TECHNISCHE UNIVERSITÄT WIEN

Exercise 3: Sockets

191.002 Operating Systems VU
2024W

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Overview

Inter-process communication

Considered so far. . .

Exchanging data between processes on the same system

- Explicit synchronization between unrelated processes
  - Shared Memory
  - Semaphores
- Implicit synchronization between related processes
  - Blocking read- and write operations
  - Non-related processes via sockets
  - Related processes via unnamed pipes

Today. . .

Exchanging data via sockets - either on the same system or over a network

- Implicit synchronization between unrelated processes

Byte Order or Endianness

- Sequential ordering of bytes in memory

```c
int i = 0x12345678; // 8 hex digits = 4 bytes
```

  - Little endian: little end first = least significant byte first

Byte address	&i	&i + 1	&i + 2	&i + 3
Byte content	0x78	0x56	0x34	0x12

  - Big endian: big end first = most significant byte first

Byte address	&i	&i + 1	&i + 2	&i + 3
Byte content	0x12	0x34	0x56	0x78

- Byte order in memory depends on processor architecture (x86 is little endian)
- When writing multiple bytes, program must take care of byte order
- Network byte order is big endian

Byte Order or Endianness

Write bytes explicitely in little endian order:

```c
int i = 0x12345678;
uint8_t buf[sizeof(int)];
int pos;
for (pos = 0; pos < sizeof(int); pos++)
    buf[pos] = i >> 8 * pos;

fwrite(buf, sizeof(int), 1, out);
```

Read bytes explicitely in little endian order:

```c
uint8_t buf[sizeof(int)];
fread(buf, sizeof(int), 1, in);
int i = 0;
int pos;
for (pos = 0; pos < sizeof(int); pos++)
    i |= (int)buf[pos] << 8 * pos;
// i == 0x12345678
```

Byte Order or Endianness

uint32_t **htonl**(uint32_t netlong)

- Convert a 32-bit from host byte order to network byte order

uint32_t **ntohl**(uint32_t netlong)

- Convert a 32-bit integer from network byte order to host byte order

Sockets

- What is a socket?
  - Method for interprocess communication (IPC)
  - Either on a single host or between different hosts in a network (or via internet)
- Common scenario: communication between a client and a server
- Sockets are handled like files
  - Each socket gets a file descriptor
  - Reading and writing to the associated file descriptor

Socket API

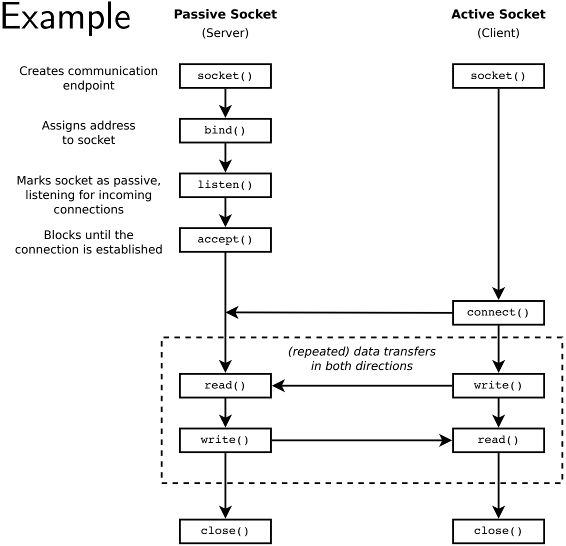
- Sockets are an interface to the transport layer of a communication protocol
  - Direct communication between client and server: no need to know the network layout
  - Sockets do not implement application protocols (HTTP, FTP, . . .)
- Connection-oriented, bidirectional and reliable communication channel
- The connection is established between two endpoints
  - Endpoint on server side: Server IP + known port number
  - Endpoint on client side: Client IP + unused port number

