Programming Ethernet with Socket API

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Acknowledgements

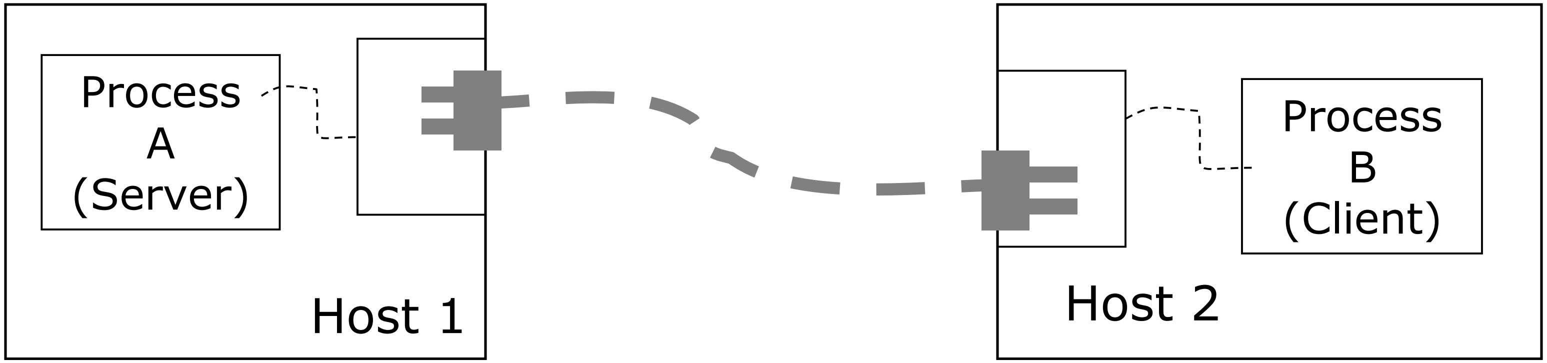
- Some pictures used in this presentation were obtained from the Internet
- The instructor used the following references
  - Larry L. Peterson and Bruce S. Davie, Computer Networks: A Systems Approach, 5th Edition, Elsevier, 2011
  - Andrew S. Tanenbaum, Computer Networks, 5th Edition, Prentice-Hall, 2010
  - James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 5th Ed., Addison Wesley, 2009
  - Larry L. Peterson's (http://www.cs.princeton.edu/~llp/) Computer Networks class web site
  - IBM e-server iSeries Socket Programming Manual Version 5 Release 3 (http://publib.boulder.ibm.com/infocenter/iseries/v5r3/index.jsp?topic=/rzab6/rzab6soxoverview.htm)

Outline

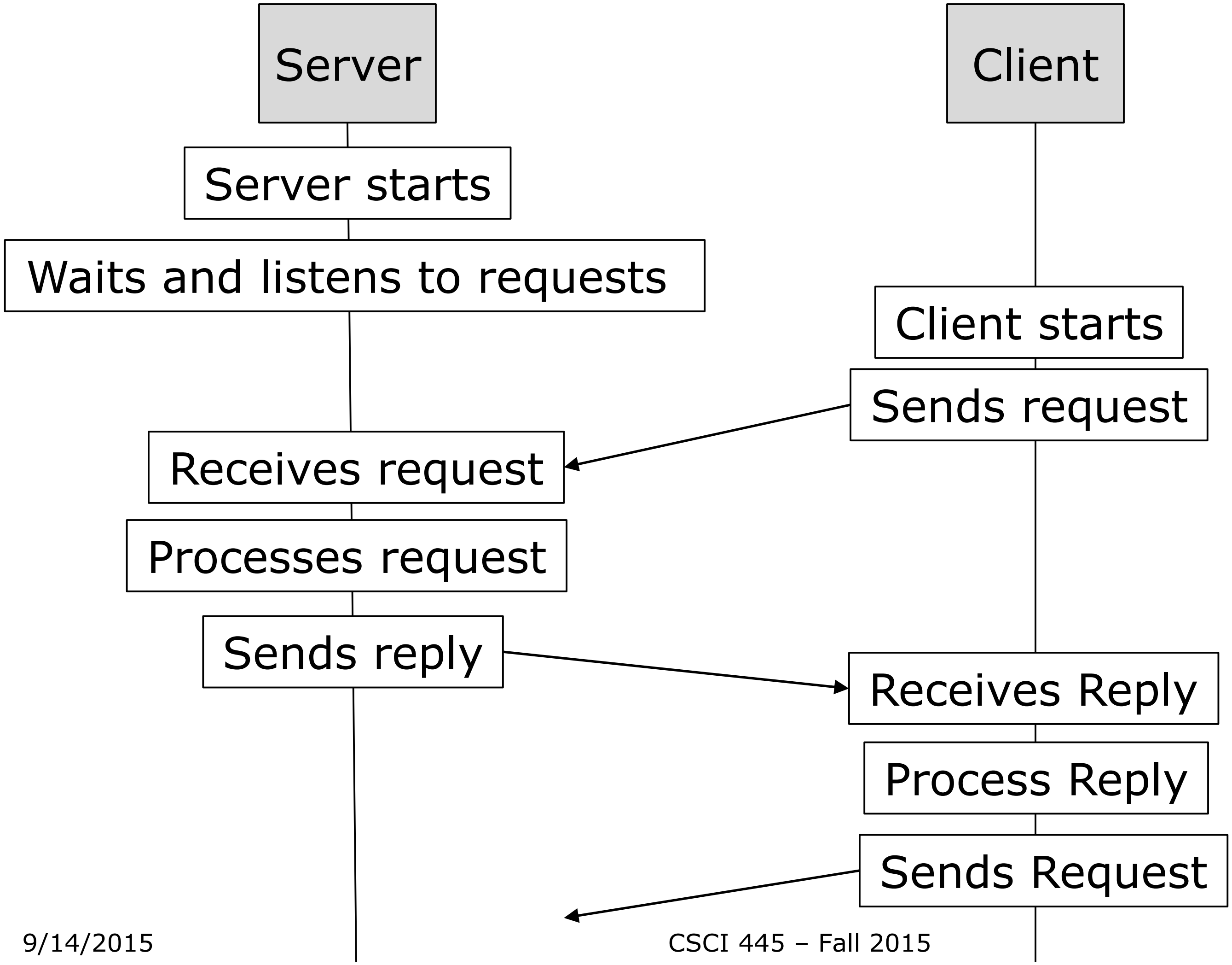
- Networking communication modes
- Network application models
- Programming and experimentation environment
- Ethernet implementation in practice
- Berkeley sockets for programming Ethernet

