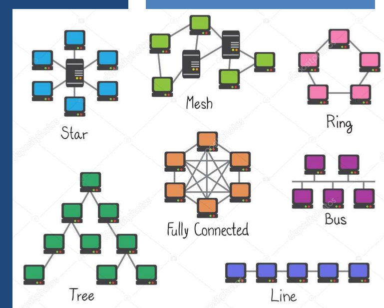
TCSS 558: APPLIED DISTRIBUTED COMPUTING

Communication



Wes J. Lloyd
Institute of Technology
University of Washington - Tacoma

OBJECTIVES

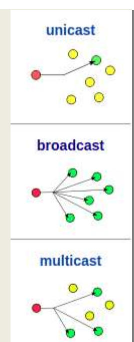
- Assignment 1 questions
- The role for UDP
- Ch. 4 – Communications
  - Protocols
  - Remote procedure calls / RMI
  - Message-oriented communication:
    - sockets, zeromq, MPI

CONNECTIONLESS / CONNECTION-ORIENTED

- Connection-oriented communication (TCP)
- Two parties connect, exchange messages, and the disconnect
- Typically this is a synchronous process, but it can be asynchronous

- Connectionless communication (UDP)
- Calling program does not enter into a connection with the target process
- Receiving application simply acts on the request
- This may, or may not, involve sending a response

WHAT ARE USE CASES FOR UDP?



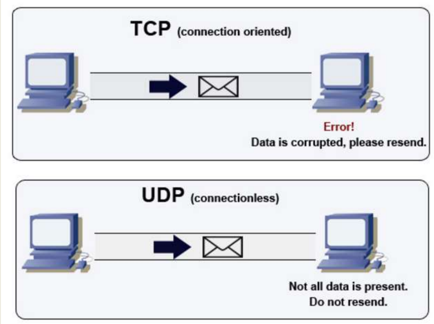
- Processes/applications that already provide:
  - Internal flow control (packet ordering)
  - Error control (management of retransmission requests)

- Broadcasting (sending to subnet)
- Multicasting (addressing to multiple clients)
  - Typically in a LAN

- Simple request-response communication
  - UDP makes sense for really small transactions because there is no TCP establishment/tear-down overhead
  - Latency is reduced: one-way trip, or out-and-back, but no negotiation
  - Bandwidth user: When total communication is less than MTU
  - Maximum Transmission Unit: < largest packet size (~1500 avg)

UDP USE CASES

- When overhead for creating a TCP connection far outweighs data payload
  - DNS servers (quick negotiation of names)
  - Network Time servers
  - Service discovery (via LAN broadcast): finding a printer
  - When delivering data that CAN be lost without consequence because newer data is always flowing in to replace previous state
  - Weather data, video/audio (VoIP) streaming, video gaming data



November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.5

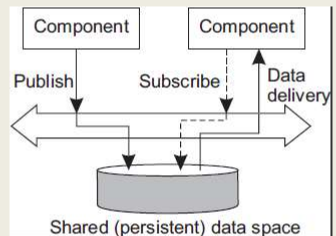
UDP USE CASES - 2

- UDP can be used for every type of application TCP can
- Requires implementation of proper retransmission mechanism.
- UDP can be very fast, with low delay, not affected by congestion on a connection basis, transmits fixed sized datagrams and can be used for multicasting.
- ***If implementing an application level protocol . . .***
- **What would the advantages be for using UDP ?**
- **What would the advantages be for using TCP ?**

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.6

CONNECTIONLESS / CONNECTION-ORIENTED - 2

- A component interacts requests to establish a subscription to receive notifications regarding particular data from a *shared "tuple" data space*
  - ***IS THIS: Connection-less or connection oriented?***
- Components publish data to a *shared "tuple" data space*
  - ***IS THIS: Connection-less or connection oriented?***



