LEC03.
SOCKET API INTRODUCTION

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Content

- Socket
- Stream Socket
- Datagram Socket
- APIs for managing names and IP addresses
- Socket Address Structures

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Socket

- What is a socket ?
- *Sockets* (in plural) are an application programming interface (API) application program and the TCP/IP stack
- A *socket* is an abstraction through which an application may send and receive data
- A socket allows an application to plug in to the network and communicate with other applications that are plugged into the same network.

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Socket (cont)

- The main types of sockets in TCP/IP are
  - *stream sockets :* use TCP as the end-to-end protocol (with IP underneath) and thus provide a reliable byte-stream service
  - *datagram sockets :* use UDP (again, with IP underneath) and thus provide a ***best-effort*** datagram service
  - *raw socket:* allows direct sending and receiving of Internet Protocol packets without any protocol-specific transport layer formatting.
- Socket Address(excluding raw socket) : include host name and port

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Stream sockets (TCP)

- TCP provides connections between clients and servers
- TCP also provides reliability : When TCP sends data to the other end, it requires an acknowledgment in return
- TCP provides flow control
- TCP connection is full-duplex

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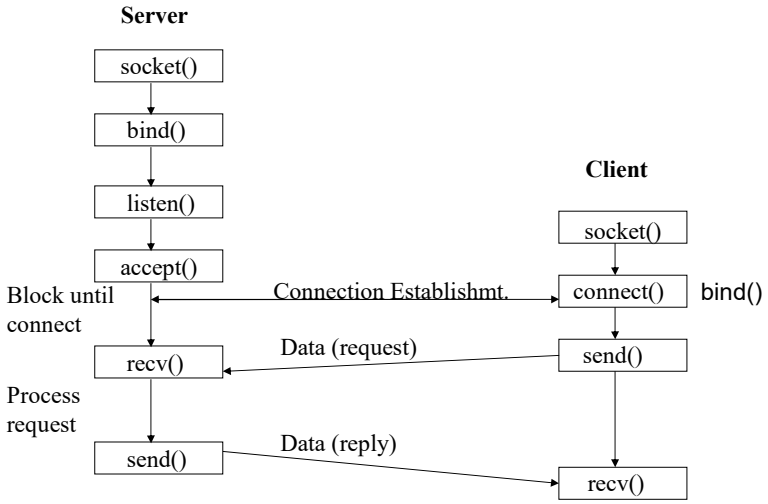
Stream sockets(TCP)



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Stream Socket APIs

- socket()
  - creates a socket of a given domain, type, protocol (buy a phone)
  - Returns a file descriptor (called a socket ID)
- bind()
  - Assigns a name to the socket (get a telephone number)
  - Associate a socket with an IP address and port number (Eg : 192.168.1.1:80)
- connect()
  - Client requests a connection request to a server
  - This is the first of the client calls

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Stream Socket APIs (cont)

- accept() :
  - Server accept an incoming connection on a listening socket (request from a client)
  - There are basically three styles of using accept:
    - *Iterating server*: Only one socket is opened at a time.
    - *Forking server*: After an accept, a child process is forked off to handle the connection.
    - *Concurrent single server*: use select to simultaneously wait on all open socketIds, and waking up the process only when new data arrives

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Stream Socket APIs (cont)

- listen()
  - Specifies the number of pending connections that can be queued for a server socket. (call waiting allowance)
- send()
  - Write to connection (speak)
  - Send a message
- recv()
  - read from connection (listen)
  - Receive data on a socket
- close()
  - close a socket (end the call)

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Datagram Socket (UDP)

- UDP is a simple transport-layer protocol
- If a datagram is errored or lost, it won't be automatically retransmitted (can process in application)
- UDP provides a *connectionless* service, as there need not be any long-term relationship between a UDP client and server

