1.3 A Simple OS

- OS Structure
- Processes, Address Spaces, & Threads
- Managing Processes
- Loading Program Into Processes
- *Files*
  - (first 13 slides overlap with "A Simple OS" slides)

Files

- Our primes program wasn't too interesting
  - it has no output!
  - cannot even verify that it's doing the right thing
  - other program cannot use its result
  - how does a process write to someplace outside the process?

- The notion of a *file* is our Unix system's sole abstraction for this concept of "someplace outside the process"
  - modern Unix systems have additional abstractions

- Files
  - abstraction of persistent data storage
  - means for fetching and storing data outside a process
    - including disks, another process, keyboard, display, etc.
    - need to *name* these different places
      - hierarchical naming structure
    - part of a process's *extended address space*

Naming Files

- Directory system
  - shared by all processes running on a computer
    - although each process can have a different view
    - Unix provides a means to restrict a process to a subtree
      - by redefining what "root" means for the process
  - name space is outside the processes
    - a user process provides the name of a file to the OS
    - the OS returns a *handle* to be used to access the file
      - after it has verified that the process is allowed *access* along the *entire path*, starting from root
    - user process uses the handle to read/write the file
      - avoid access checks

- Using a handle to refer to an object managed by the kernel is an important concept
  - handles are essentially an *extension* to the process's *address space*
    - can even survive execs!

The File Abstraction

- A file is a simple array of bytes
- Files are made larger by writing beyond their current end
- Files are named by paths in a naming tree
- System calls on files are *synchronous*
- File API
  - `open()`, `read()`, `write()`, `close()`
  - e.g., `cat`

File Handles (File Descriptors)

```
int fd;
char buffer[1024];
int count;
if ((fd = open("/home/bc/file", O_RDWR) == -1) {
  // the file couldn't be opened
  perror("/home/bc/file");
  exit(1);
}
if ((count = read(fd, buffer, 1024)) == -1) {
  // the read failed
  perror("read");
  exit(1);
}
// buffer now contains count bytes read from the file
```

- what is O_RDWR?
- what does `perror()` do?
- *cursor* position in an opened file depends on what functions/system calls you use
  - what about C++?

Standard File Descriptors

- Standard File Descriptors
  - 0 is stdin (by default, the keyboard)
  - 1 is stdout (by default, the display)
  - 2 is stderr (by default, the display)

```
main() {
  char buf[BUFSIZE];
  int n;
  const char *note = "Write failed\n";

  while ((n = read(0, buf, sizeof(buf))) > 0)
    if (write(1, buf, n) != n) {
      (void)write(2, note, strlen(note));
      exit(EXIT_FAILURE);
    }
  return(EXIT_SUCCESS);
}
```

Back to Primes

- Have our primes program write out the solution, i.e., the `primes[]` array

```
int nprimes;
int *prime;
int main(int argc, char *argv[]) {
  ...
  for (i=1; i<nprimes; i++) {
    ...
  }
  if (write(1, prime, nprimes*sizeof(int)) == -1) {
    perror("primes output");
    exit(1);
  }
  return(0);
}
```

  - the output is not readable by human

Human-Readable Output

```
int nprimes;
int *prime;
int main(int argc, char *argv[]) {
  ...
  for (i=1; i<nprimes; i++) {
    ...
  }
  for (i=0; i<nprimes; i++) {
    printf("%d\n", prime[i]);
  }
  return(0);
}
```

Allocation of File Descriptors

- Whenever a process requests a new file descriptor, the lowest numbered file descriptor not already associated with an open file is selected; thus

```
#include <fcntl.h>
#include <unistd.h>
...
close(0);
fd = open("file", O_RDONLY);
```

  - will always associate "file" with file descriptor 0 (assuming that the open succeeds)

Running It

```
if (fork() == 0) {
  /* set up file descriptor 1 in the child process */
  close(1);
  if (open("/home/bc/Output", O_WRONLY) == -1) {
    perror("/home/bc/Output");
    exit(1);
  }
  execl("/home/bc/bin/primes", "primes", "300", 0);
  exit(1);
}
/* parent continues here */
while(pid != wait(0)) /* ignore the return code */
  ;
```

- `close(1)` removes file descriptor 1 from *extended address space*
- file descriptors are allocated *lowest first* on `open()`
- *extended address space* survives *execs*
- new code is same as running

```
% primes 300 > /home/bc/Output
```

I/O Redirection

```
% primes 300 > /home/bc/Output
```

- The ">" parameter in a shell command that instructs the command shell to *redirect* the output to the given file
  - If ">" weren't there, the output would go to the display
- Can also redirect input

```
% cat < /home/bc/Output
```

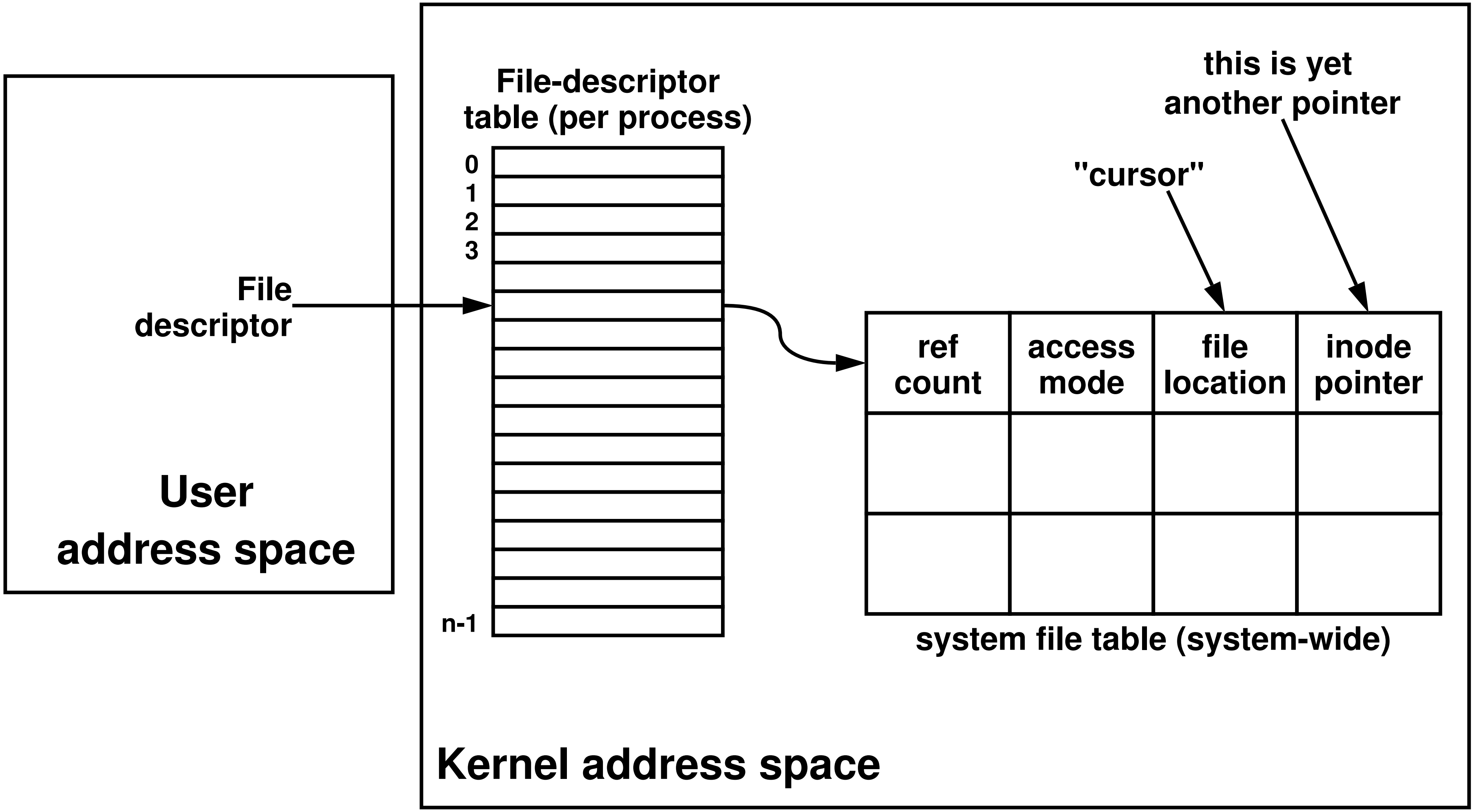
  - when the "`cat`" program reads from file descriptor 0, it would get the data byes from the file "/home/bc/Output"

File-Descriptor Table

- A file descriptor refers not just to a file
  - it also refers to the *process's* current *context* for that file
    - includes how the file is to be accesses (how `open()` was invoked)
    - *cursor* position

- *Context* information must be maintained by the OS and not directly by the user program
  - let's say a user program opened a file with O_RDONLY
  - later on it calls `write()` using the opened file descriptor
  - how does the OS knows that it doesn't have write access?
    - stores O_RDONLY in context
  - if the user program can manipulate the context, it can change O_RDONLY to O_RDWR
  - therefore, user program must not have access to context!
    - all it can see is the handle
    - the handle is an *index* into an array maintained for the process in kernel's address space

File-Descriptor Table



- context is not stored directly into the file-descriptor table
  - one-level of *indirection*

Put It All Together

open()

```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```

Applications

OS

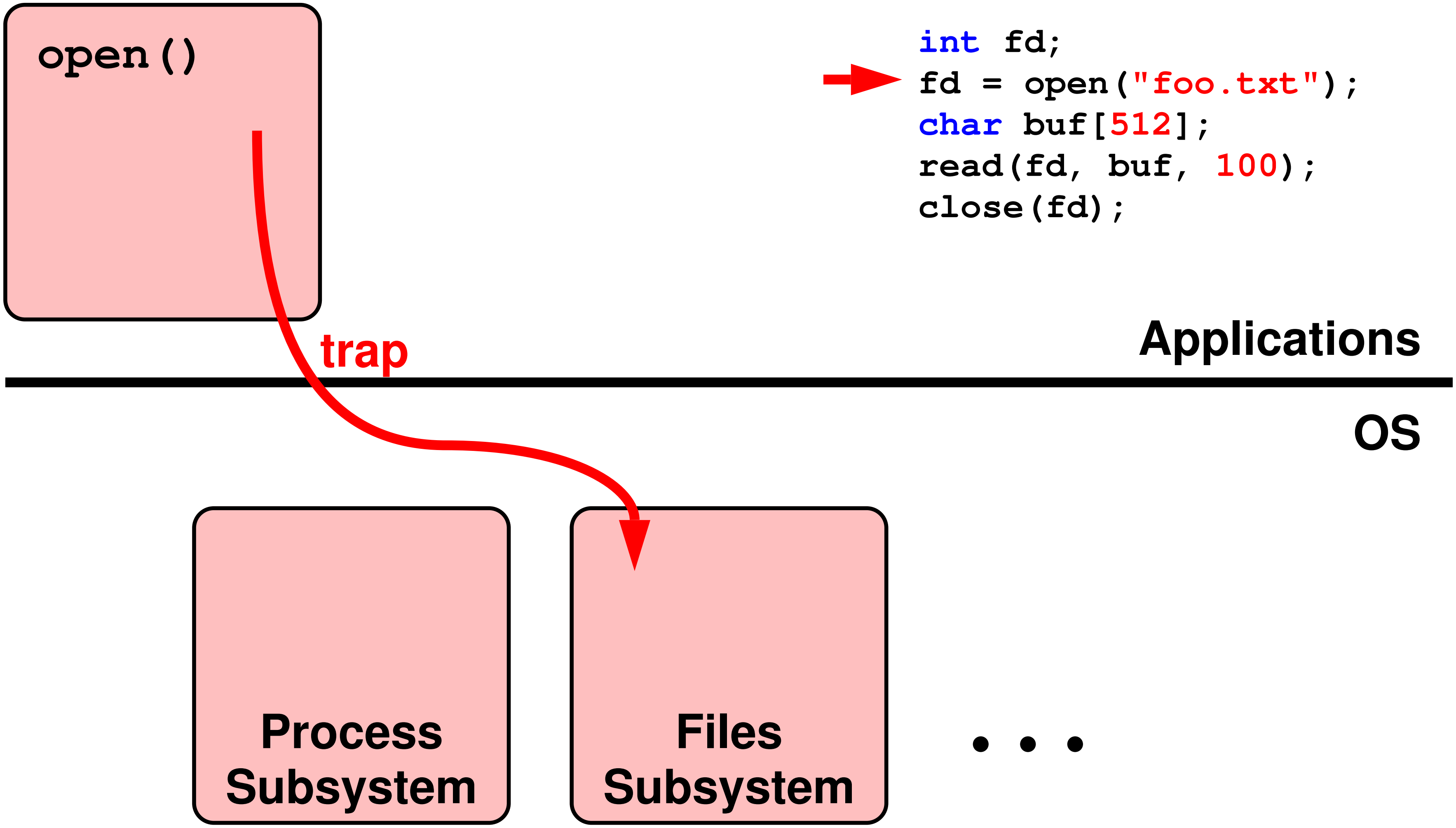
Process Subsystem

Files Subsystem

. . .

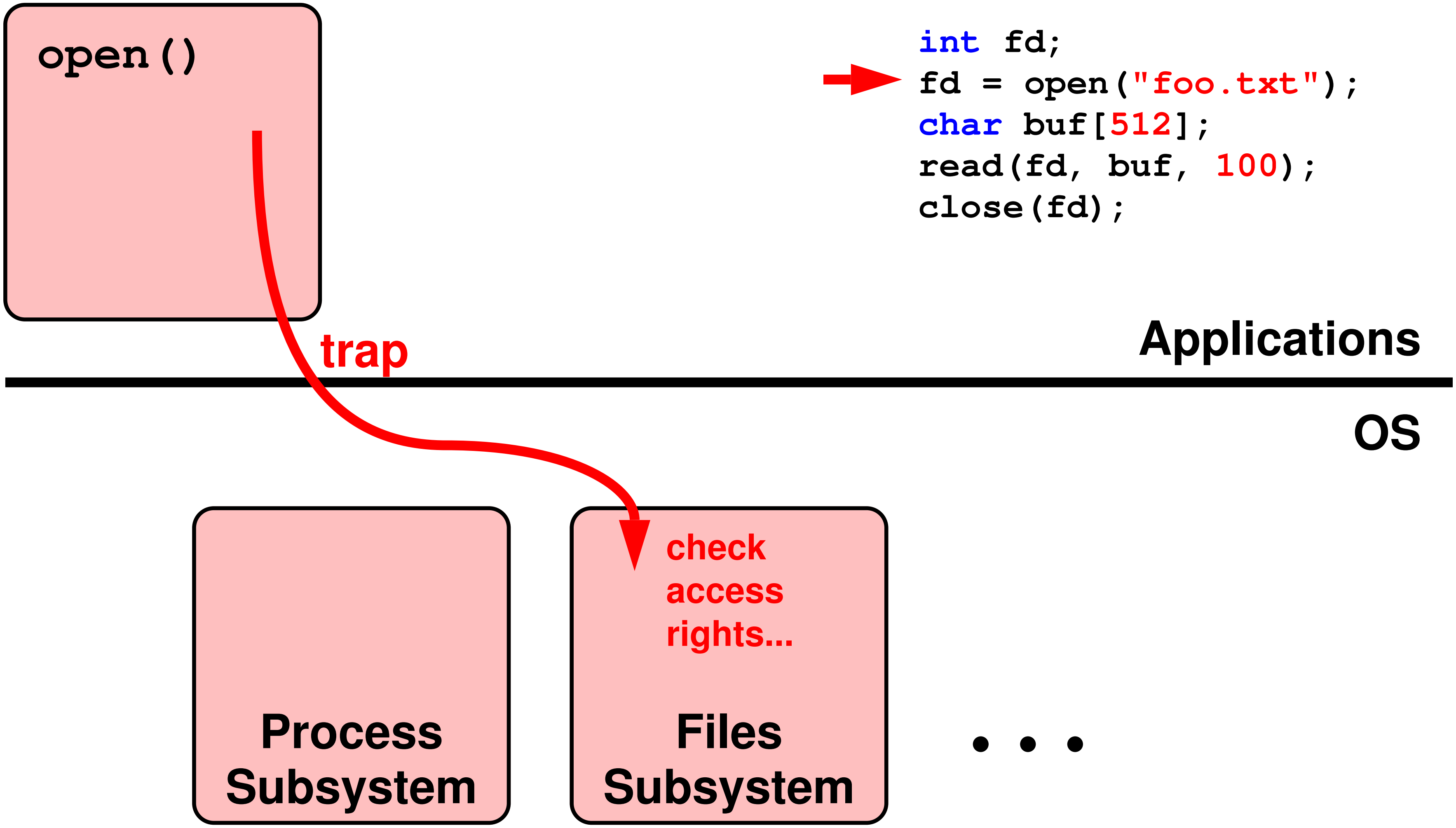
Put It All Together

