Lecture 33: Network I/O using sockets

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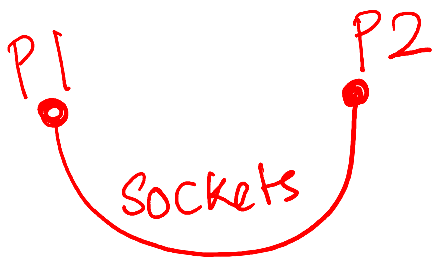
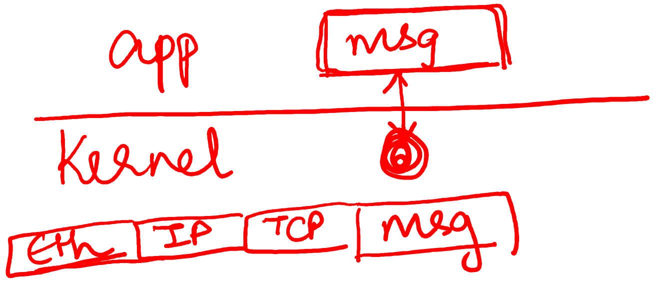


Sockets



- Socket API lets two processes in different machines to communicate with each other over the TCP/IP network stack
  - Unix domain sockets used for Inter Process Communication (IPC) between processes on the same machine
- Application reads/writes message into sockets, network protocol processing by kernel and network interface card (NIC)
  - Kernel handles protocol processing for higher layers (e.g., L4=TCP/UDP, L3=IP, L2=Ethernet), and NIC handles lower layers (L1=physical layer)
  - Raw sockets: app receives “raw” packets directly with all headers
  - Application message boundaries are not preserved in network packets
- TCP sockets: reliable delivery, congestion control (none in UDP)
- Network socket identified by a 16-bit port number on a machine
  - Socket bound to IP address of a network interface and a port number
- TCP socket communication: a “server” listens on a well-known port number, a “client” connects to the server, both exchange messages

Socket system calls

- TCP client
  - socket: create new socket (returns socket file descriptor)
  - Binding client socket to IP/port is optional
  - connect: connects to a server socket using the server's IP address and port number (initiates TCP 3 way handshake to server)
  - read: read data from a connected socket into a memory buffer
  - write: write data from a memory buffer into socket

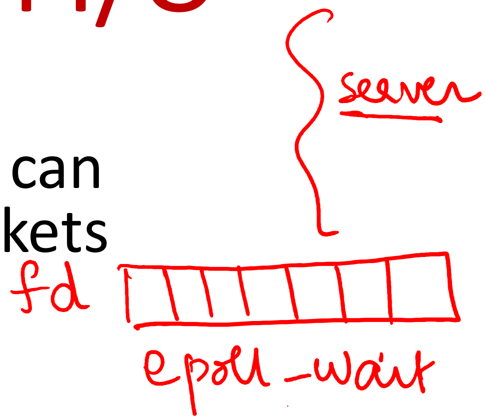
- TCP server
  - socket: create new socket (returns socket file descriptor)
  - bind: bind server socket to well-known port number and IP address
  - listen: start listening for new connections on server socket
  - accept: accept a new connection on server socket (returns a new socket to talk to this specific client)
  - read: read data from client into memory buffer
  - write: write data from memory buffer into socket connected to client

Server design for concurrent I/O

C2 C1 accept read

- What if server is talking to multiple clients concurrently?
  - Read system call blocks waiting for client data (by default)
  - Accept system call blocks waiting for new requests
  - Single process/thread of server cannot afford to block in any one of these system calls, will impact performance for other clients
- One way to handle concurrent I/O with blocking sockets: one process/thread per client
  - Multi-process: server forks a new child for each new client accepted, child process blocks on client reads, main parent server blocks on accept
  - Multi-threaded: master-worker thread pool model, master server thread blocks on accept and obtains new client sockets, worker threads handle client requests and block as needed
- Advantage of multi process/thread design: easy to scale server to multiple cores, easy to program (each thread/process is dedicated to handling a single client and can block for the client)
- Disadvantages of multi process/thread design: large number of concurrent clients can exhaust server memory due to too many threads/processes in the system, need for locking and synchronization across processes/threads

Alternative: event-driven I/O



- Event-driver I/O: single server process/thread can simultaneously perform I/O from multiple sockets
  - Examples: select, epoll
- Overview of epoll API
  - Process creates an epoll instance, adds file descriptors of interest to be monitored
  - Process blocks on epoll_wait, which returns when there is an event on any of the file descriptors
  - Process handles events by performing suitable actions (accept, read etc.) on the ready file descriptors
  - File descriptors set as non-blocking
- Single-threaded server process can handle network I/O from multiple concurrent clients
- Event-driven APIs available for network, not popular for disk

Event-driver I/O: pros and cons

disk

S worker

epoll_wait

- Easy to write single-threaded server, without locking and synchronization overheads across threads
- But single-threaded server cannot block for any reason
  - If the only server thread blocks, server is unresponsive
- How to handle disk I/O requests from clients?
  - In practice, multiple worker threads used in epoll server for disk I/O
- How to utilize multiple CPU cores and achieve multicore scalability?
  - One thread receives events in epoll_wait, and distributes event processing to worker threads across multiple CPU cores
  - Or, multiple threads call epoll_wait and process events in parallel across multiple CPU cores
  - Synchronization across threads needed in these scenarios

epoll epoll

- Event-driven programming is harder, because logic to handle a client is split across multiple event handlers
  - Using a dedicated thread per client and blocking system calls leads to more readable code

Summary

- Socket API to build networking applications
  - Enable processes to communicate across systems using TCP/IP protocol stack
- Concurrently handling multiple clients at a server can be done in two ways
  - One process/thread dedicated to a client, blocking system calls for network I/O
  - Event-driven I/O, single process can handle multiple clients concurrently
  - Pros and cons of both techniques