


深圳大学 计算机与软件学院

College of Computer Science and Software Engineering of Shenzhen University

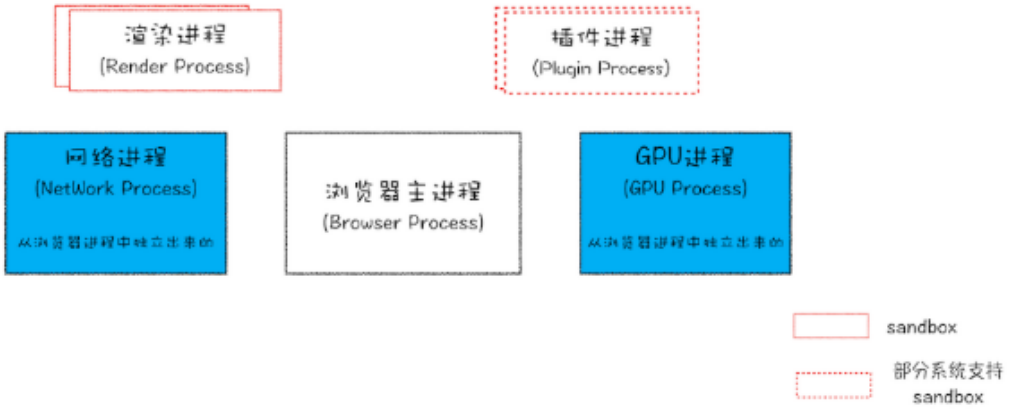
系统编程

基于TaiShan服务器/openEuler OS 的实践

第二讲：进程间通信 – 管道

进程间通信

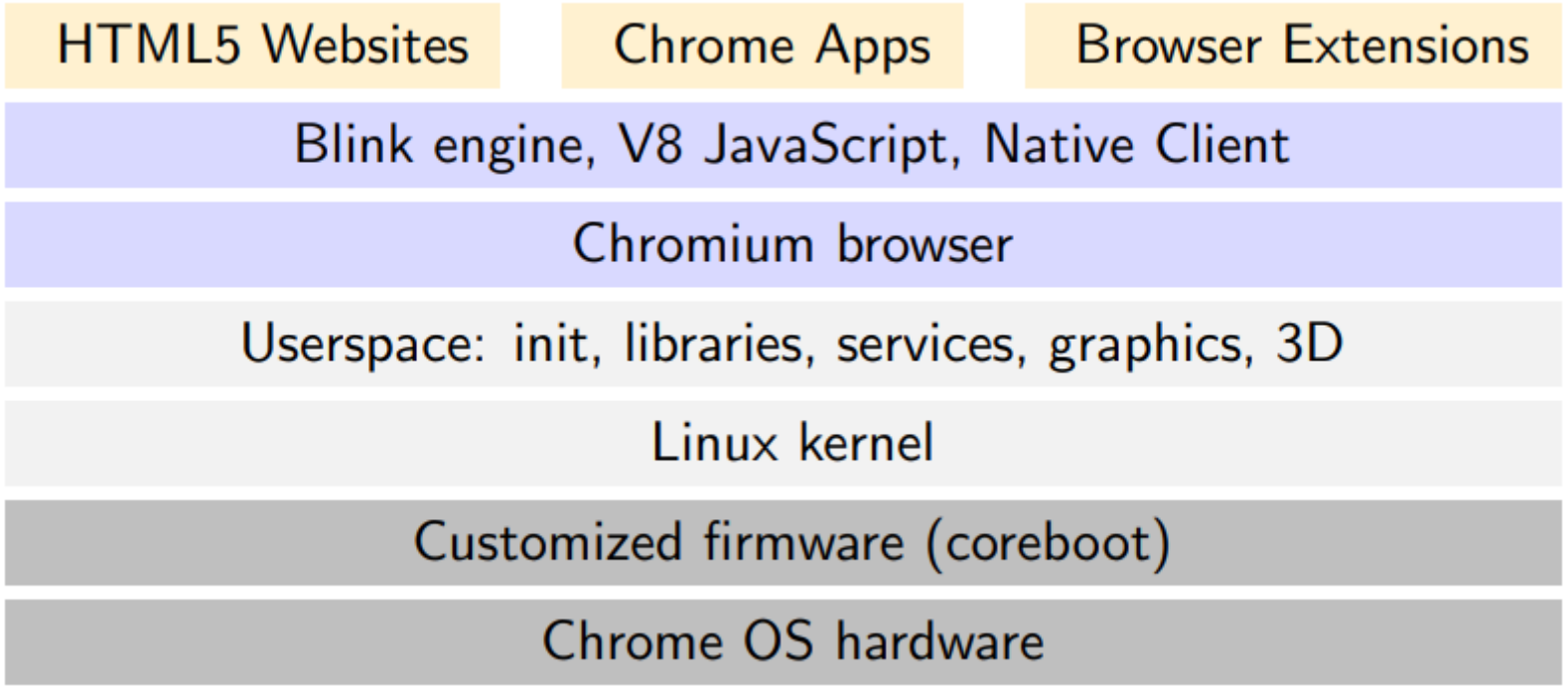
- **What is Inter-Process Communication (IPC)**
  - 进程间传送数据的机制
- **Why is it needed?**
  - 所有任务都由一个进程完成
    - 串行
    - 效率低
    - 可用性差
    - 安全性差
  - 多进程分工协作完成
    - 并行/并发
    - 数据/资源隔离
    - 通信同步