```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```

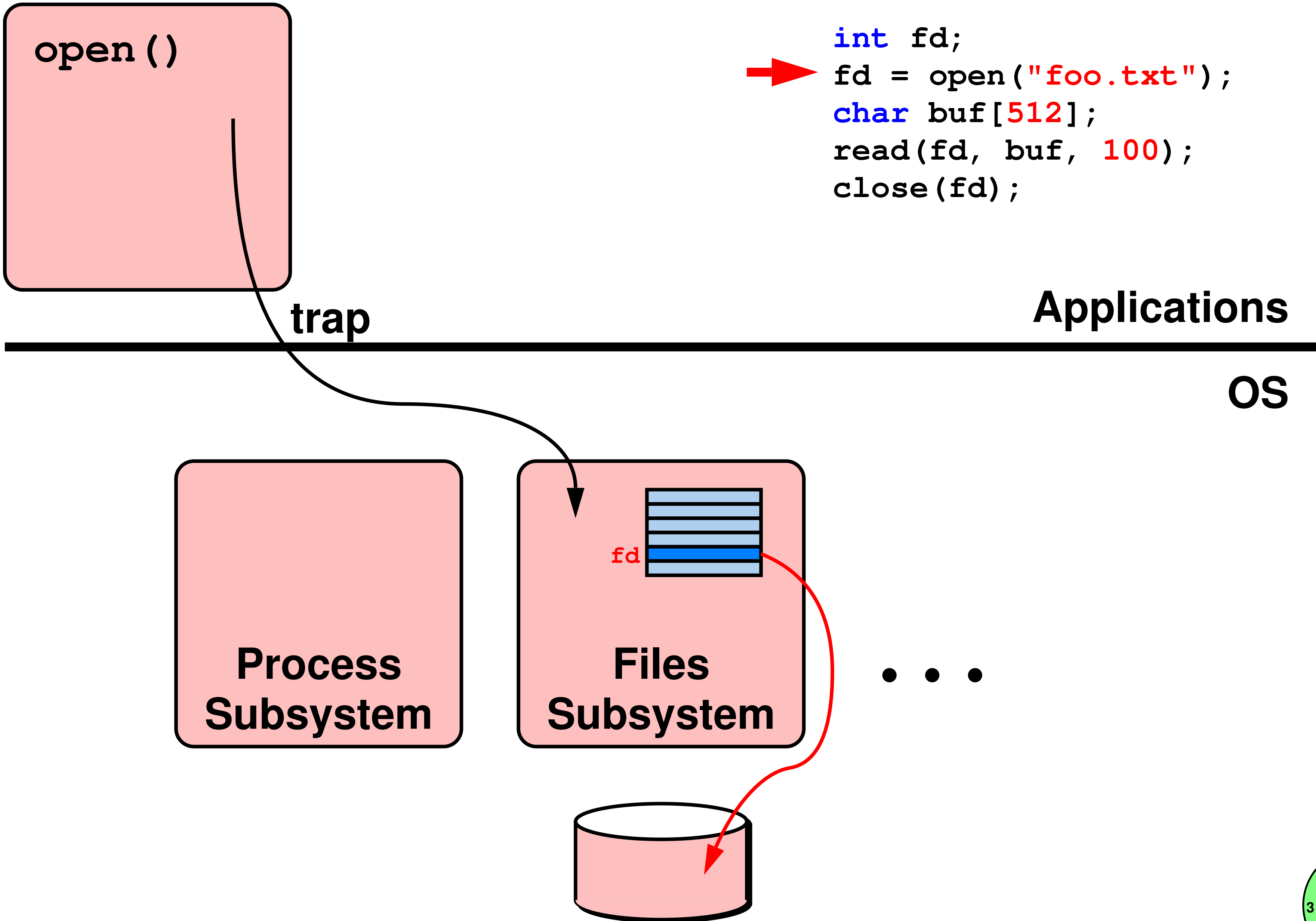


Put It All Together

```c
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```



Put It All Together

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Put It All Together

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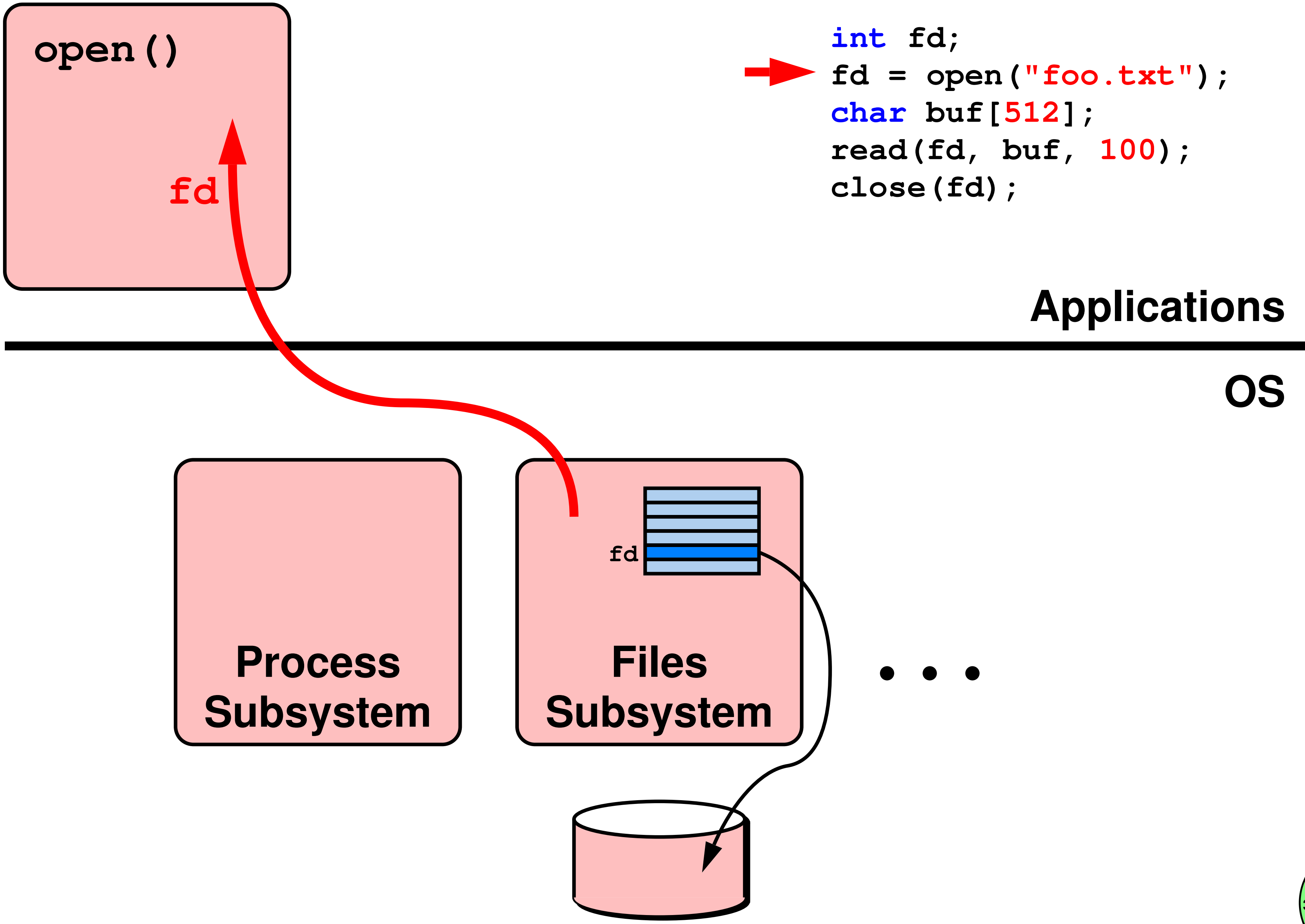

Put It All Together

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int fd;
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read(fd, buf, 100);
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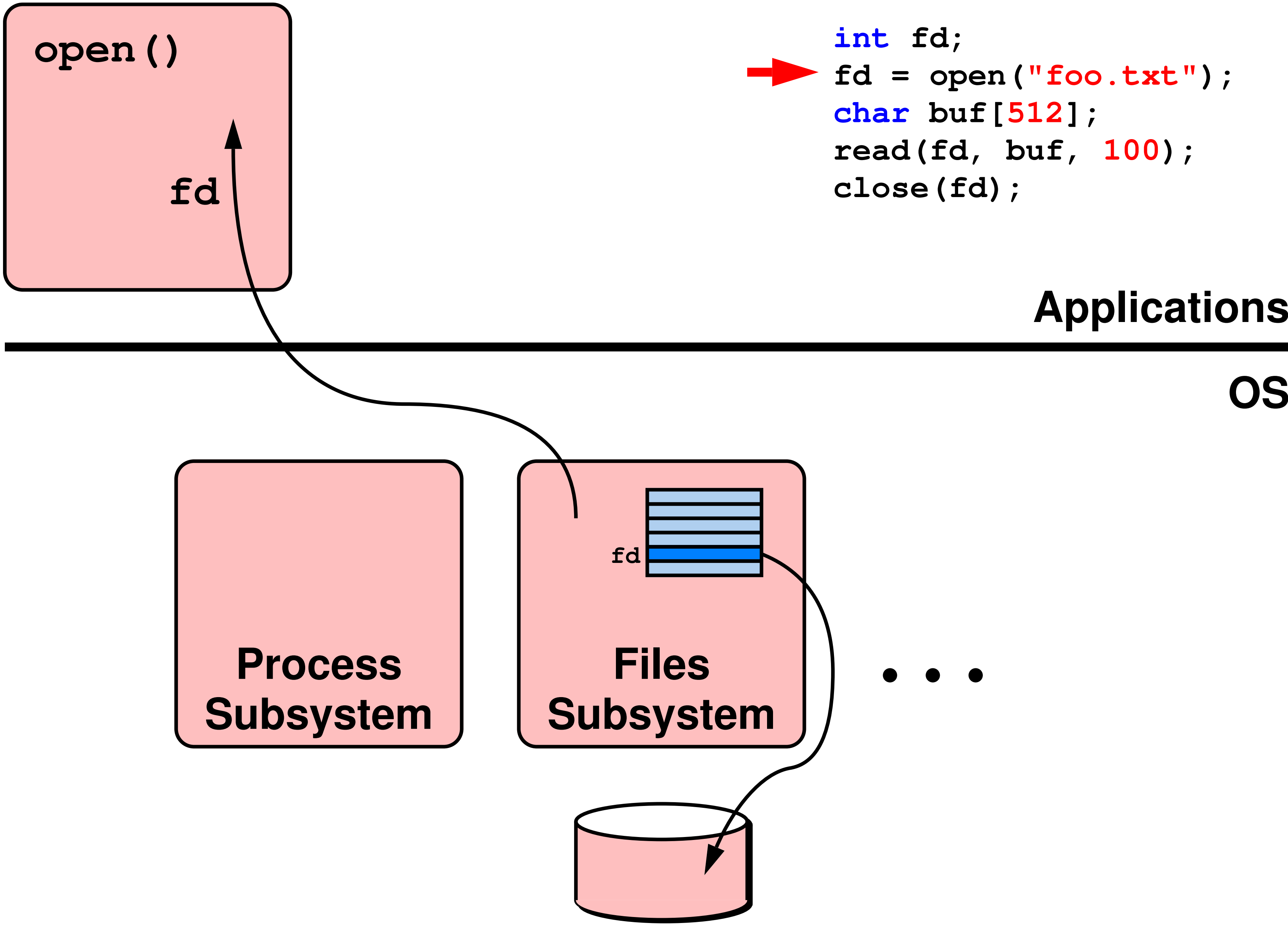
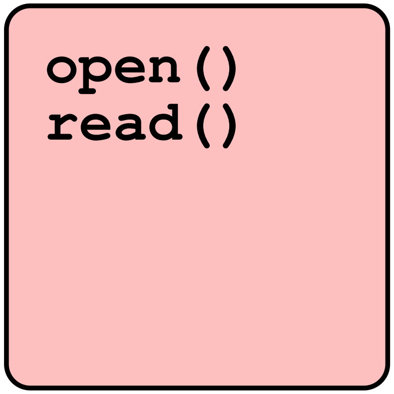


Put It All Together

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int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
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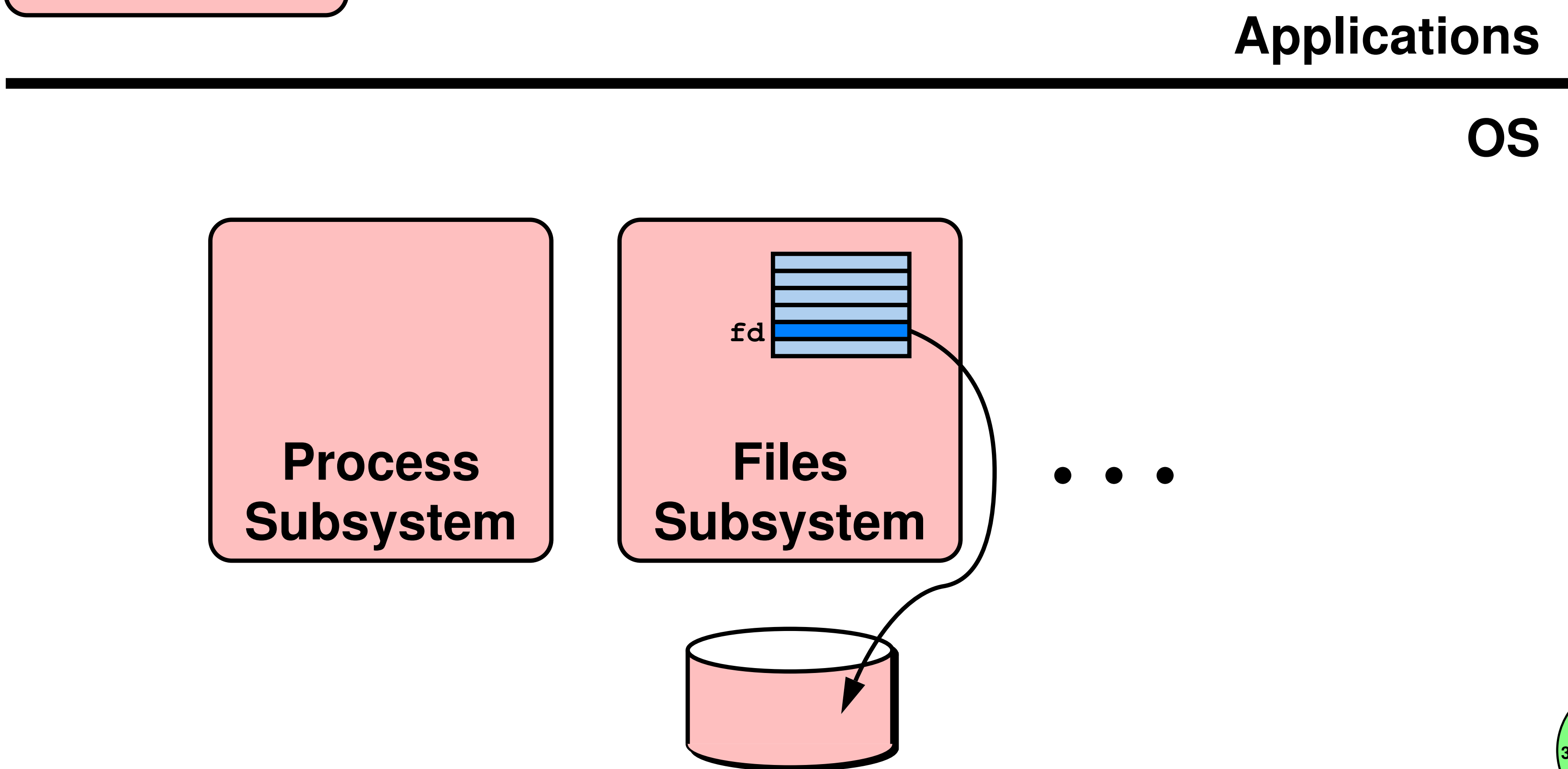

Put It All Together

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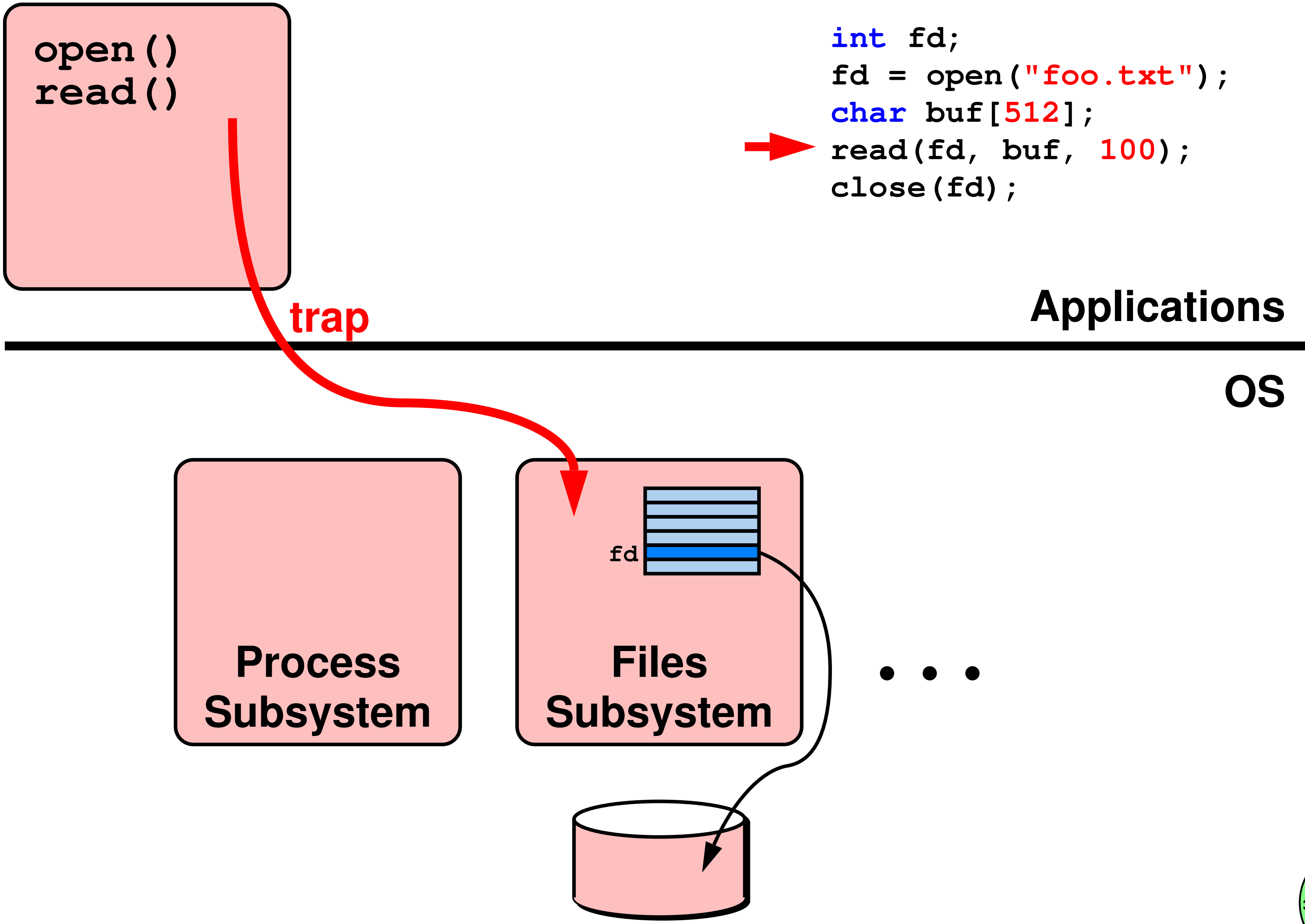
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```



Put It All Together

```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
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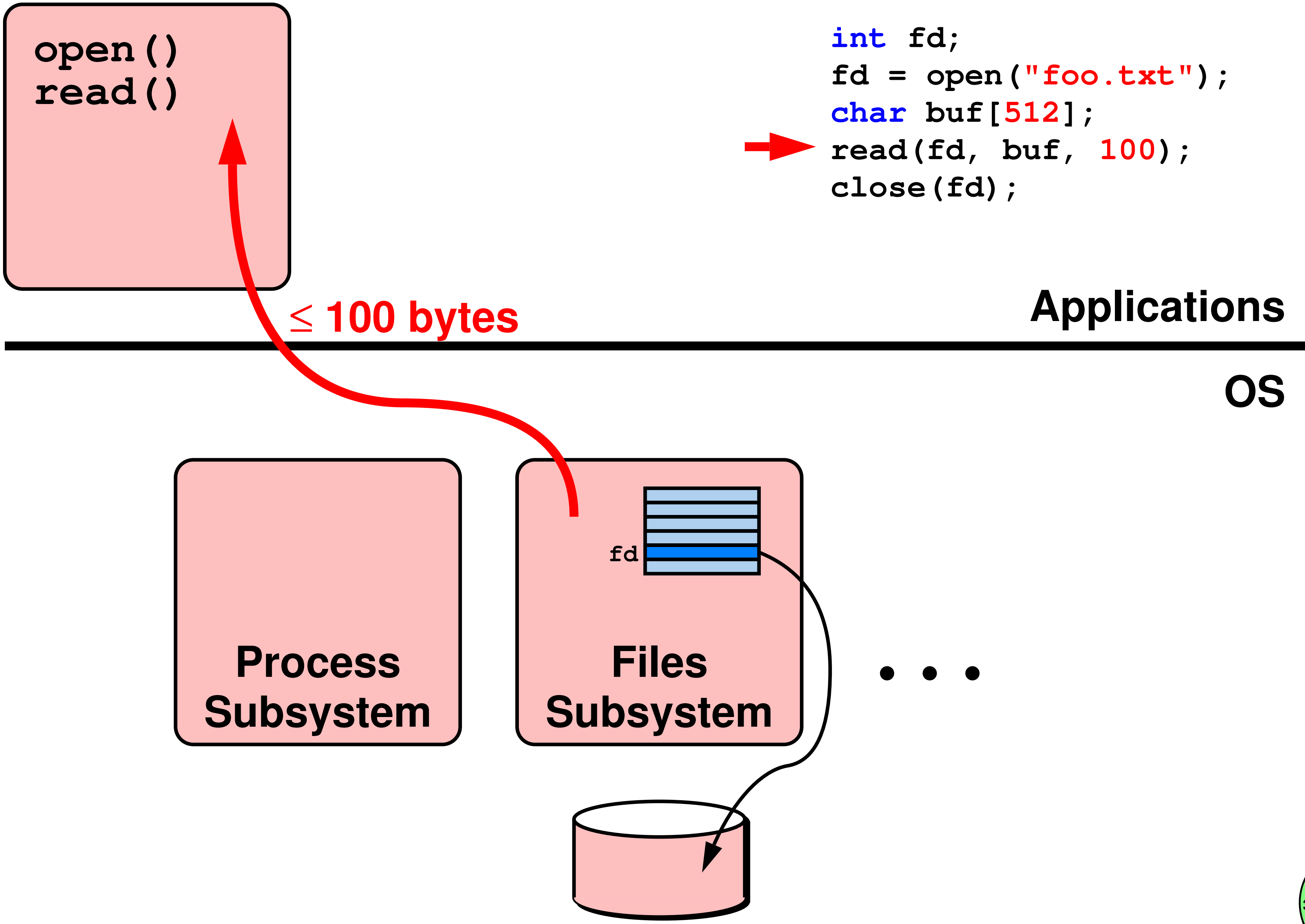


