CSCE 455/855
Distributed Operating Systems

Process Communication Paradigms

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1

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Lecture 3

Process Communication Paradigms

- OSI, ATM, Ethernet, TCP/IP only half the story
  - » provides for sending/receiving messages
  - » How are communications organized?
    - ❖ coordinate *when* messages are sent
    - ❖ *where* system services should reside

2

Page 2

Process Communication Paradigms (cont.)

- Communicating to remote processes
  - » message passing
    - simplest form of communication
    - client/server model
    - messages explicitly manipulated by the user
  - » remote procedure call (RPC)
    - procedure calls + stubs
    - implicit bi-directional flow of information
    - messages implicit
  - » transactions
    - synchronization and serialization of communication
    - messages implicit, handle multiple messages (chapter 3)

3

Client-Server Model

- Server: provides some service to client processes
  - » a process that “listens” to a port
  - » accepts connections from a client
  - » is passive -- waits for a request
- Client: requests services
  - » must know name of the service (an address)
  - » establishes connection with server
  - » requests services (provide data, perform calculations, etc.)

4

Client-Server Model (cont.)

- Addressing a server
  - » a “well-known socket” address
  - » port address hardwired
    - ❖ port is just an address
    - ❖ operating system gets a message with a port address
    - ❖ sends message to the code handling the port
  - » bind address to a name
  - » client requests the service by name or address

5

Client-Server Model (cont.)

- Limited number of servers
  - » clients can be from anywhere
  - » knowledge of “well-known address” is all that’s needed
- Servers vs. services
  - » service: a software facility (sometimes implemented as a set of servers)
  - » server: software running on one machine
- Some problems with C/S model:
  - » extendibility: as nodes added to system, servers may become over-loaded with clients
  - » single point of failure
  - » multiple servers increase costs

6

Dimensions of the Client/Server Model

- Addressing
  - » how to find server addresses
- Blocking and Non-Blocking methods
  - » can either block or continue when *sending* or *receiving* messages
- Buffered vs. Unbuffered methods
  - » choice of buffering messages at the server or with the kernel
- Reliable vs. Unreliable methods
  - » choices on when to acknowledge a message

7

C/S Addressing Schemes

- Process-to-process message passing
  - » machine.process hardwired into client
    - i.e. the “well-known address”
  - » Unix sockets
  - » not transparent to user (programmer)
    - if addressed server machine is down, system breaks

8

C/S Addressing Schemes (cont.)

- Broadcasting for process addressing
  - » each process has unique global address
    - ❖ central server assigns number to process
    - ❖ OR process chooses from a sparse address space
  - » client broadcasts ‘locate packet’ with server address it needs
    - ❖ server responds with ‘here I am’
    - ❖ client caches the address
    - ❖ sends subsequent messages to that address
  - » problem: broadcast takes up bandwidth

9

C/S Addressing Schemes (cont.)

- Name service approach
  - » name server hold name-address mappings
    - ❖ server must register this mapping
  - » client does a look-up on name service
    - ❖ caches address (machine.address)
  - » uses address from then on
  - » problem: name service is a central component

10

Blocking vs. Non-Blocking Primitives

- Blocking (synchronous) primitives
  - » when message is sent, sending process waits until message has been successfully sent
  - » receiving message is blocked until message is in process' buffer
  - » clearest semantics, easiest to implement
- Non-Blocking (asynchronous) primitives
  - » *send* returns immediately
  - » can't use buffer until message sent
    - sender doesn't know when that's happened
    - copy into kernel buffer, then re-use the process buffer
    - but overhead of copy is prohibitive
  - » *receive* gets the buffer and returns control
    - process must determine if buffer has been written to
    - can use an explicit *wait* to block or *test* to poll kernel

11

Buffered vs. Unbuffered Primitives

- Buffered (buffer at kernel)
  - » server requests a *mailbox* from the kernel
  - » *receive* removes a message from the mailbox
  - » mailboxes can fill up
    - messages can be discarded or kept for a time
- Unbuffered (buffer at server)
  - » kernel copies message to process buffer and unblocks process
  - » What if message is received before process does a *receive*?
    - discard the message (sender will re-transmit)
    - keep message for a time period
  - » What happens while the server is processing a previous request?
    - multiprogrammed servers