最新的 Chrome 进程架构图

图片出自：
https://www.cnblogs.com/linm/p/12598933.html

Google Chrome 体系结构

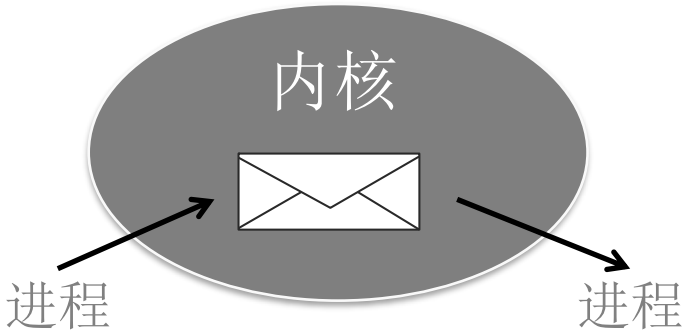


图片出自：
https://events.static.linuxfound.org/sites/events/files/slides/chrome.pdf

https://sites.google.com/a/chromium.org/dev/developers/design-documents/multi-process-architecture

两大类 IPC

“Intermediary” -中介

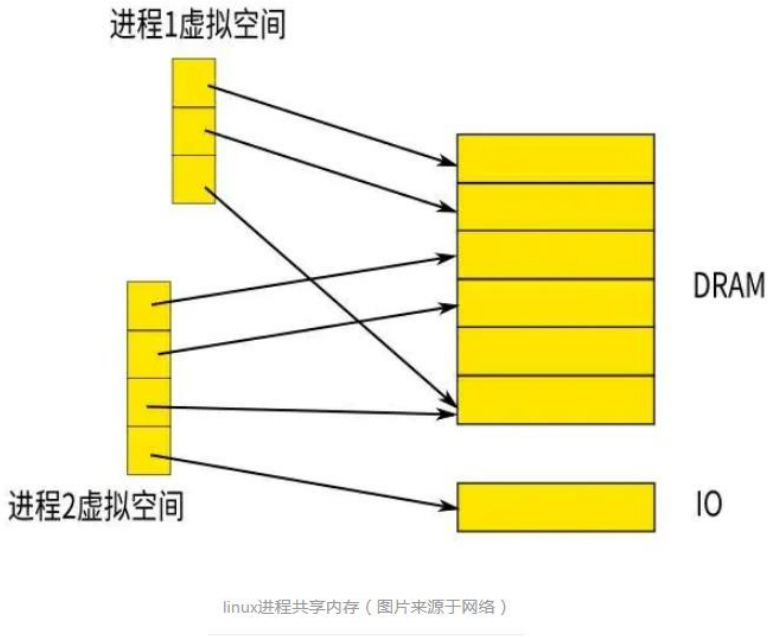


消息通过内核从一个地址空间传到另一个

- 管道
- 命名管道
- 信号
- 信号量
- 消息队列
- 套接字(socket)

课堂学习内容

“Mind meld” （融合）



共享地址空间

- 共享内存
- 内存映射文件

图片来源：https://www.jianshu.com/p/18b71feba27b

进程间通信 – 管道

- **Shell管道命令**

$ls | more

$cat firstpipe.c | grep “pipe”

- 半双工方式的通信
- 只用于创建管道的进程的子孙进程间（含创建管道的进程）的通信
- 管道也是文件

图片来源：
http://img.alicdn.com/imgextra/i3/1993033942/T2xl5gXGtXXXXXXXXX_%21%211993033942.jpg

pipe() 函数

- 创建管道

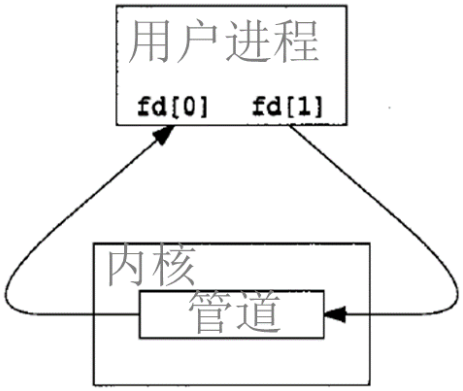
```
#include <unistd.h>
int pipe(int pipefd[2]);
```

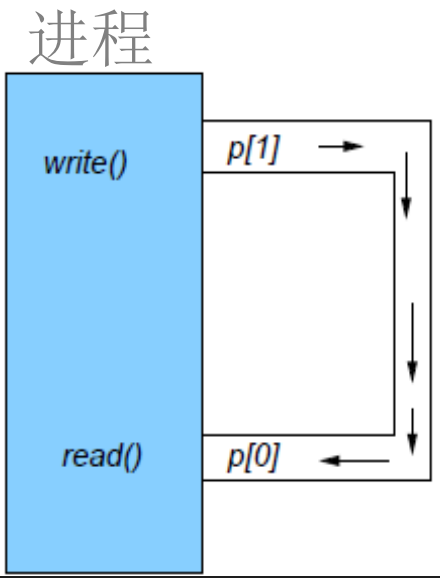
pipefd数组用来返回两个文件描述符,分别指向管道的两端

- pipefd[0]: 管道的读端
- pipefd[1]: 管道的写端
- 先进先出

单个进程中管道的使用

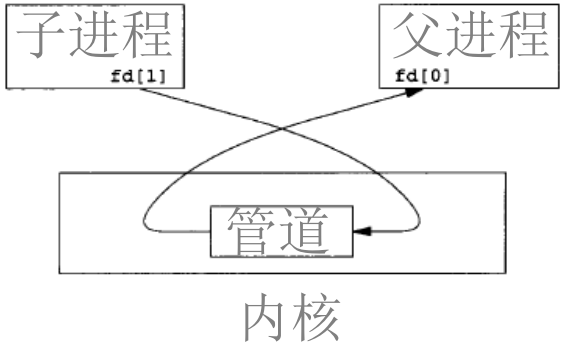
```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
#define READ 0
#define WRITE 1
#define BUFSIZE 100
#define NUM 3
char *msgs[NUM] = {"Good morning.","Good afternoon.","Good night."};
int main(int argc, char *argv[])
{
    pid_t cid;
    int pipefd[2], readbytes;
    char msg[BUFSIZE];
    if (pipe(pipefd) == -1) {perror("pipe\n"); exit(EXIT_FAILURE);}
    for (int i = 0; i < NUM; i++){
        write(pipefd[WRITE], msgs[i], strlen(msgs[i])+1);
    }
    for (int i = 0; i < 3; i++){
        memset(msg,'\n',sizeof(msg));
        readbytes = read(pipefd[READ],msg,strlen(msgs[i])+1);
        printf("%.*s\n",readbytes, msg);
    }
}
```






```
[szu@taishan02-vm-10 pipe]$ gcc -o msgselfbypipe_1 msgselfbypipe_1.c
[szu@taishan02-vm-10 pipe]$ ./msgselfbypipe_1
Good morning.
Good afternoon.
Good night.
```

