CSCE 313-200
Introduction to Computer Systems
Spring 2024

File System

Dmitri Loguinov
Texas A&M University

March 20, 2024

Chapter 11: Roadmap

- 11.1 I/O devices
- 11.2 I/O function
- 11.3 OS design issues
- 11.4 I/O buffering
- 11.5 Disk scheduling
- 11.6 RAID
- 11.7 Disk cache
- 11.8-11.10 Unix, Linux, Windows

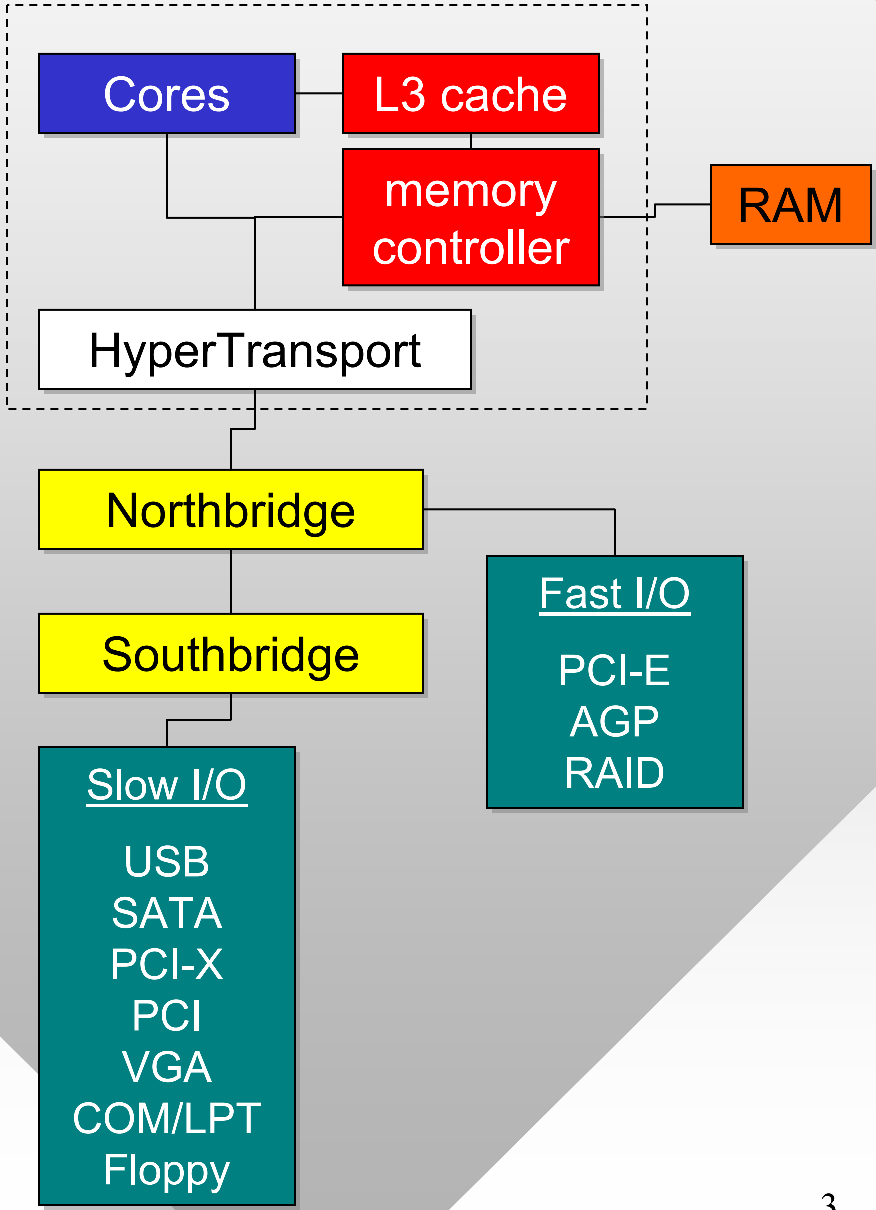
Part V

Part V
Chapter 11: I/O
Chapter 12: Files

I/O Devices

- I/O usually refers to physical devices
  - Such as disk, network card, printer, keyboard
- Almost all components in the system do I/O
  - Except RAM & CPU, and possibly certain chipsets built into the motherboard
- Transfer of data between devices and RAM thru DMA

Example: AMD Opteron



I/O Devices

- How fast is I/O compared to RAM speed?
  - Usually slow, but it depends…
- How to measure speed?
  - Kbps, Mbps, Gbps refer to bits/sec
  - KB/s, MB/s, GB/s refer to bytes/sec
- Use a notation with K = 1000 bits/bytes