CHAPTER 4

CH. 4.1: FOUNDATIONS

L12.9

MIDDLEWARE PROTOCOLS

- Communication frameworks/libraries
- Reused by multiple applications
- Provided needed functions apps build and depend on
- Example:
  - Authentication protocols: supports granting users and processes access to authorized resources
  - General, application-independent in nature
  - Doesn't fit as an "application specific" protocol
  - Considered as a "Middleware protocol"

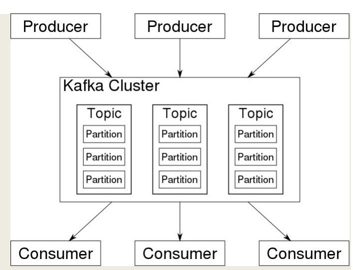
November 9, 2017 | TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma | L12.10

MIDDLEWARE PROTOCOLS - 2

- **Distributed commit protocols**
  - Coordinate a group of processes (nodes)
  - Facilitate all nodes carrying out a particular operation
  - Or abort transaction
  - Provides distributed atomicity (all-or-nothing) operations
- **Distributed locking protocols**
  - Protect a resource from simultaneous access from multiple nodes
- **Remote procedure call**
  - One of the oldest middleware protocols
  - Distributed objects

MIDDLEWARE PROTOCOLS - 3

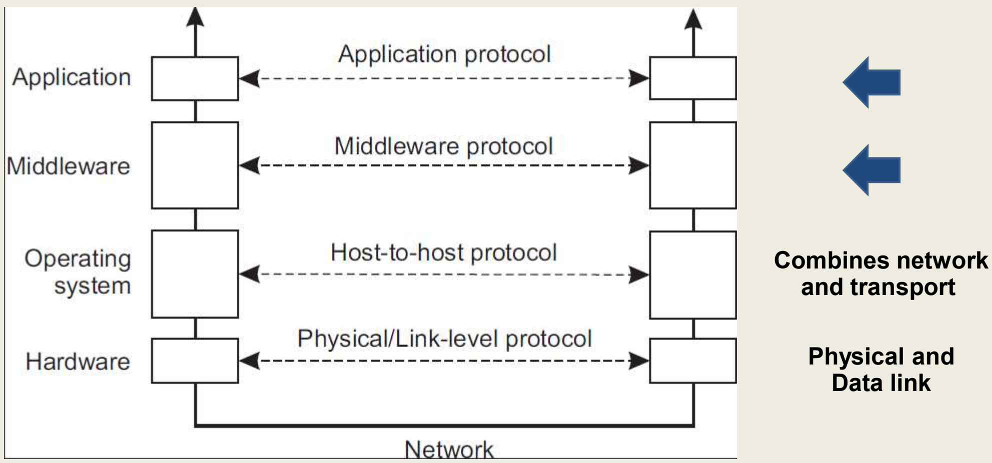
- **Message queueing services**
  - Support synchronization of data streams
  - Transfer real-time data
  - Distributed and scalable implementation



- **Multicast services**
  - Scale communication to thousands of receivers spread across the Internet

ADAPTED REFERENCE MODEL

- *Shows layers actually used*

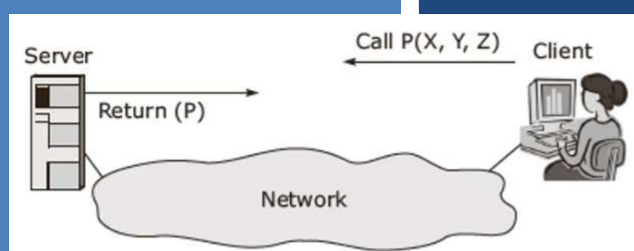


TYPES OF COMMUNICATION

- **Persistent communication**
  - Message submitted for transmission is stored by communication middleware as long as it takes to deliver it
  - Example: email system (SMTP)
  - Receiver can be offline when message sent
  - Temporal decoupling (delayed message delivery)
- **Transient communication**
  - Message stored by middleware only as long as sender/receiver applications are running
  - If recipient is not active, message is dropped
  - Transport level protocols typically are transient (*no msg storage*)
- **At what reference model layer is the SMTP Protocol?**
- **From an implementation point-of-view what major component is required to implement persistent communication ?**