Sockets

Address families and socket types

- Address family (network layer)
  - Internet Protocol, version 4 (IPv4)
    AF_INET → man 7 ip
  - Internet Protocol, version 6 (IPv6)
    AF_INET6 (IPv6) → man 7 ipv6
  - Unix Domain Sockets (local IPC)
    AF_UNIX → man 7 unix
- Socket type
  - Connection-oriented sockets (stream based)
    - SOCK_STREAM, default for IP is TCP
    - Connection is identified by two endpoints
  - Connection-less sockets (datagram/message based)
    - SOCK_DGRAM, default for IP is UDP

Client-Server Example


Passive Socket
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Active Socket
(Client)
Creates communication endpoint
socket()
socket()
Assigns address to socket
bind()
Marks socket as passive, listening for incoming connections
listen()
Blocks until the connection is established
accept()
connect()
(repeated) data transfers in both directions
read()
write()
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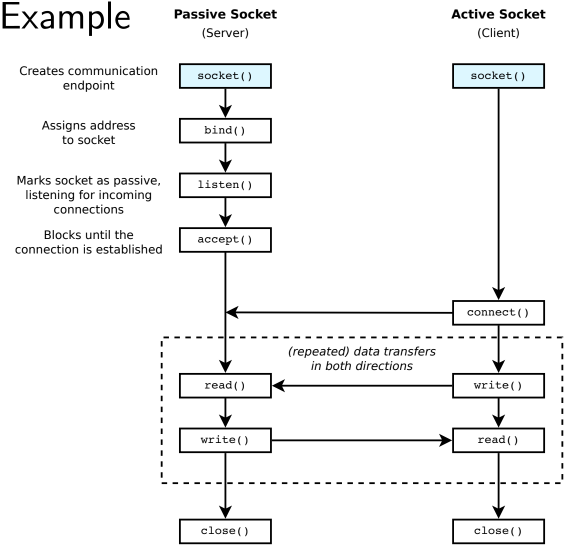
read()
close()
close()

Client-Server Example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System Call: socket()

int **socket**(int family, int type, int protocol)

- Creates a communication endpoint (socket)

  family address family

  type socket type

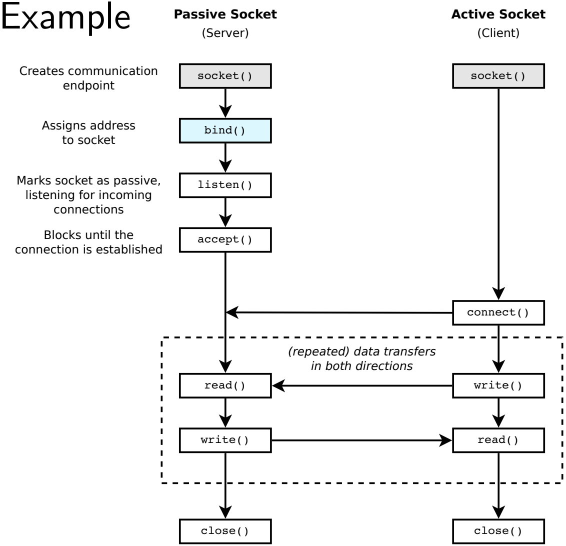
  protocol communication protocol to be used

  - address family + type usually implies protocol
  - 0 for default-protocol
- Return value: File descriptor of the newly created socket or -1 on failure (→ errno)

```c
int sockfd = socket(AF_INET, SOCK_STREAM, 0);

if (sockfd < 0)
    // error, check errno for details
```

Client-Server Example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System Call: bind()

int **bind**(int socket, struct sockaddr *address,
socklen_t addr_len)

- Assigns the specified address to a socket

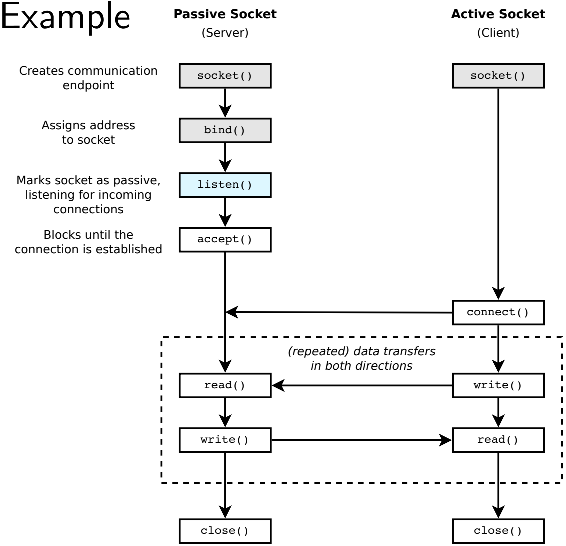
  socket file descriptor of the socket
  address data structure with the desired address
  addr_len size of the address data structure

