CSC 4304 - Systems Programming
Fall 2010

Lecture - XI
Midterm Review

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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

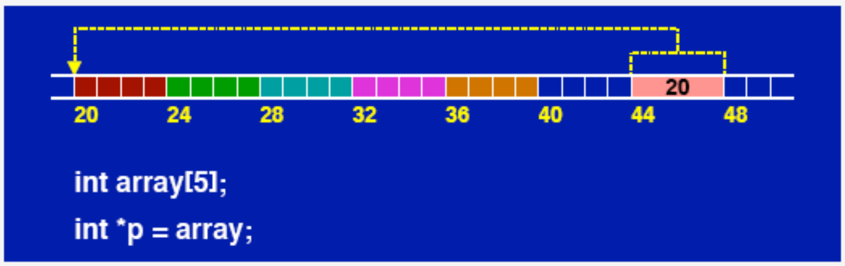
- Pointers are just a special kind of variable
- You can do **calculations** on pointers
  - You can use +, −, ++, −− on pointers
  - This has no equivalent in Java
- Be careful, operators work with the **size** of variable types!

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

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

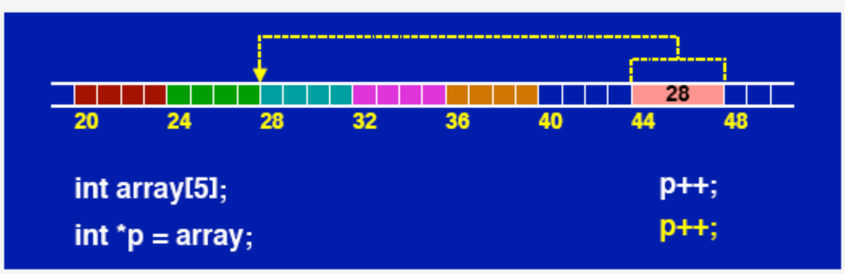
Pointer Arithmetic

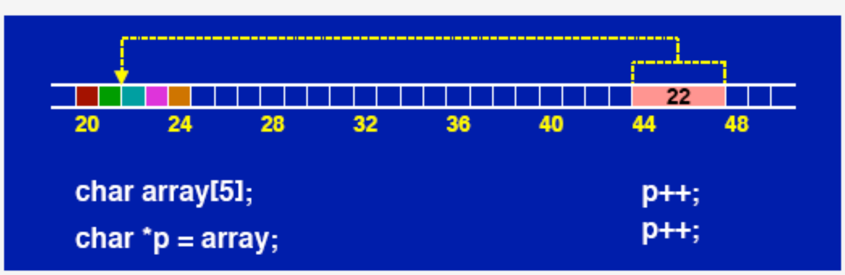
- This is obvious when using pointers as arrays:

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

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



Pointer Arithmetic





Exercise

-
```
int main ()
{
  int i, r[6] ={1,1,1,0,0,0};
  int *ptr;
  ptr = r;
  *ptr = 10;
  *(ptr +1) = 5;
   r[2] = *ptr;
  *(ptr++)=20;
  ptr+=2;
  *(++ptr)=20;
  for (i=0; i < 6; i++)
    printf (" r[%d] = %d\n", i, r[i]);
 }
```


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

Exercise

1. int *a[] :

2. int (*a)[] :

3. int* (*a)() :

4. int* ((a())[])() :

5. int (*(*a())[])() :

6. int* (*(*a[])())[] :

Solutions

int *a[]	: array[] of pointer to int
int (*a)[]	: pointer to array[] of int
int* (*a)()	: pointer to function which returns pointer to int
int* ((a())[])()	: function which returns array[] of functions that return pointer to int
int (*(*a())[])()	: function which returns pointer to array of pointers to functions which return pointer to int
int* (*(*a[])())[]	: array of pointer to function which returns pointer to array of pointer to int

