Server Design

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Topics

- Types of servers
- Server algorithms
  - Iterative, connection-oriented servers
  - Iterative, connectionless servers
  - Iterative, connectionless servers
  - Concurrent, connection-oriented servers
- Server design issues

Server examples based on BSD-compatible socket functions and POSIX Threads.

Need for Concurrency in Servers

- A simple server
  - Server creates a socket, binds address, and makes it passive
  - Server accepts a connection, services the request, the connection is closed, and this is repeated indefinitely
- Simple server is inadequate for most applications since the request may take arbitrarily long to service
  - Other clients are blocked from service

Concurrent versus Iterative Servers

- An *iterative* server services one request at a time
- A *concurrent* server services multiple requests at the same time
  - The actual implementation may or may not be concurrent
  - More complex than iterative servers

Three Dimensions of Server Design

- Iterative versus concurrent
  - Truly a server design issue as it is independent of the application protocol
- Connection-oriented versus connectionless
  - Usually constrained by the application protocol
- Stateless versus stateful
  - Usually constrained by the application protocol

Four Classes of Servers

		Connection-
Concurrent	-	++
Iterative	+	-

- Concurrent, connection-oriented is the most common server design

Iterative, Connection-Oriented (1)

1) **Create a socket**
   - sock = socket(PF_INET, SOCK_STREAM, 0)

2) **Bind to well-known address**
   - bind(sock, localaddr, addrlen)
   - For port number, server can use getservbyname(name, protocol)
   - For host IP address, “wild card” address is usually used: INADDR_ANY

3) **Place socket in passive mode**
   - listen(sock, queuelen)
   - Need to establish queue length (maximum is implementation dependent)

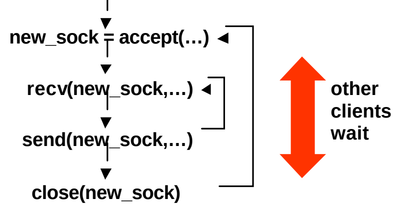
Iterative, Connection-Oriented (2)

4) **Accept a connection from a client**
   - new_socket = accept(sock, addr, addrlen)
   - accept() blocks until there is at least one connection request
   - Based on the queue length value in listen(), connection requests may be “accepted” by the operating system and queued to be accepted later by the server with the accept() call

5) **Interact with client**
   - recv(new_socket, ...)
   - send(new_socket, ...)

Iterative, Connection-Oriented (3)

6) **Close connection and return to accept() call (step 4)**
   - close(new_socket)



Iterative, Connection-Oriented (4)

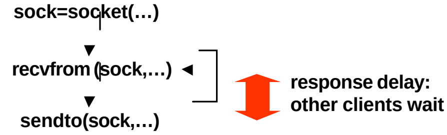
- **Only one connection at a time is serviced by an iterative, connection-oriented server**
  - Others wait in queue to be accepted
  - Or, their connection is refused
- **TCP provides reliable transport, but there is overhead in making and breaking the connection**
  - Simplifies application design
  - At the expense of a performance penalty

Iterative, Connectionless Server (1)

1) **Create socket**
   - sock = socket(PF_INET, SOCK_DGRAM)

2) **Interact with one or more clients**
   - recvfrom (sock, buf, buflen, flags, from_addr, from_addrlen)
     - Each subsequent recvfrom() can receive from a different client
     - fromaddr parameter lets server identify the client
   - sendto(sock, buf, buflen, flags, to_addr, to_addrlen)
     - to_addr is usually from_addr of preceding recvfrom()

Iterative, Connectionless Server (2)



- **Other clients block while one *request* is processed, not for a full connection time**
- **UDP is not reliable, but there is no connection overhead**

Concurrent, Connectionless (1)

- Concurrency is on a *per request* basis for a connectionless server
- There are two way to achieve concurrency
  - Create a new process, e.g. using fork() or exec()
  - Create a new thread, using pthread_create()
- *"Master" thread* uses pthread_create() to create a *"slave" thread* for each request

Concurrent, Connectionless (2)

Master

M1) Create socket
- sock = socket(PF_INET, SOCK_DGRAM)

M2) Read request
- recvfrom (sock,…)

M3) Create thread
- pthread_create()
- Thread knows:
  - IP address and port of client
  - Request information
  - Global data and socket

Return to M2

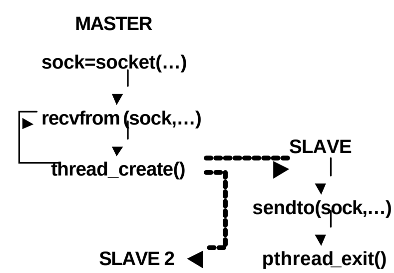
Concurrent, Connectionless (3)

Slave

S1) Respond to request
- sendto(sock,…)

S2) Terminate
- pthread_exit()

Concurrent, Connectionless (4)



Concurrent, Connectionless (5)