12

Reliable vs. Unreliable Primitives

- Reliable
  - » acknowledge each message
    - results in 4 message per c/s exchange
  - » reply serves as implicit acknowledge
    - reply from server is acknowledgment for the client
    - can choose to ack the server's reply
      - if not, server sends reply again
    - 2-3 messages per c/s exchange
    - but hard for client to distinguish between a slow server and one that's down
  - » server sends ack only if service takes too long
    - after a time-out, server sends explicit ack
- Unreliable
  - » no acknowledgments
  - » reliability up to users (program designers)
    - note any reliability must be distributed

13

Client/Server Design Issues

- Many trade-offs between choices
  - » acknowledge only entire messages
    - fewer ack messages
    - but recovery is more complicated or inefficient
    - works bet for reliable networks
  - » acknowledge individual packets
    - more ack messages
    - but recovery is easier, more efficient (less packets re-transmitted)
    - may want to use on unreliable networks
- Packet exchanges
  - » packet types for "I am alive," "Try again," etc.
  - » use to design different protocols

14

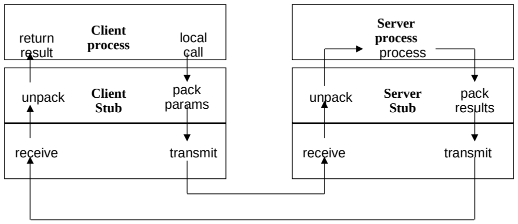
Remote Procedure Calls

- Procedure calls for remote communication
  - » call: blocking send
  - » called procedure: blocking read, return results
  - » allows type-checked communication
    - ❖ compiler detects inconsistencies
    - ❖ treated like any other procedure call
- Language-level calls on each end of communication
  - » caller:
    - remote procedure X (parameters)
  - » callee:
    - int remote procedure X (parameters)

15

Remote Procedure Calls
Procedure-to-message conversion

- Server stub (caller)
  - » packs parameter into frame
  - » receives reply, unpacks
- Client stub (callee)
  - » unpacks parameters
  - » sends reply



16

RPC Stubs

- Stub compiler
  - » programmer specifies server specification
  - » calls compiler with RPC switches
    - cc prog.c -lrpcsvc -lsun
  - » compiler automatically creates stub
- Server stub
  - » also created with stub compiler
  - » server needs to register its services
- Server specification
  - » can choose from a set of parameter types
  - » or can create own

17

Low-Level RPC - Server

```
#include <stdio.h>
#include <rpc/rpc.h>

int *nuser (int *indata) {
  int  total;

  total = *indata + 2;
  printf ("input data was: %d\n", *indata);
  return (&total);
}

main() {
   registerrpc (200012, 2, 2, nuser, xdr_int, xdr_int);
   svc_run();
   printf ("ERROR, svc_run() returned!!\n");
   exit(1);
}
```

18

Low-Level RPC - Client

```
#include <stdio.h>
#include <rpc/rpc.h>

main (int argc, char *argv[]) {
  int  outdata;
  int  stat, indata;

  if (argc < 2) {
    printf ("Usage: rpc-c host\n");
    exit(0);
  }

  indata = 2;
  if (stat = callrpc (argv[1], 200012, 2, 2, xdr_int, &indata,
                      xdr_int, &outdata) != 0) {
    clnt_perrno(stat);
    exit(1);
  }
  printf ("result received: %d\n\n", outdata );
  exit(0);
}
```

19

Higher-Level RPC - rpcgen

```
/* msg.x: used by rpcgen()
      to generate;
      msg_svc.c (server stub) and msg_clnt.c (client stub)
      these were compiled with the client and server code
      gcc server.c msg_svc.c -lsun -o serv
      gcc client.c msg_clnt.c -lsun -o clnt

      serv was run in the background (serv &)
      clnt was given a host name and a number (i.e. clnt cse 4)
*/

program MESSAGEPROG {
        version MESSAGEVERS {
                string PRINTMESSAGE(string) = 1;
        } = 1;
} = 0x2000099;
```