- Return value: 0 on success, -1 on failure (→ errno)

```c
struct sockaddr_in *sa;
...

if (bind(sockfd, sa, sizeof(struct sockaddr_in)) < 0)
    // error
```

Client-Server Example



Passive Socket
(Server)

Active Socket
(Client)

Creates communication endpoint

Assigns address to socket

Marks socket as passive, listening for incoming connections

Blocks until the connection is established

(repeated) data transfers in both directions

System Call: listen()

int **listen**(int socket, int backlog)

- Listen for connections on a socket (= mark it as passive)
- For connection-oriented protocols only

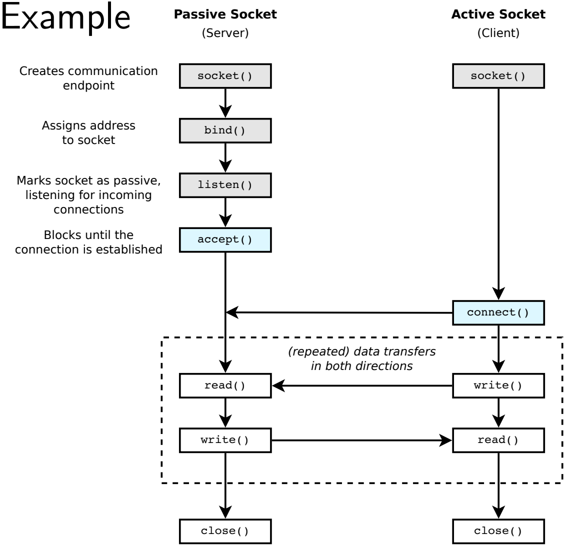
socket socket file descriptor

backlog number of connection requests, which are managed in a queue by the OS, until the server accepts them

- Return value: 0 on success, -1 on failure (→ errno)

```c
if (listen(sockfd, 1) < 0)
    // error
```

Client-Server Example



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System Call: accept()

```
int accept(int socket, struct sockaddr *address,
                        socklen_t *addr_len)
```

- Accept a new connection on a socket (passive, server)

  socket socket file descriptor

  address pointer to a sockaddr structure where the address of the connecting socket is returned (actual type depends on protocol, e.g. `sockaddr_in`), `NULL` possible

  addr_len pointer to the size of the structure in address
- Blocks if there is no pending request
- Returns a new socket (file descriptor) for the first pending connection or -1 on error (→ errno)

```c
int connfd = accept(sockfd, NULL, NULL);
if (connfd < 0)
    // error
```

System Call: connect()

```
int connect(int socket, const struct sockaddr *address,
                                    socklen_t addr_len)
```

- Initiate a connection (active, client)

socket	socket file descriptor
address	address of the server (destination)
addr_len	size of the address structure

- Returns after the connection has been established
- The operating system of the client selects an arbitrary, unused port

```
struct sockaddr_in server_addr;
...

if (connect(sockfd, &server_addr, sizeof(server_addr)) < 0)
    // error
```

getaddrinfo(3)

int **getaddrinfo**(const char *node, const char *service,
const struct addrinfo *hints, struct addrinfo **res)

- Create a suitable socket address with getaddrinfo(3)

  node Hostname (e.g. “localhost”, “173.194.44.232”, “google.com”) or NULL (for usage with bind())

  service port no. or name of service (e.g. “80”, “http”)

  hints Selection criteria

  res Destination address for the resulting `addrinfo` structure (filled by getaddrinfo)