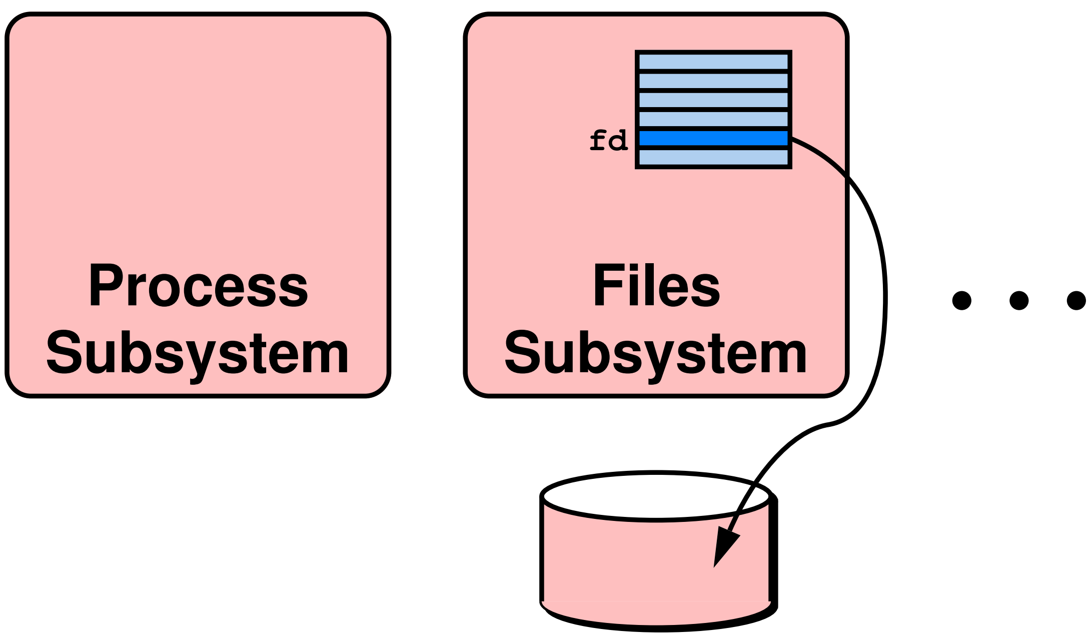
Put It All Together

```
open()
read()
close()
```

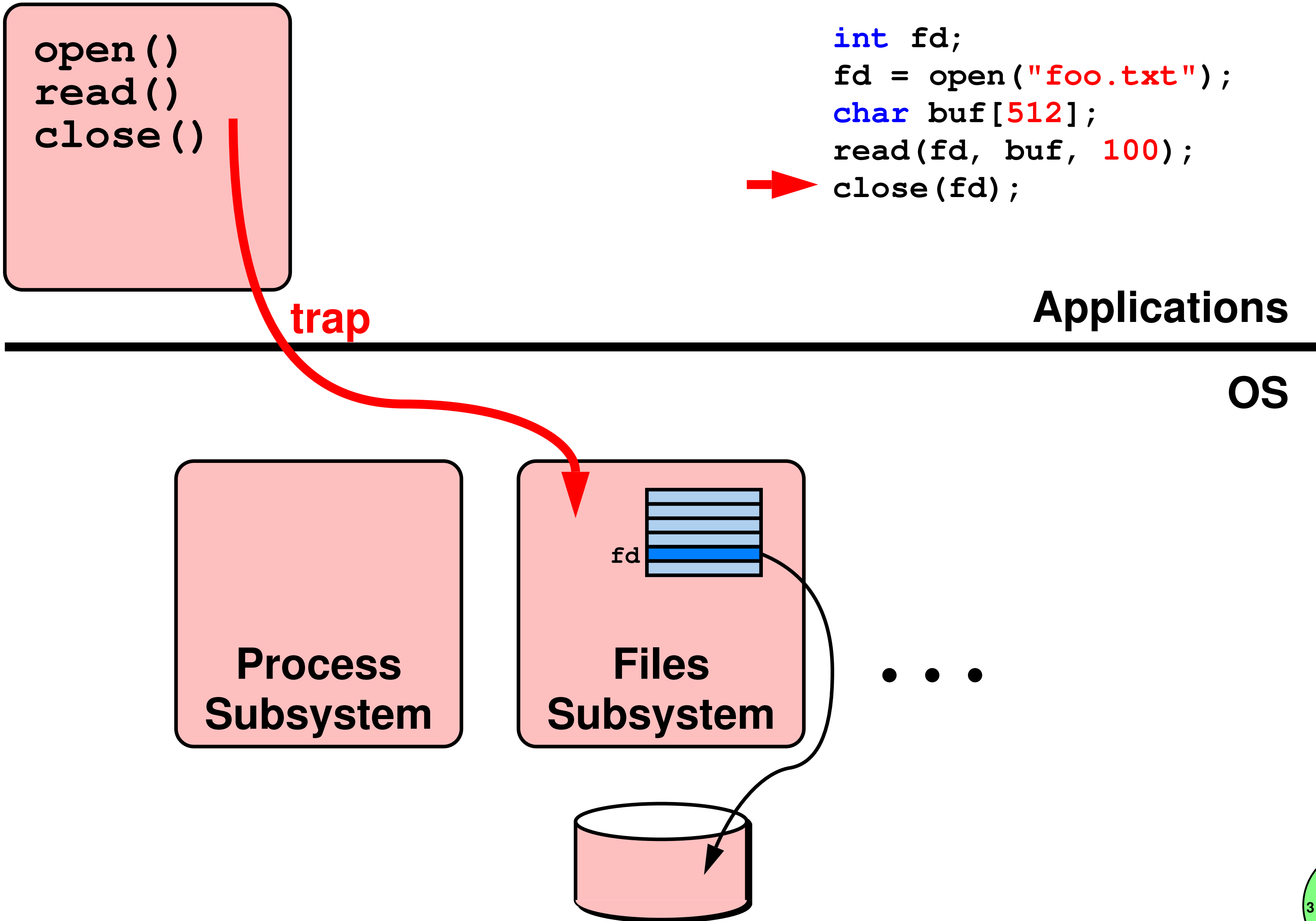
```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```

Applications

OS



Put It All Together




```
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fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```
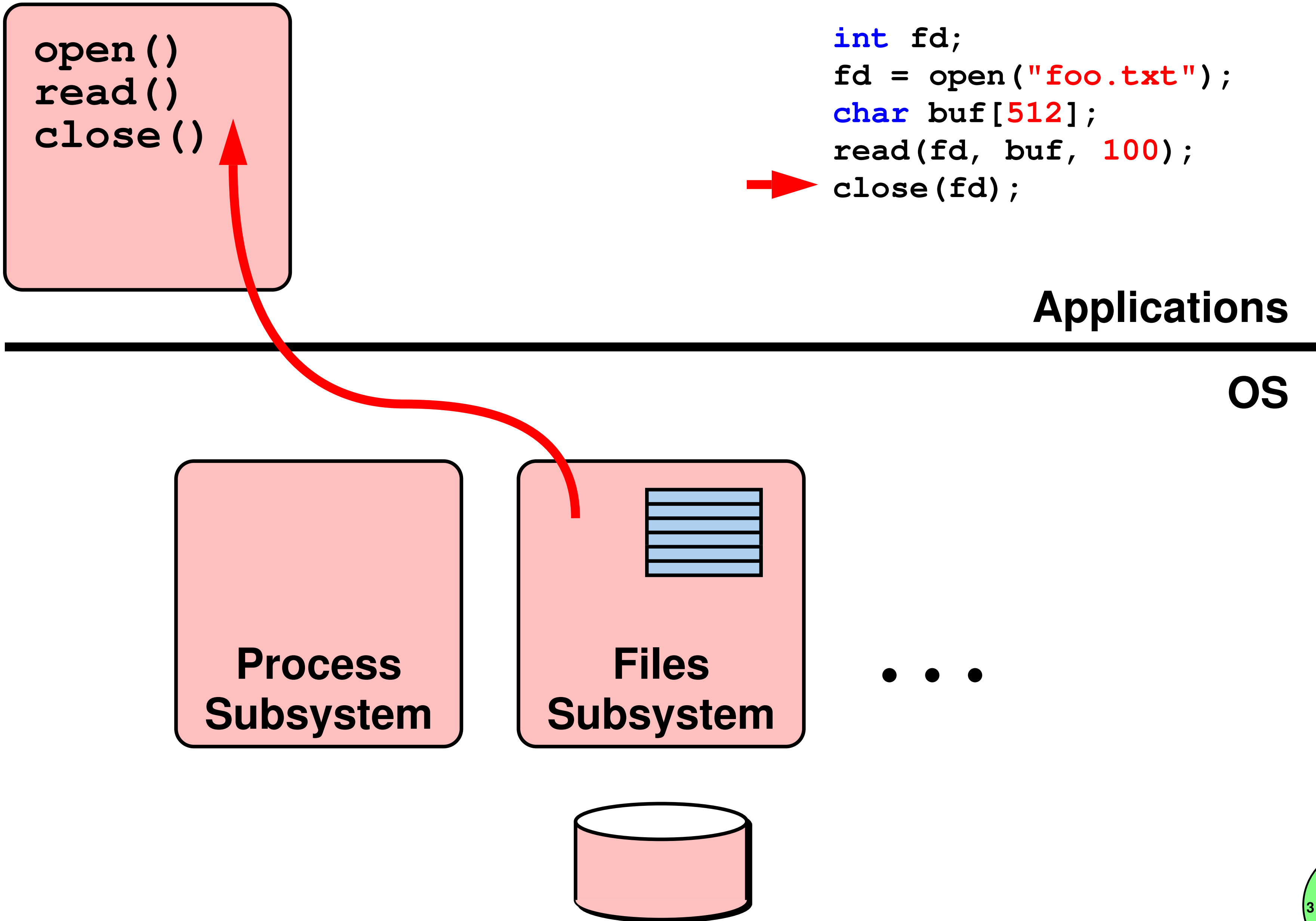

Put It All Together




```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```

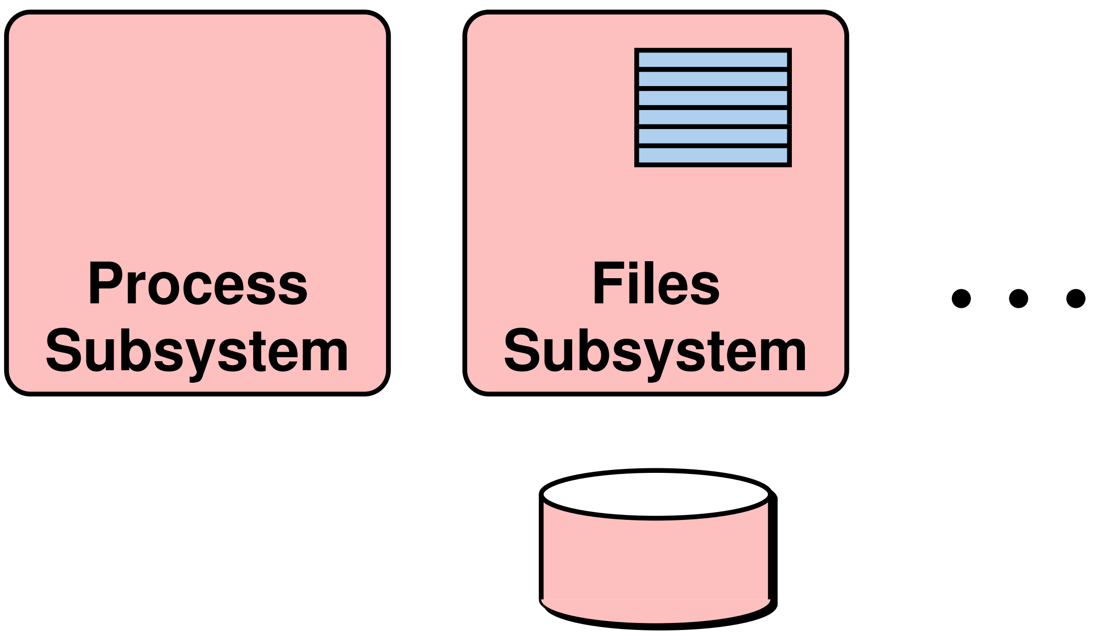
Put It All Together

```
open()
read()
close()
```

```
int fd;
fd = open("foo.txt");
char buf[512];
read(fd, buf, 100);
close(fd);
```

Applications

OS



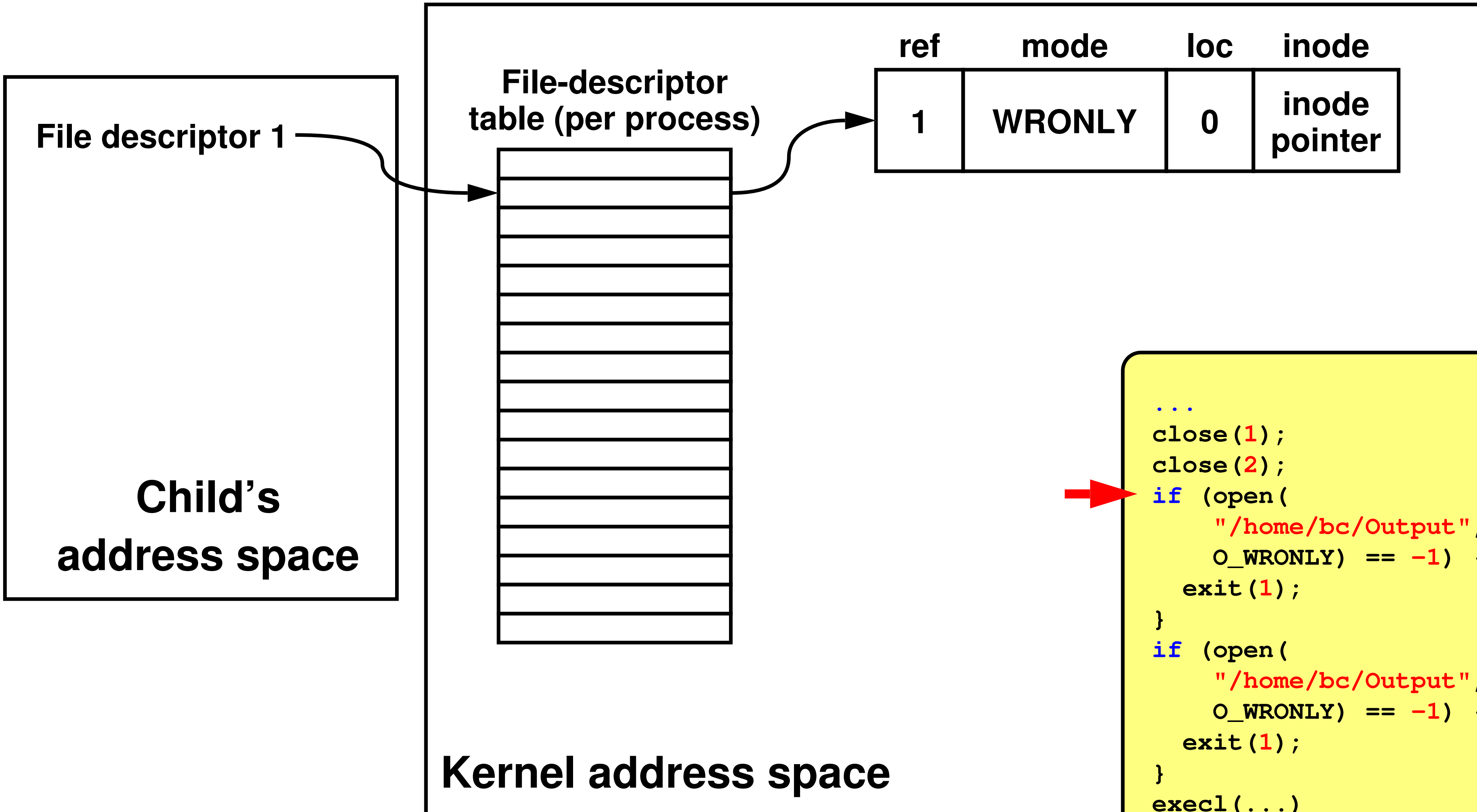
Redirecting Output ... Twice

- Every calls to `open()` creates a new entry in the system file table

```
if (fork() == 0) {
  /* set up file descriptors 1 and 2 in the child
     process */
  close(1);
  close(2);
  if (open("/home/bc/Output", O_WRONLY) == -1) {
    exit(1);
  }
  if (open("/home/bc/Output", O_WRONLY) == -1) {
    exit(1);
  }
  execl("/home/bc/bin/program", "program", 0);
  exit(1);
}
/* parent continues here */
```

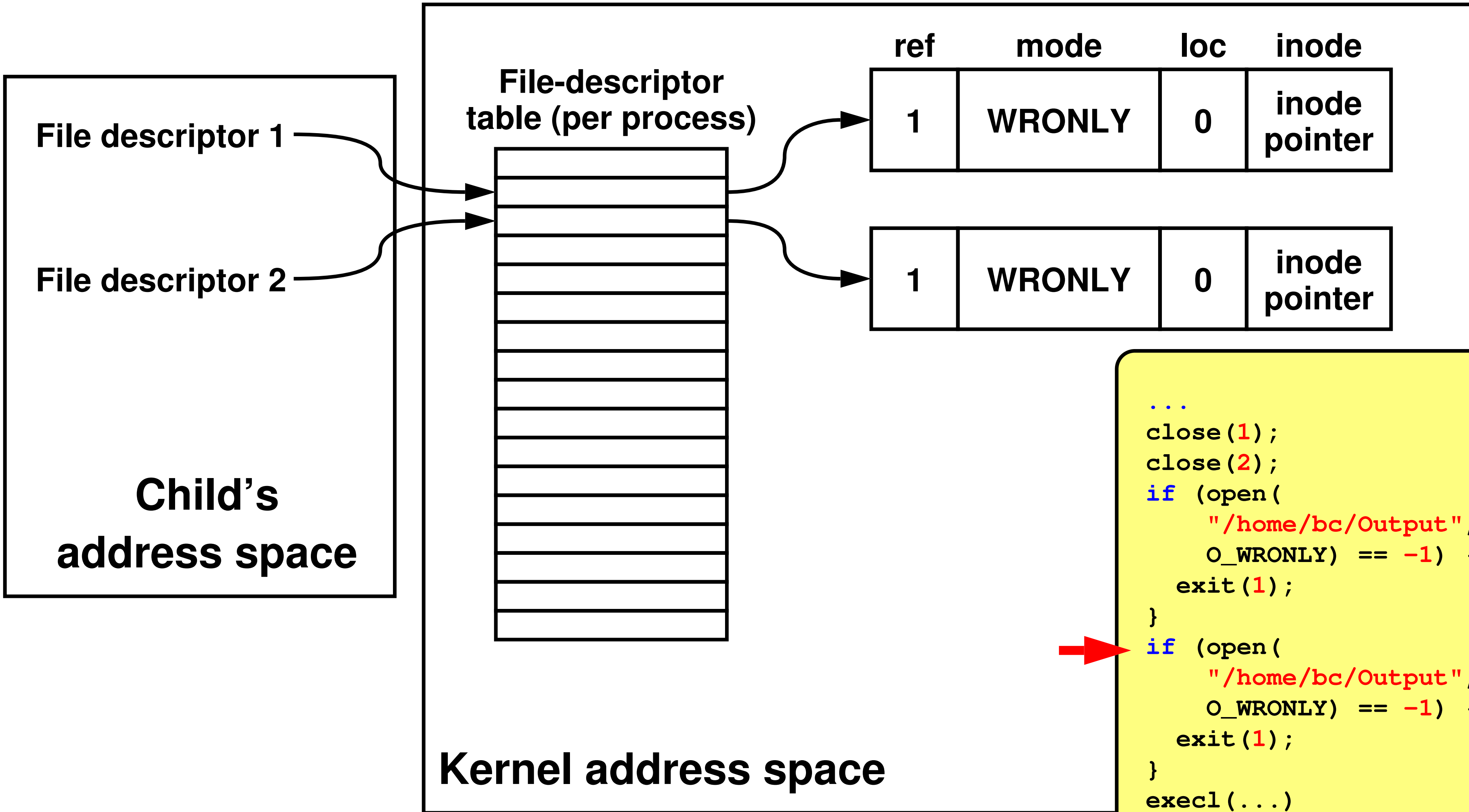
- `stdout` and `stderr` both go into the same file
  - would it cause any problem?

Redirected Output



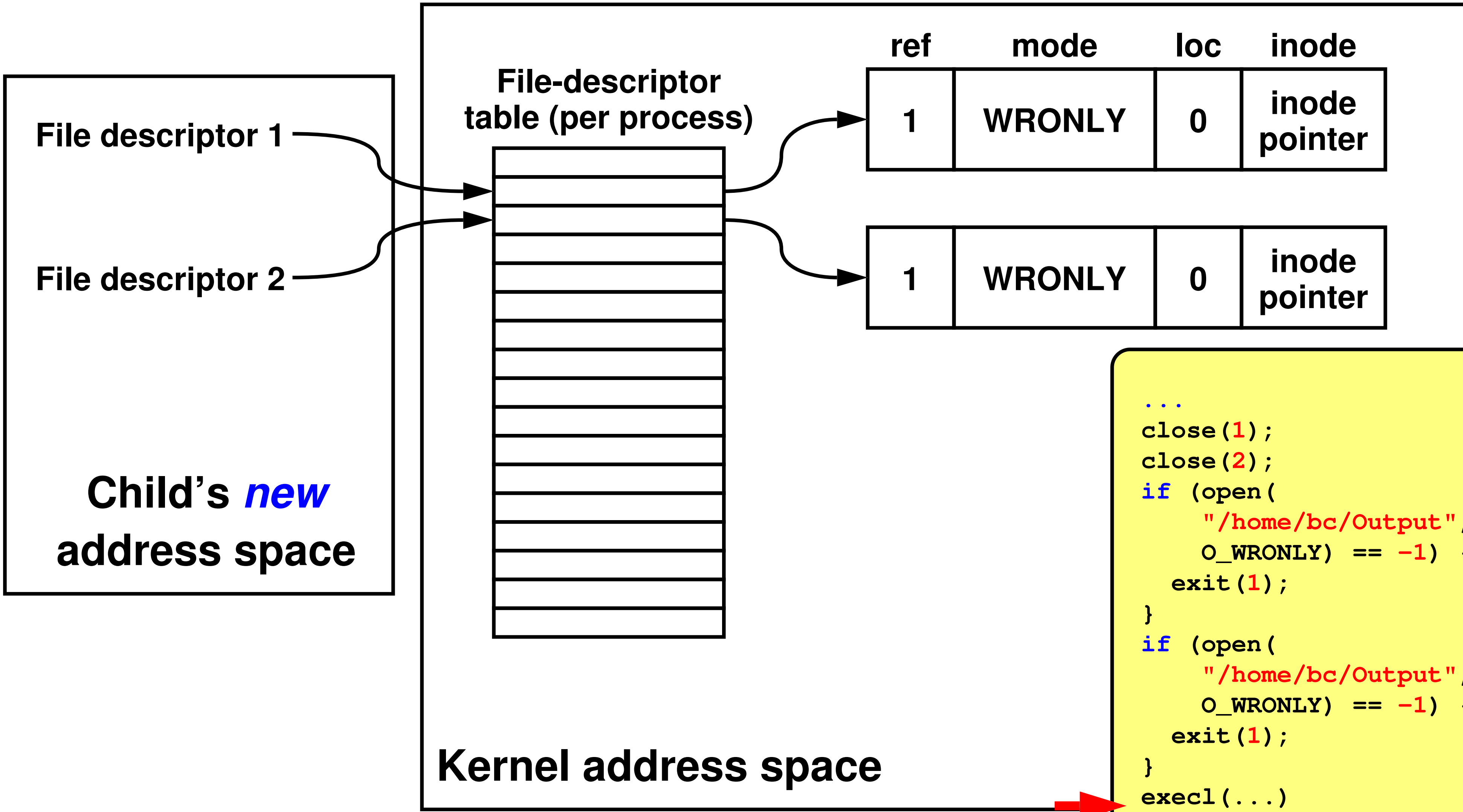