20

Higher-Level RPC - Server

```
#include<stdio.h>
#include<rpc/rpc.h>
#include "msg.h"

/* SERVER */
/* msg_proc.c*/

char ** printmessage_1( char **msg) {
  static char *result;
  int rec_num,i;
  char buffer[80];
        rec_num = atoi(*msg);
        for (i=0;i<rec_num;i++) {
                strcpy(&buffer[i*6],"HELLO ");
        }
        printf("SERVER RECEIVED %d, SENT: %s \n",
             rec_num,buffer);
        result = buffer;
        return (&result);
}
```

21

Higher-Level RPC - Client

```
#include<stdio.h>
#include<rpc/rpc.h>
#include "msg.h"

main(int argc, char *argv[]) {
 CLIENT *cl;  char **result;  char *server;
 char *message;
 server = argv[1];   /* Should check for 2 arguments!!! */
 message = argv[2];
 cl = clnt_create(server, MESSAGEPROG,  MESSAGEVERS, "tcp");
 if (cl == NULL) {
        clnt_pcreateerror(server);
        exit(1);
 }
 result = printmessage_1(&message, cl);
 if (result == NULL) {
        clnt_perror(cl,server);
        exit(1);
 }
 if (*result == 0) {
        printf("message unavailable \n");
        exit(1);
 }
 printf("CLIENT RECEIVED MESSAGE: %s\n",*result);
 exit(0);
}
```

22

RPC Parameter Passing

- Call-by-value
  - » easy, just pass the value
- Call-by-reference
  - » address, not value is passed
  - » address must make sense on remote machine
- Call-by-copy/restore
  - » copy address space in message
    - ❖ for example, must pass entire array, not just pointer to array
  - » server manipulates data in its address space
  - » client must overwrite the data structure when reply is received
  - » What about a linked list?

23

Parameter Passing (cont.)

- Call-by-reference through messages
  - » whenever pointer referenced, send message to client to get value
  - » client stub must be set up to answer server
- Parameter marshaling
  - » problem: different machines represent numbers, characters, etc., differently
  - » network-wide canonical form
    - ❖ each machine only responsible for converting from canonical to local form, but may end up doing unnecessary conversions
      - ◆ from 'big endian' to canonical to 'big endian'...
  - » client identifies message format
    - ❖ only server needs conversion routines

24

Client/Server Binding

- Duration of connection
  - » make connection each time service needed
  - » keep virtual circuit active between calls
- Communication binding
  - » static: direct communication determined at compile time
  - » dynamic: communicate through a name service
    - server exports (registers) its services with the binder
      - a kind of name server
    - client makes an import call to binder
    - if server exists, binder gives address to client

25

Handling RPC Failures

- When RPC fails:
  - » transparency is lost
  - » client programmers may want to make exception handlers (transparency is lost)
- Lost request messages
  - » kernel re-sends message after time out
- Reply message is lost
  - » idempotent operations - just ask for service again
  - » non-idempotent operations are more difficult
    - assign request number to each request
    - server refuses to re-do requests

26

Handling RPC Failures (cont.)

- Client can’t locate server
  - » need exception handlers
- Server crashes
  - » server crashes (some time) after receiving request
  - » at least once semantics
  - » at most once semantics
    - difficult to guarantee
- Client crashes
  - » client crashes before server replies
  - » server is active - but can’t send result
    - known as an orphan
  - » various methods to remove the orphans

27

RPC Implementation Issues

- Protocols
  - » same issues as in client-server
  - » connectionless protocols dominate
    - performance is needed, LANS are reliable
  - » customized RPC protocols are common
- Acknowledgments
  - » stop-and-wait
  - » blast
    - client sends all packets
    - server acknowledges with one ack
    - re-send entire message vs. selective repeat
    - network chips don’t always have capacity for blast

28

RPC Implementation Issues (cont.)

- Critical path analysis
  - » context switching most expensive
    - ❖ busy wait; then multiprogramming suffers
  - » also copying between user and kernel address spaces
- Copying between address spaces
  - » varies from 1 to 8 copies per message
  - » changing memory map to achieve “copying”
    - ❖ kernel changes memory map so buffer is now in user’s memory map
    - ❖ user program has access to memory without copying
    - ❖ message needs to be on page boundaries

29

RPC Implementation Issues (cont.)