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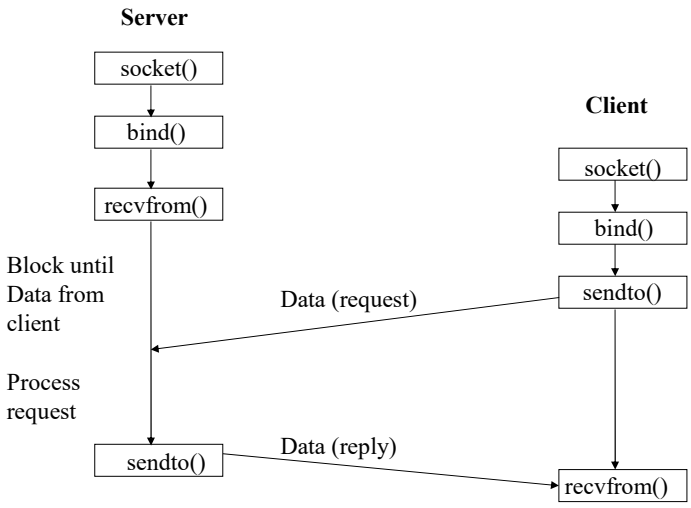
Datagram Socket (UDP)



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APIs for managing names and IP addresses

- `gethostname()`: Returns the name of the system
- `gethostbyname()` : Get an IP address for a hostname, or vice-versa
- `htons(), htonl(), ntohs(), ntohl()`: ***byte ordering***
- `inet_ntoa(), inet_aton()` : Convert IPv4 addresses from a dots-and-number string (eg : 192.168.1.1) to a struct in_addr and back
- `inet_pton(), inet_ntop()`: conversion of IPv4 or IPv6 numbers between presentation and strings

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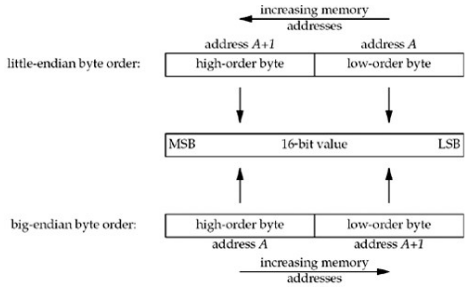
Byte Ordering

- There are two ways to store the two bytes in memory
  - little-endian byte order
  - big-endian byte order



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Byte Ordering (cont)

- There is no standard between these two byte orderings
- A variety of systems that can change between little-endian and big-endian byte ordering
- Problem : Converting between
  - *host byte order*
  - *network byte order* (The Internet protocols use big-endian byte ordering)
- Four functions to convert between these two byte orders.

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htons(), htonl(), ntohs(), ntohl()

- Convert multi-byte integer types from host byte order to network byte order

```
#include <netinet/in.h>
uint32_t htonl(u_long hostlong);  /* host to network long */
uint16_t htons(u_short hostshort);/* host to network short */
uint32_t ntohl(u_long netlong);   /* network to host long */
uint16_t ntohs(u_short netshort); /* network to host short */
```

- Each function returns the converted value.

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IP Number translation

- IP address strings to 32 bit number
- Hence, these routines translate between the address as a string and the address as the number.
- Hence, we have 4 representations:
  - IP number in host order
  - IP number in network order
  - Presentation (eg. dotted decimal)
  - Fully qualified domain name

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Socket Address Structures

- Most socket functions require a pointer to a socket address structure as an argument.
- Each supported protocol suite defines its own socket address structure.
- A Socket Address Structure is a structure which has information of a socket to create or connect with it
- There are three types of socket address structures
  - IPv4
  - IPv6

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IPv4 socket address structure

```
#include <netinet/in.h>
struct in_addr {
   in_addr_t s_addr;          /* 32-bit IPv4 address */
                              /* network byte ordered */
};

struct sockaddr_in {
   uint8_t sin_len;           /* length of structure */
   sa_family_t sin_family;    /* AF_INET */
   in_port_t sin_port;        /* 16-bit TCP or UDP port number
                              network byte ordered */
   struct in_addr sin_addr;   /* 32-bit IPv4 address network byte
                              ordered */
   char sin_zero[8];          /* unused */
};
```

