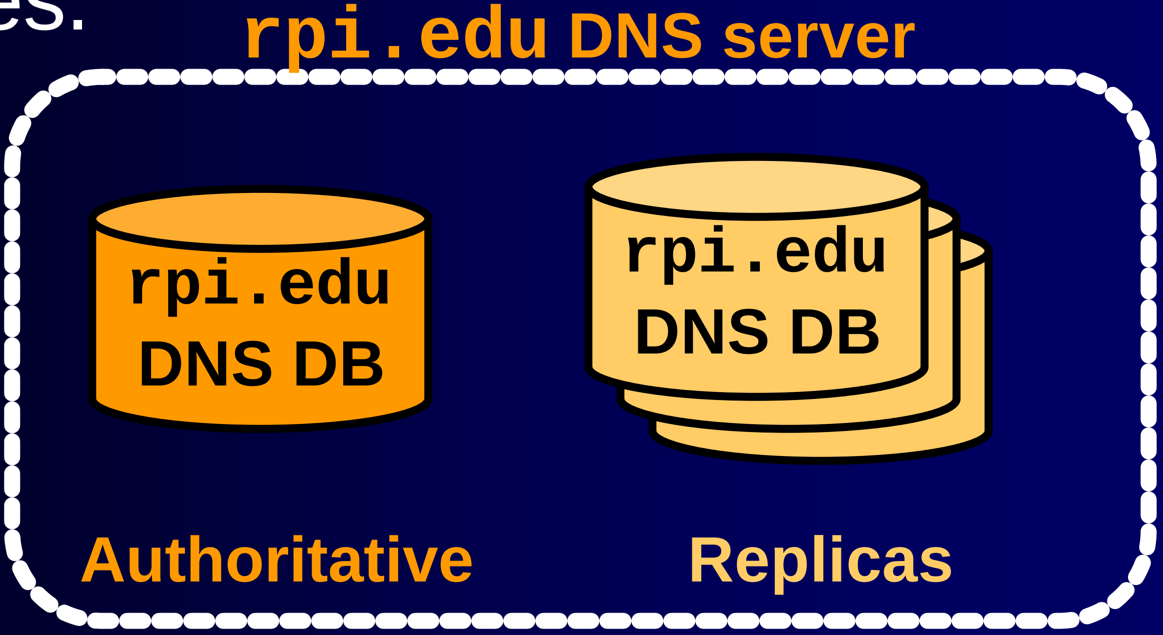
  .aero .biz .coop .info .name .pro

DNS Organization

- Distributed Database
  - The organization that owns a domain name is responsible for running a DNS server that can provide the mapping between hostnames within the domain to IP addresses.
  - So - some machine run by RPI is responsible for everything within the rpi.edu domain.

DNS Distributed Database

- There is one primary server for a domain, and typically a number of secondary servers containing replicated databases.



DNS Clients

- A DNS client is called a *resolver*.

- A call to **`getByName(host)`**is handled by a resolver (typically part of the client).

- Most Unix workstations have the file **`/etc/resolv.conf`** that contains the local domain and the addresses of DNS servers for that domain.

/etc/resolv.conf

```
domain rpi.edu
128.113.1.5
128.113.1.3
```

nslookup

- nslookup is an interactive resolver that allows the user to communicate directly with a DNS server.

- nslookup is usually available on Unix workstations.

```
$ nslookup
Default Server:  oldtotter.cs.rpi.edu
Address:  128.213.8.12

> rpi.edu
Server:  oldtotter.cs.rpi.edu
Address:  128.213.8.12

Non-authoritative answer:
Name:    rpi.edu
Addresses:  128.113.26.42, 128.113.26.41
```

DNS Servers

- Servers handle requests for their domain directly.
- Servers handle requests for other domains by contacting remote DNS server(s).
- Servers cache external mappings.

Server - Server Communication

- If a server is asked to provide the mapping for a host outside it’s domain (and the mapping is not in the server cache):
  - The server finds a nameserver for the target domain.
  - The server asks the nameserver to provide the host name to IP translation.
- To find the right nameserver, use DNS!

