CSC 4304 - Systems Programming
Fall 2008

LECTURE - XII

MIDTERM REVIEW

Tevfik Koşar

Louisiana State University

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Parameter Passing in C

- In C, function parameters are passed **by value**
  - Each parameter is copied
  - The function can access the copy, not the original value

```
#include <stdio.h>

void swap(int x, int y) {
  int temp = x;
  x = y;
  y = temp;
}

int main() {
  int x = 9;
  int y = 5;
  swap(x, y);
  printf("x=%d y=%d\n", x, y);
  return 0;
}
```


Parameter Passing in C

- To pass parameters by reference, use pointers
  - The pointer is copied
  - But the copy still points to the same memory address

```
#include <stdio.h>

void swap(int *x, int *y) {
  int temp = *x;
  *x = *y;
  *y = temp;
}

int main() {
  int x = 9;
  int y = 5;
  swap(&x, &y);
  printf("x=%d y=%d\n", x, y); /* This will print: x=5 y=9 */
  return 0;
}
```


Pointer Arithmetic

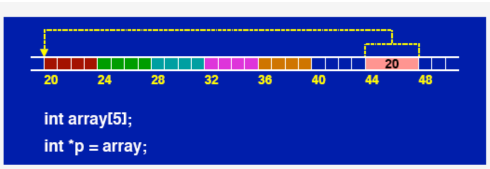
- Pointers are just a special kind of variable
- You can do **calculations** on pointers
  - You can use +, −, ++, −− on pointers
  - This has no equivalent in Java
- Be careful, operators work with the **size** of variable types!

```
int i = 8;
int *p = &i;
p++;  /* increases p with sizeof(int) */

char *c;
c++; /* increases c with sizeof(char) */
```

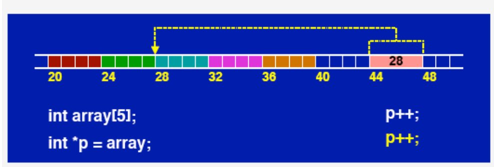

Pointer Arithmetic

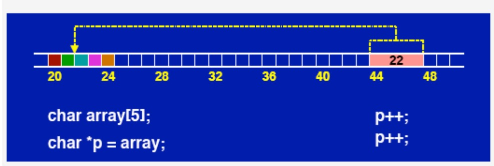
- This is obvious when using pointers as arrays:

```
int i;
int array[5];
int *p = array;

for (i=0;i<5;i++) {
   *p = 0;
   p++;
}
```



Pointer Arithmetic





Function Pointers

- Functions are not variables but we can define pointers to functions which will allow us to manipulate functions like variables..

- int f() : a function which returns an integer
- int* f() : a function which returns a pointer to integer
- int (*f)(): a pointer to a function which returns integer
- int (*f[])(): an array of pointer to a function which returns integer

Example

```
void sum(int a, int b) {printf("sum: %d\n", a+b);}
void dif(int a, int b) {printf("dif: %d\n", a-b);}
void mul(int a, int b) {printf("mul: %d\n", a*b);}
void div(int a, int b) {printf("div: %f\n", a/b);}

void (*p[4]) (int x, int y);

int main(void)
{
  int result;
  int i=10, j=5, op;

  p[0] = sum; /* address of sum() */
  p[1] = dif; /* address of dif() */
  p[2] = mul; /* address of mul() */
  p[3] = div; /* address of div() */

  for (op=0;op<4;op++) (*p[op]) (i, j);

}
```


Operator Precedence

Operators	Associativity	Type
() [] -> .	left to right	primary expr.
++ *(postfix)* -- *(postfix)*	right to left	postfix
+ - ! ++ *(prefix)* -- *(prefix)* (*type*)	right to left	unary
* / %	left to right	multiplicative
+ -	left to right	additive
< <= > >=	left to right	relational
== !=	left to right	equality
&&	left to right	logical AND
||	left to right	logical OR
?:	right to left	conditional
= += -= *= /= %=	right to left	assignment
,	left to right	comma

Complicated Declarations

- int *a[10]: array[10] of pointer to int
- int (*a)[10]: pointer to array[10] of int
- void *f(): function returning pointer to void
- void (*f)(): pointer to a function returning void
- char (*(*x())[])(): ??
- char (*(*x[3])())[5]: ??