```
...
close(1);
close(2);
if (open(
     "/home/bc/Output",
     O_WRONLY) == -1) {
  exit(1);
}
if (open(
     "/home/bc/Output",
     O_WRONLY) == -1) {
  exit(1);
}
execl(...)
```

Redirected Output




```
...
close(1);
close(2);
if (open(
      "/home/bc/Output",
      O_WRONLY) == -1) {
    exit(1);
}
if (open(
      "/home/bc/Output",
      O_WRONLY) == -1) {
    exit(1);
}
execl(...)
```

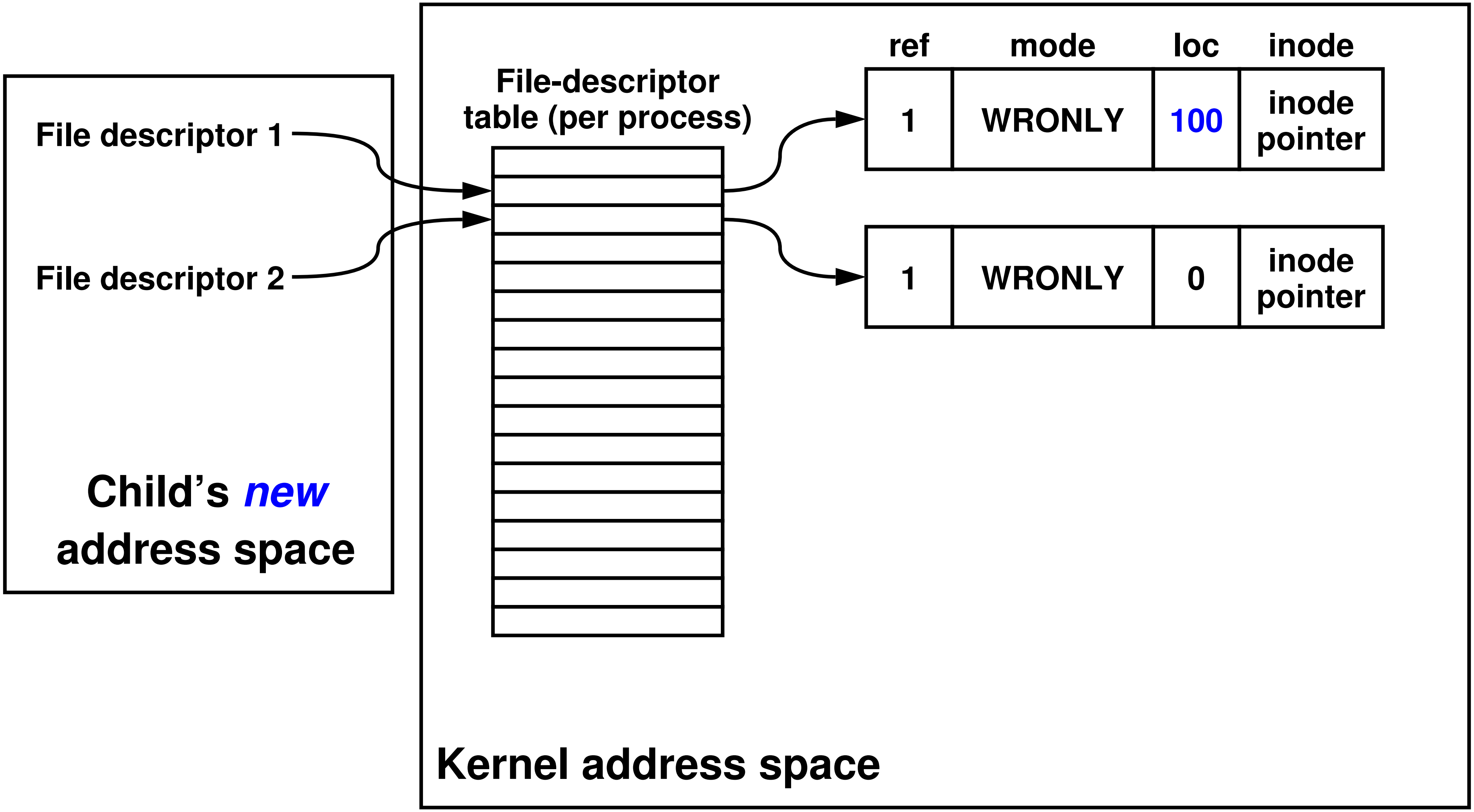
Redirected Output




```
...
close(1);
close(2);
if (open(
     "/home/bc/Output",
     O_WRONLY) == -1) {
  exit(1);
}
if (open(
     "/home/bc/Output",
     O_WRONLY) == -1) {
  exit(1);
}
execl(...)
```

- remember, extended address space survives execs

Redirected Output After Writing 100 Bytes



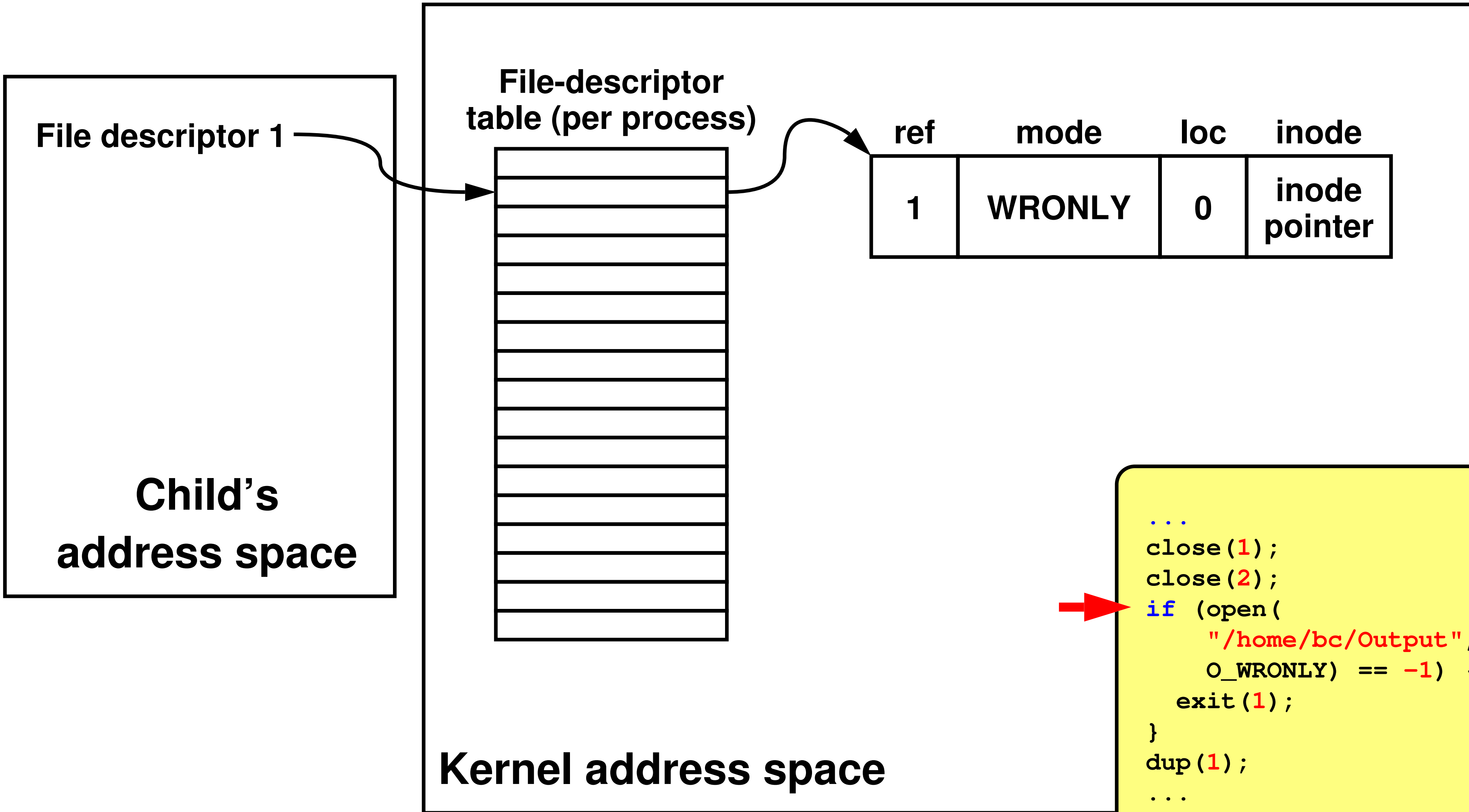
- `write()` to fd=2 will wipe out data in the first 100 bytes
  - that may not be the intent

Sharing Context Information

```
if (fork() == 0) {
   /* set up file descriptors 1 and 2 in the child
     process */
   close(1);
   close(2);
   if (open("/home/bc/Output", O_WRONLY) == -1) {
      exit(1);
   }
   dup(1);
   execl("/home/bc/bin/program", "program", 0);
   exit(1);
}
/* parent continues here */
```

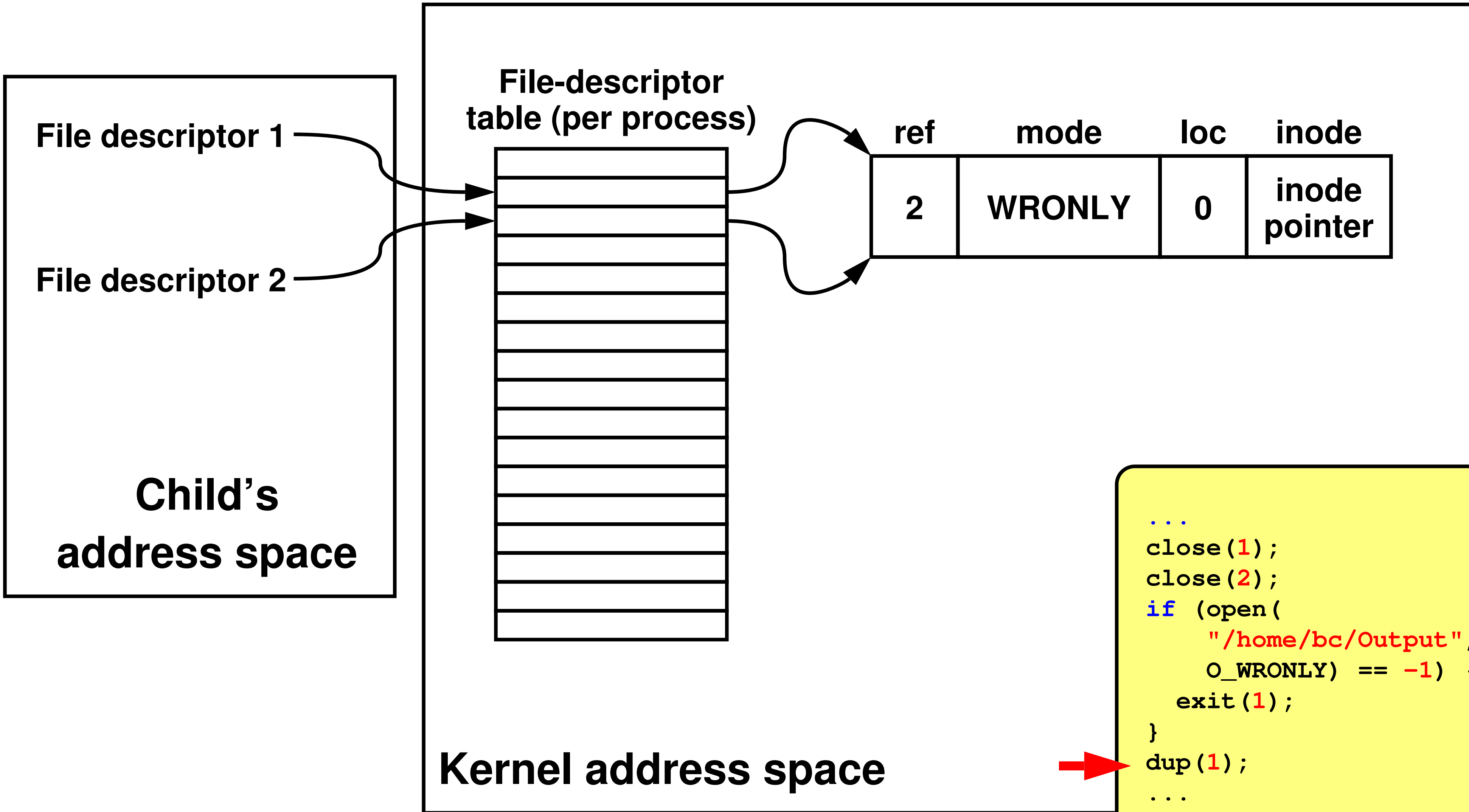
- use the `dup()` system call to *share* context information
  - if that's what you want

Redirected Output After Dup




```
...
close(1);
close(2);
if (open(
      "/home/bc/Output",
      O_WRONLY) == -1) {
   exit(1);
}
dup(1);
...
```

Redirected Output After Dup




```
...
close(1);
close(2);
if (open(
     "/home/bc/Output",
     O_WRONLY) == -1) {
  exit(1);
}
dup(1);
...
```

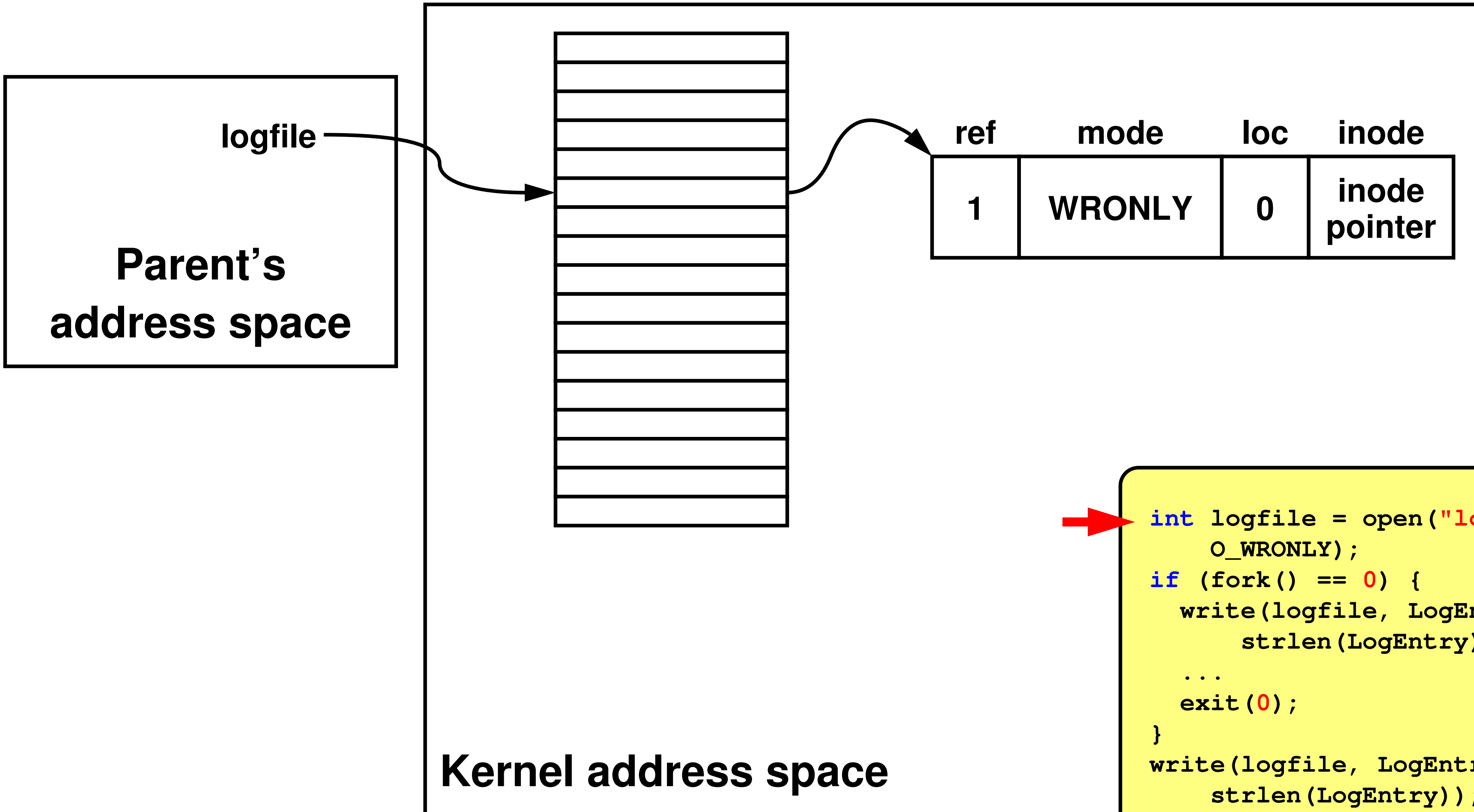
Fork and File Descriptors

- When `fork()` is called, the child process gets a *copy* of the parent's file descriptor table