- Requests from multiple clients (or multiple requests from a single client) can be serviced concurrently
  - No long blocking periods
- pthread_create() does have overhead
  - Thread overhead can dominate if time to respond to request is small
  - Concurrent, connectionless server is a good design choice only if average processing time is long relative to thread overhead
- UDP offers no reliability, has no connection overhead

Concurrent, Connection-Oriented (1)

- Concurrency is on a *per connection* basis for a connection-oriented server
  - Depending on application, additional concurrency may also be possible
- There are three ways to achieve concurrency
  - Create a new process -- high overhead
  - Create a new thread -- lower overhead
  - Use *apparent concurrency* within a single thread
    - Lowest overhead
    - Based on select() call for *asynchronous* operation

Concurrent, Connection-Oriented (2)

Master, using thread

M1) Create socket
- sock = socket(PF_INET, SOCK_STREAM)

M2) Bind address
- bind(sock, …)

M3) Put socket in passive mode
- listen(sock, …)

Concurrent, Connection-Oriented (3)

Master, using threads (continued)

M4) Accept a new connection
- new_sock = accept(sock,…)

M5) Create thread
- pthread_create()
- Thread knows:
  - New socket -- new_sock
  - Global data

Return to M4

Concurrent, Connection-Oriented (4)

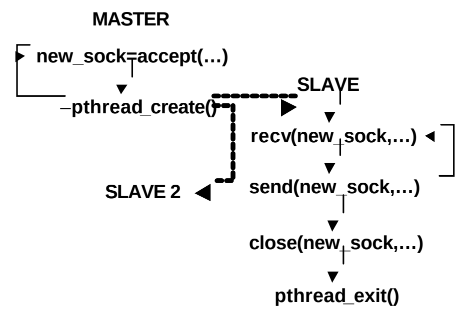
Slave, using threads

S1) Interact with client
- recv (new_sock,…)
- send(new_sock,…)

S3) Close socket
- close(new_sock,…)

S2) Terminate
- pthread_exit()

Concurrent, Connection-Oriented (5)

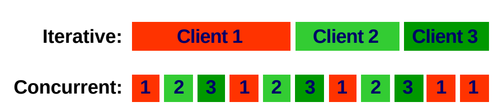


Concurrent, Connection-Oriented (6)

- **Clients do not block while other clients are connected**
  - One thread per client
  - Could have additional threads per client, but based on particular features of the application
- **pthread_create() has overheads**
  - Thread overhead can dominate if connection time is small
  - Concurrent, connection-oriented server is a good design choice only if average client connection time is long relative to thread overhead

Concurrent, Connection-Oriented (7)

- **Except on a true multiprocessor, "concurrency" from threads does *not* generally increase throughput!**
  - Transactions per second do *not* increase
  - Delay for first service and variance for service time *do* decrease



Concurrent, Connection-Oriented (8)

- May be able to increase throughput for some applications, e.g. by overlapping disk I/O with processing in the CPU
- TCP provides reliability at the expense of connect/disconnect overhead

Apparent Concurrency (1)

0) Maintain a set of socket descriptors (SOCKETS) using the fd_set structure
   – Initialize SOCKETS = { } (empty)
1) Create socket
   – sock = socket(PF_INET, SOCK_STREAM)
   – SOCKETS = { sock }
2) Bind address
   – bind(sock, ...)
3) Put socket in passive mode
   – listen(sock, ...)

Apparent Concurrency (2)

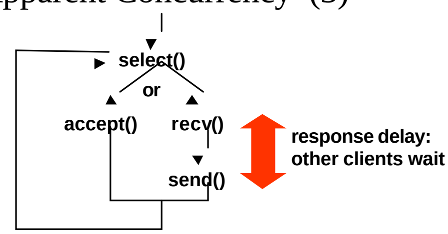
4) Use select() to determine sockets that have activity (are ready for “service”)
   – ret = select(maxfd, rdfds, wrfds, exfds, time)

5a) If select() indicates main socket (sock) is ready, accept a new connection
   – new_sock = accept(sock,...)
   – SOCKETS = SOCKETS È { new_sock }

5b) If select() indicates another socket (ready) is ready
   – recv(ready,...) to read request, and then
   – send(read,...) to send response

Return to step 4

Apparent Concurrency (3)



- While another connection is accepted or while one *request* from another client is serviced
- Clients do not wait full connection time

Apparent Concurrency (4)

- Data can be conveniently (or dangerously) shared between different clients
  – Not easy with multiple threads

Server Design Factors (1)

- Time per request
  – If high, a multithreaded design is best
  – If low, thread overhead may dominate performance and an iterative server or a server using apparent concurrency is best
- Time per connection (connection-oriented)
  – If high, a concurrent (threaded or apparent) server is best
  – If low, an iterative server is best
- Number of active clients
  – If high, concurrent server is best
  – If low, iterative server is best

Server Design Factors (2)

- Overhead for thread creation
  - Trade-offs for connection time and request response time are relative to thread creation time
  - Operating systems with low overhead thread creation increase opportunities to use multithreaded design
- Need to share information between clients
  - Easier in an iterative server or a server with apparent concurrency
  - More complex in a multithreaded server

Server Design Factors (3)