Complicated Declarations

- int *a[10]: array[10] of pointer to int
- int (*a)[10]: pointer to array[10] of int
- void *f(): function returning pointer to void
- void (*f)(): pointer to a function returning void
- char (*(*x())[])(): function returning pointer to array[] of pointer to function returning char
- char (*(*x[3])())[5]: array[3] of pointer to function returning pointer to array[5] of char

Static Local Variables

- Declaring a static variable means it will persist across multiple calls to the function

```
void foo() {
  static int i=0;
  i++;
  printf("i=%d\n",i);  /* This prints the value of i on the screen */
}

int main() {
  int i;
  for (i=0;i<3;i++) foo();
}
```

This program will output this:

```
i=1
i=2
i=3
```

Dynamic Memory Management

- `malloc()` will allocate any amount of memory you want:

```
#include <stdlib.h>
void *malloc(size_t size);
```

  - malloc takes a size (in bytes) as a parameter
    - If you want to store 3 integers there, then you must reserve `3*sizeof(int)` bytes
  - It returns a pointer to the newly allocated piece of memory
    - It is of type `void *`, which means "pointer to anything"
    - Do not store it as a `void *`! You should "cast" it into a usable pointer:

```
#include <stdlib.h>
int *i = (int *) malloc(3*sizeof(int));
i[0] = 12;
i[1] = 27;
i[2] = 42;
```


malloc & free Example

```
int main ()
{
   int x = 11;
   int *p, *q;
   p = (int *) malloc(sizeof (int));
  *p = 66;
   q = (int *) malloc(sizeof (int));
  *q = *p - 11;
   free(p);
   printf ("%d %d %d\n", x, *p, *q);
   x = 77;
   p = q;
   q = (int *) malloc(sizeof (int));
  *q = x + 11;
   printf ("%d %d %d\n", x, *p, *q);
   p = &x;
   p = (int *) malloc(sizeof (int));
  *p = 99;
   printf ("%d %d %d\n", x, *p, *q);
   q = p;
   free(q);
   printf ("%d %d %d\n", x, *p, *q);
}
```

```
./free
11 ? 55
77 55 88
77 99 88
77 ? ?
```


Exercise

The subroutine free() frees a block of memory so that it can be reused by malloc(). However, free() is passed only a pointer to the block to be freed.

1. How does free() know how big this block is?

1. `malloc()` allocates 8 extra bytes in front of the pointer that it returns. The first four of these bytes contain the size of the amount of memory that `malloc()` allocated. Thus, `free9)` can use this size to put this chunk of memory back on `malloc()`'s free list.

Exercise *(cont.)*

2. "Bad arguments" can be passed to free(). Describe what a bad argument to free() is and what are the possible results of passing bad arguments to free()?

2. If `free()` is given an address that was *not* returned from `malloc()`, or an address that has already been `freed()`'d, then it will do bad things. It will assume that the address was returned by `malloc()`, and it will look 8 bytes back from that address and treat whatever is there as the size of the region to free. There are many possible results of calling `free()` on a bad address. These are:
   - Segmentation violation – the address is not a legal address.
   - Bus error – the address is not aligned, so when `free()` tries to glean the size, it will generate a bus error.
   - Unknown – it will put some chunk of memory on the free list that is perhaps still in use, and will then get `malloc()`'d later. Or it will put an already-`free()`'d chunk of memory on the free list, and it will get `malloc()`'d twice. In any case, the `free()` call will succeed, but subsequent `malloc()`'s will cause very strange results.