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IPv6 socket address structure

```
#include <netinet/in.h>
struct in6_addr {
   uint8_t s6_addr[16];       /* 128-bit IPv6 address */
                              /* network byte ordered */
};

#define SIN6_LEN              /* required for compile-time tests  */

struct sockaddr_in6 {
   uint8_t sin6_len;          /* length of this struct */
   sa_family_t sin6_family;   /* AF_INET6 */
   in_port_t sin6_port;       /* transport layer port# network byte
                              /* ordered */
   uint32_t sin6_flowinfo;    /* flow information, undefined */
   struct in6_addr sin6_addr;/* IPv6 address network byte ordered */
   uint32_t sin6_scope_id;    /* set of interfaces for a scope */
};
```

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inet_aton()

```
#include <arpa/inet.h>
int inet_aton(const char *cp, struct in_addr *inp)
```

- Convert IP addresses from a dots-and-number string to a struct `in_addr`
- Return:
  - The value non-zero if the address is valid
  - The value 0 if the address is invalid

```
struct in_addr someAddr;
if(inet_aton("10.0.0.1", &someAddr))
   printf("The address is valid");
else printf ("The address is invalid");
```

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[[deprecated]] inet_ntoa()

```
#include <arpa/inet.h>
char *inet_ntoa(struct in_addr in);
```

- Convert IP addresses from a struct `in_addr` to a dots-and-number string
- Return: the dots-and-numbers string

```
struct in_addr someAddr;
if(inet_aton("10.0.0.1", someAddr))
   printf("The address is valid");
else printf ("The address is invalid");
char *addrStr;
addrStr = inet_ntoa(someAddr);
```

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inet_addr()

```
#include <arpa/inet.h>
in_addr_t inet_addr(const char *cp);
```

- Convert IP addresses from a dots-and-number string to a struct `in_addr_t`
- Return:
  - The value -1 if there's an error
  - The address as an `in_addr_t`

```
struct in_addr someAddr;
someAddr.s_addr = inet_addr("10.0.0.1");
```

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inet_pton()

```
#include <arpa/inet.h>
int inet_pton(int family, const char *cp, void *addr)
```

- Convert IP addresses from a dots-and-number string to a struct `in_addr` or `in6_addr`
- `family` is `AF_INET` or `AF_INET6`
- Return:
  - The value non-zero if the address is valid
  - The value 0 if the address is invalid

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inet_ntop()

```
#include <arpa/inet.h>
const char *inet_ntop(int family, const void *addr,
                      char *cp, size_t len);
```

- Convert IP addresses from a struct `in_addr` to a dots-and-number string
- Return: the dots-and-numbers string

```
struct sockaddr_in sa;
char str[INET_ADDRSTRLEN];

// store this IP address in sa:
inet_pton(AF_INET, "192.0.2.33", &(sa.sin_addr));

// now get it back and print it
inet_ntop(AF_INET, &(sa.sin_addr), str, INET_ADDRSTRLEN);
printf("%s\n", str);
```

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ADDRESS RESOLUTION

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Content

- IPv4 and IPv6
- DNS
- Address and Name APIs

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IPv4

- Developed in APRANET (1960s)
- 32-bit number
- Divided into classes that describe the portion of the address assigned to the network (netID) and the portion assigned to endpoints (hosten)
  - A : netID – 8 bit
  - B : netID – 16 bit
  - C : netID – 24 bit
  - D : use for multicast
  - E : use for experiments

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IPv4 problem

- IPv4 addresses is being exhausted
- Have to map multiple private addresses to a single public IP addresses (NATs)
  - Connect 2 PCs use private address space ?
  - NAT must be aware of the underlying protocols
- IPv4 addressing is not entirely hierarchical → router must maintain routing table to deliver packets to right locations

→ Develope a new version of IP Address : IPv6

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IPv6

- IPv6 address is 128 bits
  - To subdivide the available addresses into a hierarchy of routing domains that reflect the Internet's topology
- IPv6 address is typically expressed in 16-bit chunks displayed as hexadecimal numbers separated by colons