- Timer management
  - » lot of time-outs - very CPU intensive
    - ❖ fortunately few need exact time
  - » sorted list
    - ❖ expensive to update when reply received
  - » sweep algorithms
    - ❖ each process in process table has ‘timer’ field
    - ❖ zero means timer is off
    - ❖ kernel scans process table for expired timers

30

Problems Inherent to RPC

- Global variables
  - » remote procedures don’t have access to globals
  - » Will RPC ever achieve full transparency?
- Pipe structures
  - » p1 <f1 | p2 | p3 >f2
  - » read-driven: each program is an active client requesting a read
    - ❖ p1 requests read from f1
    - ❖ p2 requests read from p1
    - ❖ p3 requests read from p2
    - ❖ file server needs to act as a client requesting read from p3 - but it’s role is as a server!
  - » write-driven: mirror image problem

RPC vs. Message Passing

- Message Passing
  - » user is explicitly concerned with message manipulation
  - » need to define syntax and semantics
  - » flexibility, any semantics can be defined
- RPC
  - » message passing accomplished transparently
  - » syntax and semantics are given
  - » semantics are set
    - ❖ blocking send by client
    - ❖ blocking read by server
- Performance issues still an open issue
  - » concurrency not supported well by RPC
  - » applications may experience different performance differences
    - ❖ implementation is crucial and not yet well-established

Group Communication

- RPC: communication only involves two processes
  - » note: not so for general client/server model
- Group definition
  - » set of processes working together
  - » processes free to join or leave group
  - » messages sent to all in a group
  - » only group has access to communication

33

Group Communication (cont.)

- Multicasting
  - » special network address used to define groups
  - » machine listens only if part of group
- Broadcasting
  - » message sent to all machines
  - » kernel determines if any processes in the group
- Unicasting
  - » send point-to-point message to all in group

34

Group Communication Design Issues

- Closed vs. open groups
  - » closed doesn't allow outside messages - parallel processing
- Peer vs. hierarchical groups
  - » decision making in groups
  - » all participate vs. coordinator
  - » with coordinator, must have election algorithm if coordinator dies
- Group membership
  - » group server to maintain group status
    - ❖ falls into centralized trap
  - » member crashes must be discovered
  - » when joining group, must get all messages immediately
    - ❖ when leaving, cannot receive any more messages

35

Group Communication Design Issues (cont.)

- Group addressing
  - » multicast
    - ❖ message sent to all machines with process in group
  - » broadcast
    - ❖ message must be discarded by machines not in group
  - » unicast
    - ❖ kernel sends message to each machine
  - » group members send to group members
    - ❖ requires each member to maintain group list

36

Group Communication Design Issues (cont.)

- Send and receive primitives
  - » problem: there are potentially *n* different replies
  - » solution: treat replies as separate messages
    - ❖ but difficult to merge with RPC
  - » different calls for group communication
    - ❖ group_send
    - ❖ group_receive

37

Group Communication Design Issues (cont.)

- Atomic broadcast
  - » either all get the message or none do
    - ❖ simple semantics: if one member doesn't get message, just re-send
    - ❖ no need for selective re-send
  - » difficult to achieve in practice
  - » one method:
    - ❖ sender sends message to all in group
    - ❖ if receiver has seen message before, discard it
    - ❖ if message is new to receiver, send to all in group
    - ❖ all (non-crashed) processes will get message
    - ❖ lots of overhead in the form of unnecessary messages

38

Group Communication Design Issues (cont.)

- Message ordering
  - » arrival times over LAN is nondeterministic
  - » global time ordering
  - » consistent time ordering

39

Group Communication Design Issues (cont.)

- Overlapping groups
  - » global time ordering only within a group
- Scalability
  - » sending multicasts & broadcasts to interconnected LANs
    - ❖ gateways just forward the message
    - ❖ messages will be repeated
  - » packets can be actively transmitting simultaneously when LAN interconnected
    - ❖ destroys global ordering

40