Exercise *(cont.)*

3. Free() should be fixed so that bad arguments are recognized (or are almost always recognized). Discuss how this can be achieved.

3. One good way is to put a checksum in the 4 bytes following the size. That way when `free()` is first called, it can check the 4 bytes preceeding the address and see if they equal the checksum. If so, then `free()` can be reasonably certain that the address is a good one. Otherwise, `free()` can flag the error instantly.

   Another way is to keep a list or hash table or rb-tree of `malloc()`'d chunks, and check to see if the address given in `free()` has been `malloc()`'d. This is less efficient than the checksum given above.

Buffered I/O

- Unbuffered I/O: each read write invokes a system call in the kernel.
  - read, write, open, close, lseek
- Buffered I/O: data is read/written in optimal-sized chunks from/to disk --> streams
  - standard I/O library written by Dennis Ritchie

Standard I/O Library

- Difference from File I/O
  - File Pointers vs File Descriptors
  - fopen vs open
    - When a file is opened/created, a *stream* is associated with the file.
    - FILE object
      - File descriptor, buffer size, # of remaining chars, an error flag, and the like.
  - stdin, sdtout, stderr defined in <stdio.h>
    - STDIO_FILENO, STDOUT_FILENO,…

Standard I/O Eficiency

- Copy stdin to stdout using:

	total time	kernel time	
fgets, fputs	2.6 sec	0.3 sec	
fgetc, fputc	5 sec	0.3 sec	
read, write	423 sec	397 sec	(1 char at a time)

Effect of Buffer Size

- cp file1 to file2 using read/write with buffersize: *(5 MB file)*

buffersize	exec time
1	50.29
4	12.81
16	3.28
64	0.96
256	0.37
1024	0.22
4096	0.18
16384	0.18

Exercise

Below are two implementations of the same function:

```
#include <fcntl.h>
#include "dlist.h"

Dlist file_to_dlist_1(char *fn)
{
  int n_ints;
  Dlist d;
  int i, j;
  int fd;

  fd = open(fn, O_RDONLY);

  d = make_dl();
  read(fd, &n_ints, sizeof(int));
  for (i = 0; i < n_ints; i++) {
    read(fd, &j, sizeof(int));
    dl_insert_b(d, j);
  }
  close(fd);
  return d;
}
```

```
#include <stdio.h>
#include "dlist.h"

Dlist file_to_dlist_2(char *fn)
{
  int n_ints;
  Dlist d;
  int i, j;
  FILE *f;

  f = fopen(fn, "r");

  d = make_dl();
  fread(&n_ints, sizeof(int), 1, f);
  for (i = 0; i < n_ints; i++) {
    fread(&j, sizeof(int), 1, f);
    dl_insert_b(d, j);
  }
  fclose(f);
  return d;
}
```

Which of the functions above will be more efficient if the file being read is large, and why?

Solution

`File_to_dlist_2` is more efficient because it uses the standard I/O library, which buffers input. `File_to_dlist_1` makes the system call `read()` once for every integer in the file. `File_to_dlist_2` makes a procedure call which copies the input from a buffer, and only calls `read()` when the buffer is empty. As the buffer is larger than one integer (usually something like 4Kbytes), it saves the user on the order of 1000 system calls from `file_to_dlist_1`.

Write a function file_to_dlist_3() which is functionally equivalent to these two functions, and is at least as efficient as the best of these two.

Solution

`File_to_dlist_2` is more efficient because it uses the standard I/O library, which buffers input. `File_to_dlist_1` makes the system call `read()` once for every integer in the file. `File_to_dlist_2` makes a procedure call which copies the input from a buffer, and only calls `read()` when the buffer is empty. As the buffer is larger than one integer (usually something like 4Kbytes), it saves the user on the order of 1000 system calls from `file_to_dlist_1`.