  Example : 21DA:00D3:0000:2F3B:02AA:00FF:FE28:9C5A

  or : 21DA:D3:0:2F3B:2AA:FF:FE28:9C5A

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DNS (Domain Name System)

- Computers use IP Addresses to connect hosts
  - What about humans ? – IP Addresses are very complex and hard to remember (for people)
- Use name instead of IP Address → Domain Name System
- Problem of DNS
  - People use names, Computers use IP Addresses → translate between two spaces
  - Domain name system must be hierarchical (for management and maintain)
- Domain name space : divide to zones

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DNS (cont)

- How to translate between domain name-IP Address and reverse ?
  - DNS Resolver
  - DNS Server
- A DNS query
  - A *non-recursive query* : DNS server provides a record for a domain for which it is authoritative itself, or it provides a partial result without querying other servers
  - A *recursive query* : DNS server will fully answer the query by querying other name servers
- DNS primarily uses User Datagram Protocol (UDP) on port number 53 to serve requests

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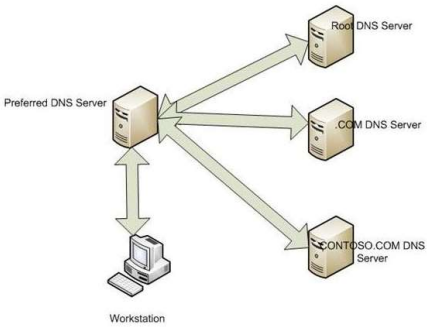
DNS (cont)

- Address resolution mechanism
  - Local system is pre-configured with the known addresses of the root server in a file of *root hints*
  - Query one of the root servers to find the server authoritative for the next level down
  - Querying level down server for the address of a DNS server with detailed knowledge of the lower level domain until reach the DNS

  Server return final address



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DNS (cont)

- A *Resource Record* (RR) is the basic data element in the domain name system
- All records use the common format specified in RFC 1035 (in IP networks)
- **RR (Resource record) fields**
  - NAME (variable)
    - Name of the node to which this record pertains.
  - TYPE (2)
    - Type of RR. For example, MX is type 15
  - CLASS (2)
    - Class code
  - TTL (4)
    - Unsigned time in seconds that RR stays valid
  - RDLENGTH (2)
    - Length of RDATA field
  - RDATA (variable)
    - Additional RR-specific data

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List of Address and Name APIs

#include <sys/socket.h>

- **gethostbyaddr()**
  - Retrieve the name(s) and address corresponding to a network address.
- **gethostname()**
  - Retrieve the name of the local host.
- **gethostbyname()**
  - Retrieve the name(s) and address corresponding to a host name.
- **getprotobyname()**
  - Retrieve the protocol name and number corresponding to a protocol name.
- **getprotobynumber()**
  - Retrieve the protocol name and number corresponding to a protocol number.
- **getservbyname()**
  - Retrieve the service name and port corresponding to a service name.
- **getservbyport()**
  - Retrieve the service name and port corresponding to a port.

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New APIs for IPv6

- Those APIs only supports IPv4 but IPv6 will be replace IPv4 in the future, so we need APIs support IPv6
- They are
  - getaddrinfo
  - getnameinfo
- These APIs have replaced the IPv4 specific routines

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[[deprecated]] gethostbyaddr()

```
#include <netdb.h>
#include <sys/socket.h>
struct hostent *gethostbyaddr (in_addr *addr, socklen_t len,
                               int family);
```

- Get host information corresponding to an address.
- Parameters:
  - [IN] `addr`: A pointer to an address in network byte order.
  - [IN] `len`: The length of the address, which must be 4 for AF_INET addresses.
  - [IN] `family`: The type of the address, which must be AF_INET.
- Return value
  - If no error occurs, returns a pointer to the `hostent` structure
  - Otherwise it returns a NULL pointer and a specific error number

