Linux Programming

Topics

1) How can we do multitasking?
2) How can our multiple tasks communicate?
3) How can we communicate over the network?

Concurrency:
Processes & Threads

Processes: fork() / exec__()

- Each process has a separate..
- fork():..
- exec__(): replaces current process with an executable file.

```
pid_t child_pid = fork();
if (child_pid != 0)
        printf ("Parent process: id %d\n", (int) getpid());
else {
        printf ("Child process: id %d\n", (int) getpid());

        // Exchange child for executing /bin/ls
        char *args[] = {"/bin/ls", "-l", "/dev/tty", (char *) 0};
        execv("/bin/ls", args);

        printf("Won't see this!\n");   ...
}
```

Threads

- All threads of a process..
- Thread function:

```
void *myThreadFn(void *args)
{
    // Do stuff
    return NULL;
}
```

Direct access to shared (global) variables.

- Call:
  -

```
pthread_t id;
pthread_create(&id, NULL, &myThreadFn, NULL);
```

Thread attributes

void* Arguments

- Wait till thread finishes (and cleans up some memory):
  - `pthread_join(id, NULL);`
- `#include <pthread.h>`

Can be void** to hold return value from thread function

Race Case

- Race case
  if a memory location (a global variable) is..
  - What is the value of count after executed as two threads?

```
#define MAX 1000000
long long count = 0;

void* foo(void* args)
{
        for(long long i = 0; i < MAX; i++) {
                count++;
        }
        return NULL;
}
```

```
COUNT is:    1107469
Off by:       892531
```

  - What helps? volatile? static?

_Atomic

- ..
  - Add _Atomic to a type to make updates atomic (including ++)

```
#define MAX 1000000
_Atomic long long count = 0;

void* foo(void* args)
{
        for(long long i = 0; i < MAX; i++) {
                count++;
        }
        return NULL;
}
```

```
COUNT is:    2000000
```

Works On

Primitives

```
_Atomic int count;
_Atomic unsigned char ch;
```

Pointers

```
_Atomic long long *pValue;
```

Does Not Work On

Structs / Unions / Arrays

```
typedef struct {
        long count;
} sData;
_Atomic sData bad;
...
        bad.count++;
```

Bad

But Does Work On

Structs Fields

```
typedef struct {
        _Atomic long count;
} sData;
sData data;
...
        data.count++;
```

<stdatomic.h>

- <stdatomic.h> defines some useful types
  - Nothing special, just for convenience

```
typedef _Atomic _Bool                atomic_bool;
typedef _Atomic char                 atomic_char;
typedef _Atomic int                  atomic_int;
typedef _Atomic unsigned int         atomic_uint;
typedef _Atomic long                 atomic_long;
typedef _Atomic unsigned long        atomic_ulong;
typedef _Atomic long long            atomic_llong;
typedef _Atomic unsigned long long   atomic_ullong;
typedef _Atomic __CHAR16_TYPE__      atomic_char16_t;
typedef _Atomic __CHAR32_TYPE__      atomic_char32_t;
typedef _Atomic __INTMAX_TYPE__      atomic_intmax_t;
typedef _Atomic __UINTMAX_TYPE__     atomic_uintmax_t;
...
```

Thread Synchronization

- Mutex:
  - Control access to critical sections.
  -
- Create:

```
pthread_mutex_t myMutex =
  PTHREAD_MUTEX_INITIALIZER;
```

- Critical Section:

```
pthread_mutex_lock(&myMutex);
{
      // Do critical stuff here!
}
pthread_mutex_unlock(&myMutex);
```

```
static int data[SIZE];
void foo()
{
      int sum = 0;
      pthread_mutex_lock(&dataMutex);
      {
            for (int i = 0; i < SIZE; i++) {
                  sum += data[i];
            }
      }
      pthread_mutex_unlock(&dataMutex);
      printf("Sum of elements: %d\n", sum);
}
```

IO outside of critical section.

Thread considerations

- Tips for Critical Sections:
  - Keep critical sections short:
    avoid blocking other threads.
  - Calculate values with temporary variables;
    then update shared variables in critical section.
  - Use extra {...} to highlight the critical section.
  - Always unlock!
- Compiling (linking)

```
arm-linux-gnueabihf-gcc -Wall -g demo_thread.c \
    -o demo_thread    -pthread
```

Communicating Between Threads

- Code in different threads can interact in many ways
  - ..
    Use to signal events between threads.
  - ..
    Accessible between threads
    (but may need to be atomic or protected by critical sections).
  - .. (next)
    Can push data between threads or processes.

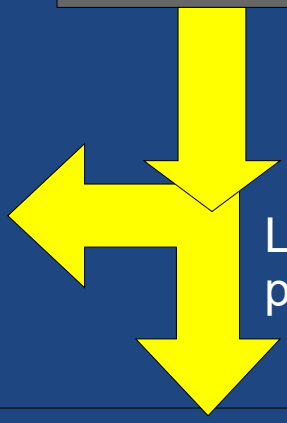
Pipes

Basics

- Pipe:
  -
  - Good for inter-thread and inter-process communication.
- Needed Functions:
  - pipe() to create file descriptors for read and write ends of pipe.
  - fdopen() to open the pipe (from descriptor)
  - fprintf() to write (or other functions)
  - fgets() to read [blocking] (or other functions)
  - close() to close the file descriptor.