父/子进程通过管道进行通信




```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
#define READ 0
#define WRITE 1
#define BUFSIZE 100

char *str = "Welcome home, child.";

int main(int argc, char *argv[])
{
        pid_t cid;
        int pipefd[2], readbytes;
        char msg[BUFSIZE];

        if (pipe(pipefd) == -1) { perror("pipe\n"); exit(EXIT_FAILURE);}
        if ((cid = fork()) < 0) { perror(“fork\n");exit(EXIT_FAILURE);}

        if (cid > 0) {//Parent, sender
                write(pipefd[WRITE], str, strlen(str)+1);
        } else {//Child, receiver
                readbytes = read(pipefd[READ],msg,sizeof(msg));
                printf("Receive %d bytes from Parent: %s\n",readbytes, msg);
        }
       close(pipefd[WRITE]);close(pipefd[WRITE]);
}
```

```
[szu@taishan02-vm-10 pipe]$ ./p2cbypipe
Receive 21 bytes from Parent: Welcome home, child.
```

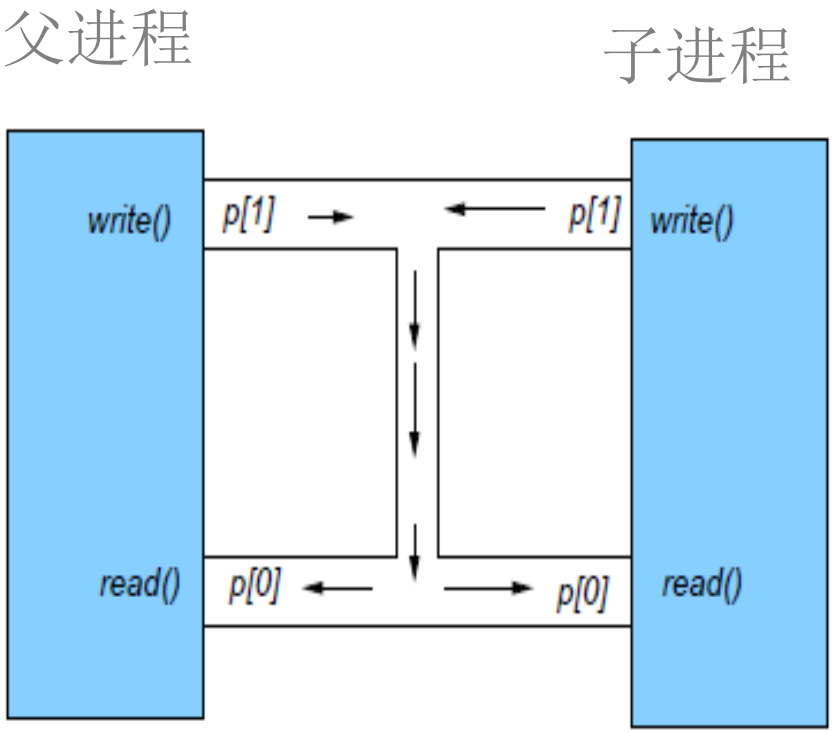
习题一、请问如下程序运行结果是什么？

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>
#define BUFSIZE 10

int main(void){
   char bufin[BUFSIZE]="empty";
   char bufout[BUFSIZE]="hello";
   int  bytesin;
   pid_t  childpid;
   int fd[2];

   if (pipe(fd) == -1 ){
      perror("failed to create pipe"); exit(23);
      }

   bytesin=strlen(bufin);
   childpid = fork();
   if (childpid == -1) { perror("failed to fork"); exit (23);}
   if (childpid)  // parent code
       write(fd[1],bufout,strlen(bufout)+1);
   else           // child code
       bytesin=read(fd[0],bufin,strlen(bufin)+1);

   printf("[%ld]: my bufin is {%.*s}, my bufout is {%s} (parent process %ld)\n",
       (long)getpid(), bytesin, bufin, bufout, (long)getppid());
   return 0;
}
```