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struct hostent

```
struct hostent {
    char    *h_name;        /* official (canonical) name of host*/
    char    **h_aliases;    /* pointer to array of pointers to
                               alias names  */
    int       h_addrtype;   /* host address type: AF_INET  */
    int       h_length;     /* length of address: 4 */
    char    **h_addr_list;  /* ptr to array of ptrs with IPv4
                               addrs */
};
```

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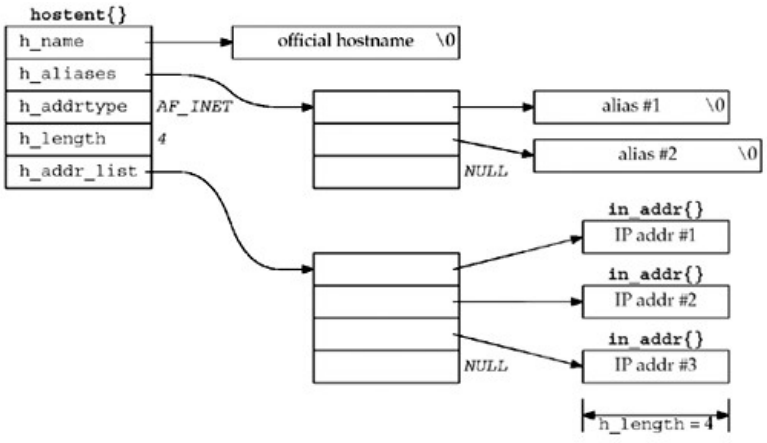
struct hostent



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gethostname()

```
#include <sys/unistd.h>
#include <sys/socket.h>
int gethostname(char *name, size_t len);
```

- Return the standard host name for the local machine.
- Parameters:
  - [OUT] `name`: points to a buffer that will receive the host name.
  - [IN] `len`: the length of the buffer
- Return value
  - If no error occurs, returns 0
  - Otherwise it returns SOCKET_ERROR and a specific error code

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[[deprecated]] gethostbyname()

```
#include <netdb.h>
#include <sys/socket.h>
struct hostent *gethostbyname (const char *hostname);
```

- Get host information corresponding to a hostname.
- [IN] `name`: Points to the name of the host
- Returns a pointer to a `hostent` structure
- Return value
  - If no error occurs, returns a pointer to the `hostent` structure described above.
  - Otherwise it returns a NULL pointer and a specific error number

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getaddrinfo()

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
int getaddrinfo(const char *node, const char *service, const
struct addrinfo *hints, struct addrinfo **res);
```

- Get host information corresponding to a `node` and `service`.
- [IN] `node`: name of the host
- [IN] `service`: name of the service
- [IN] `hint`: limit the set of uddresses returned by `getaddrinfo()`
- [OUT] `res`: points to linked-list containing host information
- Return value
  - If no error occurs, returns 0
  - Otherwise it returns error code

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freeaddrinfo()

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
int freeaddrinfo(struct addrinfo *res);
```

- Frees the memory that was allocated for the dynamically allocated linked list `res`.

gai_strerror()

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
const char* gai_strerror(int errcode);
```

- Translates these error codes to a human readable string

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struct addrinfo

```
typedef struct addrinfo {
  int         ai_flags;       /*additional options*/
  int         ai_family;      /*desired address family for the
                              returned addresses*/
  int         ai_socktype;    /*preferred socket type*/
  int         ai_protocol;    /*protocol for the returned socket
                              addresses */
  size_t      ai_addrlen;     /*length of ai_addr */
  char             *ai_canonname; /*canonical name */
  struct sockaddr  *ai_addr;  /*binary address */
  struct addrinfo  *ai_next;  /*next structure in linked list*/
};
```

- ai_family: AF_INET, AF_INET6 or AF_UNSPEC
- ai_socktype: SOCK_STREAM, SOCK_DGRAM or 0 for any type
- ai_protocol: 0 for any protocol

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Example

```
struct addrinfo* result;
struct addrinfo* res;
struct sockaddr_in  *address;
int error;
char ipStr[INET_ADDRSTRLEN];