Pipe Code

```
// File descriptors for pipe ends
int fds[2];
// Create a pipe.
pipe (fds);
```



Likely fork() or
pthread_create()

```
// Writer: Convert the write file descriptor
// to a FILE object
FILE* streamW = fdopen (fds[1], "w");
fprintf (streamW, "Hello World!\n");
fflush (streamW);
close (fds[1]);
```

```
// Reader: Convert read file descriptor to a FILE object.
FILE* streamR = fdopen (fds[0], "r");

// Read until end of the stream.
char buffer[1024];
while (!feof (streamR) && !ferror (streamR)
            && fgets (buffer, sizeof (buffer), streamR) != NULL) {
      printf("%s", buffer);
}
close (fds[0]);
```

popen() = Fork & pipe

- Execute a shell command using a pipe for output [or input].

```c
#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
int main()
{
	// Execute the shell command (output into pipe)
	FILE *pipe = popen("ls -l /dev/tty*", "r");

	// Dump contents of pipe to the screen.
	char buffer[1024];
	while (!feof(pipe) && !ferror(pipe)) {
		if (fgets(buffer, sizeof(buffer), pipe) == NULL)
			break;
		printf("--> %s", buffer);
	}

	// Close pipe, check program's exit code
	int exitCode = WEXITSTATUS(pclose(pipe));
	if (exitCode != 0) {
		printf("program failed: %d\n", exitCode);
	}
	return 0;
}
```

= demo_popen.c

Sockets:
Bidirectional network communication

Socket Intro

- Socket
  -
  - Used to send data between processes on the same computer, or across the network.
    - Like a pipe, but works across a network too.
- Use
  - Server:..
    - Usually at a known port number.
    - When data received, it knows client IP and port.
  - Client:..
    - May also wait for a reply.

Socket Types

I know a great joke about UDP,
but I'm not sure anyone would get it.

- Connection (TCP):
  - in order delivery, automatic retransmission
  - single connection between specific host and server.
  - Better for long term connections with large amount of data (fetch web-page).
- Datagram (UDP):
  - no persistent connection (connectionless):
    ..
  - Better for short, single packet messages.
- See section 5.5 of Advanced Linux Programming for socket examples.

UDP Constants

- FYI: Here are what some of the socket constants mean:
  - sockaddr_in: Socket Address for INternet (struct)
  - sin: Socket INternet, such as in sin_family
  - AF_INET: Address Family, Internet (IP v4)
  - PF_INET: Protocol Family, Internet (IP v4)
  - SOCK_DGRAM: Socket, user Datagram protocol (UDP)

  (You don’t need to memorize these).

UDP Server Programming (1/3 - Init)

- Address Structure

```
#define MAX_LEN 1024
#define PORT  22110

struct sockaddr_in sin;
memset(&sin, 0, sizeof(sin));
sin.sin_family = AF_INET;
sin.sin_addr.s_addr = htonl(INADDR_ANY);
sin.sin_port = htons(PORT);
```

_in means internet

Connection may be from network

ntonl = host to network long;
htons = host to network short

- Create and bind to socket

```
int socketDescriptor = socket(PF_INET, SOCK_DGRAM, 0);
bind (socketDescriptor, (struct sockaddr*) &sin, sizeof(sin));
```

C has numerous socket address structures:
sockaddr (generic), sockaddr_in (internet), ...
bind() accepts a generic sockaddr and decides what to do based on the family field (shared by all sockaddr structs).

UDP Server Programming (2/3 - Read)

- Receive Data

```
struct sockaddr_in sinRemote;
unsigned int sin_len = sizeof(sinRemote);
char messageRx[MAX_LEN];
int bytesRx = recvfrom(socketDescriptor,
    messageRx, MAX_LEN - 1, 0,
    (struct sockaddr *) &sinRemote, &sin_len);


// Null terminated (string):
messageRx[bytesRx] = 0;

printf("Message received (%d bytes): '%s'\n",
    bytesRx, messageRx);
```

Client's data written into messageRx string

sinRemote is output parameter; sinLen is in/out parameter.

What if recvfrom filled the buffer 100%? Overflow?

UDP Socket Programming (3/3 Reply)

- Create Reply

```
// Watch for buffer overflow!
char messageTx[MAX_LEN];
snprintf(messageTx, MAX_LEN, "Hello %d\n", 42);
```

- Send Reply

```
sin_len = sizeof(sinRemote);
sendto( socketDescriptor,
    messageTx, strlen(messageTx),
    0,
    (struct sockaddr *) &sinRemote, sin_len);
```

Have client's IP address and port from receiving the message.

- Close socket (when done)

```
close(socketDescriptor);
```

  - May take a few seconds for OS to finish closing.

Byte Order

-
  - 2 bytes of 0xa1cf transmitted as 0xa1, 0xcf
  - Big-endian = network byte order:..
  - x86 is little-endian; ARM is bi-endian (supports both)
- Never assume your processor is network order: use host-to-network to adjust:

Prototypes

```
uint32_t htonl(uint32_t hostlong);
uint16_t htons(uint16_t hostshort);
uint32_t ntohl(uint32_t netlong);
uint16_t ntohs(uint16_t netshort);
```

Example

```
#include <netdb.h>

short toTransmit1 = htons(myVal1);
long toTransmit2 = htonl(myVal2);
```

Summary

- Use processes for coarse multitasking:
  - Use fork() and exec__().
  - Example: A server and a client with well defined separate roles.
- Use threads for fine-grained multitasking.
  - Use pthread_create(), pthread_join
  - Use _Atomic for shared variables
  - Mutex with pthread_mutex_t: pthread_mutex_lock(), pthread_mutex_unlock().
- Pipes for inter process/thread communication.
- Sockets for network communication.