In order to write an efficient `file_to_dlist_3`, we must provide our own buffering. By this, we read in the number of integers, and then `malloc` space for all of them. Then we read all of them from the file in one system call, and then create the dlist. When we're done, we call `free` to free up the allocated memory. The code is below:

```
Dlist file_to_dlist_3(char *fn)
{
  int n_ints;
  Dlist d;
  int i;
  int fd;
  int *buffer;

  fd = open(fn, O_RDONLY);

  d = make_dl();
  read(fd, &n_ints, sizeof(int));
  buffer = (int *) malloc(sizeof(int) * n_ints);
  read(fd, buffer, sizeof(int) * n_ints);
  for (i = 0; i < n_ints; i++) {
    dl_insert_b(d, buffer[i]);
  }
  close(fd);
  free(buffer);
  return d;
}
```

Restrictions

Type	r	w	a	r+	w+	a+
File exists?	Y			Y		
Truncate		Y			Y	
R	Y			Y	Y	Y
W		Y	Y	Y	Y	Y
W only at end			Y			Y

* When a file is opened for reading and writing:

- Output cannot be directly followed by input without an intervening *fseek, fsetpos, or rewind*
- Input cannot be directly followed by output without an intervening *fseek, fsetpos, or rewind*

Files and Directories

- Objectives
  - Additional Features of the File System
  - Properties of a File.

```
struct stat {
    mode_t   st_mode; /* type & mode */
    ino_t    st_ino; /* i-node number */
    dev_t    st_dev; /* device no (filesystem) */
    dev_t    st_rdev; /* device no for special file */
    nlink_t  st_nlink; /* # of links */
    uid_t    st_uid;        gid_t   st_gid;
    off_t    st_size; /* sizes in byes */
    time_t   st_atime; /* last access time */
    time_t   st_mtime; /* last modification time */
    time_t   st_ctime; /* time for last status change */
    long     st_blk_size; /* best I/O block size */
    long     st_blocks; /* number of 512-byte blocks allocated */
};
```


Directories

- dirent : file system independent directory entry

```
struct dirent{
    ino_t  d_ino;
    char   d_name[];
    ....
};
```


Directories - System View

- user view vs system view of directory tree
  - representation with “dirlists (directory files)”
- The real meaning of “A file is in a directory”
  - directory has a link to the inode of the file
- The real meaning of “A directory contains a subdirectory”
  - directory has a link to the inode of the subdirectory
- The real meaning of “A directory has a parent directory”
  - “..” entry of the directory has a link to the inode of the parent directory

Example inode listing

```
$ ls -iaR demodir
865 .    193 ..    277 a    520 c    491 y

demodir/a:
277 .    865 ..    402 x

demodir/c:
520 .    865 ..    651 d1    247 d2

demodir/c/d1:
651 .    520 ..    402 xlink

demodir/c/d2:
247 .    520 ..    680 xcopy
```


Link Counts

- The kernel records the number of links to any file/ directory.
- The *link count* is stored in the inode.
- The *link count* is a member of *struct stat* returned by the *stat* system call.

Set-User-ID Bit

- How can a regular user change his/her password?

```
cs4304_kos@classes:~> ls -l /etc/passwd
-rw-r--r--  1 root root 70567 2008-09-23 09:28 /etc/passwd
```

- Permission is given to the program, not to you!

```
cs4304_kos@classes:~> ls -l /usr/bin/passwd
-rwsr-xr-x  1 root shadow 79520 2005-09-09 15:56 /usr/bin/passwd
```

```
04000 : set user ID
02000 : set group ID
01000 : sticky bit - keep the program in swap device
```


Exercise

```
UNIX> cp /bin/rm .    ; chmod 04755 rm          ; sleep 3600 ; /bin/rm rm
UNIX> cp /bin/sh .    ; chmod 04755 sh          ; sleep 3600 ; rm sh
UNIX> cp /bin/chmod . ; /bin/chmod 04755 chmod  ; sleep 3600 ; rm chmod
UNIX> cp /usr/local/bin/gcc . ; chmod 04755 gcc ; sleep 3600 ; rm gcc
```

What these lines do is the following: For each of the programs **rm**, **sh**, **chmod** and **gcc**, it makes a copy of the program in my home directory, sets the *setuid* bit of the program, and waits for an hour before removing the program.