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;
```

Exercise

```
int main ()
  {
     int x = 10;
     int *p, *q;
     q = (int *) malloc(sizeof (int));
    *q = 60;
     p = (int *) malloc(sizeof (int));
     p = q;
     free(p);
     printf ("%d %d %d\n", x, *p, *q);
     q = &x;
     x = 70;
     p = q;
     (*p)++;
     q = x + 11;
     printf ("%d %d %d\n", x, *p, *q);
  }
```


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

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

Exercise

Given the following directory information:

```
$ ls -iaR home
  865 .         193 ..        277 a         520 c      491 y   492 z
home/a:
  277 .         865 ..        402 x
home/c:
  520 .        865 ..        651 d1          247 d2
home/c/d1:
  651 .        520 ..        402 xlink
home/c/d2:
  247 .        520 ..        680 xcopy
```

Exercise (cont)

a) Show the user view of this directory structure

b) Show the system view of this directory structure

c) Assume we perform the following operations:

```
$ rm home/c/d2/xcopy
$ cp home/y home/c/d1
$ ln home/z home/c/d2/z
$ mv home/c/d2 home/c/d1
```

Show the system view of the new directory structure

Link Counts

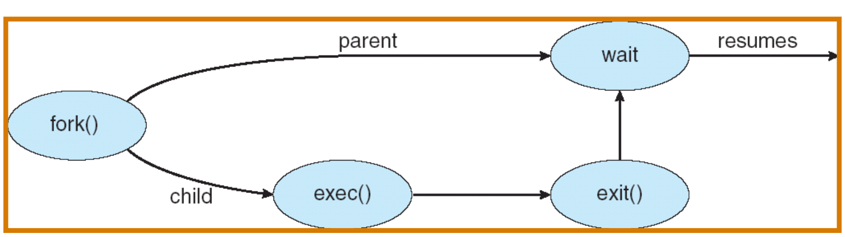
- The kernel records the number of links to any file/directory.
- The *link count* is stored in the inode.
- The *link count* is a member of *struct stat* returned by the *stat* system call.

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 */
```

Exercise

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

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

      ret = fork();
        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) ;
        }
}
```

What would be the output of this program?

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

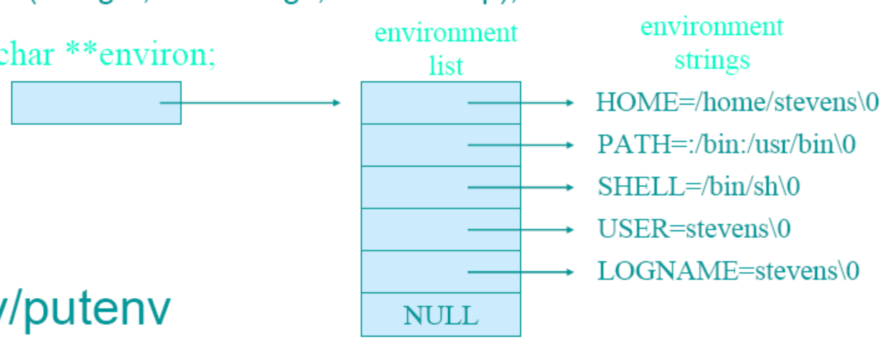
vfork example

```
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);

extern char **environ;



- 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

Pipes

- one-way data channel in the kernel
- has a reading end and a writing end

- e.g. **who | sort** or **ps | grep ssh**

Process Communication via Pipes

```
int pipe(int filedes[2]);
```

- pipe creates a pair of file descriptors, pointing to a pipe inode, and places them in the array pointed to by filedes. filedes[0] is for reading filedes[1] is for writing

Exercise

- UNIX> **sort < f1 | head -5 | cat -n**
- Hints: **"head -5"** displays first 5 lines of a file
  "cat –n" reads a file, writes it to stdout with line numbers
- **What happens to the given process in terms of how it exits?**
  - **i.e. when file f1 does not exist??**

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.

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
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