Network Application

- At least two processes
  - *Server* logic: listening to client's requests
  - *Client* logic: sending request to server
- Example setup
  - Process A: server logic
  - Process B: client logic



Server and Client Interaction: An Example



Client-Server and Peer-to-Peer Models

Client-Server Model

- Server
  - Runs server logic
  - Passively waiting: listening to client requests
  - Serving client requests
- Client
  - Runs client logic
  - Actively requesting service from server

Peer-to-Peer Model

- Any of the communicating party contains both server and client logics
- Each party listens to and serves requests from other parties
- Each party can initiate requests and send requests

Hybrid Model combines the above

Network Programming

- Example programs using a client-server model
  - Write two programs (A, B)
    - Program A contains the server logic
    - Program B contains the client logic

Connectionless & Connection-Oriented Modes

- Network applications or protocols can follow either one of the two communication modes
- Connectionless communication
  - Does not require to *establish a connection* before transmitting data and to *tear down the connection* after transmitting the data
- Connection-oriented communication
  - Requires to *establish a connection* before transmitting data

Connection-Oriented Mode

- Setting up a connection
  - Determine whether there is a communication path between the two communication parties
  - Reserve network resources
- Transmitting and receiving data
- Tearing down the connection
  - Release resources

Choosing Connected-Oriented or Connectionless Modes

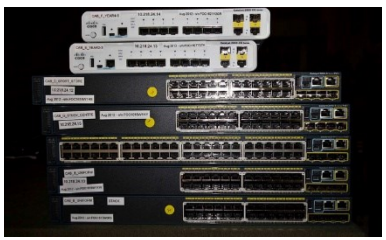
- Consider application requirement and decide which one works best for the application*
  - How reliable must the connection be?
  - Must the data arrive in the same order as it was sent?
  - Must the connection be able to handle duplicate data packets?
  - Must the connection have flow control?
  - Must the connection acknowledge the messages it receives?
  - What kind of service can the application live with?
  - What level of performance is required?
- If reliability is paramount, then connection-oriented transport services (COTS) is the better choice.

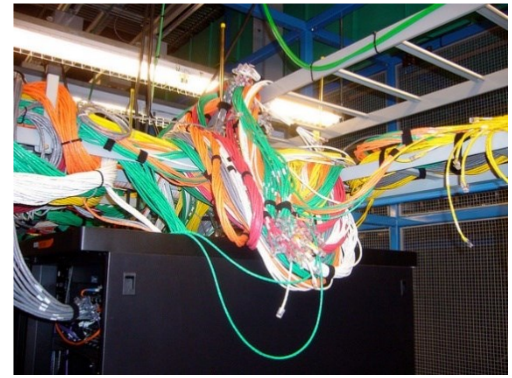
*From *Transport Interfaces Programming Guide, SunSoft, 1995*

Experiment Environment

- Use multiple Linux virtual machines
- Recommend Oracle Virtual Box
  - Free for Mac OS X, Windows, and Linux
  - Support various networking setups
- See class website for additional information

Ethernet: Where Are They?





Ethernet: Where Are They?

- Ethernet Adapter





Ethernet: Where Are They?

- Beside hardware, firmware inside
  - Example
    - Encoding
    - Error Detection
    - Medium Access Control (CSMA/CD)

Ethernet: Upper Layer Protocol Design and Programming

- How to access functionality of Ethernet adapter?