```
[6679]: my bufin is {empty}, my bufout is {hello} (parent process 3420)
[6680]: my bufin is {hello}, my bufout is {hello} (parent process 6679)
```

然而,这将发生问题…

- 父or子进程都可通过p[1]写入数据
- 父or子进程都可从p[0]读数据

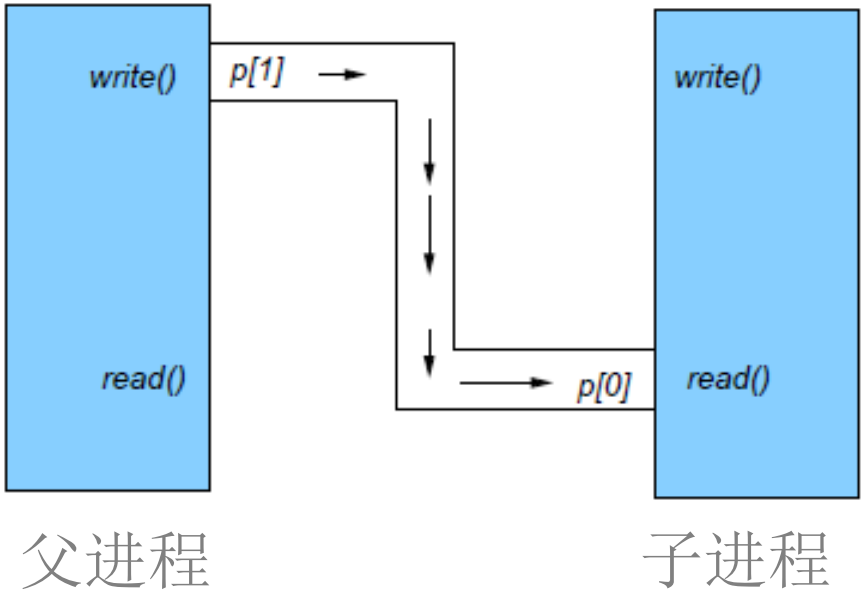


父子进程无差别读/写管道,难以区分特定信息的接收者：父？子？

代码该做些什么改变?...

确定读者/写者角色，
关闭不再需要写/读端

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
#define READ 0
#define WRITE 1
#define BUFSIZE 100
char *str = "Welcome home, child.";
int main(int argc, char *argv[])
{
        pid_t cid;
        int pipefd[2], readbytes;
        char msg[BUFSIZE];

        if (pipe(pipefd) == -1) { perror("pipe\n"); exit(EXIT_
        if ((cid = Fork()) < 0) { perror("Fork\n");exit(EXIT_F

        if (cid > 0) {//Parent, sender
                close(pipefd[READ]);
                write(pipefd[WRITE], str, strlen(str)+1);
                close(pipefd[WRITE]);
        } else {//Child, receiver
                close(pipefd[WRITE]);
                readbytes = read(pipefd[READ],msg,sizeof(msg));
                printf("Receive %d bytes from Parent: %s\n",readbytes, msg);
        }
}
```



管道的读与写（一）

```c
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MSGSIZE 16

char *msg1 = "Buenos Dias! #1";
char *msg2 = "Buenos Dias! #2";
char *msg3 = "Buenos Dias! #3";


main(){
        char inbuf[MSGSIZE];
        int p[2], i = 0, rsize = 0;
        pid_t pid;

        time_t t;

        if (pipe(p) == -1) {
                perror("pipe call");
                exit(1);
        }

        switch (pid=fork()){
        case -1: perror("fork call");exit(2);
        case 0:
                sleep(5);
                write(p[1],msg1,MSGSIZE);//if child then write!
                sleep(5);
                write(p[1],msg2,MSGSIZE);
                sleep(5);
                write(p[1],msg3,MSGSIZE);
                break;
        default: for (i=0; i < 3; i++){
                        printf("trying to read at time: %ld\n",(long)time(&t));
                        rsize = read(p[0],inbuf,MSGSIZE);//if parent then read!
                        printf("read data %.*s at time %ld\n",rsize,inbuf,(long)time(&t));
                }
                wait(NULL);
        }
        exit(0);
}
```

场景1：写者进程打开了管道，还没写，此时，读者进程读管道，会发生什么？

```
trying to read at time: 1302364256
read data Buenos Dias! #1 at time 1302364261
trying to read at time: 1302364261
read data Buenos Dias! #2 at time 1302364266
trying to read at time: 1302364266
read data Buenos Dias! #3 at time 1302364271
```

管道的读与写（二）

场景2：写者进程已退出、尚未启动或尚未打开管道，此时，读者进程打开空管道进行读操作，会发生什么？

```
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MSGSIZE 16

char *msg1 = "Buenos Dias! #1";
char *msg2 = "Buenos Dias! #2";
char *msg3 = "Buenos Dias! #3";

main(){
        char inbuf[MSGSIZE];
        int p[2], i = 0, rsize = 0;
        pid_t pid;

        time_t t;

        if (pipe(p) == -1) {
                perror("pipe call");
                exit(1);
        }

        switch (pid=fork()){
        case -1: perror("fork call");exit(2);
        case 0:
                break;
        default:
                close(p[1]);
                for (i=0; i < 3; i++){
                        printf("trying to read at time: %ld\n",(long)time(&t));
                        rsize = read(p[0],inbuf,MSGSIZE);//if parent then read!
                        printf("read data %.*s at time %ld\n",rsize,inbuf,(long)time(&t));
                }
                close(p[0]);
                wait(NULL);

        }
        exit(0);
}
```

```
trying to read at time: 1302364352
read data  at time 1302364352
trying to read at time: 1302364352
read data  at time 1302364352
trying to read at time: 1302364352
read data  at time 1302364352
```