Suppose we define an "unsafe" state to be one in which a malignant user can overwrite or delete some or all of my files, regardless of how they are protected.

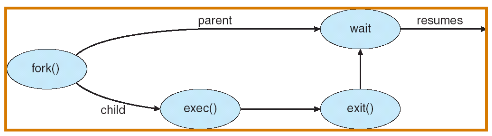
Which lines are unsafe? Why?

How to Create a New Process?

- Parent process create children processes, which, in turn create other processes, forming a tree of processes
- Resource sharing
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call used after a **fork** to replace the process' memory space with a new program



How fork works?

pid_t fork(void);

- Allocates a new chunk of memory and data structures
- Copies the original process into the new process
- Adds the new process to the set of running processes
- Returns control back to both processes

Fork Implementation

```
int main()
{
    Pid_t  pid;
   /* fork another process */
   pid = fork();
   if (pid < 0) { /* error occurred */
       fprintf(stderr, "Fork Failed");
       exit(-1);
   }
   else if (pid == 0) { /* child process */
       execlp("/bin/ls", "ls", NULL);
   }
   else { /* parent process */
       /* parent will wait for the child to
   complete */
```

vfork function

```
pid_t vfork(void);
```

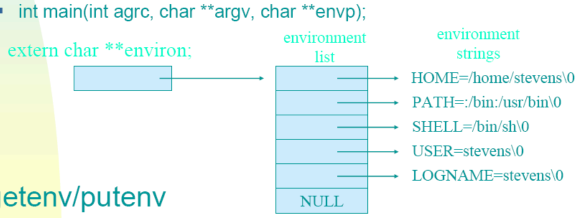
- Similar to fork, but:
  - child shares all memory with parent
  - parent is suspended until the child makes an **exit** or **exec** call

vfork example

```
main()
{
        int     ret, glob=10;


        printf("glob before fork: %d\n", glob);
        ret = vfork();

        if (ret == 0) {
                glob++;
                printf("child: glob after fork: %d\n", glob) ;
                exit(0);
        }

        if (ret > 0) {

                //if (waitpid(ret, NULL, 0) != ret) printf("Wait error!\n");
                printf("parent: glob after fork: %d\n", glob) ;
        }
```


How is Environment Implemented?

- Environment Variables
  - int main(int agrc, char **argv, char **envp);



- getenv/putenv

Example 1

```
#include <stdio.h>
#include <malloc.h>


extern char **environ;

main()
{
        char ** ptr;

        for (ptr=environ; *ptr != 0; ptr++)
                printf("%s\n", *ptr);

}
```


Process Accounting

- Kernel writes an accounting record each time a process terminates
- acct struct defined in <sys/acct.h>

```
typedef u_short comp_t;
struct acct {
    char   ac_flag; /* Figure 8.9 – Page 227 */
    char   ac_stat; /* termination status (core flag + signal #) */
    uid_t  ac_uid; gid_t   ac_gid;  /* real [ug]id */
    dev_t ac_tty;  /* controlling terminal */
    time_t ac_btime; /* staring calendar time (seconds) */
    comp_t ac_utime; /* user CPU time (ticks) */
    comp_t ac_stime; /* system CPU time (ticks) */
    comp_t ac_etime; /* elapsed time (ticks) */
    comp_t ac_mem; /* average memory usage */
    comp_t ac_io; /* bytes transferred (by r/w) */
    comp_t ac_rw; /* blocks read or written */
    char      ac_comm[8]; /* command name: [8] for SVR4, [10] for
4.3 BSD */
  };
```


Process Accounting

- Data required for accounting record is kept in the process table
- Initialized when a new process is created
  - (e.g. after fork)
- Written into the accounting file (binary) when the process terminates
  - in the order of termination
- No records for
  - crashed processes
  - abnormal terminated processes