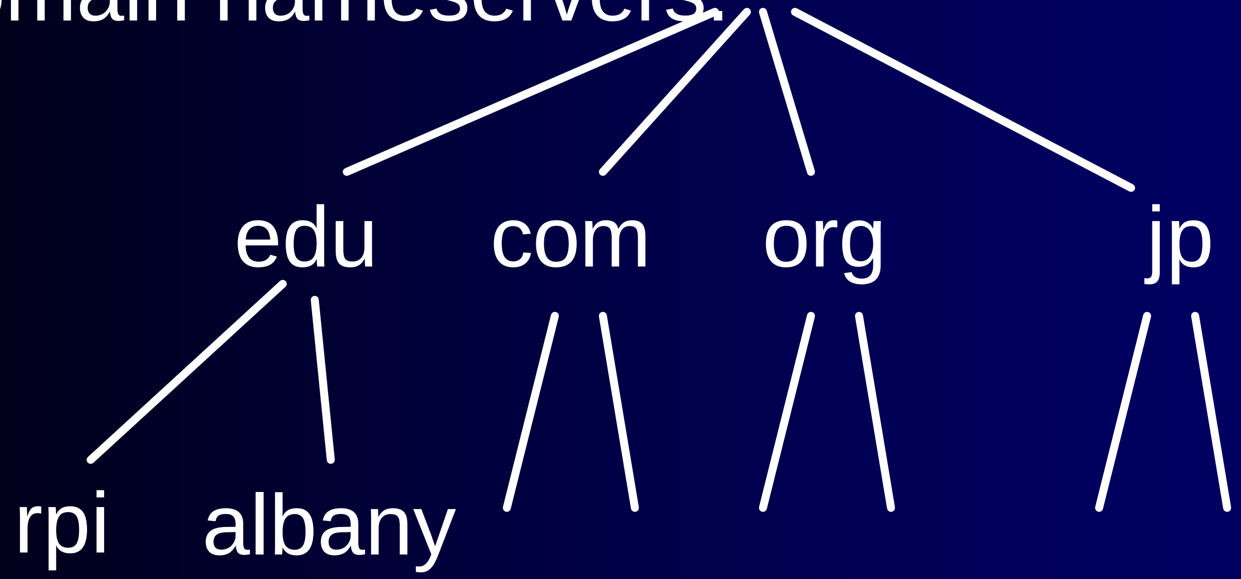
DNS Data

- DNS databases contain more than just hostname-to-address records:

– Name server records	NS
– Hostname aliases	CNAME
– Mail Exchangers	MX
– Host Information	HINFO

The Root DNS Server

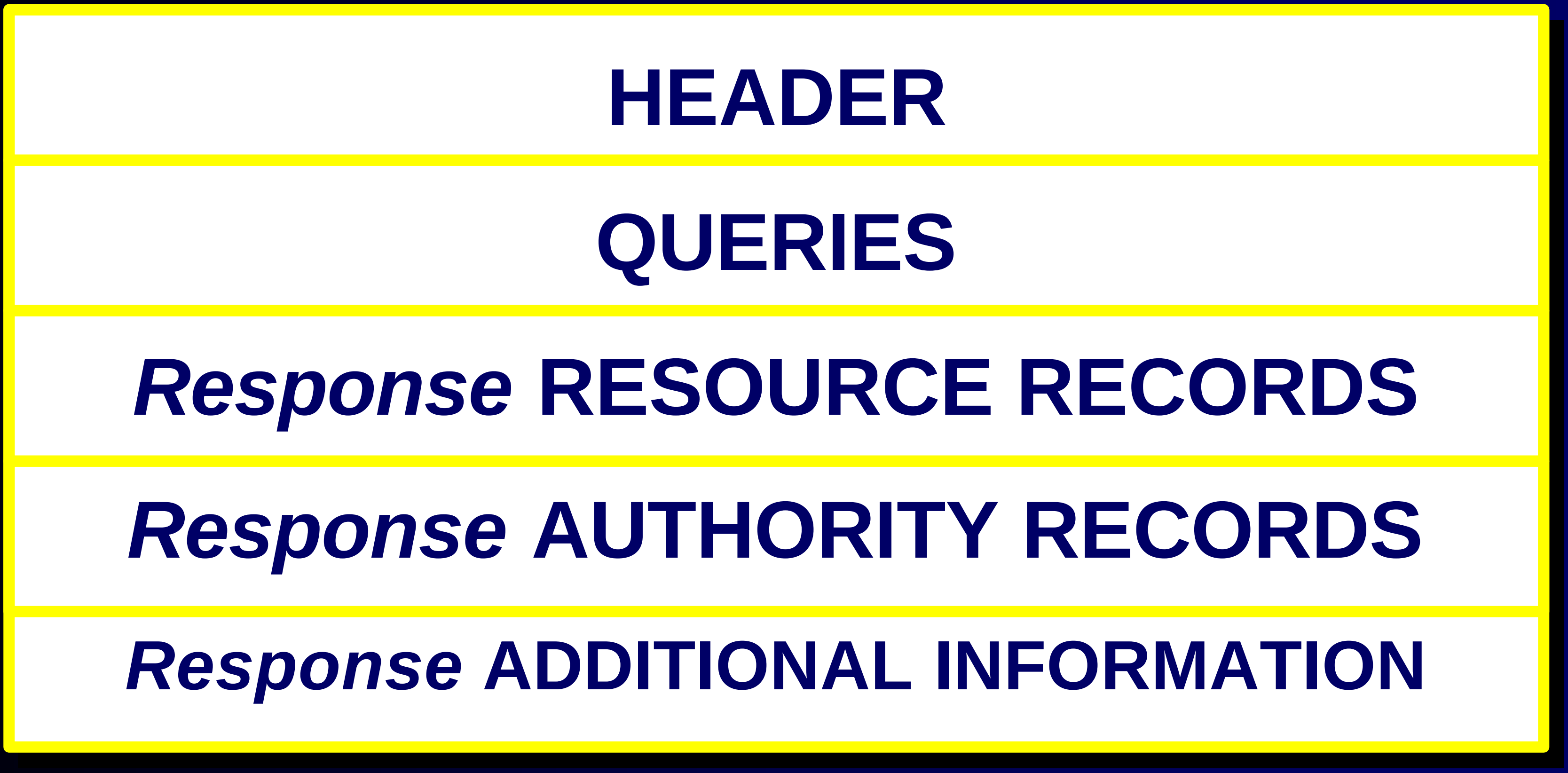
- The root server needs to know the address of 1st (and many 2nd) level domain nameservers.