```
int logfile = open("log", O_WRONLY);
if (fork() == 0) {
  /* child process computes something, then does: */
  write(logfile, LogEntry, strlen(LogEntry));
  ...
  exit(0);
}
/* parent process computes something, then does: */
write(logfile, LogEntry, strlen(LogEntry));
...
```

  - remember, extended address space survives execs
    - also `fork()`

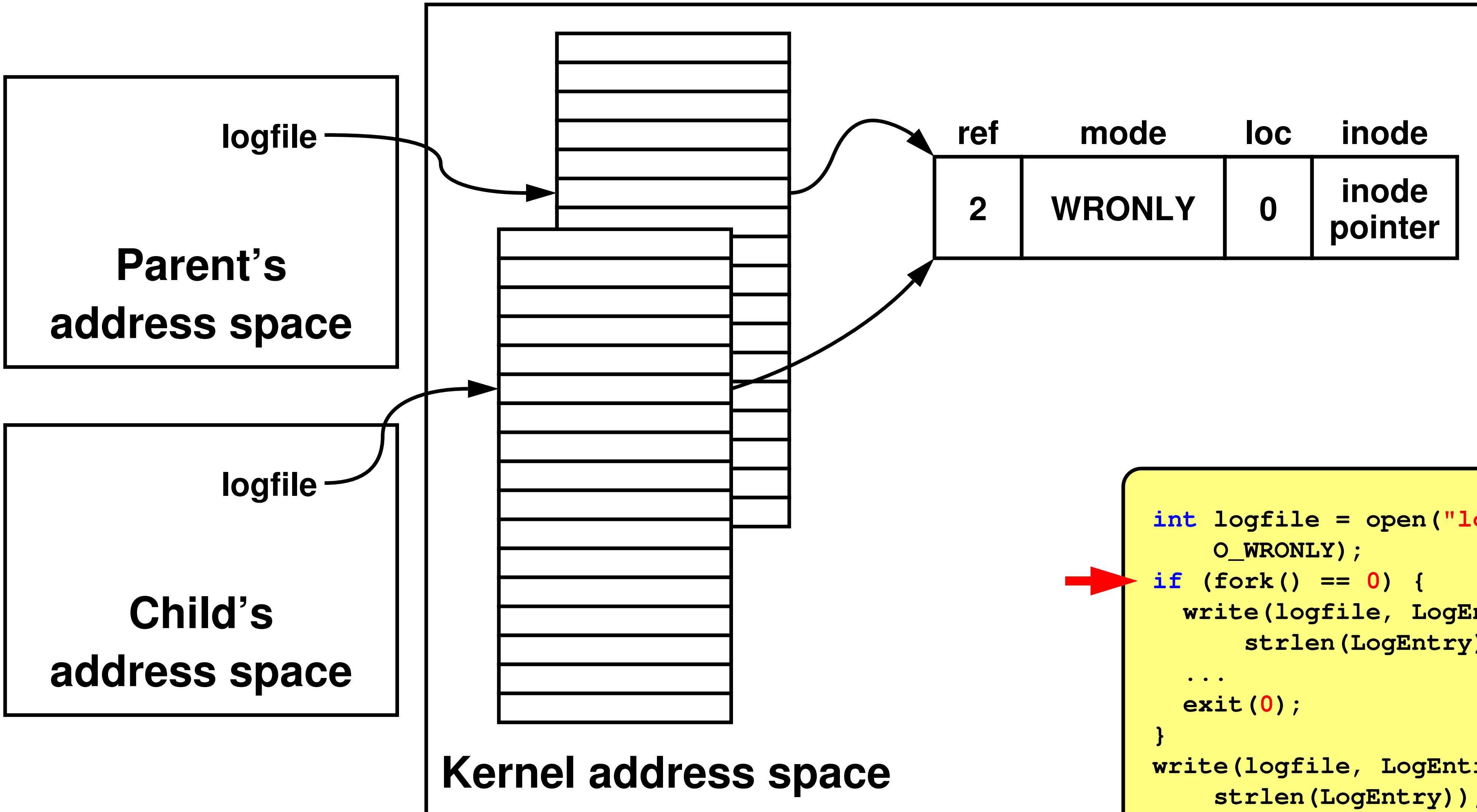
File Descriptors After Fork




```
int logfile = open("log",
    O_WRONLY);
if (fork() == 0) {
  write(logfile, LogEntry,
      strlen(LogEntry));
  ...
  exit(0);
}
write(logfile, LogEntry,
    strlen(LogEntry));
```

- parent and child processes get *separate* file descriptor table but *share* extended address space

File Descriptors After Fork

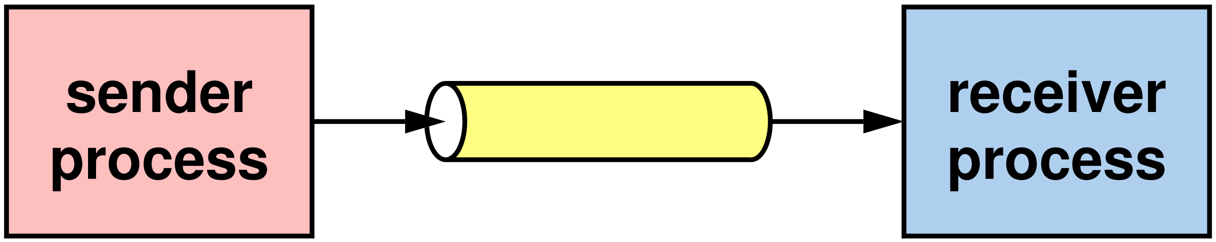



```
int logfile = open("log",
    O_WRONLY);
if (fork() == 0) {
  write(logfile, LogEntry,
      strlen(LogEntry));
  ...
  exit(0);
}
write(logfile, LogEntry,
    strlen(LogEntry));
```

- parent and child processes get *separate* file descriptor table but *share* extended address space

Pipes

- A pipe is a means for one process to send data to another directly, as if it were writing to a file



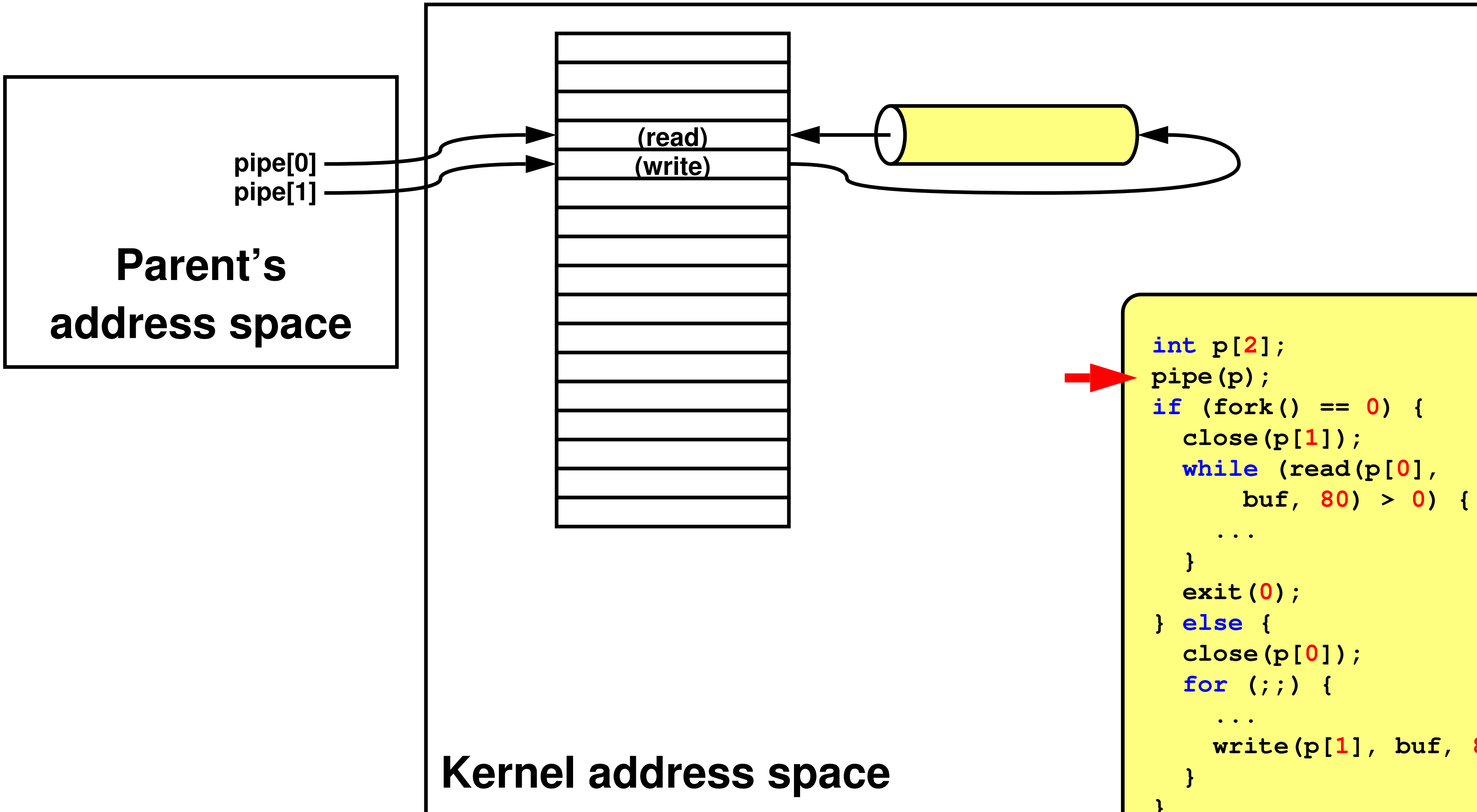
  - the sending process behaves as if it has a file descriptor to a file that has been opened for writing
  - the receiving process behaves as if it has a file descriptor to a file that has been opened for reading

- The `pipe()` system call creates a pipe object in the kernel and returns (via an output parameter) the two file descriptors that refer to the pipe
  - one, set for write-only, refers to the input side
  - the other, set for read-only, refers to the output side
  - a pipe has no name, cannot be passed to another process

Pipes

```
int p[2]; // array to hold pipe's file descriptors
pipe(p);  // creates a pipe, assume no errors
  // p[0] refers to the read/output end of the pipe
  // p[1] refers to the write/input end of the pipe
if (fork() == 0) {
  char buf[80];
  close(p[1]); // not needed by the child
  while (read(p[0], buf, 80) > 0) {
    // use data obtained from parent
    ...
  }
  exit(0); // child done
} else {
  char buf[80];
  close(p[0]); // not needed by the parent
  for (;;) {
    // prepare data for child
    ...
    write(p[1], buf, 80);
  }
}
```

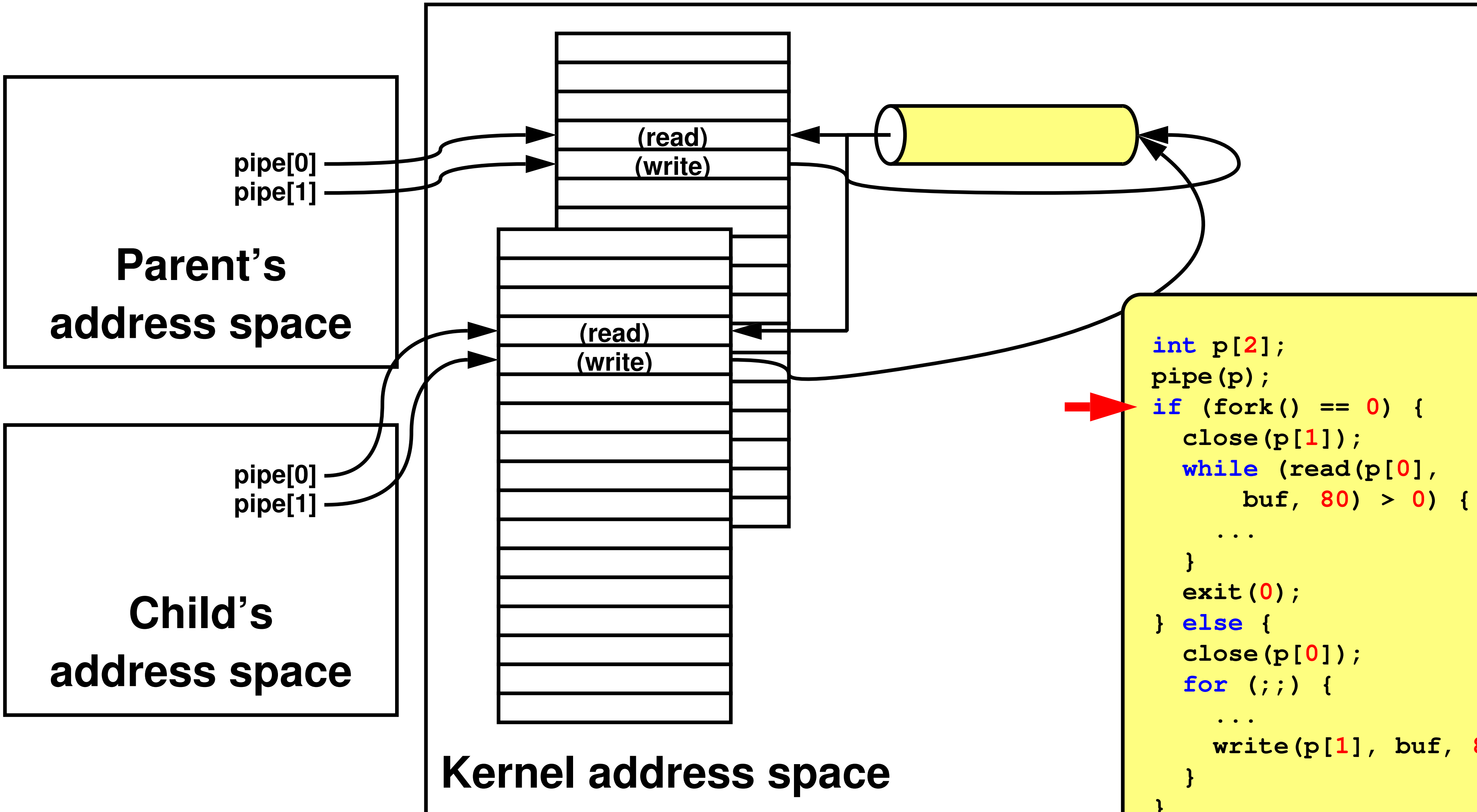
Pipes




```
int p[2];
pipe(p);
if (fork() == 0) {
  close(p[1]);
  while (read(p[0],
      buf, 80) > 0) {
    ...
  }
  exit(0);
} else {
  close(p[0]);
  for (;;) {
    ...
    write(p[1], buf, 80);
  }
}
```

- parent creates a pipe object in the kernel

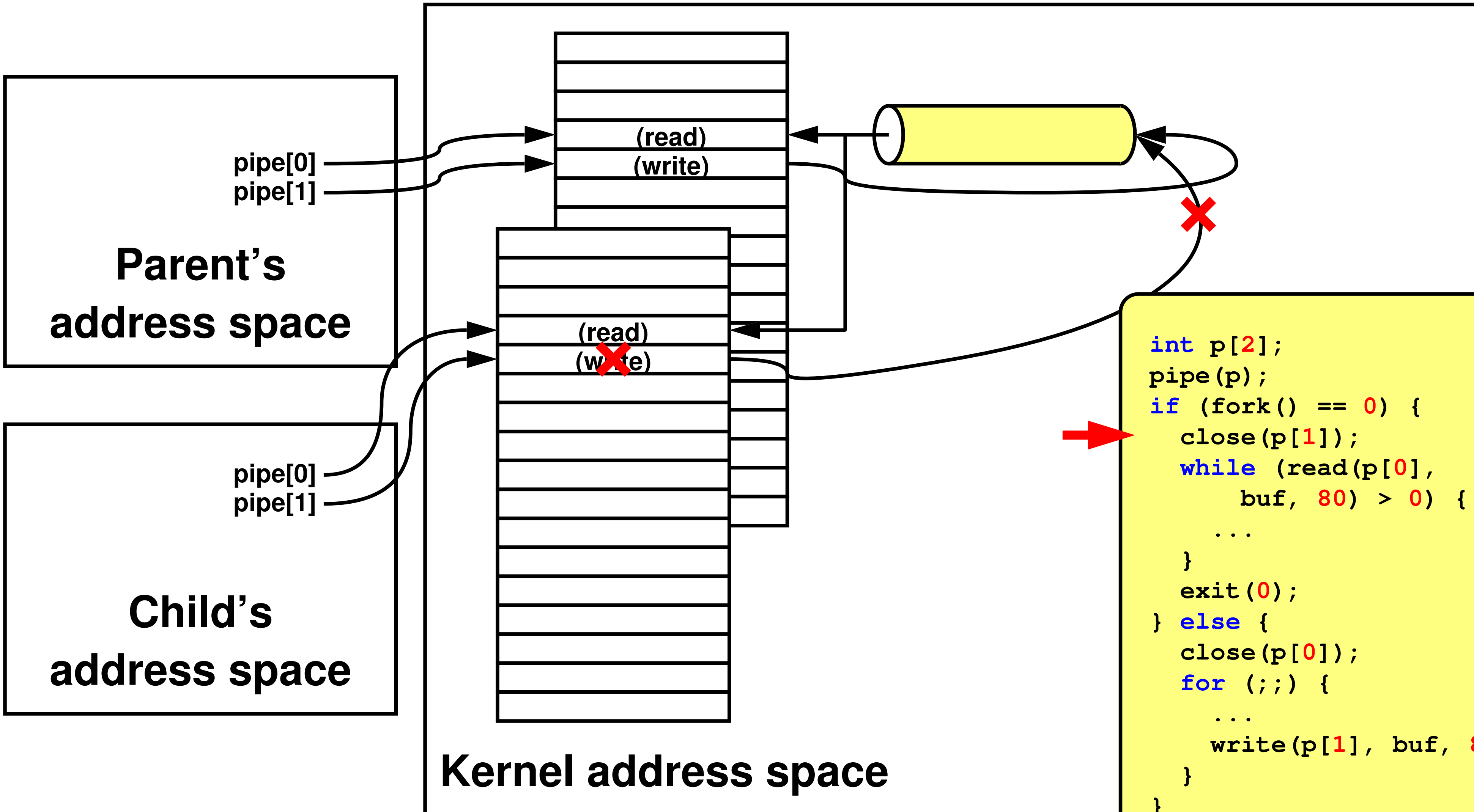
Pipes




```
int p[2];
pipe(p);
if (fork() == 0) {
  close(p[1]);
  while (read(p[0],
      buf, 80) > 0) {
    ...
  }
  exit(0);
} else {
  close(p[0]);
  for (;;) {
    ...
    write(p[1], buf, 80);
  }
}
```

- parent and child processes get *separate* file descriptor table but *share* extended address space

Pipes