- LAN- versus WAN-based application
  - TCP's reliability is more important in a WAN where packet loss and out-of-order delivery is more likely
  - LAN-based applications may be able to provide reliability with less "expense" using UDP than TCP
- Inherent reliability in the application
  - May eliminate the need to use TCP

Simple Deadlock

- Deadlock occurs when
  - Client is blocked waiting on server
  - Server is blocked waiting on client
- Simple example of server deadlock

SERVER — CLIENT

accept() ◄- - - - - - ► connect()

recv() — never_never_land()

Server is blocked waiting for data from the client ☹

More Subtle Deadlock (1)

- Deadlock may be much more subtle

SERVER — CLIENT

accept() ◄- - - - - - ► connect()

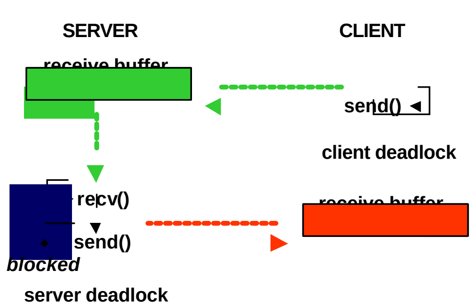
recv() — send(BIG_BUFFER)

X send()

Server eventually blocks at send() since client never receives ☹

Client blocks at send() since server is not receiving ☹

More Subtle Deadlock (2)



Terminating a Connection (1)

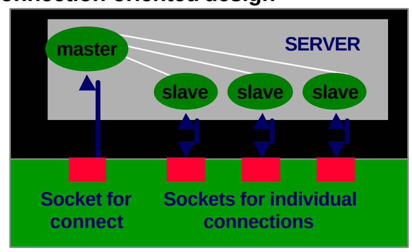
- The application protocol determines when a connection should be closed
- Client may know when transaction is done
  - Examples:
    - FTP
    - HTTP 1.1 (persistent connections)
  - A "misbehaving" client can keep connections open, consuming server resources
  - Solutions
    - Time-out for the session (connect, idle, etc.)
    - Trusted clients

Terminating a Connection (2)

- Even if the server controls connection termination, there may still be problems
  - Operating system maintains connection information for 2´ MSL (maximum segment life)
    - Allows OS to reject delayed, duplicate packets
    - Uses OS resources
  - Client can make lots of requests and consume resources faster than the server can free them
- Vulnerability to *denial of service attacks*

Example: Threaded ECHO Server (1)

- Multiple-threaded concurrent, connection-oriented design

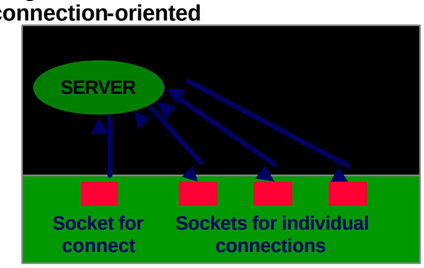


Example: Concurrent ECHO Server (2)

- Operation of concurrent ECHO server
  - pthread_create() called for each new connection
  - TCPechod() invoked for each thread
    - recv() and send() repeated until client closes the connection
    - Note that TCPechod() does *not* call exit() to exit the process if there's an error -- just the thread terminates I.e. the thread calls pthread_exit.
    - Calling exit will terminate all threads and the process, a bad idea in this case

Example: Asynch ECHO Server (1)

- Single-thread concurrent, connection-oriented



Example: Asynch ECHO Server (2)

- Uses select() call
  - select() indicates which sockets are ready for service
    - Input or connection for ECHO server
  - fd_set structures record the sets of sockets

```
typedef struct fd_set {
  u_int   fd_count;
  SOCKET fd_array[FD_SETSIZE];
}
```

Example: Asynch ECHO Server (3)

- fd_set structures manipulated with macros
  - FD_CLR(fd, set): remove fd from set
  - FD_SET(fd, set): add fd to set
  - FD_ZERO(set): empty set
  - FD_ISSET(fd, set): test if fd is in set

```
FD_ZERO(&afds);        // empty afds
FD_SET(msock, &afds);  // add msock
```

Example: Asynch ECHO Server (4)

- **select()**
  - Checks all sockets in sets
    - set for input and connection request
    - set for output
    - set for exceptions
  - Blocks until at least one of the sockets is ready or time-out
  - Returns with the set changed to contain just the sockets ready for service

```
select(FD_SETSIZE, &rfds,
  (fd_set *)0, (fd_set *)0,
  (struct timeval *)0)
```

Example: Asynch ECHO Server (5)

- **Operation**
  - Steps through all active sockets and checks to see if socket is ready
  - Accepts a new connection and adds to set if master server socket (msock) is ready
  - Calls echo() to echo new data if client connection socket is ready
- **There may be several sockets ready for service**

You should now be able to …

- **Identify the three dimensions of server design**
- **Identify factors and application requirements that affect design choice**
- **Select server design based on factors application requirements**
- **Design, implement, and test servers based on the four classes**
- **Recognize causes of deadlock**