Application Layer

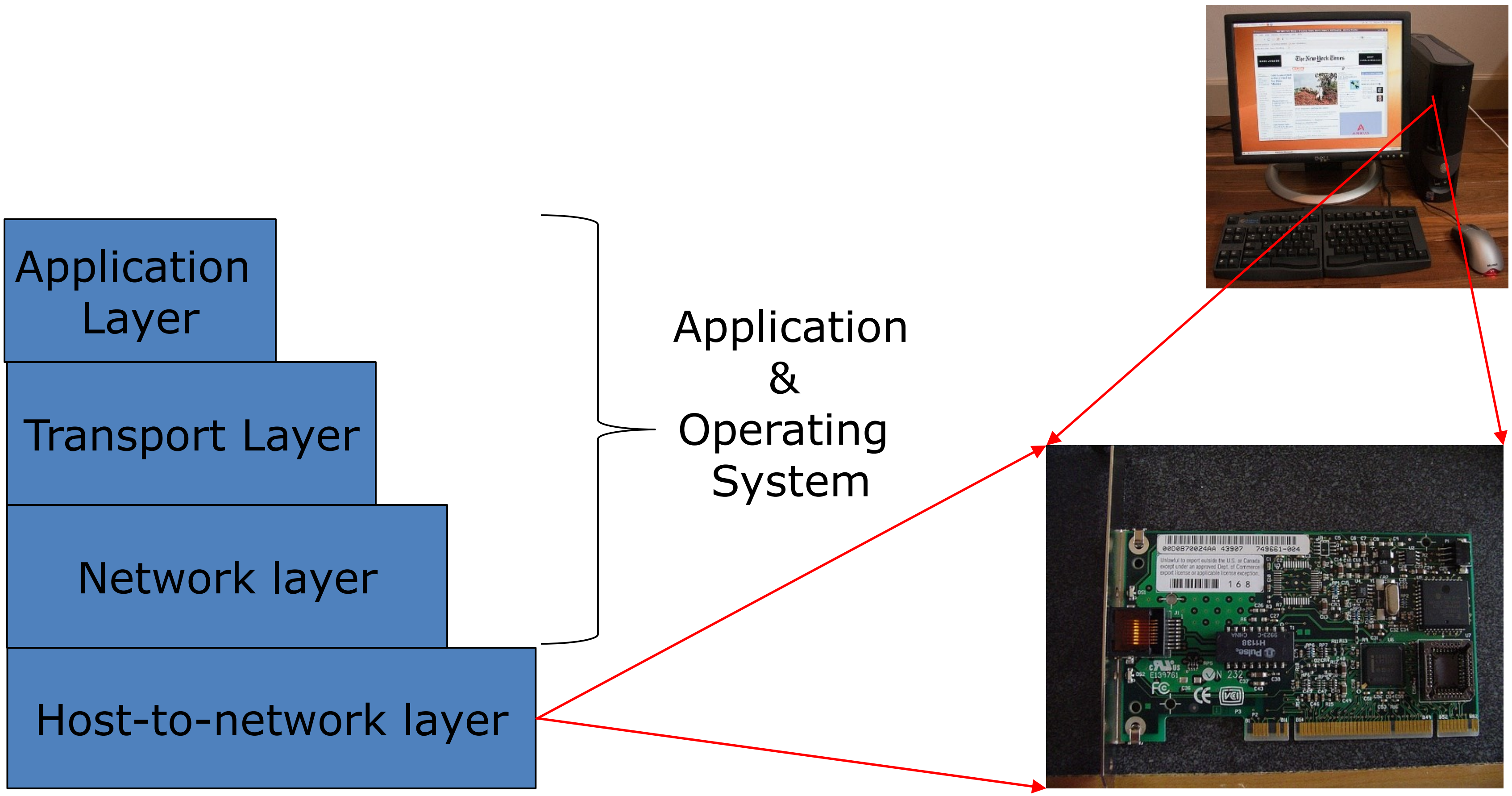
Transport Layer

Network layer

Host-to-network layer

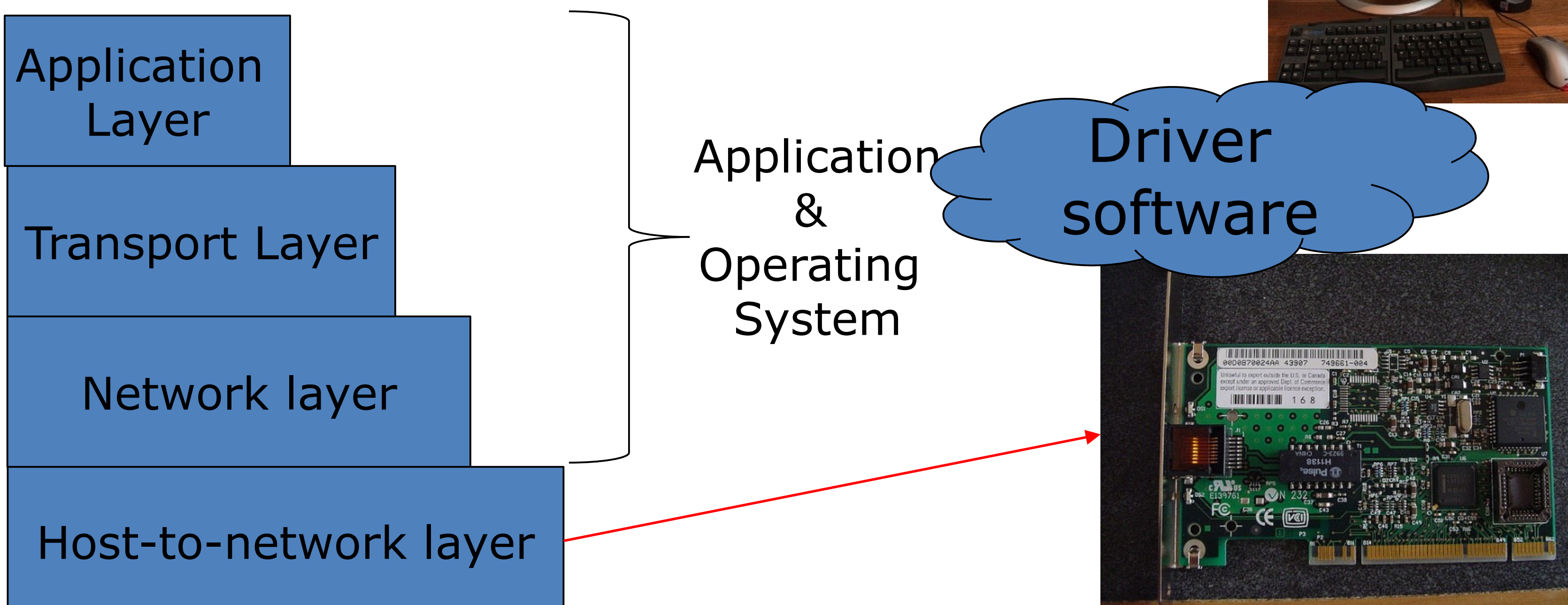
Application & Operating System