```
int p[2];
pipe(p);
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  close(p[1]);
  while (read(p[0],
      buf, 80) > 0) {
    ...
  }
  exit(0);
} else {
  close(p[0]);
  for (;;) {
    ...
    write(p[1], buf, 80);
  }
}
```
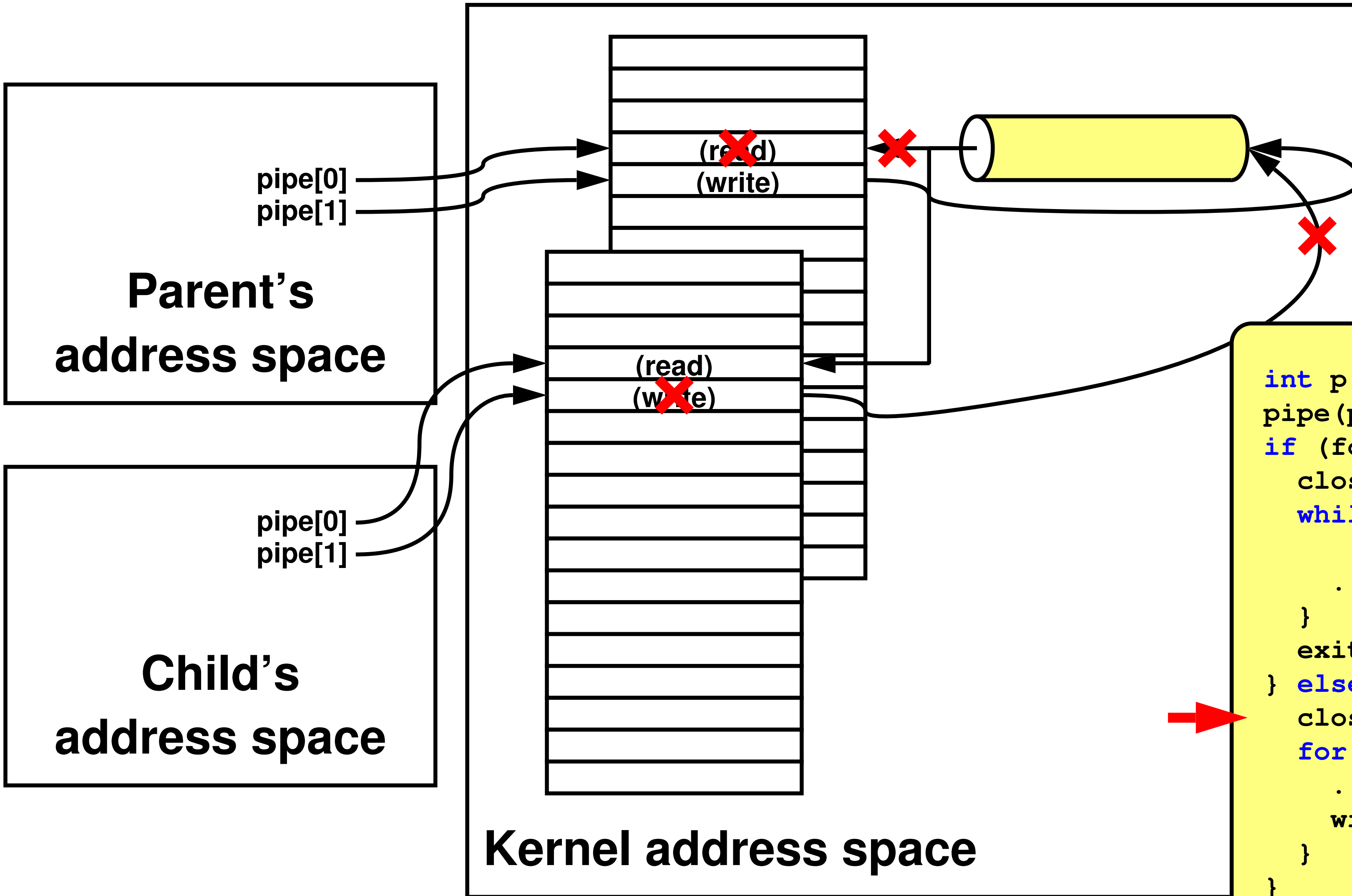

- parent and child processes get *separate* file descriptor table but *share* extended address space

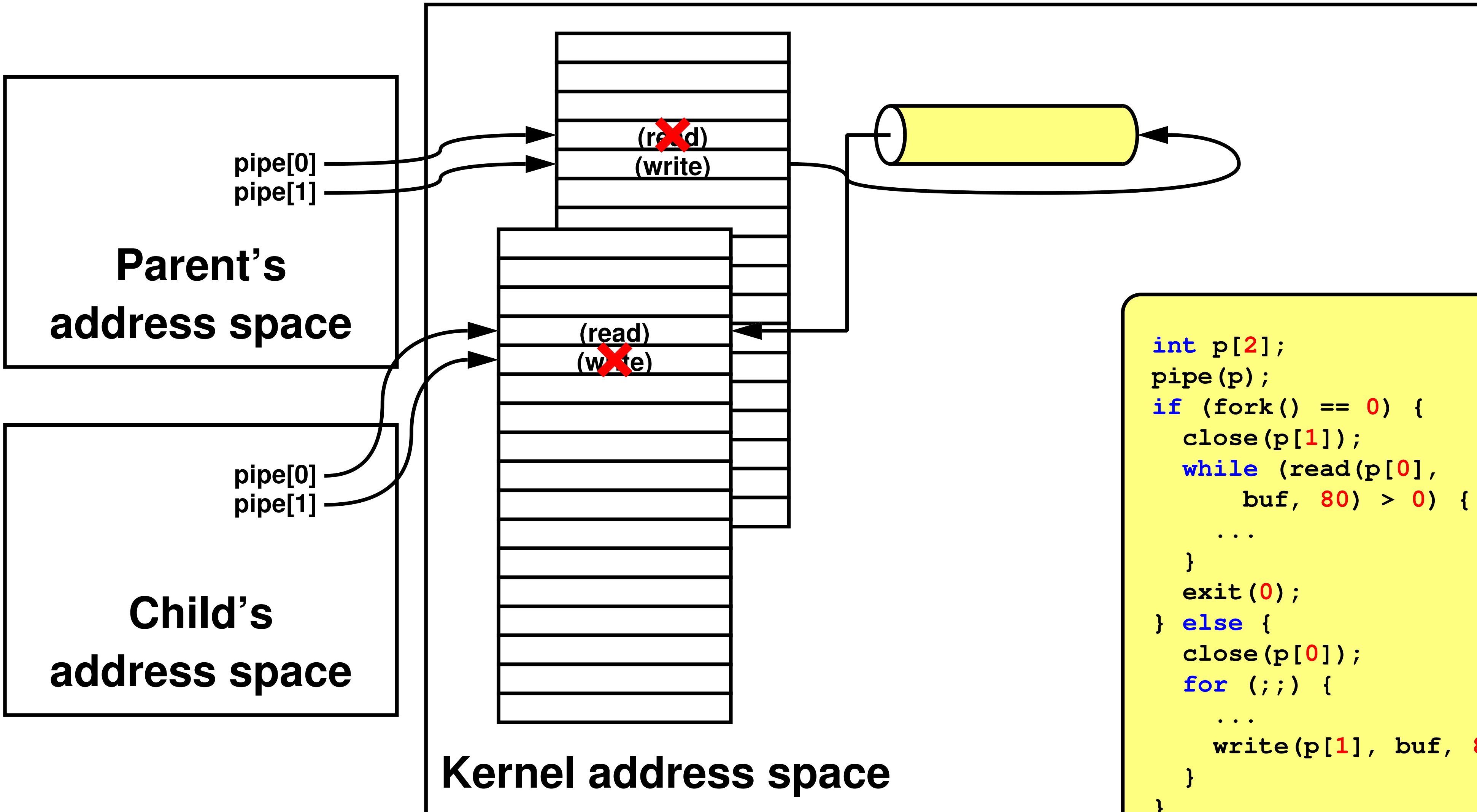
Pipes




```
int p[2];
pipe(p);
if (fork() == 0) {
  close(p[1]);
  while (read(p[0],
      buf, 80) > 0) {
    ...
  }
  exit(0);
} else {
  close(p[0]);
  for (;;) {
    ...
    write(p[1], buf, 80);
  }
}
```

- parent and child processes get *separate* file descriptor table but *share* extended address space

Pipes




```
int p[2];
pipe(p);
if (fork() == 0) {
  close(p[1]);
  while (read(p[0],
      buf, 80) > 0) {
    ...
  }
  exit(0);
} else {
  close(p[0]);
  for (;;) {
    ...
    write(p[1], buf, 80);
  }
}
```

- parent closes the read-end of the pipe
  child closes the write-end of the pipe

Command Shell

- Now you know enough to write a command shell
  - execute a command
  - redirect I/O
  - pipe the output of one program to another

    ```
    cat f0 | ./warmup1 sort
    ```

    - the shell needs to create a pipe
    - create two child processes
    - in the first child
      - have `stdout` go to the write-end of the pipe
      - close the read-end of the pipe
      - exec "`cat f0`"
    - in the 2nd child
      - have `stdin` come from the read-end of the pipe
      - close the write-end of the pipe
      - exec "`./warmup1 sort`"
  - run a program in the background

    ```
    primes 1000000 > primes.out &
    ```

Random Access

```
fd = open("textfile", O_RDONLY);
// go to last char in file
fptr = lseek(fd, (off_t)(-1), SEEK_END);
while (fptr != -1) {
  read(fd, buf, 1);
  write(1, buf, 1);
  fptr = lseek(fd, (off_t)(-2), SEEK_CUR);
}
```

- "man lseek" gives

  `off_t lseek(int fd, off_t offset, int whence);`
- `whence` can be SEEK_SET, SEEK_CUR, SEEK_END
- if succeeds, returns cursor position (always measured from the beginning of the file)
  - otherwise, returns (-1)
  - `errno` is set to indicate the error
- `read(fd,buf,1)` advances the cursor position by 1, so we need to move the cursor position back 2 positions

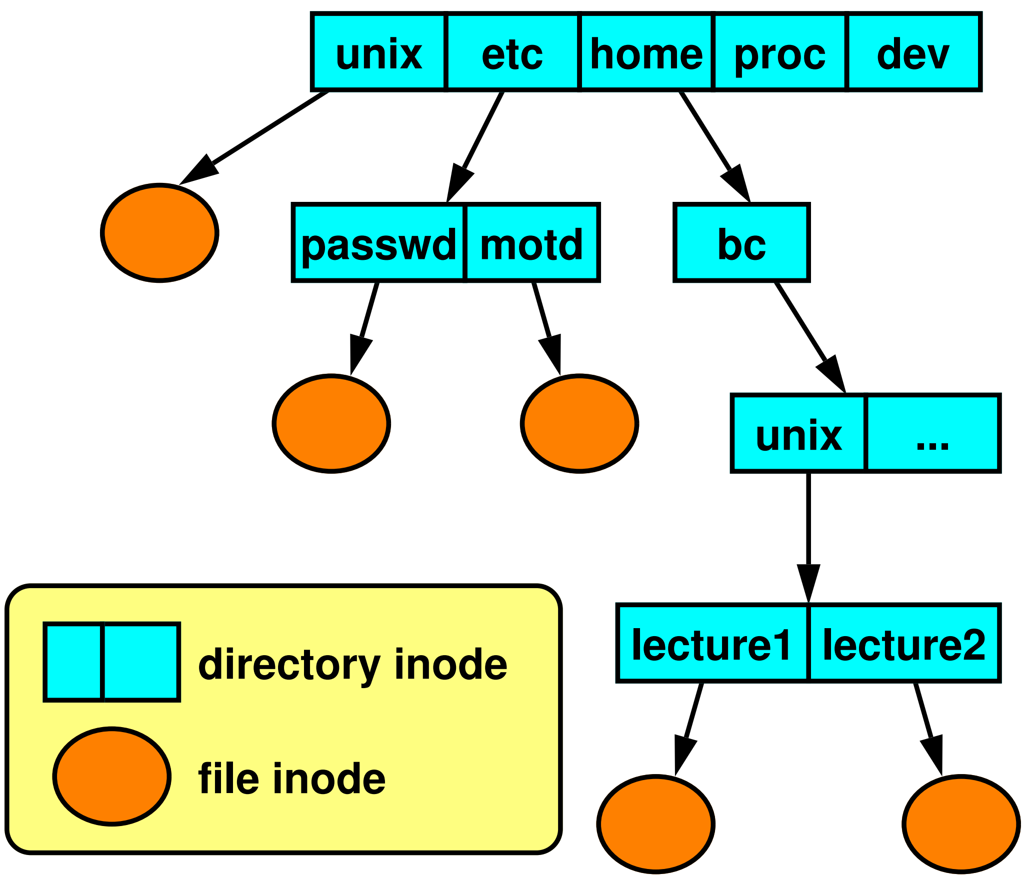
More On Naming

- (Almost) everything has a path name
  - files
  - directories
  - devices (known as *special files*)
  - keyboards
  - displays
  - disks
  - etc.
- Uniformity

```
// opening a normal file
int file = open("/home/bc/data", O_RDWR);

// opening a device (one's terminal or window)
int device = open("/dev/tty", O_RDWR);