管道的读与写（三）

场景3：写者进程已退出，此时，读者进程打开非空管道进行读操作，会发生什么？

管道的读与写（四）

场景4：读者进程打开管道，忙，未进行读操作。写者进程持续写管道，将会发生什么？

管道的读与写

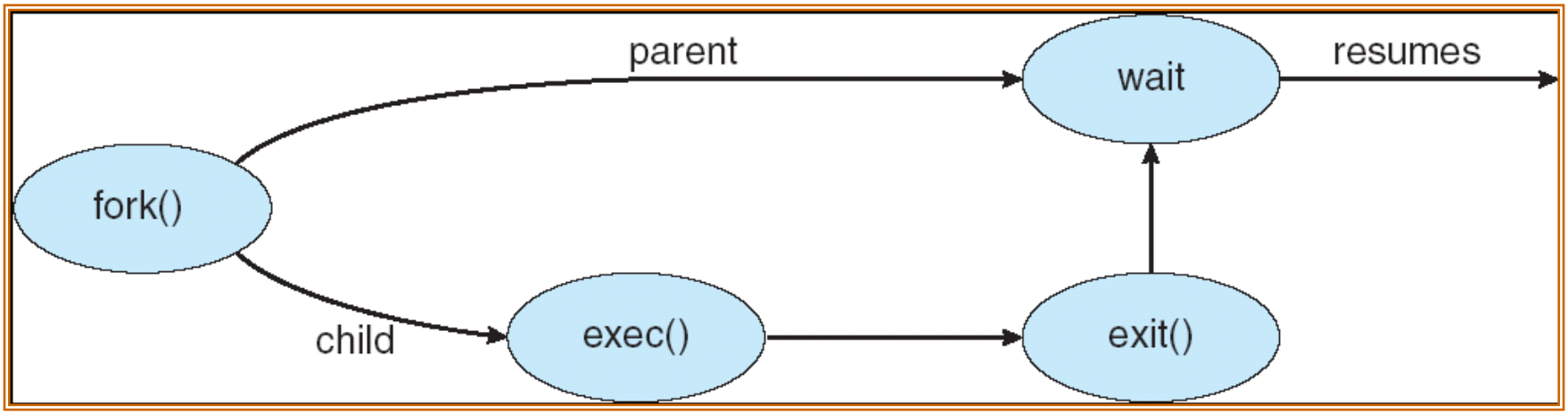
- 管道的一端关闭时
  - 写端关闭，读管道
    - 管道非空，读取数据，并返回读取数据的长度
    - 管道为空，返回0
  - 读端关闭，写管道
    - 引发信号SIGPIPE
- 常数PIPE_BUF设定内核中管道缓存器的大小

```
[szu@taishan02-vm-10 pipe]$ sudo find / -name "*.h" -exec grep "PIPE_BUF" {} \; -print | more
[sudo] password for szu:
/* Define if the system reports an invalid PIPE_BUF value. */
/* #undef HAVE_BROKEN_PIPE_BUF */
/usr/include/python2.7/pyconfig-64.h
/* Define if the system reports an invalid PIPE_BUF value. */
/* #undef HAVE_BROKEN_PIPE_BUF */
/usr/include/python2.7-debug/pyconfig-64.h
#define PIPE_BUF        4096    /* # bytes in atomic write to a pipe */
/usr/include/linux/limits.h
#define _POSIX_PIPE_BUF         512
# define _POSIX_HIWAT           _POSIX_PIPE_BUF
/usr/include/bits/posix1_lim.h
```

子进程调用exec()家族函数后,还能使用从父进程继承来的管道与父进程通信吗?

exec函数

- 有些应用程序需要子进程执行与其父进程不同的代码
  - exec族函数用新的代码覆盖调用进程代码段
  - fork—exec是父子进程配合工作的方式之一
    - 子进程调用exec族函数加载并执行新的二进制代码
    - 父进程继续执行原来的代码。



exec()族函数

```
#include <unistd.h>

int execl(const char *path, const char *arg0, ….., 
  NULL)
```

- path:　　可执行文件的路径名
- arg0,...:　　所有参数
- NULL指针:　　参数终结

exec()族函数（一）

2. 172.31.234.200 (szu)

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

int main(int argc, char *argv[])
{
        int ret = 0;
        printf("My Id is %ld",getpid());
        if ((ret=fork())>0){
                printf("...\n");
        } else {
                ret = execl("/bin/ls","ls","-l",".",NULL);
        }
}
```

场景1：用户态缓冲区资源会被子进程继承吗？

```
[szu@taishan02-vm-10 execdemo]$ vi execls.c
[szu@taishan02-vm-10 execdemo]$ gcc execls.c
[szu@taishan02-vm-10 execdemo]$ ./a.out
My Id is 386369...
总用量 20
-rwxrwxr-x. 1 szu szu 71344  9月 16 21:43 a.out
-rw-rw-r--. 1 szu szu   224  9月 16 21:43 execls.c
[szu@taishan02-vm-10 execdemo]$ vi execls.c
[szu@taishan02-vm-10 execdemo]$
```

exec()族函数（二）

```c
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <errno.h>

#define READ 0
#define WRITE 1

int main(int argc, char *argv[]){
        int p1[2], p2[2], filedesc = -1;
        char myinputparam[20];
        pid_t pid;

        if ( (filedesc = open("MytestFile", O_WRONLY|O_CREAT, 0666)) == -1){
                perror("file creation");exit(1);
        }

        if (pipe(p1) == -1) {
                perror("pipe call");exit(1);
        }

        if (pipe(p2) == -1){
                perror("pipe call");exit(1);
        }

        if ( (pid = fork()) == -1){
                perror("fork");exit(1);
        }

        if (pid != 0){
                close(filedesc);close(p1[READ]);close(p1[WRITE]);close(p2[READ]);close(p2[WRITE]);
                close(0);close(1);close(2);
                if (wait(NULL) != pid){
                        perror("Waiting for child\n");exit(1);
                }
        } else {
                printf("filedesc=%d\n",filedesc);
                printf("p1[READ]=%d, p1[WRITE]=%d,\n",p1[READ],p1[WRITE]);
                printf("p2[READ]=%d, p2[WRITE]=%d,\n",p2[READ],p2[WRITE]);
                dup2(p2[WRITE],11);
                execlp(argv[1],argv[1],"11",NULL);
                perror("execlp");
        }
}
```

场景2：打开的文件资源会被子进程继承吗？

$gcc –o parent parent.c

exec()族函数（二）

场景2：打开的文件资源会被子进程继承吗？

```
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <errno.h>
#include <string.h>

#define READ 0
#define WRITE 1

int main(int argc, char *argv[]){
        char message[]="Hello there!";

        printf("Operating after the execlp invocation!\n");
        if (write(3,message,strlen(message)+1)==-1)
                perror("Write to 3-file\n");
        else printf("Write to file with file descriptor 3 succeeded\n");
        if (write(5,message,strlen(message)+1)==-1)
                perror("Write to 5-pipe");
        else printf("Write to pipe with file descriptor 5 succeeded\n");
        if (write(7,message,strlen(message)+1)==-1)
                perror("Write to 7-pipe");
        else printf("Write to pipe with file descriptor 7 succeeded\n");
        if (write(11,message,strlen(message)+1)==-1)
                perror("Write to 11-dup2");
        else printf("Write to dup2ed file descriptor 11 succeeded\n");
        if (write(13,message,strlen(message)+1)==-1)
                perror("Write to 13-invalid");
        else printf("Write to invalid file descriptor 13 not feasible\n");
        return 1;
}
```