Ethernet: Upper Layer Protocol Design and Programming



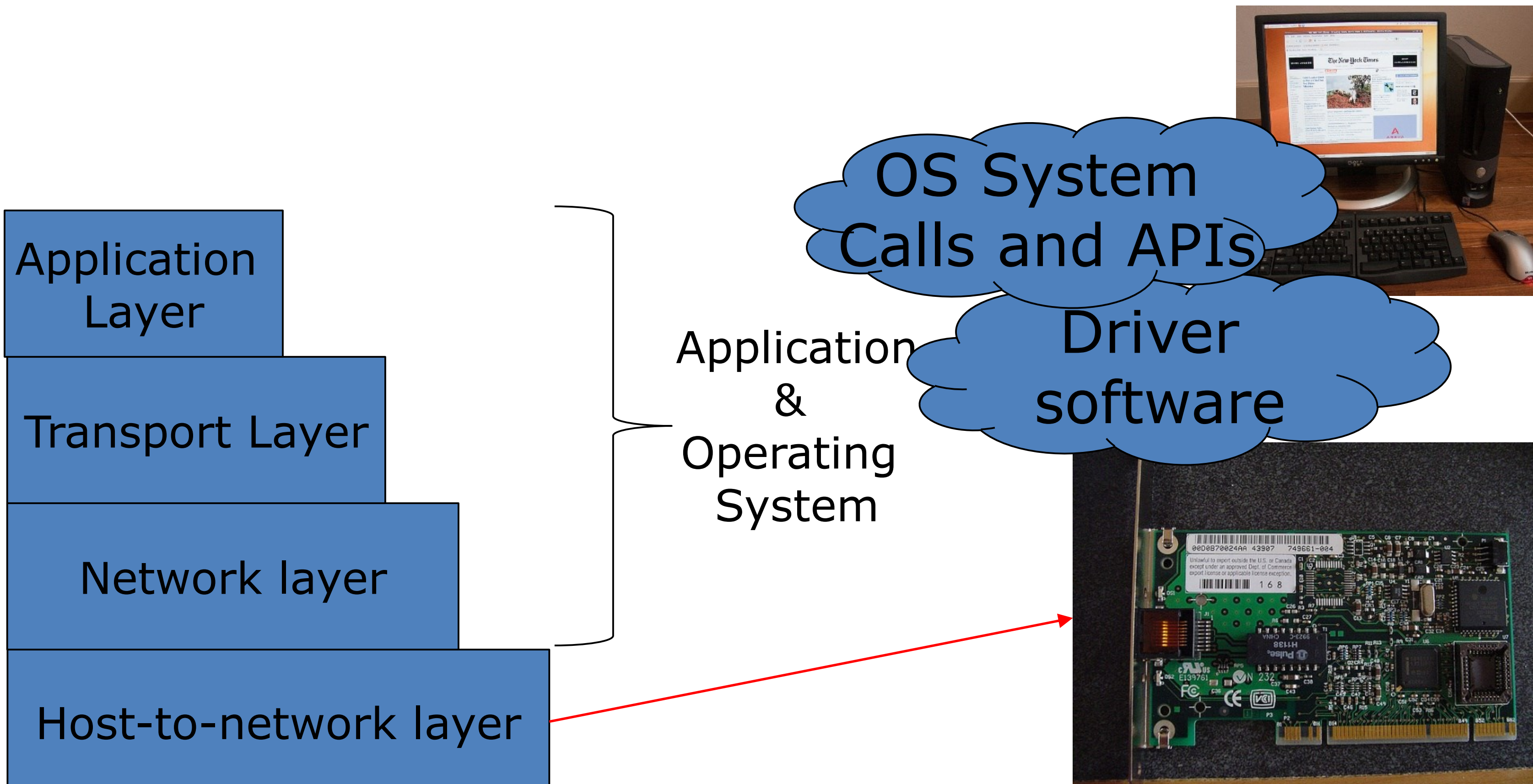
Ethernet: Upper Layer Protocol Design and Programming

- How to access functionality of Ethernet adapter?