TYPES OF COMMUNICATION - 2

- Asynchronous communication
  - Client does not block, continues doing other work
- Synchronous communication
  - Client blocks and waits
- Three types of blocking
  1. Until middleware notifies it will take over delivering request
  2. Sender may synchronize until request has been delivered
  3. Sender waits until request is processed and result is returned
- *Persistence + synchronization*
  - Common scheme for message-queueing systems
- Consider each type of blocking (1, 2, 3). Are these modes connectionless (UDP)? connection-oriented (TCP)?



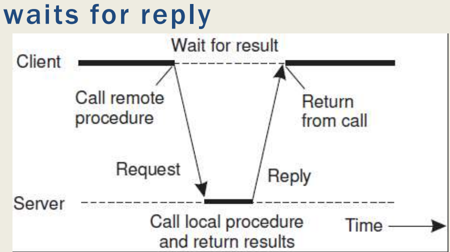
CH. 4.2: RPC

RPC – REMOTE PROCEDURE CALL

- In a nutshell,
- Allow programs to call procedures on other machines
- Process on **machine A** calls procedure on **machine B**
- Calling process on **machine A** is suspended
- Execution of the called procedure takes place on **machine B**
- Data transported from caller **(A)** to provider **(B)** and back **(A)**.
- No message passing is visible to the programmer
- **Distribution transparency**: make remote procedure call look like a local one
- `newlist = append(data, dbList)`

RPC - 2

- Transparency enabled with client and server "stubs"
- Client has "stub" implementation of the server-side function
- Interface exactly same as server side
- But client **DOES NOT HAVE THE IMPLEMENTATION**
- **Client stub**: packs parameters into message, sends to server. Calls blocking receive routine and waits for reply
- **Server stub**: transforms incoming request into local procedure call
- Server blocks waiting for msg
- Server stub unpacks msg, calls server procedure
- ***It's as if the routine were called locally***



RPC - 3

- Server packs procedure results and sends back to client.
- Clients "receive" call unblocks and data is unpacked
- Client can't tell method was called remotely over the network (*except when there's HIGH network latency…*)
- Call abstraction ***allows clients to invoke functions in alternate languages, on different machines***
- Differences are handled by the RPC "framework"

RPC STEPS

1. Client procedure **calls** client stub
2. Client stub **builds** message and calls OS
3. Client's OS **send** message to remote OS
4. Server OS **gives** message to server stub
5. Server stub **unpacks** parameters, calls server
6. Server **performs** work, **returns** results to server-side stub
7. Server stub **packs** results in messages, **calls** server OS
8. Server OS **sends** message to client's OS
9. Client's OS **delivers** message to client stub
10. Client stub **unpacks** result, returns to client

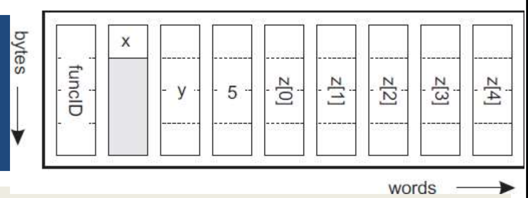
RPC STEPS

1. Client procedure calls client stub
2. Client stub builds message and calls OS
3. (
4.
5.
6. tub
7. s
8.
9. Client's OS delivers message to client stub
10. Client stub unpacks result, returns to client

Consider the overhead of an RPC call vs. an ordinary local procedure call where data elements are pushed/popped, to/from, the call stack

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.21

PARAMETER PASSING



- Stubs: take parameters, pack into message, send across network
- Parameter marshaling:
- `newlist = append(data, dbList)`
- Two parameters must be sent over network and correctly interpreted
- Message is transferred as a series of bytes
- Data is serialized into a "stream" of bytes
- Must under stand how to unmarshal (unserialize) data
- Processor architecture vary with how bytes are numbered: Intel (right→left), older ARM (left→right)