/* resolve the domain name into a list of addresses */
error = getaddrinfo("facebook.com", NULL, NULL, &result);
if (error != 0) {
   if (error == EAI_SYSTEM) {
      perror("getaddrinfo");
   }
   else {
      fprintf(stderr, "error: %s\n", gai_strerror(error));
   }
   exit(EXIT_FAILURE);
}
address = (struct sockaddr_in *) result->ai_addr;
inet_ntop(AF_INET, &address->sin_addr, ipStr, sizeof(ipStr));
printf("IPv4 address: %s\n", ipStr);

freeaddrinfo(result);
```

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getnameinfo()

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
int getnameinfo(const struct sockaddr *sa, socklen_t salen, char
*node, socklen_t nodelen, char *service, socklen_t servicelen, int
flag);
```

- Converts a socket address to a corresponding host and service.
- [IN] `sa`: points to a socket address structure
- [OUT] `node`: points to a buffer able to contain hostname
  - `node` = NULL, `nodelen` = 0: hostname shall not be returned
- [OUT] `service`: points to a buffer able to contain service name
  - `service` = NULL, `servicelen` = 0: service name shall not be returned
- [INT] `flag`: changes the default actions of the function
- Return value
  - If no error occurs, returns 0
  - Otherwise it returns error code

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Example

```
struct sockaddr_in addr;
int ret;
char hostname[NI_MAXHOST];
char servInfo[NI_MAXSERV];
addr.sin_family = AF_INET;
inet_pton(AF_INET, "8.8.8.8", &addr.sin_addr);

ret = getnameinfo((struct sockaddr *) &addr, sizeof(struct
sockaddr), hostname, NI_MAXHOST, servInfo, NI_MAXSERV, 0);

if (ret != 0)
   printf("Failed: %s\n", gai_strerror(ret));
else
   printf("Hostname: %s\nService: %s\n", hostname, servInfo);
```

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getservbyname()

```
#include <netdb.h>
#include <sys/socket.h>
struct servent *getservbyname (const char *servname,
                               const char *protoname);
```

- Get service information corresponding to a service name and protocol.
- Parameters:
  - [IN] `servname`: A pointer to a service name.
  - [IN] `protoname`: An optional pointer to a protocol name.
    - If this is NULL, getservbyname() returns the first service entry for which the name matches the `s_name` or one of the `s_aliases`.
    - Otherwise getservbyname() matches both the name and the proto.
- Returns
  - non-null pointer if OK
  - NULL on error

```
struct servent *sptr;
sptr = getservbyname("ftp", "tcp");
```

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struct servent

```
struct servent {
        char *s_name;
        char **s_aliases;
        int s_port;
        char *s_proto;
};
```

- `s_name`
  - Official name of the service.
- `s_aliases`
  - A NULL-terminated array of alternate names.
- `s_port`
  - The port number at which the service may be contacted. Port numbers are returned in network byte order.
- `s_proto`
  - The name of the protocol to use when contacting the service.

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getservbyport()

```
#include <netdb.h>
#include <sys/socket.h>
struct servent *getservbyport (int port, const char *protoname);
```

- Get service information corresponding to a port and protocol.
- Parameters:
  - [IN] `port`: The port for a service, in network byte order.
  - [IN] `protoname`: An optional pointer to a protocol name.
    - If this is NULL, returns the first service entry for which the port matches the `s_port`.
    - Otherwise getservbyport() matches both the port and the proto.
- Return
  - non-null pointer if OK
  - NULL on error

```
struct servent *sptr;
sptr = getservbyport (htons (53), "udp");
```

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getpeername ()

```
#include <sys/socket.h>
int getpeername(int sockfd, struct sockaddr *addr,
                                socklen_t *addr_len);
```

- Retrieve the address associated with the remote socket
- Parameters:
  - [IN] `sockfd`: the local socket connecting to remote socket
  - [OUT] `addr`: points to the `sockaddr` struct
  - [IN, OUT] `addr_len`: points to the `socklen_t` value initiated to indicate the amount of space pointed to by `addr`.
- Return:
  - On success, returns 0
  - On error, return -1 and `errno` set to indicate the error

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