Ethernet: Upper Layer Protocol Design and Programming

- How to access functionality of Ethernet adapter?

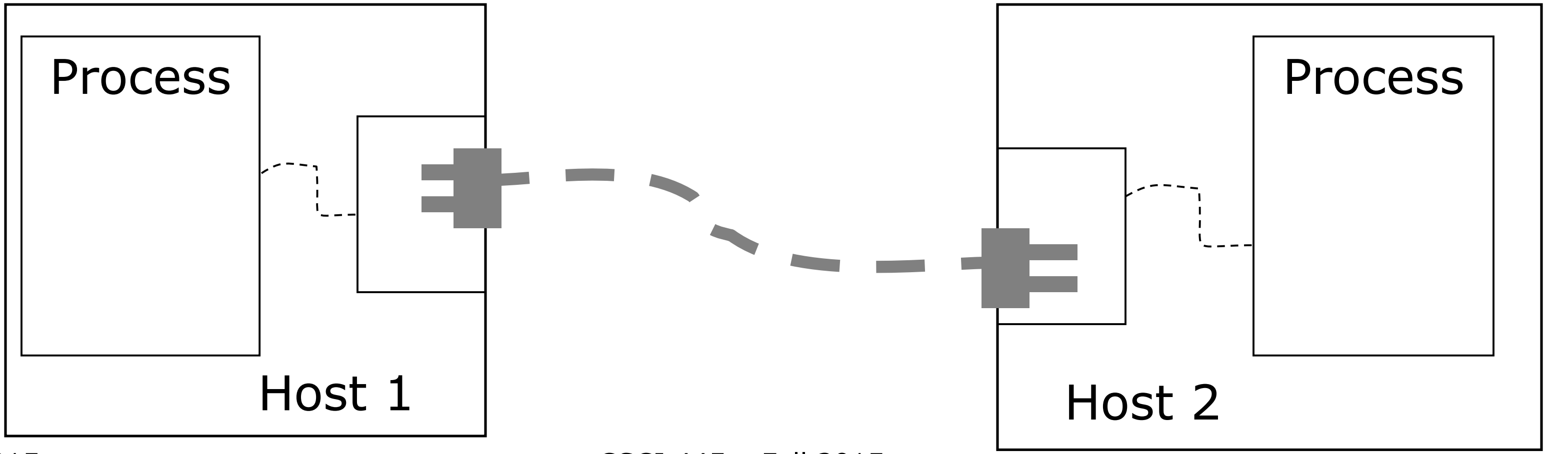


Programming Ethernet

- Writing programs using functionality provided by Ethernet adapters and availed by their drivers
- Low-level program for creating network applications
- Useful to create new upper-layer network protocols or application

Berkeley Sockets

- Protocol provides a set of interfaces → abstract
- API (application programming interface) → how the interfaces exposed in a particular operating system
- Berkeley socket interfaces
  - APIs to multiple protocols
  - Socket: a “point” where an application process attaches to the network; “end-point” of communication



Programming Ethernet with Socket API

- Learn socket APIs to
  - Create a socket
  - Send messages via the socket
  - Receive message via the socket
- Example programs using a typical setup
  - Write two programs (A, B)
    - Program A contains and runs the server logic
    - Program B contains and runs the client logic

Creating Socket

```
int socket(int domain, int type, int protocol)
```

- Creates an endpoint for communication and returns a descriptor.
- Look it up in Linux manual: see socket(2)
  - which means issue command "*man 2 socket*".

Communication Domain

- `int socket(`**`int domain`**`, int type, int protocol)`

- AF_PACKET is our interest: Low level packet interface

  "*Packet sockets are used to receive or send raw packets at the device driver (OSI Layer 2) level. They allow the user to implement protocol modules in user space on top of the physical layer.*"

- More information, see packet(7)

Communication Type

- `int socket(int domain, int type, int protocol)`

- Specify a communication semantics with a communication domain
- For AF_PACKET domain
  - SOCK_RAW: for raw packets (including the link level header)
  - SOCK_DGRAM: for cooked packets (with the link level header removed)

Protocol

- `int socket(int domain, int type, int protocol)`
- Specifies a particular protocol to be used with the socket.
- Protocol is a protocol number in network order
- For AP_PACKET domain
  - Protocol can be the IEEE 802.3 protocol number in network order.
  - linux/if_ether.h lists acceptable protocol numbers for Ethernet (typical location: /usr/include/linux/if_ether.h)

Protocol Number for Ethernet

- linux/if_ether.h lists acceptable protocol numbers for Ethernet
  - typical location: /usr/include/linux/if_ether.h

```
……
#define ETH_P_LOOP  0x0060      /* Ethernet Loopback packet */
#define ETH_P_PUP   0x0200      /* Xerox PUP packet     */
#define ETH_P_PUPAT 0x0201      /* Xerox PUP Addr Trans packet  */
#define ETH_P_IP    0x0800      /* Internet Protocol packet */
……
#define ETH_P_802_3 0x0001      /* Dummy type for 802.3 frames  */
#define ETH_P_AX25  0x0002      /* Dummy protocol id for AX.25  */
#define ETH_P_ALL   0x0003      /* Every packet (be careful!!!) */
        ......
```