int bytes = read(file, buffer, sizeof(buffer));
write(device, buffer, bytes);
```

Directories

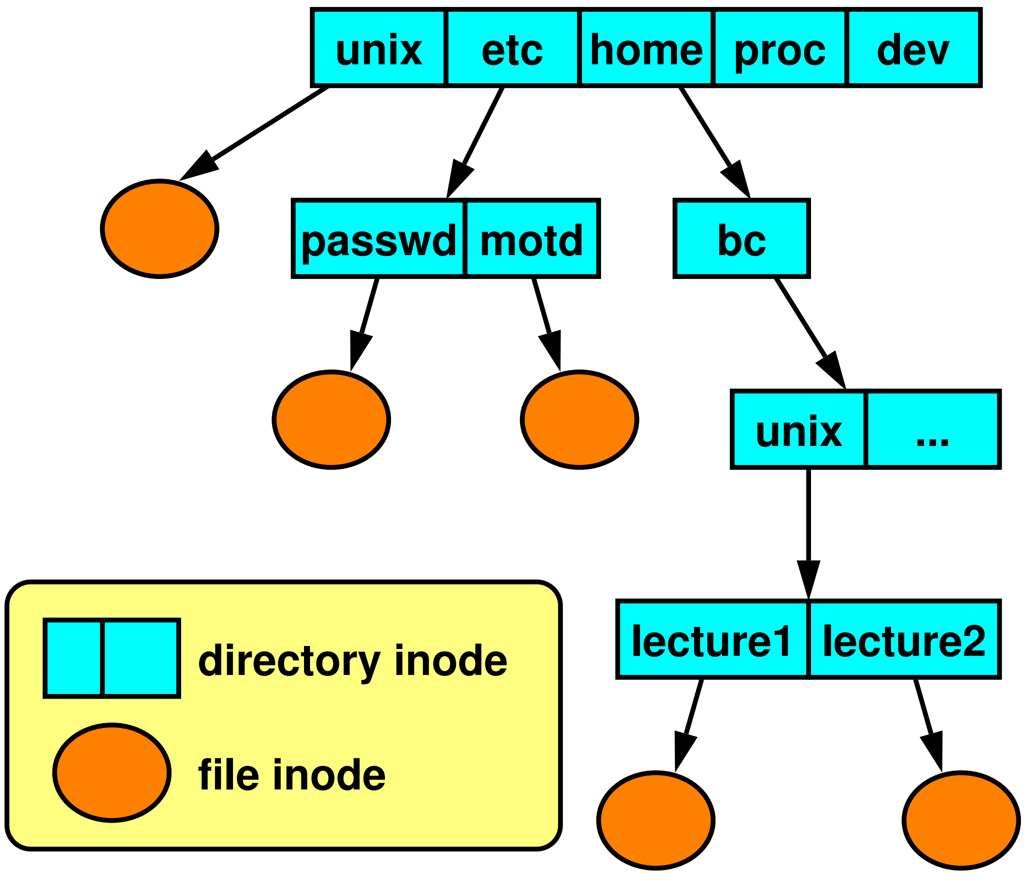
- A *directory* is a *file*
  - interprets differently by the OS as containing *references* to other files/directories
  - a file is represented as an *index node* (or *inode*) in the file system



- A *directory* maps a *file name* to an *inode number*
  - maps a string to an integer
  - done inside Virtual File System in `weenix`
- An *inode* maps an *inode number* to *sectors on disk*
  - done inside Actual File System in `weenix`

Directory Representation

- A root directory entry example
  - parent inode number = its own inode number



Component Name	Inode number

directory entry

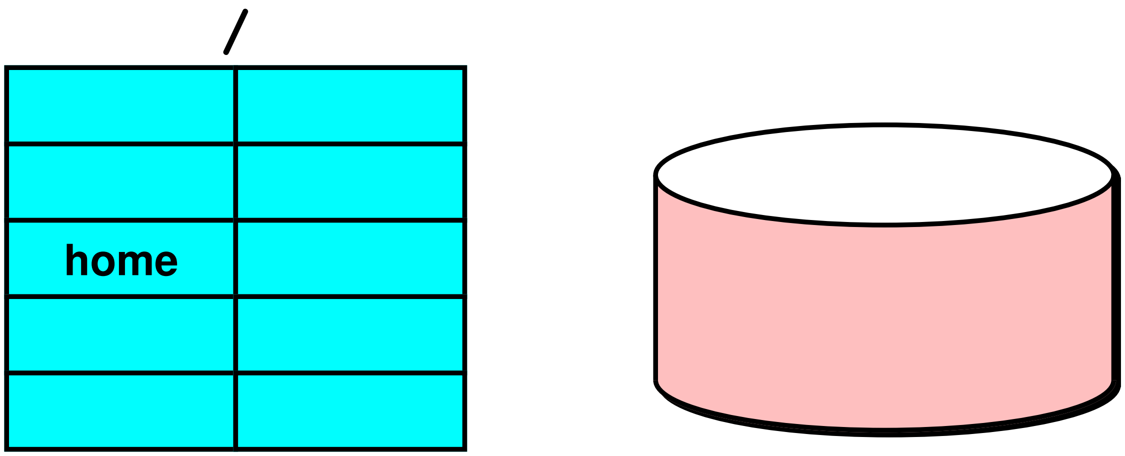
.	1
..	1
unix	117
etc	4
home	18
proc	36
dev	93

this is what a S5FS directory looks like in weenix

- Tree structured hierarchy

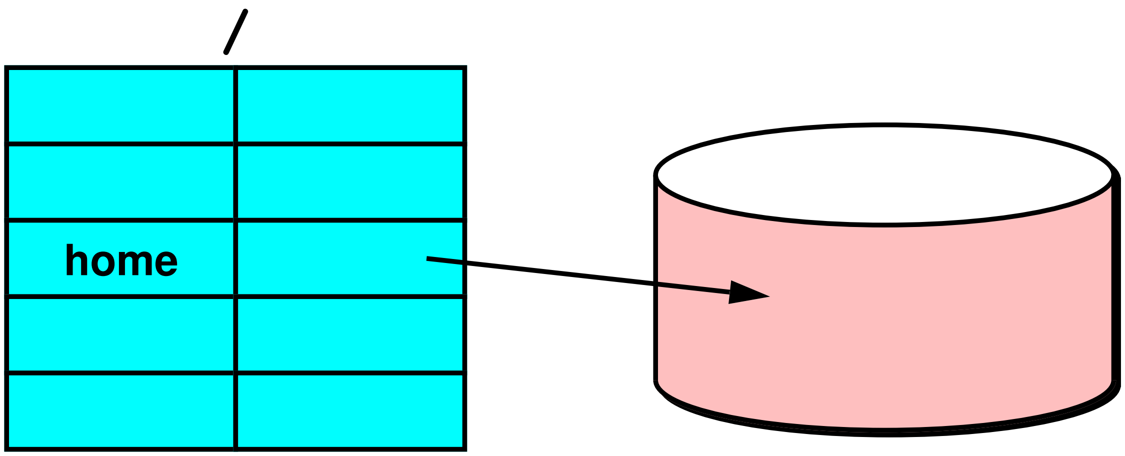
Look Up Inode Number Of A Path

- Ex: how do figure out the inode number of "`/home/bc/foo.c`"?



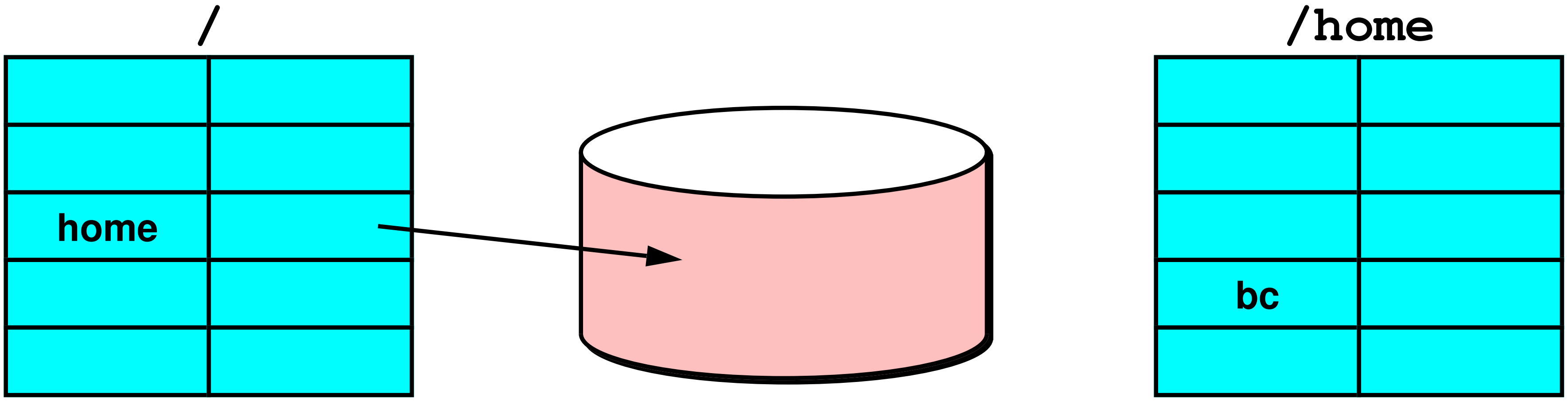
Look Up Inode Number Of A Path

- Ex: how do figure out the inode number of "`/home/bc/foo.c`"?



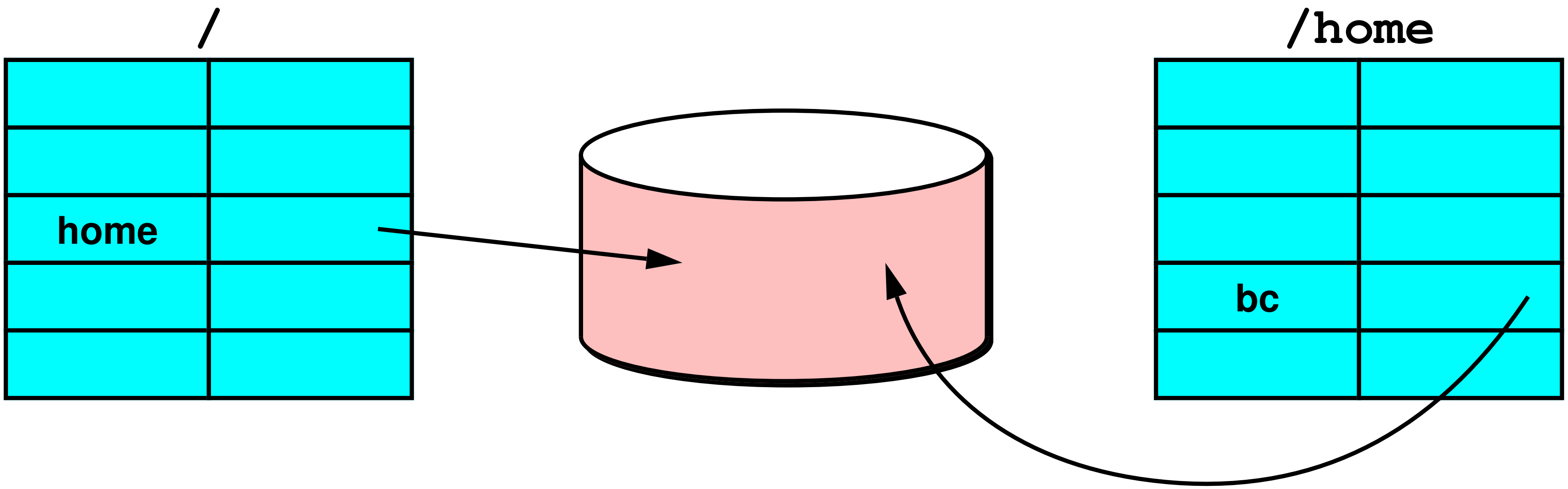
Look Up Inode Number Of A Path

- Ex: how do figure out the inode number of "`/home/bc/foo.c`"?



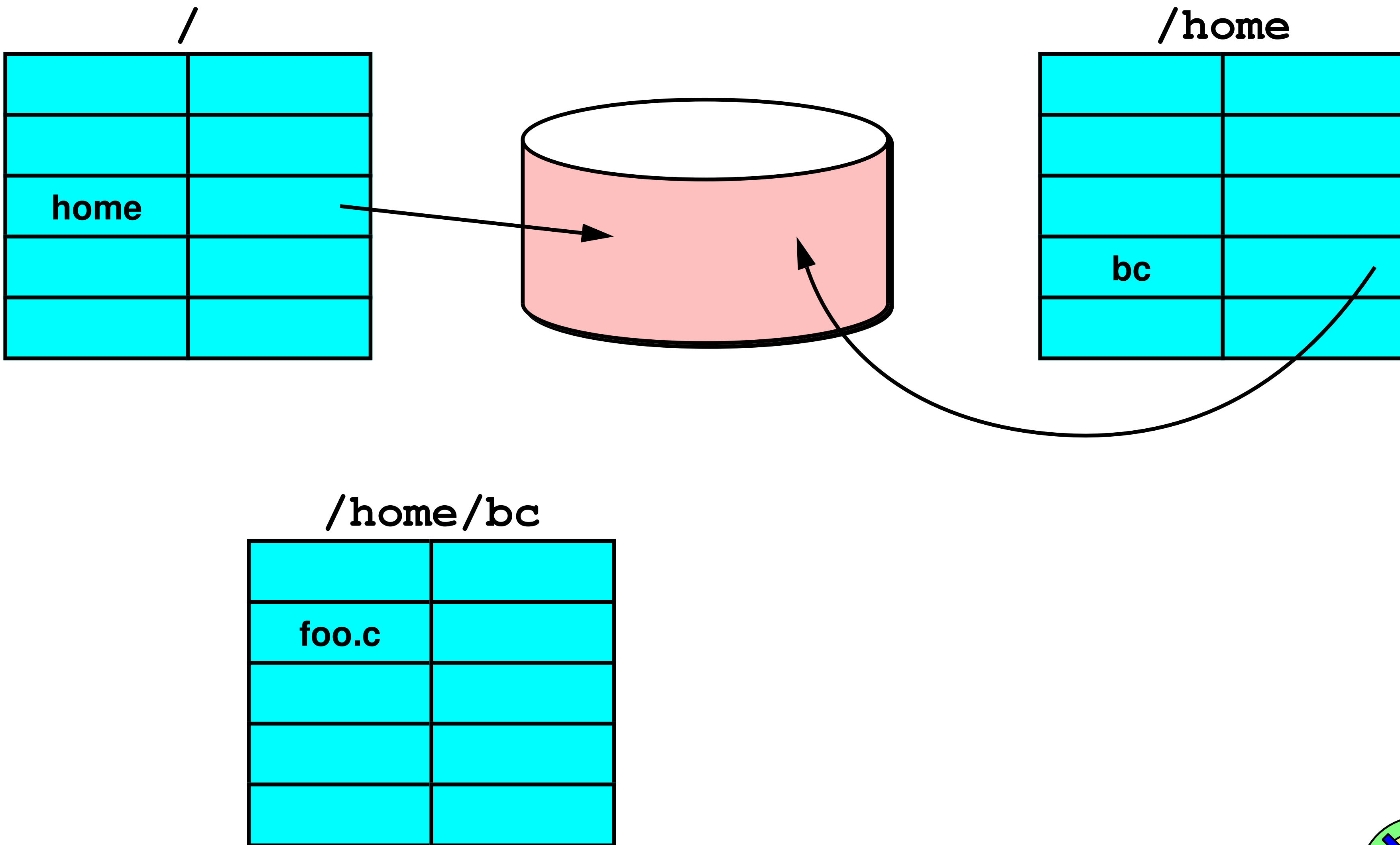
Look Up Inode Number Of A Path

- **Ex: how do figure out the inode number of "`/home/bc/foo.c`"?**



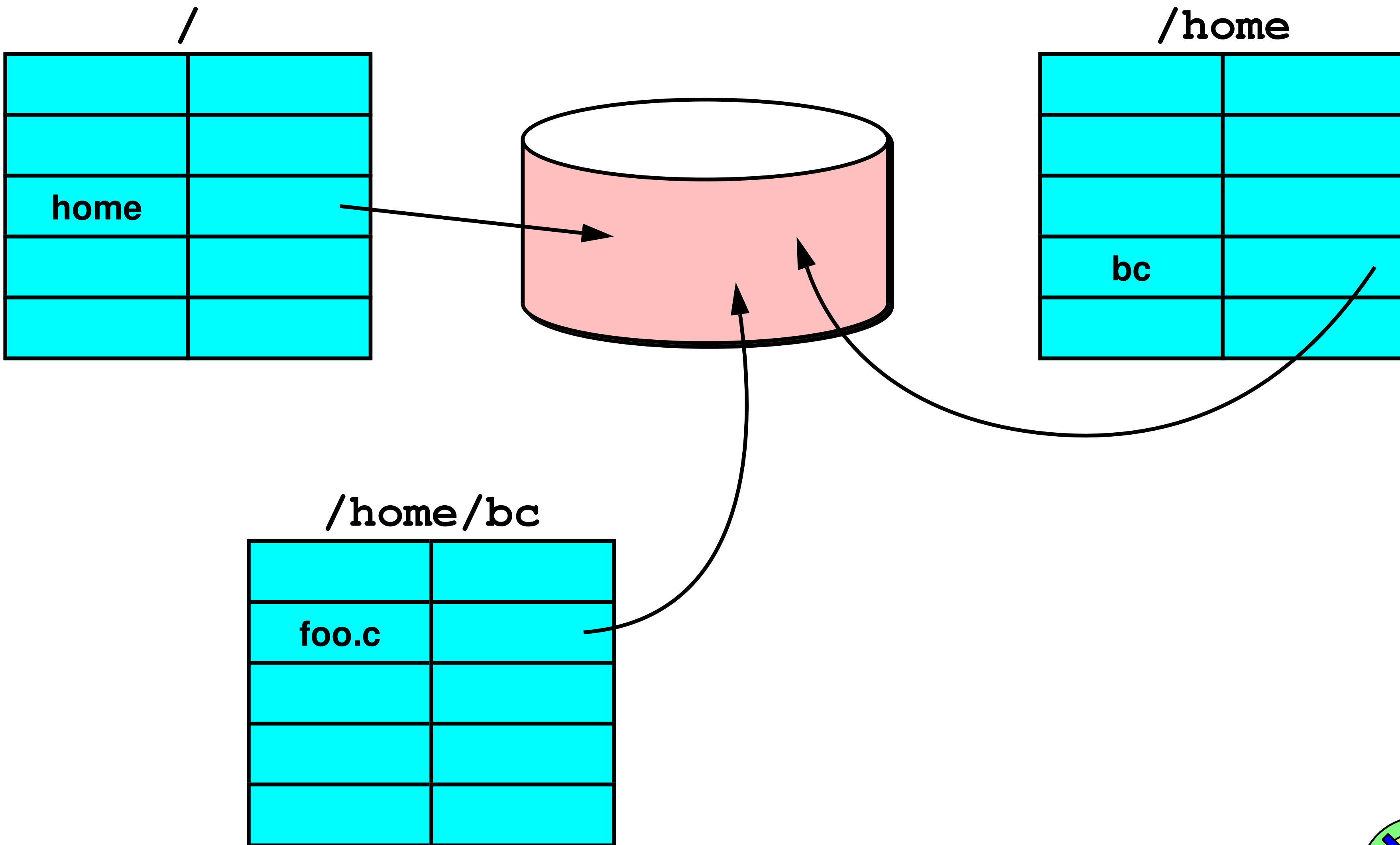
Look Up Inode Number Of A Path

- Ex: how do figure out the inode number of "`/home/bc/foo.c`"?



Look Up Inode Number Of A Path

- Ex: how do figure out the inode number of "`/home/bc/foo.c`"?



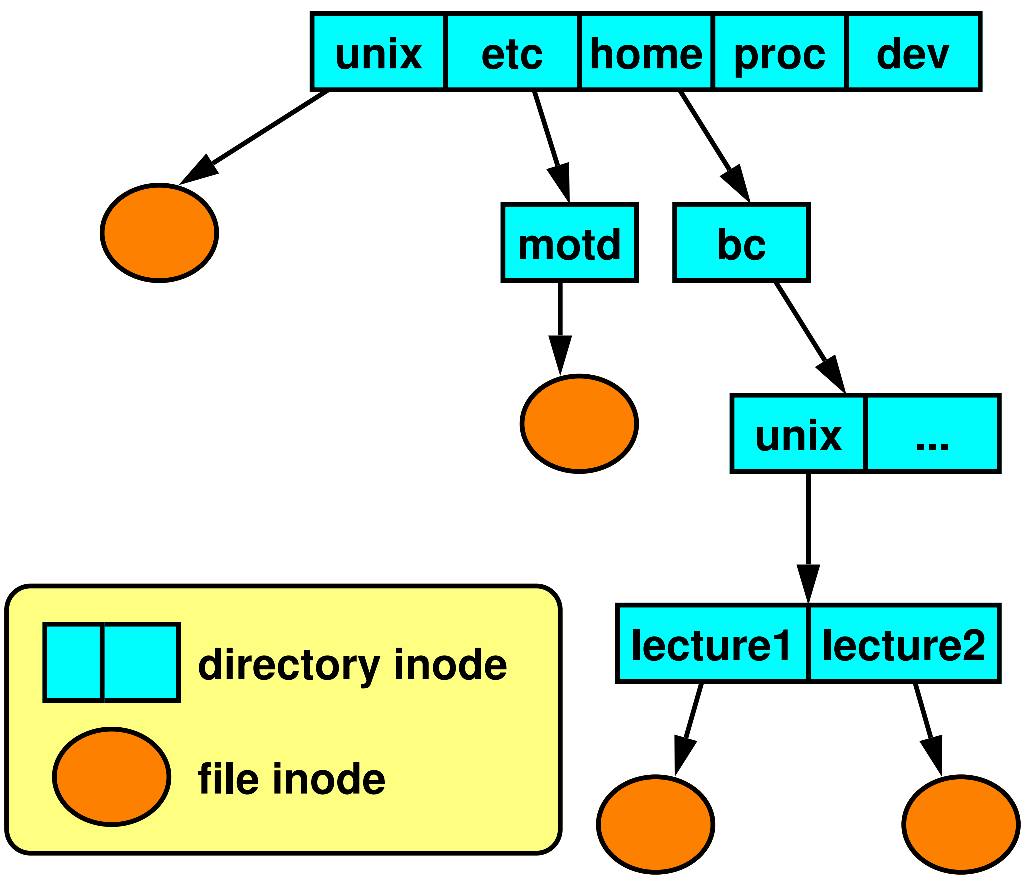
Directory Hierarchy

- Unix and many other OSes allow limited deviation from trees
  - *hard links*
    - reference to a *file* (not a directory) in one directory that also appears in another
    - using the `link()` system call or the "ln" shell command
  - *soft links* or *symbolic links*
    - a special kind of *file* containing the *name* of another file or directory
    - using the `symlink()` system call or the "ln -s" shell command

- Why hard link cannot be used on a directory?
  - to avoid cycles
  - Unix directory hierarchy can be viewed as a *directed acyclic graph* (DAG)
    - can be traversed efficiently

Hard Links

```
% ln /unix /etc/image
```

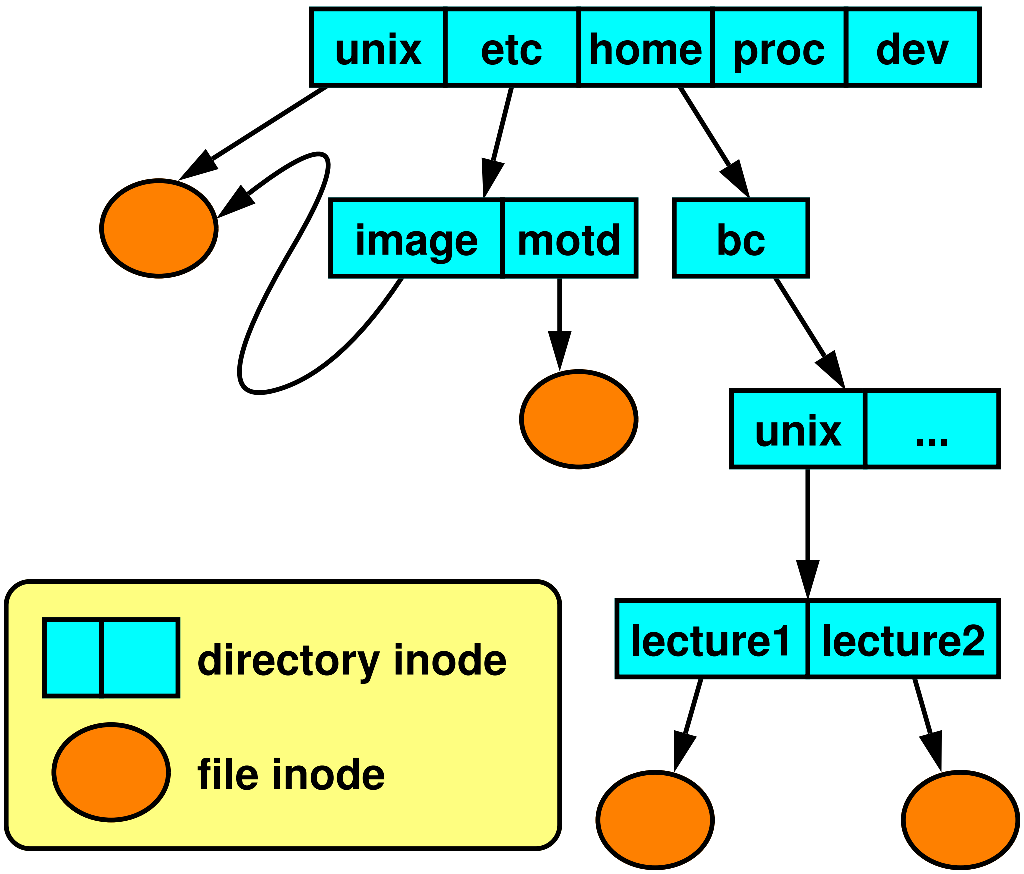


.	1
..	1
unix	117
etc	4
home	18
proc	36
dev	93

.	4
..	1
motd	33

Hard Links

```
% ln /unix /etc/image
```

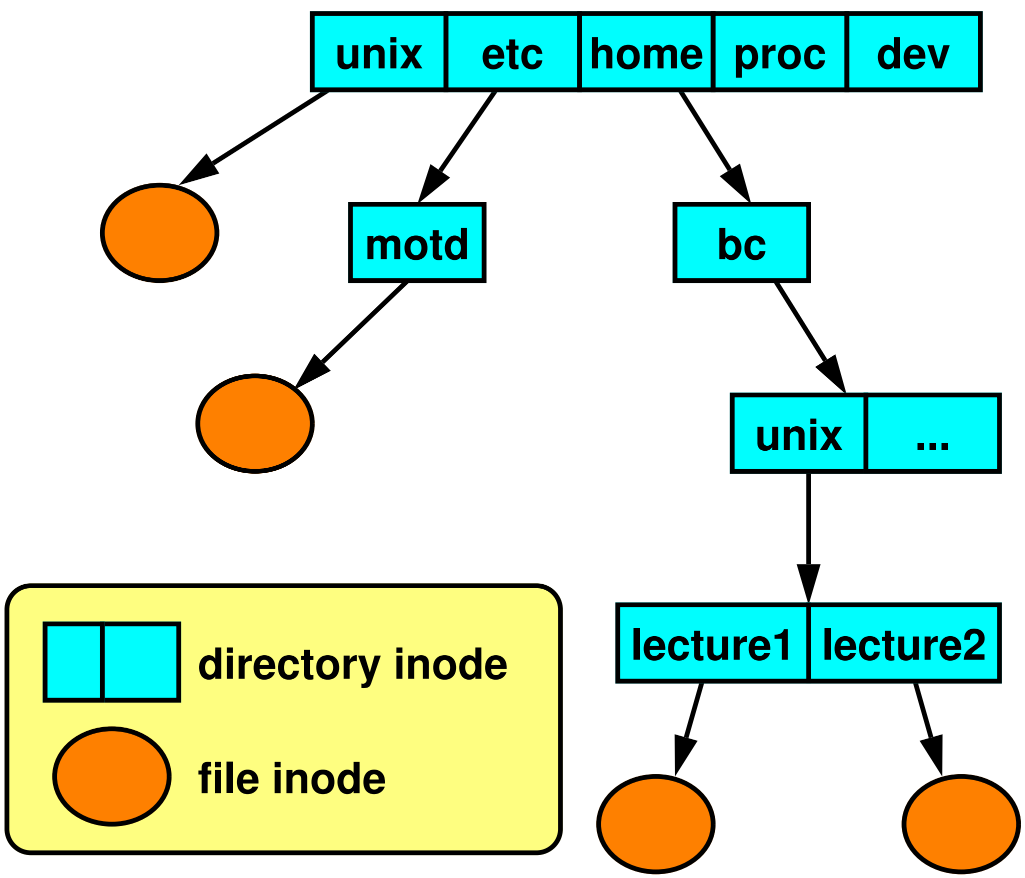


.	1
..	1
unix	117
etc	4
home	18
proc	36
dev	93

.	4
..	1
motd	33
image	117

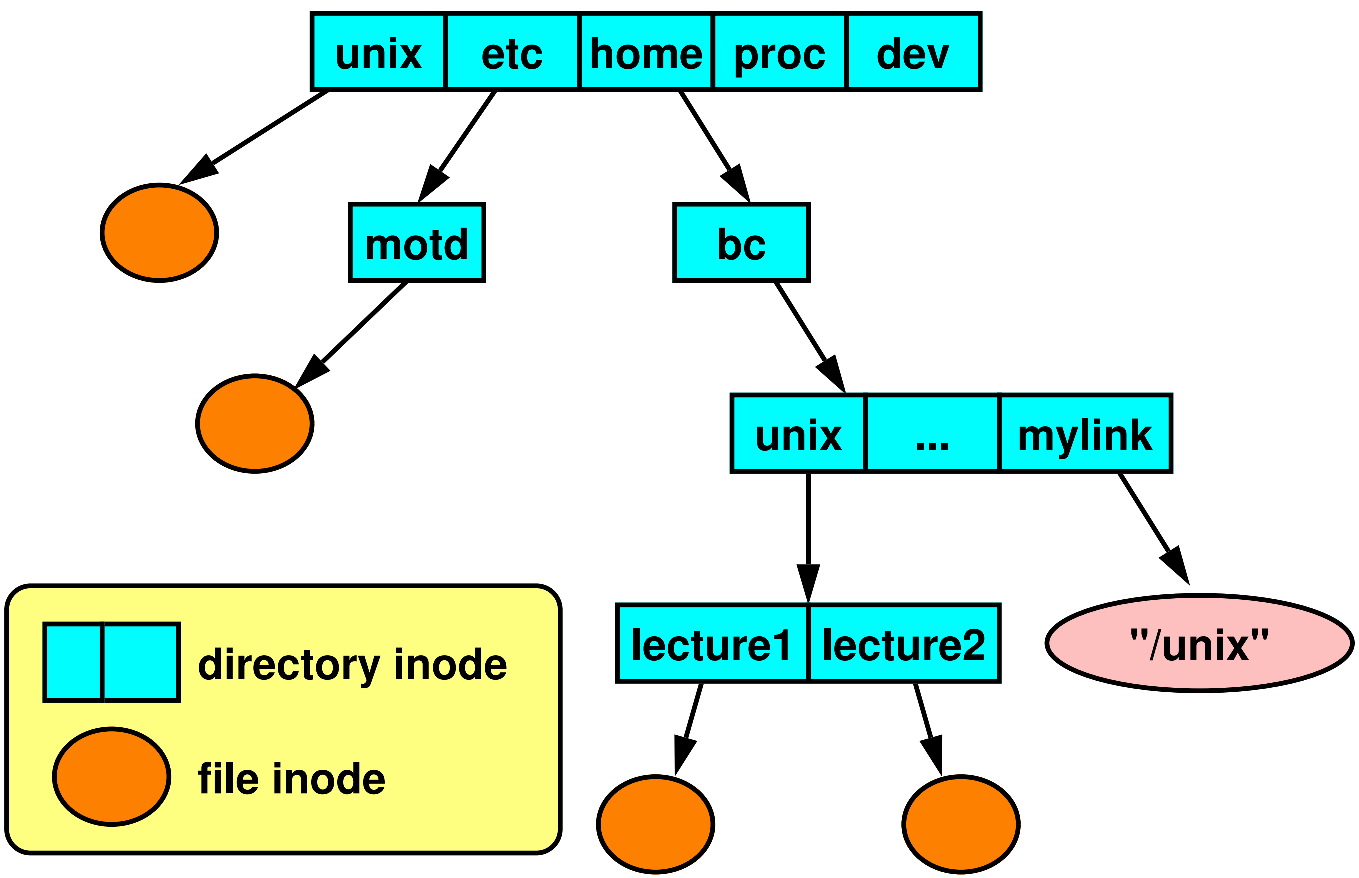
Soft Links