- Returns 0 on success or an error code **(no use of errno!)**
- See also gai_strerror(3) and freeaddrinfo(3)

```
struct addrinfo hints, *ai;   memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
```

getaddrinfo(3)

int **getaddrinfo**(const char *node, const char *service,
const struct addrinfo *hints, struct addrinfo **res)

- Create a suitable socket address with getaddrinfo(3)
  - node Hostname (e.g. “localhost”, “173.194.44.232”, “google.com”) or NULL (for usage with bind())
  - service port no. or name of service (e.g. “80”, “http”)
  - hints Selection criteria
  - res Destination address for the resulting `addrinfo` structure (filled by getaddrinfo)
- Returns 0 on success or an error code **(no use of errno!)**
- See also gai_strerror(3) and freeaddrinfo(3)

```
struct addrinfo hints, *ai;   memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
int res = getaddrinfo("localhost", "1280", &hints, &ai);
if (res != 0) { fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(res)); }
```

Example: getaddrinfo()

Client

```c
struct addrinfo hints, *ai;
memset(&hints, 0, sizeof hints);
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;

int res = getaddrinfo("localhost", "1280", &hints, &ai);
if (res != 0) {
    // error
}
int sockfd = socket(ai->ai_family, ai->ai_socktype,
                    ai->ai_protocol);
if (sockfd < 0) {
    // error
}
if (connect(sockfd, ai->ai_addr, ai->ai_addrlen) < 0) {
    // error
}
freeaddrinfo(ai);
```

Example: getaddrinfo()

Server

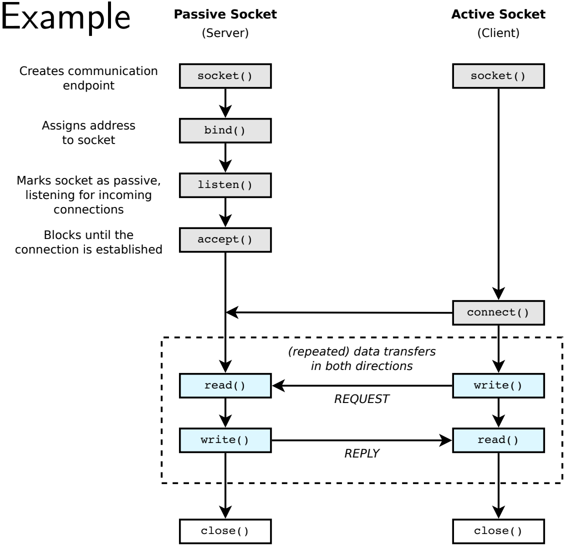
```c
struct addrinfo hints, *ai;
memset(&hints, 0, sizeof hints);
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
hints.ai_flags = AI_PASSIVE;                                          // <--
int res = getaddrinfo( NULL      , "1280", &hints, &ai);              // <--
if (res != 0) {
    // error
}
int sockfd = socket(ai->ai_family, ai->ai_socktype,
                    ai->ai_protocol);
if (sockfd < 0) {
    // error
}
if (   bind(sockfd, ai->ai_addr, ai->ai_addrlen) < 0) {              // <--
    // error
}
freeaddrinfo(ai);
```

gethostbyname(3)

getaddrinfo replaces the obsolete function gethostbyname

- gethostbyname does not support IP version 6 and is obsolete
- Most of the C socket examples that can be found online still use the old gethostbyname
- **You must not use gethostbyname and related functions (i.e. gethostbyaddr, gethostbyname2, gethostent_r, gethostbyaddr_r, gethostbyname_r, gethostbyname2_r, . . .) during the exercises or the exams!**

Client-Server Example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REQUEST
write()
read()
REPLY
close()
close()

Send and Receive

write(2) and read(2)

- After the connection has been established, the file descriptor of the socket is used to read and write data
- Use read and write the same way as with files

```c
char buf[80];
int pos, cnt;

for (pos = 0; pos < sizeof(buf); ) {
    cnt = read(sockfd, buf + pos, sizeof(buf) - pos);
    if (cnt < 0) {
      if (errno != EINTR) { /* other error than EINTR */ }
    } else
        pos += cnt;
}
```

- You can also use the Stream I/O with fdopen() (don't forget about buffering, use fflush() to send the data!)