Protocol Number

- Which protocol number to use?
- Depending on payload
  - If payload is an IP packet, use ETH_P_IP, i.e., 0x0800
  - If payload is an ARP packet, use ETH_P_ARP, i.e., 0x0806

Protocol Number: Byte Order

- Protocol number must be in network order
- Use functions to convert between host and network order

```
uint32_t htonl(uint32_t hostlong);
uint16_t htons(uint16_t hostshort);
uint32_t ntohl(uint32_t netlong);
uint16_t ntohs(uint16_t netshort);
```

- Example
  - htons (0x0800) or htons(ETH_P_IP)

Protocol Number: New Protocol

- What about developing a new protocol?
  - Choose a number not used
    - May run into the problem that other people also choose the same unused number as you
    - Get approval from the IANA
- What about receiving all frames

Protocol Number: All Frames

- What about receiving all frames
- Use protocol number ETHER_P_ALL
- In network order, htons(ETH_P_ALL) or htons(0x0003)

Putting Together: Raw Packet

```
#define MY_PROTOCOL_NUM 0x60001
int sockfd;

……
sockfd = socket(AP_PACKET,
                SOCK_RAW,
                htons(MY_PROTOCOL_NUM));

if (sockfd == -1) {
     /* deal with error */
}
```

Putting Together: Cooked Packet

```
#define MY_PROTOCOL_NUM 0x60001
int sockfd;


……
sockfd = socket(AP_PACKET,
                SOCK_DGRAM,
                htons(MY_PROTOCOL_NUM));

if (sockfd == -1) {
     /* deal with error */
}
```

Putting Together: All Raw Packet

```
int sockfd;

……
sockfd = socket(AP_PACKET,
                SOCK_RAW,
                htons(ETH_P_ALL));

if (sockfd == -1) {
     /* deal with error */
}
```

Sending Messages

```
ssize_t sendto(int sockfd, const void *buf, size_t
len, int flags, const struct sockaddr *dest_addr,
socklen_t addrlen);

ssize_t send(int sockfd, const void *buf, size_t
len, int flags);

ssize_t write(int fd, const void *buf, size_t
count);

ssize_t sendmsg(int sockfd, const struct msghdr
*msg, int flags);
```

Sending Messages: Manual Pages

- See send(2)
- See sendto(2)
- See sendmsg(2)
- See write(2)

Sending Message: Differences

- Relationship among the system calls
  - write(fd, buf, len);

    is equivalent to

    send(sockfd, buf, len, 0);
  - send(sockfd, buf, len, flags);

    is equivalent to

    sendto(sockfd, buf, len, flags, NULL, 0);
  - write(fd, buf, len);

    is equivalent to

    sendto(sockfd, buf, len, 0, NULL, 0);

Sending Messages: sendto(…)

- ssize_t sendto(int sockfd, const void *buf, size_t len, int flags, const struct sockaddr *dest_addr, socklen_t addrlen);
  - sockfd: the file descriptor of the sending socket
  - buf: message to send
  - len: message length
  - flags: the bitwise OR of flags or 0
  - dest_addr: the address of the target
  - addrlen: the size of the target address

Message

- Case 1: raw packet

  sockfd = socket(AP_PACKET, SOCK_RAW,
  htons(MY_PROTOCOL_NUM));

  - *buf* contains Ethernet header and data (i.e., payload)

- Case 2: cooked packet

  sockfd = socket(AP_PACKET, SOCK_DGRAM,
  htons(MY_PROTOCOL_NUM));

  - *buf* contains data (i.e, payload)

Destination Address

- struct sockaddr *desk_addr
  - struct sockaddr * is a place holder
  - desk_addr should points to an instance of struct sockaddr_ll

Link Layer Address

- See packet(7)

```
struct sockaddr_ll {
  unsigned short sll_family;    /* Always AF_PACKET */
  unsigned short sll_protocol; /* Physical layer protocol */
  int            sll_ifindex;  /* Interface number */
  unsigned char  sll_pkttype;  /* Packet type */
  unsigned char  sll_halen;    /* Length of address */
  unsigned char  sll_addr[8];  /* Physical layer address */
};
```

Receiving Messages

```
ssize_t recvfrom(int sockfd, void *buf, size_t len,
int flags, struct sockaddr *src_addr, socklen_t
*addrlen);

ssize_t recv(int sockfd, void *buf, size_t len, int
flags);

ssize_t write(int fd, const void *buf, size_t
count);

ssize_t recvmsg(int sockfd, struct msghdr *msg, int
flags);
```

Receiving Message: Manual Pages

- See recv(2)
- See recvfrom(2)
- See recvmsg(2)
- See read(2)

Receiving Message: Differences

- Relationship among the system calls
  - read(fd, buf, len);

    is equivalent to

    recv(sockfd, buf, len, 0);
  - recv(sockfd, buf, len, flags);

    is equivalent to

    recvfrom(sockfd, buf, len, flags, NULL, NULL);
  - read(fd, buf, len);

    is equivalent to

    recvfrom(sockfd, buf, len, 0, NULL, NULL);

Message

- Case 1: raw packet

  sockfd = socket(AP_PACKET, SOCK_RAW,
  htons(MY_PROTOCOL_NUM));