```
% ln -s /unix /home/bc/mylink
```



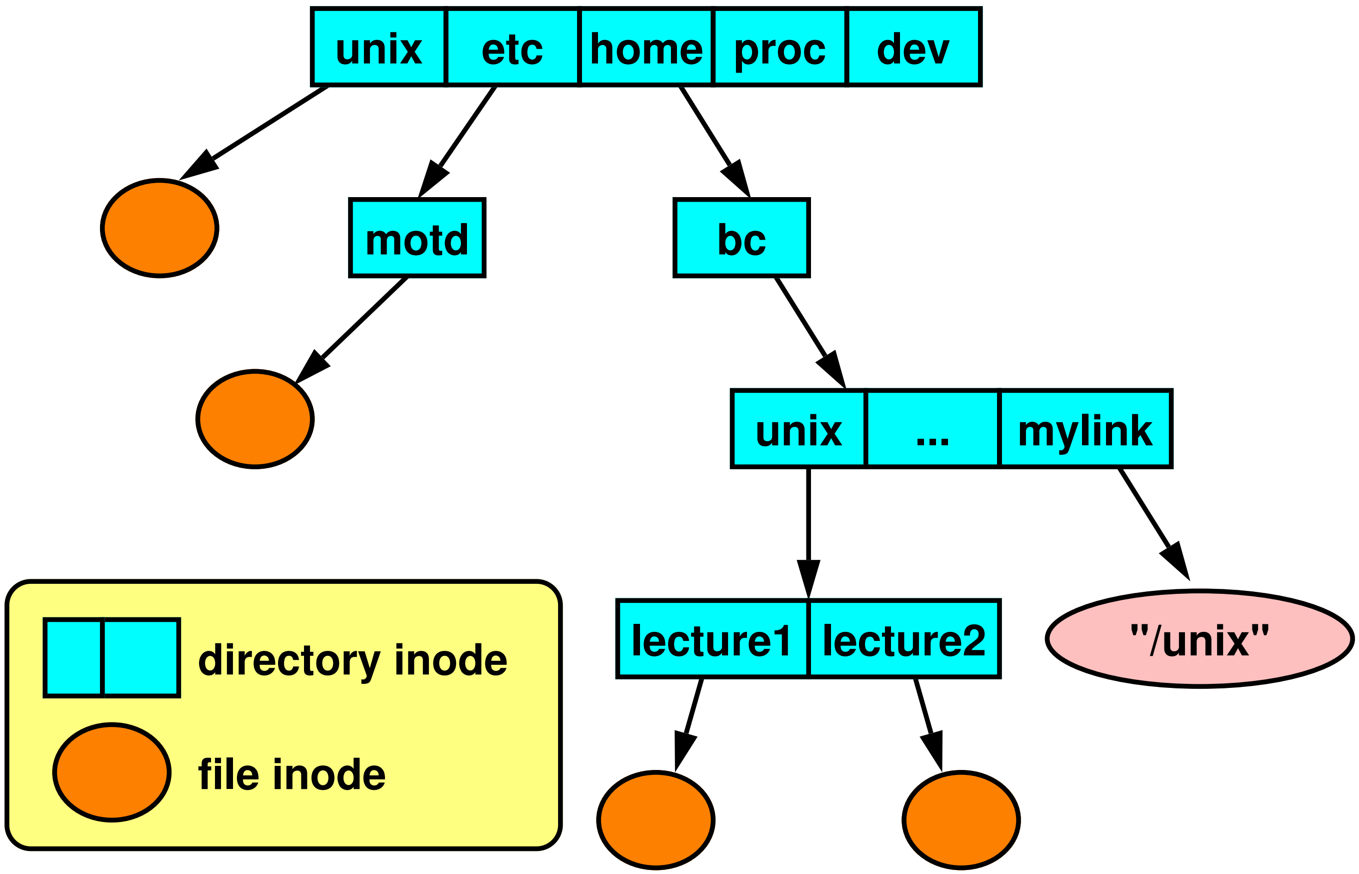
Soft Links

```
% ln -s /unix /home/bc/mylink
```



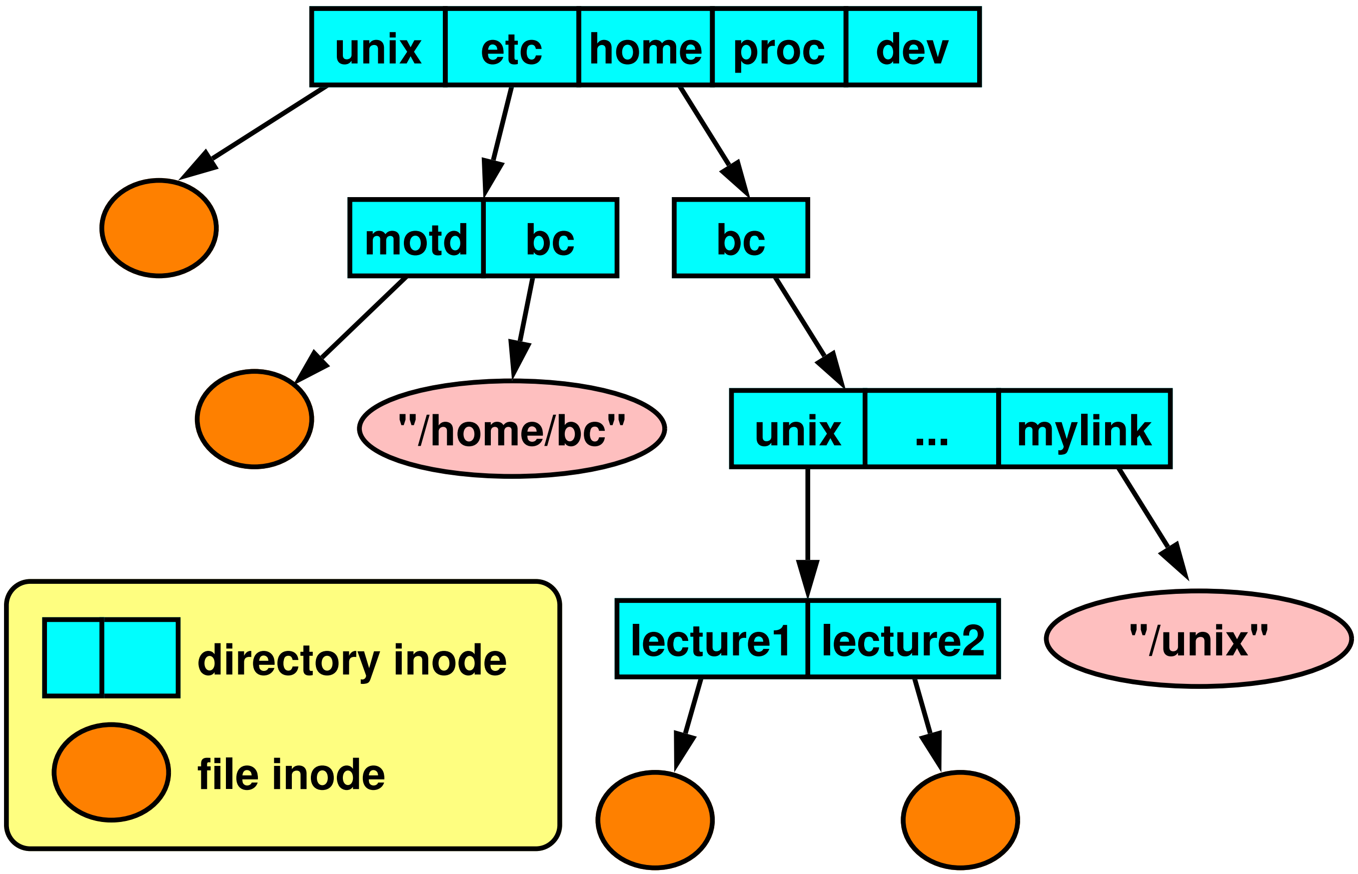
Soft Links

```
% ln -s /unix /home/bc/mylink
% ln -s /home/bc /etc/bc
```



Soft Links

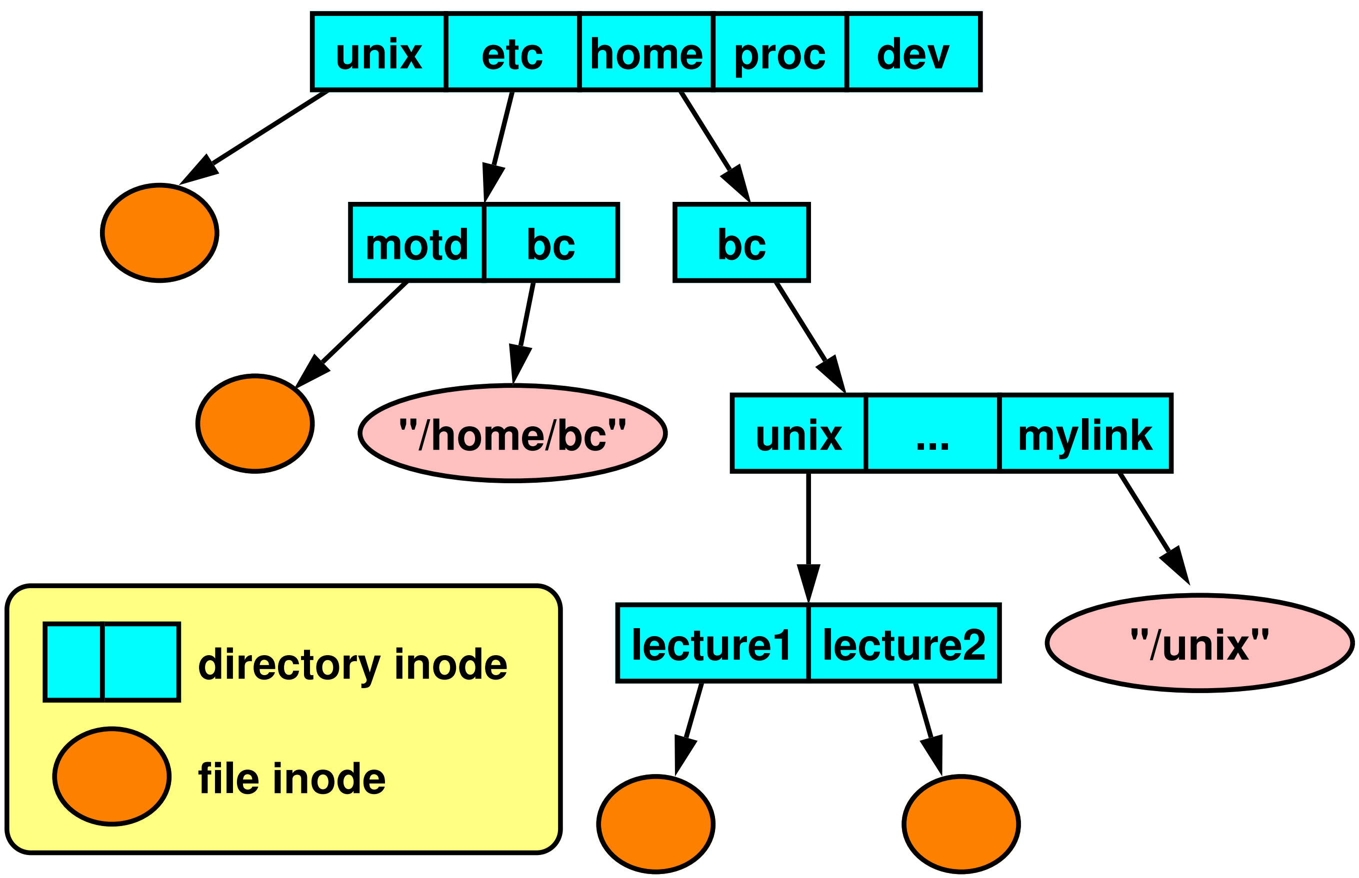
```
% ln -s /unix /home/bc/mylink
% ln -s /home/bc /etc/bc
```



Soft Links

`% ls -l /etc/bc/unix/lecture1`

- same as "`ls -l /home/bc/unix/lecture1`", or is it?
  - yes for the "`root`" account, may be no for the "`bc`" account
    - see "access protection"



Working Directory

- Maintained *in kernel for each process*
  - paths not starting from "/" start with the working directory
  - get by using the `getcwd()` system call
  - set by using the `chdir()` system call
  - displayed (via shell) using "`pwd`"

Access Protection

- OS needs to make sure that only authorized processes are allowed access to system resources
  - various ways to provide this
- Unix (and many other systems, such as Windows) associates with files some indication of which *security principals* are allowed access
  - along with what sort of access is allowed
- A *security principal* is normally a user or group of users
  - a "user" can be an identity used by processes performing system functions
  - each running process can have several security principals associated with it
    - all processes have a user identification and a set of group identifications
    - for Sixth-Edition Unix, only one user ID and one group ID

Access Protection

- Each file has associated with it a set of access permissions
  - there are 3 classes of security principals:
    - *user:* owner of the file
    - *group:* group owner of the file
    - *others:* everyone else
  - for each of the 3 classes of principals, specify what sorts of operations on the file are allowed
  - the operations are grouped into 3 classes:
    - *read:* can read a file or directory
    - *write:* can write a file or directory
    - *execute:* one must have *execute permission* for a *directory* in order to *follow a path through it*

- *Rules for checking permissions*

  1) determines the *smallest class of principals the requester belongs to* (user being smallest and others being largest)
  2) then it checks for appropriate permissions with that class

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  1) Q: May `andy` list the contents of directory `A`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x   2 bill    adm     1024 Dec 17 13:34 A
drwxr-----   2 bill    adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-   1 bill    adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-   1 bill    adm      446 Dec 17 13:34 x
-rw----rw-   1 trina   adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  1) Q: May `andy` list the contents of directory `A`?
     A: No

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  2) Q: May `andy` read `A/x`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x   2 bill    adm     1024 Dec 17 13:34 A
drwxr-----   2 bill    adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-   1 bill    adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-   1 bill    adm      446 Dec 17 13:34 x
-rw----rw-   1 trina   adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  - 2) Q: May `andy` read `A/x`?

    A: Yes

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm     1024 Dec 17 13:34 A
drwxr-----  2 bill   adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm      446 Dec 17 13:34 x
-rw----rw-  1 trina  adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  3) Q: May `trina` list the contents of directory `B`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  3) Q: May `trina` list the contents of directory `B`?
     A: Yes

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  4) Q: May `trina` modify `B/y`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm     1024 Dec 17 13:34 A
drwxr-----  2 bill   adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm      446 Dec 17 13:34 x
-rw----rw-  1 trina  adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  - 4) Q: May `trina` modify `B/y`?

    A: No

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  5) Q: May `bill` modify `B/x`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x   2 bill    adm     1024 Dec 17 13:34 A
drwxr-----   2 bill    adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-   1 bill    adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-   1 bill    adm      446 Dec 17 13:34 x
-rw----rw-   1 trina   adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  - 5) Q: May `bill` modify `B/x`?

    A: No

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x  2 bill   adm    1024 Dec 17 13:34 A
drwxr-----  2 bill   adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 bill   adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 bill   adm     446 Dec 17 13:34 x
-rw----rw-  1 trina  adm     446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  6) Q: May `bill` read `B/y`?

Permissions Example

```
% ls -lR
.:
total 2
drwxr-x--x   2 bill    adm     1024 Dec 17 13:34 A
drwxr-----   2 bill    adm     1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-   1 bill    adm      593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-   1 bill    adm      446 Dec 17 13:34 x
-rw----rw-   1 trina   adm      446 Dec 17 13:45 y
```

- Suppose that `bill` and `trina` are members of the `adm` group and `andy` is not
  6) Q: May `bill` read `B/y`?
     A: No

Open

```
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
int open(const char *path, int options [, mode_t mode])
```

- `options`
  - O_RDONLY open for reading only
  - O_WRONLY open for writing only
  - O_RDWR open for reading and writing
  - O_APPEND set the file offset to end of file prior to each write
  - O_CREAT if the file does not exist, then create it, setting its mode to mode adjusted by umask
  - O_EXCL: if O_EXCL and O_CREAT are set, then open fails if the file exists
  - O_TRUNC delete any previous contents of the file
  - O_NONBLOCK don’t wait if I/O cannot be done immediately

Setting File Permissions

```
#include <sys/types.h>
#include <sys/stat.h>
int chmod(const char *path, mode_t mode)
```

- sets the file permissions of the given file to those specified in `mode`
- only the owner of a file and the superuser may change its permissions
- nine combinable possibilities for mode (read/write/execute for user, group, and others)
- `S_IRUSR` (0400), `S_IWUSR` (0200), `S_IXUSR` (0100)
- `S_IRGRP` (040), `S_IWGRP` (020), `S_IXGRP` (010)
- `S_IROTH` (04), `S_IWOTH` (02), `S_IXOTH` (01)
  - note: numeric prefix of 0 means the number is in octal format

Creating a File

- Use either `open` or `creat`
  - `open(const char *pathname, int flags, mode_t mode)`
    - flags must include O_CREAT
  - `creat(const char *pathname, mode_t mode)`
  - `open` is preferred

- The `mode` parameter helps specify the permissions of the newly created file
  - permissions = `mode & ~umask`

Umask

- Standard programs create files with "maximum needed permissions" as *mode*
  - compilers: `0777`
  - editors: `0666`

- Per-process parameter, *umask*, used to *turn off* undesired permission bits
  - e.g., turn off all permissions for others, write permission for group: set umask to `027`
  - compilers: permissions = `0777 & ~(027)` = `0750`
  - editors: permissions = `0666 & ~(027)` = `0640`
  - set with `umask()` system call or (usually) `umask` shell command

1.4 Beyond A Simple OS

- Extensions
- New Functionality

What Else?

- Beyond Sixth-Edition Unix (1975)
  - multiple threads per process
    - how is the process model affected?
  - virtual memory
    - in Sixth-Edition Unix, all currently running process had to fit into the computer's memory at once, along with the OS
    - virtual memory separates the address space from physical resources
  - name everything using directory-system path names
    - e.g., `/proc`
  - security
    - Unix solution is pretty elegant
    - new types of requirement such as permissions to add new software, perform backups, etc.

What Else?

- New functionalities
  - networking
    - much is beyond the scope of this class
  - interactive, multimedia user interface
    - make sure interactive user receives excellent response
  - software complexity
    - in Sixth-Edition Unix, to add a new device you need to:
      - write a "device driver" to handle the device
      - modify OS source code by adding references to the driver to a few tables
      - recompile the OS and reboot your computer
    - plug-and-play is desirable
      - need to support dynamic linking of modules into a running system
    - microkernel
      - how much of the OS functionality can be moved out of the kernel?