Signal Disposition

- Ignore the signal (most signals can simply be ignored, except SIGKILL and SIGSTOP)
- Handle the signal disposition via a *signal handler* routine. This allows us to gracefully shutdown a program when the user presses Ctrl-C (SIGINT).
- Block the signal. In this case, the OS queues signals for possible later delivery
- Let the default apply (usually process termination)

Signals from a Process

- **int kill(pid_t pid, int sig)**
  - Can be used to send any signal to any process group or process.
    - **pid** > 0, signal **sig** is sent to **pid**.
    - **pid** == 0, **sig** is sent to every process in the process group of the current process.
    - **pid** == -1, **sig** is sent to every process except for process 1.
    - **pid** < -1, **sig** is sent to every process in the process group -**pid**.
    - **sig** == 0, no signal is sent, but error checking is performed.
- `raise(signo)` causes the specified signal to be sent to the process that executes the call to raise.

Default Actions

- Abort – terminate the process after generating a dump
- Exit – terminate the process without generating a dump
- Ignore – the signal is ignored
- Stop – suspends the process
- Continue – resumes the process, if suspended

Receiving Signals

- **Handling signals**
  - Suppose kernel is returning from exception handler and is ready to pass control to process p.
  - Kernel computes **pnb** = **pending** & ~**blocked**
    - The set of pending nonblocked signals for process p
  - if (**pnb** != 0) {
    - Choose least nonzero bit k in **pnb** and force process p to receive signal k.
    - The receipt of the signal triggers some action by p.
    - Repeat for all nonzero k in **pnb**.

    }
  - Pass control to next instruction in the logical flow for p.

Masking Signals - Avoid Race Conditions

- The occurrence of a second signal while the signal handler function executes.
  - The second signal can be of different type than the one being handled, or even of the same type.
- The system also contains some features that will allow us to block signals from being processed.
  - A global context which affects all signal handlers, or a per-signal type context.

Real-time Signals

- POSIX.4 adds some additional signal facilities. The key features are:
  - The real-time signals are in addition to the existing signals, and are in the range `SIGRTMIN` to `SIGRTMAX`.
  - Real-time signals are queued, not just registered (as is done for non real-time signals).
  - The source of a real-time signal (`kill`, `sigqueue`, asynchronous I/O completion, timer expiration, etc.) is indicated when the signal is delivered.
  - A data value can be delivered with the signal.

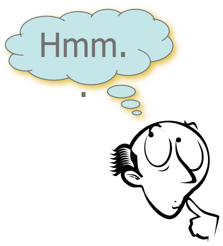
Exercise

Write a program which blocks all of the other signals (except the ones which cannot be blocked) if a signal arrives (same one or different one) while your program is inside a signal handler. Hint use sigaction() function.

Solution

```
   main()
{
        struct sigaction newhandler;         /* new settings        */
        sigset_t         blocked;            /* set of blocked sigs */
        void             inthandler();       /* the handler         */

        newhandler.sa_handler = inthandler;  /* handler function    */
        sigfillset(&blocked);               /* mask all signals      */
        newhandler.sa_mask = blocked;       /* store blockmask     */

        int i;
        for (i=1; i<65;i++)
                if (i!=9 && i!=19 && i!=32 && i!=33)
            /* catch all except these signals */

                if ( sigaction(i, &newhandler, NULL) == -1 )
                          printf("error with signal %d\n", i);
        while(1){}
}
```


Questions?



Acknowledgments

- Advanced Programming in the Unix Environment by R. Stevens
- The C Programming Language by B. Kernighan and D. Ritchie
- Understanding Unix/Linux Programming by B. Molay
- Lecture notes from B. Molay (Harvard), T. Kuo (UT-Austin), G. Pierre (Vrije), M. Matthews (SC), B. Knicki (WPI), M. Shacklette (UChicago), and J.Kim (KAIST).