Send/Receive using Stream I/O - Example (no error handling)

```c
struct addrinfo hints, *ai;
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
getaddrinfo("neverssl.com", "http", &hints, &ai);

int sockfd = socket(ai->ai_family, ai->ai_socktype,
                    ai->ai_protocol);
connect(sockfd, ai->ai_addr, ai->ai_addrlen);
```

Send/Receive using Stream I/O - Example (no error handling)

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memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;
getaddrinfo("neverssl.com", "http", &hints, &ai);

int sockfd = socket(ai->ai_family, ai->ai_socktype,
                    ai->ai_protocol);
connect(sockfd, ai->ai_addr, ai->ai_addrlen);
// send and receive data over connection
FILE *sockfile = fdopen(sockfd, "r+");

fputs("GET / HTTP/1.1\r\nHost: neverssl.com\r\n\r\n",
      sockfile);
fflush(sockfile); // send all buffered data

char buf[1024];
while (fgets(buf, sizeof(buf), sockfile) != NULL)
    fputs(buf, stdout);
```

Send and Receive

send(2) and recv(2)

```
int send(int socket, const void *msg, size_t msg_len, int flags)
int recv(int socket, void* buf, size_t buf_len, int flags)
```

- Spezializations of write und read for sockets
- Return value and first three arguments same as for write und read
- Additional argument: flags
  - MSG_DONTWAIT – Non-blocking send/receive
  - MSG_WAITALL – Block until all data was received (exceptions: error, signal received)

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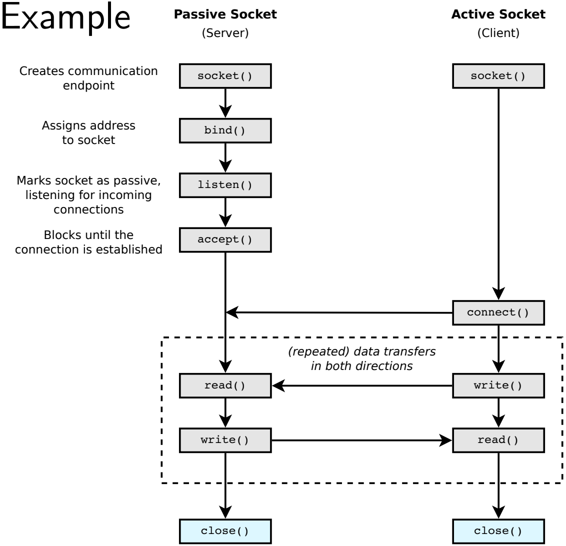
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Socket Options

int **setsockopt**(int socket, int level, int option_name,
const void *option_value, socklen_t option_len)

- Set options on a socket (see man page for full list: setsockopt(2), socket(7), ip(7))
- Useful to avoid the error "Address already in use" (EADDRINUSE) with bind upon restarting your server program (otherwise the port remains unusable for approximately 1 min after the server was terminated)

```c
int optval = 1;
setsockopt(serverfd, SOL_SOCKET, SO_REUSEADDR, &optval,
           sizeof optval);
```

Exercise 3

Client and server for HTTP

- 3A: Client
- 3B: Server
- IPC via stream-oriented sockets
- Implement a subset of the HTTP (HyperText Transfer Procotol), used for requesting websites
- Your server can serve files to a web browser (e.g. Firefox)
- Your client can request files from webservers (unfortunately most webservers require HTTPS)
    - `http://pan.vmars.tuwien.ac.at/osue/`
    - `http://neverssl.com/`
    - `http://www.nonhttps.com/`

Material

- The GNU C Library Reference Manual,
  Ch. 12 (Stream I/O), Ch. 16 (Sockets)
  `http://www.gnu.org/software/libc/manual/html_node/`
- Beej's Guide to Network Programming
  `http://beej.us/guide/bgnet/`