```
filedesc=3
p1[READ]=4, p1[WRITE]=5,
p2[READ]=6, p2[WRITE]=7,
Operating after the execlp invocation!
Write to file with file descriptor 3 succeeded
Write to pipe with file descriptor 5 succeeded
Write to pipe with file descriptor 7 succeeded
Write to dup2ed file descriptor 11 succeeded
Write to 13-invalid: Bad file descriptor
```

```
$gcc –o child child.c
$./parent ./child
```

exec()族函数（三）

场景3：进程成功调用exec()后会返回执行下一条指令吗？

2. 172.31.234.200 (szu)

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

int main(int argc, char *argv[])
{
        int ret = 0;
        ret = execl("/bin/ls","ls","-l",".",NULL);
        printf("My Id is %ld\n, exiting...",getpid());
}
```

```
[szu@taishan02-vm-10 execdemo]$ ./execls0
总用量 40
-rwxrwxr-x. 1 szu szu 71344  9月 16 21:43 a.out
-rwxrwxr-x. 1 szu szu 71248  9月 17 10:19 execls0
-rw-rw-r--. 1 szu szu   183  9月 17 10:19 execls0.c
-rw-rw-r--. 1 szu szu   224  9月 16 21:43 execls.c
[szu@taishan02-vm-10 execdemo]$
```

exec()族函数

- 更多成员函数

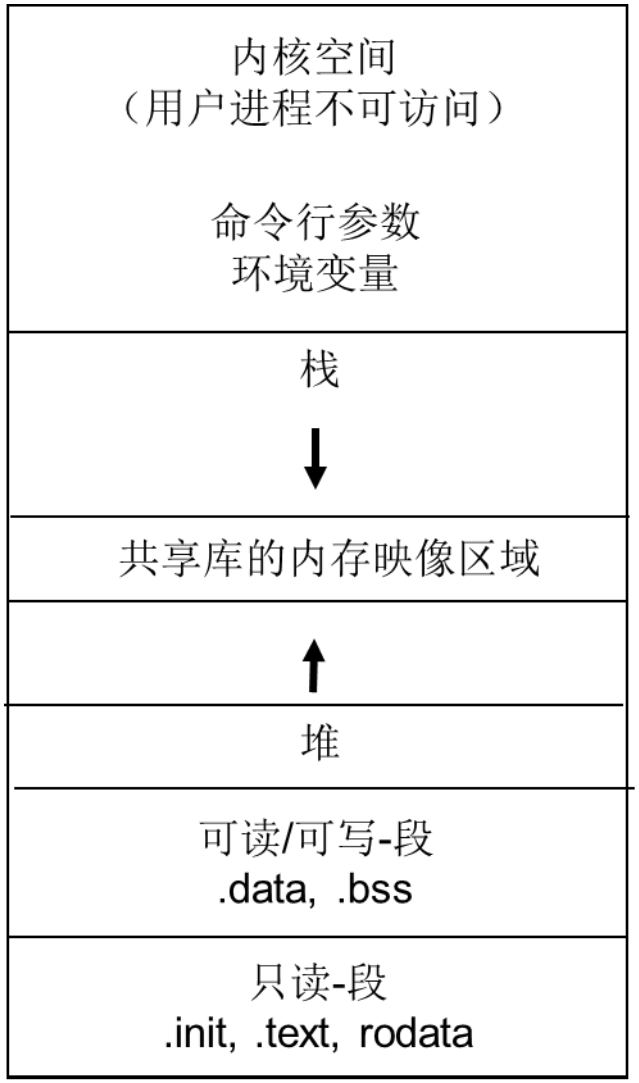
```
int execle（…….）
int execlp （…….）
int execv （…….）
int execve （…….）
int execvp （…….）
```

若调用不成功，返回-1，并设置errno

- 进程终止,操作系统执行的操作
  - 取消挂起的定时器和信号
  - 释放资源：内存、锁等
  - 关闭打开的文件
  - 发送SIGCHLD信号给父进程

进程调用exec()族函数

- **新的进程映像**
  - 新的堆栈段
  - 新的数据段
  - 新的代码段
- **打开的文件资源**
  - 默认情况下可通过文件描述符访问
    - fcntl设置后可以改变
  - 相应的逻辑符号名不可访问
- **执行成功**
  - 不返回下一条指令
  - 进程退出
- **其他**
  - 进程ID不变
  - 信号状态不变
  - 调度参数等不变



回想：管道最初的作用

ls | wc -l

cmd1 | cmd2

如何通过系统调用pipe()实现命令行管道？

要解决的问题：

- 将cmd1的标准输出重定向到pipe[1]
- 将cmd2的标准输入重定向到pipe[0]

创建文件描述符副本

```
#include <unistd.h>

int dup(int oldfd);
```

将文件描述符oldfd复制到第一个未被使用的文件描述符

- 返回值：
  - 返回值 ≥ 0 ： 成功，返回一个新的文件描述符
  - 返回值= -1: 失败，具体原因查看 errno
- 参数：
  - oldfd: 已打开的文件描述符