Server Operation

- If a server has no clue about where to find the address for a hostname, ask the root server.
- The root server will tell you what nameserver to contact.
- A request may get forwarded a few times.

DNS Message Format



HEADER

QUERIES

Response RESOURCE RECORDS

Response AUTHORITY RECORDS

Response ADDITIONAL INFORMATION

DNS Message Header

16 bit fields

- query identifier
- flags
- # of questions
- # of RRs
- # of authority RRs
- # of additional RRs

Response

Message Flags

- QR: Query=0, Response=1
- AA: Authoritative Answer
- TC: response truncated (> 512 bytes)
- RD: recursion desired
- RA: recursion available
- rcode: return code

Recursion

- A request can indicate that recursion is desired - this tells the server to find out the answer (possibly by contacting other servers).
- If recursion is not requested - the response may be a list of other name servers to contact.

Question Format

- Name: domain name (or IP address)
- Query type (A, NS, MX, …)
- Query class (1 for IP)

Response Resource Record

- Domain Name
- Response type
- Class (IP)
- Time to live (in seconds)
- Length of resource data
- Resource data

UDP & TCP

- Both UDP and TCP are used:
  - TCP for transfers of entire database to secondary servers (replication).
  - UDP for lookups
  - If more than 512 bytes in response - requestor resubmits request using TCP.

Lots more

- This is not a complete description !
- If interested - look at:
  - RFC 1034: DNS concepts and facilities.
  - RFC 1035: DNS implementation and protocol specification.
  - play with nslookup.
  - Look at code for BIND (DNS server code).

Internet Addresses in Java

- `java.net.InetAddress` class
- You get an address by using static methods:

```
ad = InetAddress.getByName(hostname);

myAddress = InetAddress.getLocalHost();
```

Printing Internet Addresses

- You get information from an InetAddress by using methods:

```
ad.getHostName();
ad.getHostAddress();
```

- Both return Strings representing the host name, and the IP address in dotted decimal format.

Additional InetAddress methods

- `getAddress()` returns the IP address.
  - in byte array format (network byte order), with highest byte at `bytearray[0]`.
- `getAllByName(hostname)` returns an array of InetAddress instances for the given host name.
  - One host name may be mapped to multiple machines.
  - One host name can map to multiple addresses in the same machine (virtual addresses).

Additional InetAddress methods

- `isMulticastAddress()` returns a boolean representing whether it is a Class D address.

- `getAllByName(hostname)` returns an array of InetAddress instances for the given host name.
  - One host name may be mapped to multiple machines.
  - One host name can map to multiple addresses in the same machine (virtual addresses).