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.22

RPC: BYTE ORDERING

- Big-Endian: write bytes left to right (ARM)
- Little-endian: write bytes right to left (Intel)
- Network: typically transfer data in Big-Endian form
- Solution: transform data to machine/network independent format
- Marshaling/unmarshaling: transform data to neutral format

BIG-ENDIAN *Memory*

...	00	01	02	03	04	05	06	07	...
	a	*a+1*	*a+2*	*a+3*	*a+4*	*a+5*	*a+6*	*a+7*	

LITTLE-ENDIAN *Memory*

...	07	06	05	04	03	02	01	00	...
	a	*a+1*	*a+2*	*a+3*	*a+4*	*a+5*	*a+6*	*a+7*	

RPC: PASS-BY-REFERENCE

- Passing by value is straightforward
- Passing by reference is ***challenging***
- Pointers only make sense on local machine owning the data
- Memory space of client and server are different
- **Solutions to RPC pass-by-reference:**

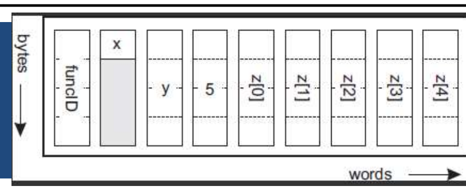
1. Forbid pointers altogether
2. Replace pass-by-reference with pass-by-value
   - Requires transferring entire object/array data over network
   - **Read-only optimization**: don't return data if unchanged on server
3. Passing global references
   - Example: file handle to file accessible by client and server via shared file system

RPC: DEVELOPMENT SUPPORT

- Let developer specify which routines will be called remotely
  - Automate client/server side stub generation for these routines
- Embed remote procedure calling into the programming language
  - E.g. Java RMI

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.25

STUB GENERATION



- `void func(char x; float y; int z[5])`
- Character transmits with 3-padded bytes
- Float as whole word (4-bytes)
  - Array as group of words, proceed by word describing length
  - Client stub must package data in specific format
  - Server stub must receive and unpackage in specific format
- Client and server must agree on representation of simple data structures: int, char, floats w/ little endian
- RPC clients/servers: must agree on protocol
  - TCP? UDP?

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.26

STUB GENERATION - 2

- Interfaces often specified using an Interface Definition Language (IDL)
- IDL interface can be used to generate language specific threads
- IDL is compiled into client and server-side stubs
- Much of the plumbing for RPC involves maintaining boilerplate-code

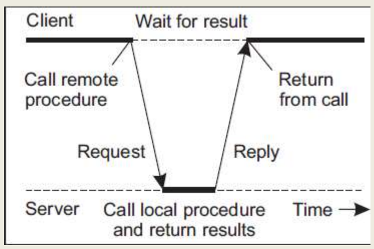
LANGUAGE BASED SUPPORT

- Leads to simpler application development
- Helps with providing access transparency
  - Differences in data representation, and how object is accessed
  - Inter-language parameter passing issues resolved:
    → ***just 1 language***
- Well known example: ***Java Remote Method Invocation*** RPC equivalent embedded in Java

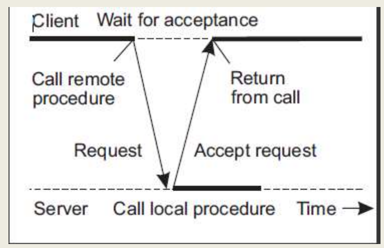
RPC VARIATIONS

- RPC: typically client blocks until reply is returned
- Strict blocking ***unnecessary*** when there is no result
- Asynchronous RPCs
  - When no result, server can immediately send reply