创建文件描述符副本

```
#include <unistd.h>
```

```
int dup2(int oldfd, int newfd);
```

- 将文件描述符oldfd复制到文件描述符newfd,如果newfd指向已打开的文件，则先关闭它

- 返回值：
  - 返回值 ≥ 0 ： 成功，返回一个新的文件描述符
  - 返回值= -1: 失败，具体原因查看 errno

- 参数:
  - oldfd:要创建副本的文件描述符
  - newfd:指向oldfd指向的文件

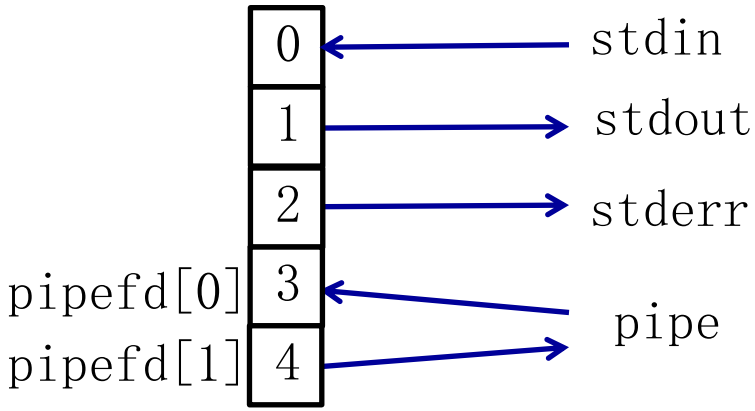
编码实现

ps axj | grep systemd

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
int main(void)
 {
        int pipefd[2];
        pipe(pipefd);
        if (!fork()) {
                close(1);       /* 关闭标准输出*/
                dup(pipefd[1]);  /* 将pipefd[1]重定向到标准输出 */
        close(pipefd[0]);
        execlp("/bin/ps", "ps", "axj",NULL);
         } else {
        close(0);       /* 关闭标准输入 */
        dup(pipefd[0]);  /* 将pipefd[0]重定向到标准输入 */
        close(pipefd[1]);
                execlp("/bin/grep", "grep", "systemd", NULL);
        }
        return 0;
}
```

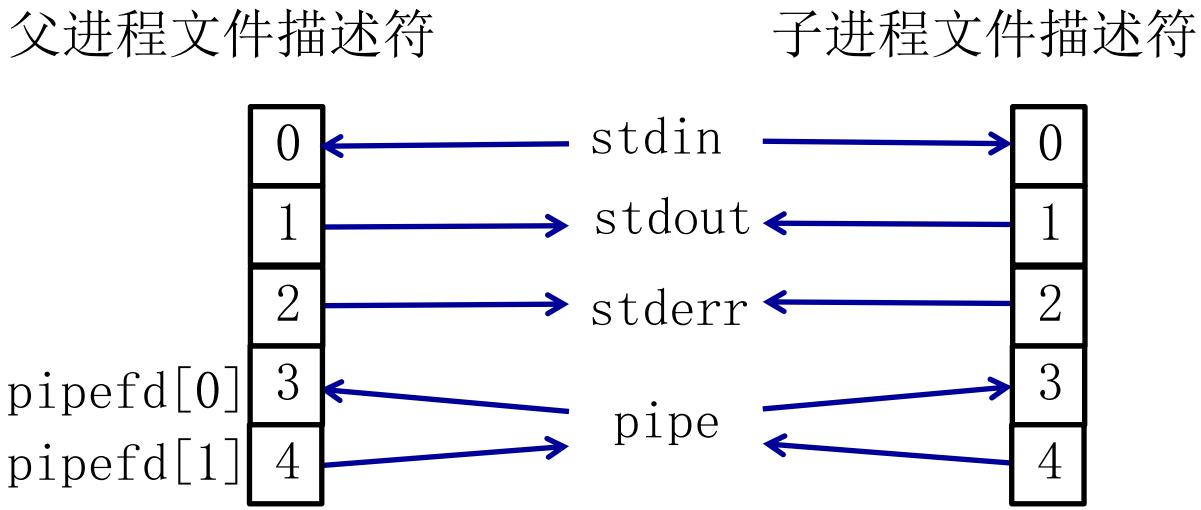
ps axj | grep systemd

父进程文件描述符



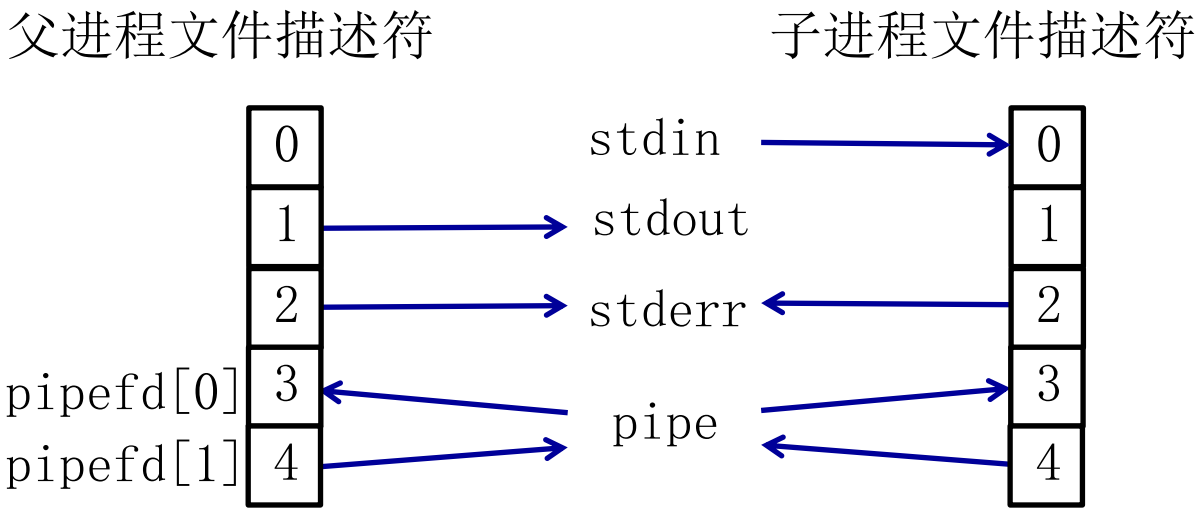