  - *buf* contains Ethernet header and data (i.e., payload)

- Case 2: cooked packet

  sockfd = socket(AP_PACKET, SOCK_DGRAM,
  htons(MY_PROTOCOL_NUM));

  - *buf* contains data (i.e., payload)

Socket Option

- Packet sockets can be used to configure *physical layer multicasting* and *promiscuous mode*.
- Get socket option
  - int getsockopt(int sockfd, int level, int optname, void *optval, socklen_t *optlen);
- Set socket option
  - int setsockopt(int sockfd, int level, int optname, const void *optval, socklen_t optlen);

Socket Option: Promiscuous Mode

- See packet(7) for PACKET_MR_PROMISC and PACKET_ADD_MEMBERSHIP
- See setsockopt(2) and getsockopt(2)

Putting Together

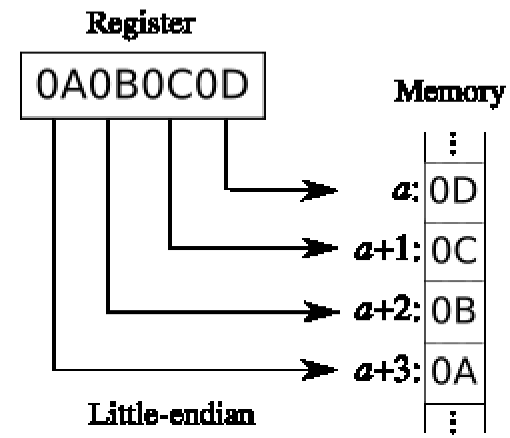
- Sample programs
- Two pairs of programs
  - ethercap and etherinj
  - ethersend and etherrecv

Summary

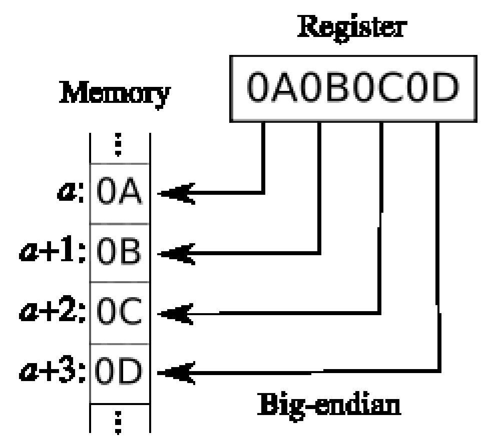
- Client-Server and Peer-to-Peer models
- Connection-oriented and Connectionless communication modes
- Programming Ethernet with Socket APIs
- Byte order and network order
  - If you forgot byte order, continue to study the rest of the slides

Byte Order: Big Endian and Little Endian

- Little Endian
  - Low-order byte of a word is stored in memory at the lowest address, and the high-order byte at the highest address → The little end comes first