Client/server synchronous RPC



Client/server asynchronous RPC



November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.29

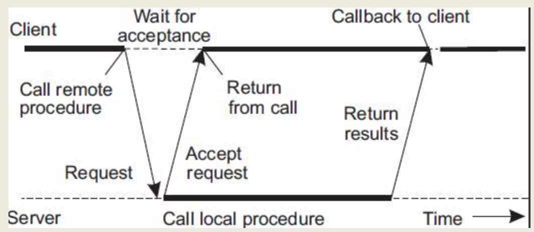
RPC VARIATIONS – 2

- What are tradeoffs for synchronous vs. asynchronous procedure calls?
  - For a local program
  - For a distributed program (system)
- Use cases for asynchronous procedure calls
  - Long running jobs allow client to perform alternate work
  - Client may need to make multiple service calls to multiple server backends at the same time…

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.30

TYPES OF ASYNCHRONOUS RPC

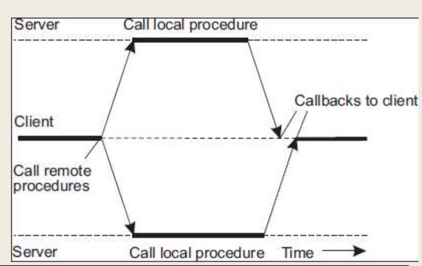
- Deferred synchronous RPC
  - Server performs ***CALLBACK*** to client
  - Client, upon making call, spawns separate thread which blocks and waits for call



- One-way RPCs
  - Client **does not wait** for ***any*** server acknowledgement – it just goes…
- Client polling
  - Client (*using separate thread*) continually polls server for result

MULTICAST RPC

- Send RPC request *simultaneously* to group of servers
- Hide that multiple servers are involved
- ***Consideration:***
  Does the client need all results or just one?
- Use cases:
  - **Fault tolerance**: wait for just one
  - **Replicate execution**: verify results, *use first result*
  - **Divide and conquer**: multiple RPC calls work in parallel on different parts of dataset, client aggregates results



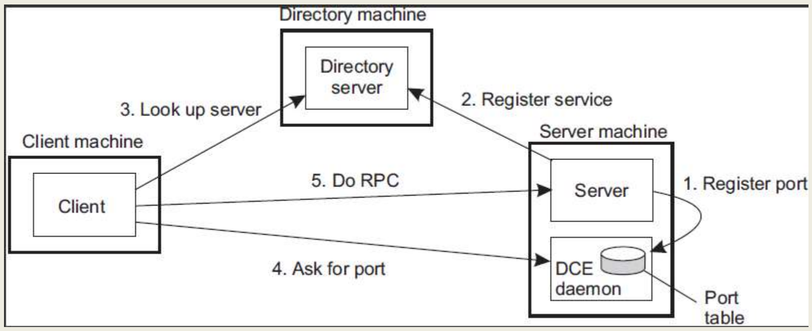
RPC EXAMPLE: DISTRIBUTED COMPUTING ENVIRONMENT (DCE)

- DCE – basis for Microsoft's distributed computing object model (DCOM)
- Used in Samba – share windows filesystem via RPC
- Midleware system: provides layer of abstraction between OS and distributed applications
- Designed for Unix, ported to all major operating systems
- Install DCE middleware on set of heterogeneous machines – distributed applications can then run and leverage resources
- Uses client/server model
- All communication via RPC
- DCE provides a daemon to track participating machines, ports

DCE – CLIENT/SERVER DEVELOPMENT

1. Create Interface definition language (IDL) files
   - IDL files contain Globally unique identifier (GUID)
   - GUIDs must match: client and server compare GUIDs to verify proper versions of the distributed object
   - 128-bit binary number
2. Next, add names of remote procs and params to IDL
3. Then compile the IDL files
   Compiler generates:
   - Header file (interface.h in C)
   - Client stub
   - Server stub

DCE - CLIENT-TO-SERVER BINDING



- Server name comes from directory server
- Server port comes from DCE daemon
  - DCE daemon has a well known port # client already knows