```
pipe(pipefd);
```

ps axj | grep systemd




```
pipe(pipefd);
fork();
```

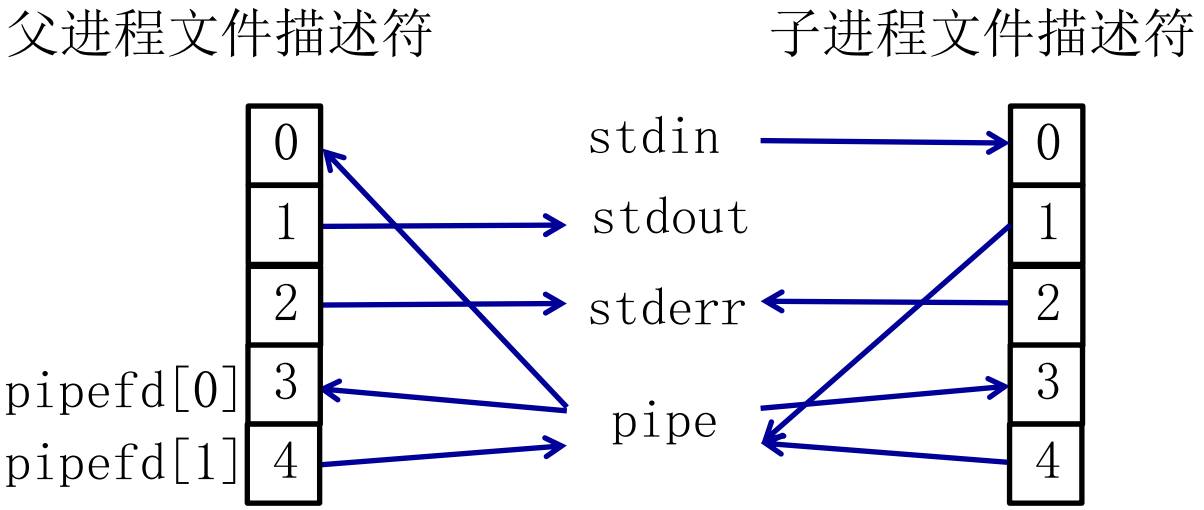
ps axj | grep systemd




```
pipe(pipefd);
fork();
close(0);
```

```
close(1);
```

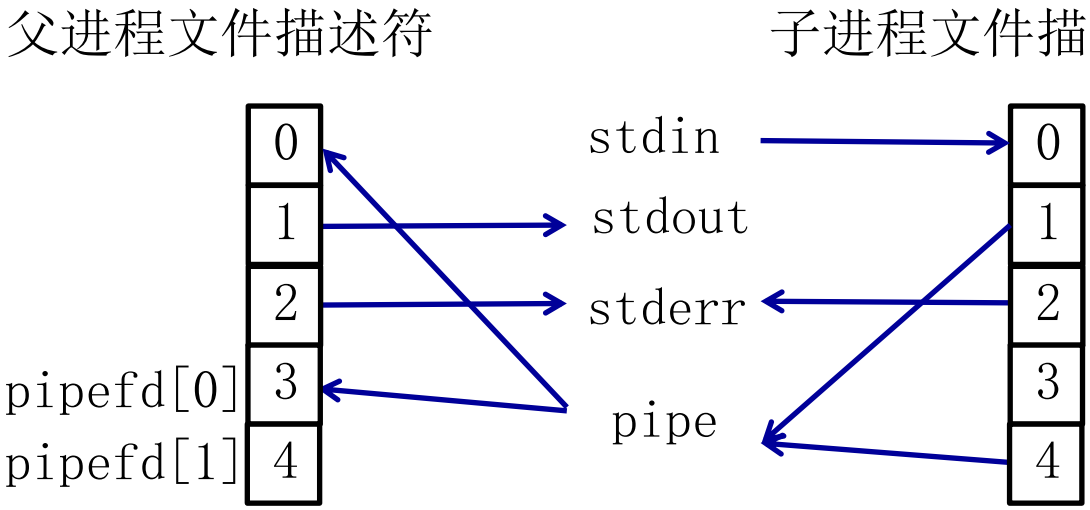
ps axj | grep systemd




```
pipe(pipefd);
fork();
close(0);
dup(pipefd[0]);
```

```
close(1);
dup(pipefd[1]);
```

ps axj | grep systemd




```
pipe(pipefd);
fork();
close(0);
dup(pipefd[0]);
close(pipefd[1]);
execlp("/bin/ps",
       "ps",
       "axj",
       NULL);
```

```
close(1);
dup(pipefd[1]);
close(pipefd[0]);
execlp("/bin/grep",
       "systemd",
       NULL);
```

ps axj | grep system
如果用dup2()或dup3()实现？

```c
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MSGSIZE 16
#define READ 0
#define WRITE 1

int main(int argc, char *argv[]){
        int p[2], bytes;
        pid_t pid;

        if (pipe(p) == -1) {
                perror("pipe call");
                exit(1);
        }

        if ( (pid = fork()) == -1){
                perror("fork");
                exit(1);
        }

        if (pid != 0){
                close(p[READ]);
                dup2(p[WRITE],1);
                close(p[WRITE]);
                execlp(argv[1],argv[1],NULL);
                perror("execlp");
        } else {
                close(p[WRITE]);
                dup2(p[READ],0);
                close(p[READ]);
                execlp(argv[2],argv[2],NULL);
        }
}
```

$gcc –o main main.c

文件(F) 编辑(E) 查看(V) 终端(T) 帮助(H)

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/time.h>
#include <sys/types.h>
#define MSGSIZE 20
#define READ 0
#define WRITE 1

int main(int argc, char const *argv[])
{
        int p[2],bytes,res,c;
        char inbuf[10240];
        int pid;

        if (pipe(p) == -1){
                perror("Fail to create a pipe!\n");exit(1);
        }
        pid = fork();
        if (pid != 0){
                close(p[READ]);
                dup2(p[WRITE],1);
                printf("123\n");
                fflush(stdout);
                wait(NULL);
        } else {
                close(p[WRITE]);
                dup2(p[READ],0);
                while ((c=getchar())!='\n'){
                        printf("%c-",c);
                }
                printf("\n");
                close(p[READ]);
        }
        return 0;
}
```

$gcc –o param param.c
$./main ./param ./param