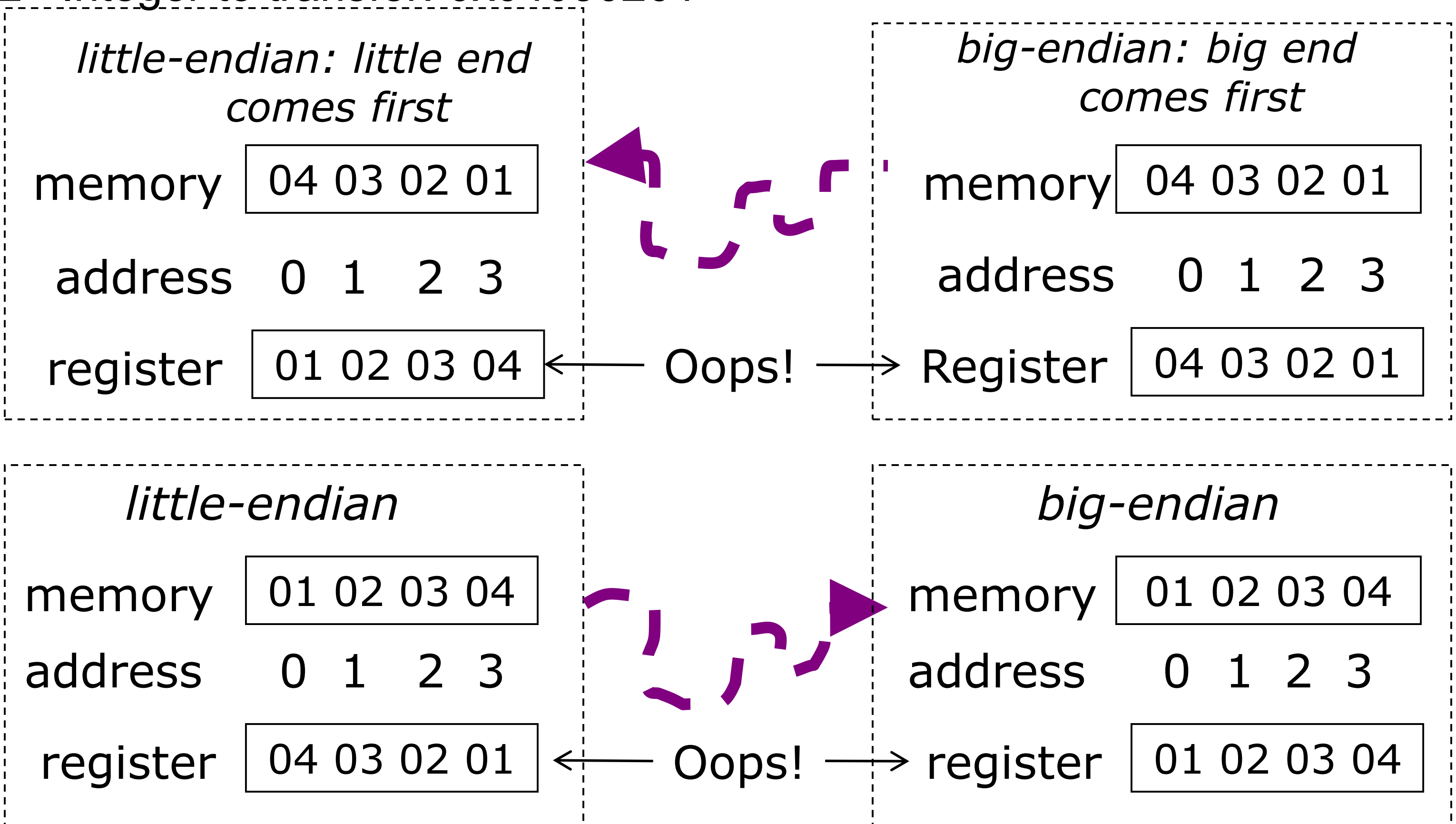


- Big Endian
  - high-order byte of a word is stored in memory at the lowest address, and the low-order byte at the highest address → The big end comes first



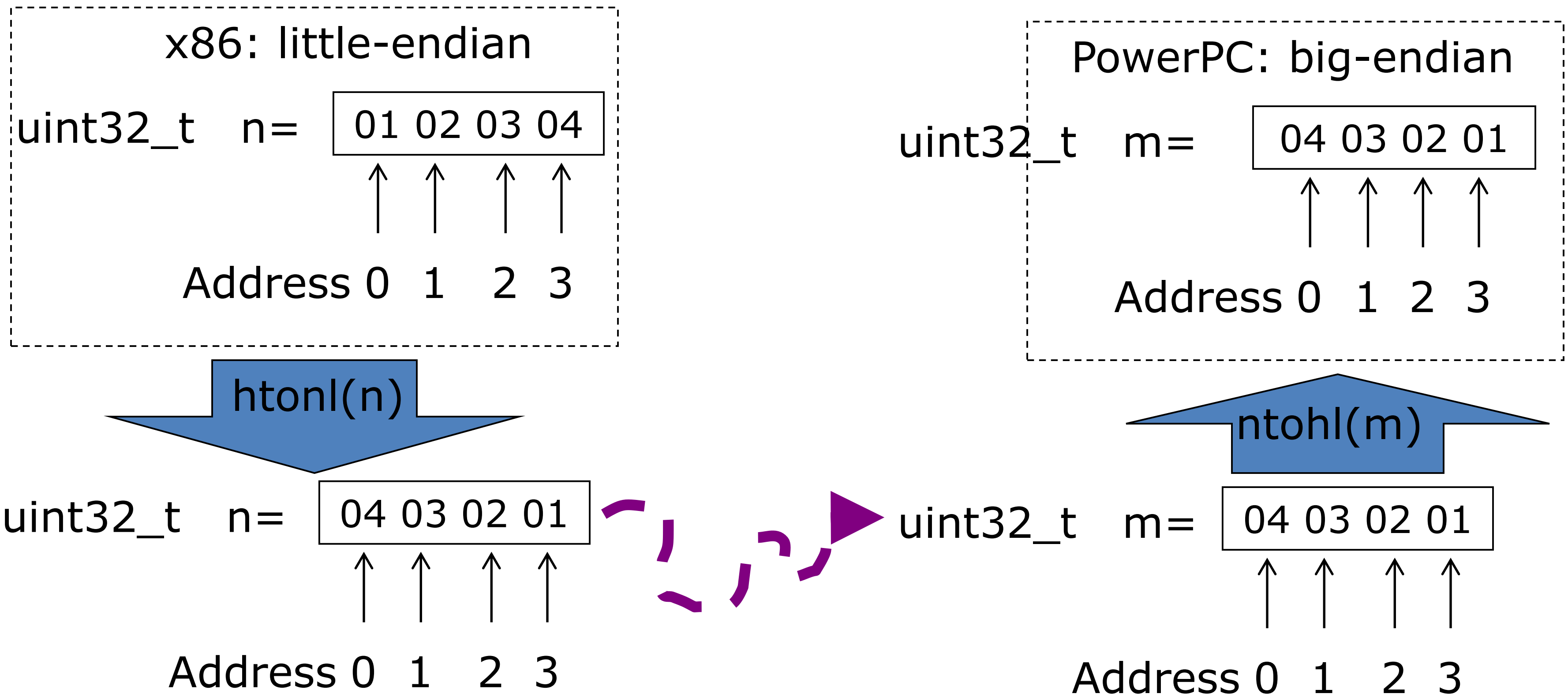
Endian-ness: Transfer Integer over Network

- Integer to transfer: 0x04030201



Network Order

- Integer to transfer: 0x04030201



Network Order

- Integer to transfer: 0x04030201