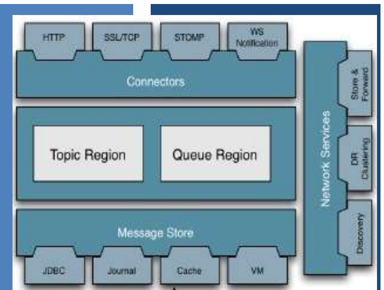
DCE - CLIENT TO SERVER BINDING - 2

- For a client to call a server, server must be registered
  - *Java: uses RMI registry*
- Client process to search for RMI server:
  1. Locate the server's host machine
  2. Locate the server (i.e. process) on the host
- Client must discover the server's RPC port

- <u>DCE daemon:</u> maintains table of (server,port) pairs

- When servers boot:

1. Server asks OS for a port, registers port with DCE daemon
2. Also, server registers with directory server, separate server that tracks DCE servers



Apache ActiveMQ

CH. 4.3: MESSAGE-ORIENTED COMMUNICATION

L12.37

MESSAGE ORIENTED COMMUNICATION

- RPC assumes that the <u>*client*</u> and <u>*server*</u> are running ***at the same time… (temporally coupled)***
- RPC communication is typically ***synchronous***

- When client and server are not running at the same time
- Or when communications should not be **blocked…**

- Use case for <u>**message-oriented communication**</u>
  - Synchronous vs. asynchronous
  - Messaging systems
  - Message-queueing systems

November 9, 2017	TCSS558: Applied Distributed Computing [Fall 2017] Institute of Technology, University of Washington - Tacoma	L12.38

SOCKETS

- Communication end point
- Applications can read / write data to
- Analogous to file streams for I/O, but ***network streams***

Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

SOCKETS - 2

- Servers execute 1st - 4 operations (socket, bind, listen, accept)
- Methods refer to C API functions
- Mappings across different libraries will vary (e.g. *Java*)

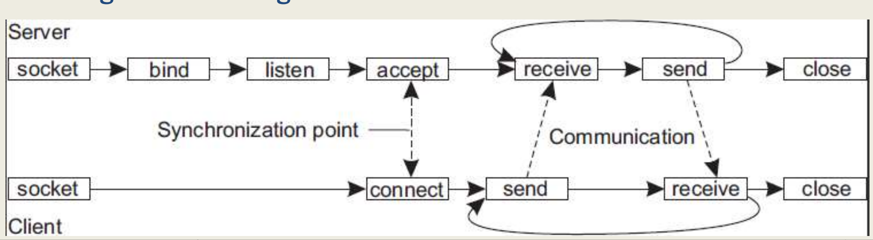
Operation	Description
socket	Create a new communication end point
bind	Attach local address to socket (IP / port)
listen	Tell OS what max # of pending connection requests should be
accept	Block caller until a connection request arrives
connect	Actively attempt to establish a connection
send	Send some data over the connection
receive	Receive some data over the connection
close	Release the connection

SERVER SOCKET OPERATIONS

- **Socket**: creates new communication end point
- **Bind**: associated IP and port with end point
- **Listen**: for connection-oriented communication, non-blocking call reserves buffers for specified number of pending connection requests server is willing to accept
- **Accept**: blocks until connection request arrives
  - Upon arrival, new socket is created matching original
  - Server spawns thread, or forks process to service incoming request
  - Server continues to wait for new connections on original socket

CLIENT SOCKET OPERATIONS

- **Socket**: Creates socket client uses for communication
- **Connect**: Server transport-level address provided, client blocks until connection established
- **Send**: Supports sending data (to: server/client)
- **Receive**: Supports receiving data (from: server/client)
- **Close**: Closes communication channel
  - Analogous to closing a file stream



SOCKET COMMUNICATION

- Sockets provide primitives for implementing your own TCP/UDP communication protocols
- Directly using sockets for transient (non-persisted) messaging is very basic, can be brittle
  - Easy to make mistakes…
- Any extra communication facilities must be implemented by the application developer
- More advanced approaches are desirable
  - E.g. frameworks with support common desirable functionality

QUESTIONS

EXTRA SLIDES

45