Keyboard/mouse	~100 bytes/s
Modem	53 Kbps
Floppy	70 KB/s
CD-ROM 1x	150 KB/s
Ethernet	10 Mbps
USB 1.0	1.5 MB/s
DVD-ROM 32x	4.7 MB/s
Fast Ethernet	100 Mbps
USB 2.0	60 MB/s
Gigabit Ethernet	1 Gbps
Hitachi 2TB drive	150 MB/s
SSD hard drive	500 MB/s
USB 3.0	600 MB/s
10G Ethernet	10 Gbps
DDR2-667 RAM	5.3 GB/s
100G Ethernet	100 Gbps
DDR4-3200 RAM	90 GB/s
L2 cache (8 core)	500 GB/s
L1 cache (8 core)	1.5 TB/s

I/O Devices

- OS also allows certain IPC to be modeled as communication with an abstract I/O device
  - Example: inter-process pipes, mailslots, network sockets
  - This explains why ReadFile is so universal
- Our main focus here is on file I/O, but similar principles apply to other types of devices
  - Just reading files is simple; however, achieving decent speed and parallelizing computation is more challenging
- Before solving this problem, we start with a general background on files and APIs
  - Homework #3 requires multi-CPU searching of Wikipedia for user-specified substrings

Background on Files

- Just like RAM, a file is a sequence of bytes
- Supports 3 main operations: read, write, and seek
- *File pointer* specifies the current position within the file
  - Read/write operations proceed from that location forward
- Example: test.txt written in notepad:

This is a text file.
Second line.

  - Byte contents give by hex viewer (e.g., HxD)

```
54 68 69 73 20 69 73 20 61 20 74 65 78 74 20 66
69 6C 65 2E 0D 0A 53 65 63 6F 6E 64 20 6C 69 6E
65 2E
```

```
This is a text f
ile...Second lin
e.
```

- What is the ASCII table?
  - Why is there 0xD and 0xA in the file?

Background on Files

- Two modes of file I/O: text and binary
  - Must be requested when you open the file
- Binary means disk contents are an exact copy of the RAM buffer that is written and vice versa
- Text means there is some library (wrapper) between the application and OS that applies certain "magic" translation before your program sees the data
  - For fopen/fprintf, this involves \r\n → \n, terminating the read at Ctrl-Z markers (ASCII code 26), and certain multi-byte to wide char mapping based on the locale
- Note: text files can be always read in binary mode, while the opposite is not true

Background on Files

```
This is a text file.
Second line.
```

- Example: binary mode reads the file as is:

```
54 68 69 73 20 69 73 20 61 20 74 65 78 74 20 66
69 6C 65 2E 0D 0A 53 65 63 6F 6E 64 20 6C 69 6E
65 2E
```

  - while text mode removes \r

```
54 68 69 73 20 69 73 20 61 20 74 65 78 74 20 66
69 6C 65 2E 0A 53 65 63 6F 6E 64 20 6C 69 6E 65
2E
```

- If the file is tweaked before it reaches your program, lots of confusing things may happen
  - E.g., file size 100,050 bytes, but your buffer gets only 99,800
- Since text-mode processing does usually unwanted things to the file and is much slower than binary mode, it is not recommended (see later for benchmarks)

Background on Files

- Number representation can be ASCII or native
  - ASCII is human-readable form (e.g., printf (“%d”, x))
  - Native is identical to how numbers are stored in RAM
- Example:

```
int x = 0x11223344;
```

```
44 33 22 11
```

native version

```
32 38 37 34 35 34 30 32 30
```

decimal ASCII version of x, i.e., string “287454020”

- ASCII output depends on how the numbers are written (e.g., decimal, hex) and the separator between them
  - Conversion to/from ASCII is usually slow
  - Format inefficient in terms of storage
- APIs that read raw buffers are usually native
  - Those that attempt to read individual variables are ASCII

Background on Files

This is a text file.
Second line.

```
54 68 69 73 20 69 73 20 61 20 74 65 78 74 20 66
69 6C 65 2E 0D 0A 53 65 63 6F 6E 64 20 6C 69 6E
65 2E
```

- Suppose we read an integer natively from the beginning of this file

```
int x;
ReadFile (&x, sizeof(int));
```

  - What is the value of x?
  - Equivalent versions →

```
char buf[] = “This”;
int x = *(int*) buf;
```

```
int x = 0x73696854;
```

- How to write contents of some class natively to disk?
  - If it has no pointers, then it’s trivial

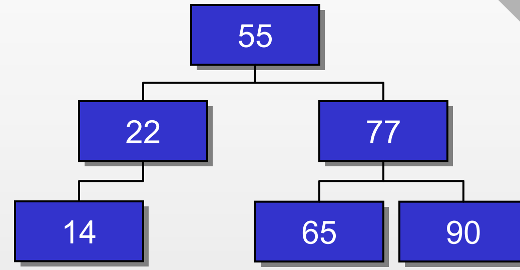
```
class MyClass {
   double a;
   uint64 b;
};

MyClass mc;
mc.a = 3.1415;
mc.b = 0x55;
WriteFile (…, &mc, sizeof(MyClass), …);
```

```
6F 12 83 C0 CA 21 09 40 55 00 00 00 00 00 00 00
```

mc.a mc.b

Notepad shows: o↕ ƒÀÊ!@U

Background on Files



- How to store pointers, e.g., a linked list or binary tree?

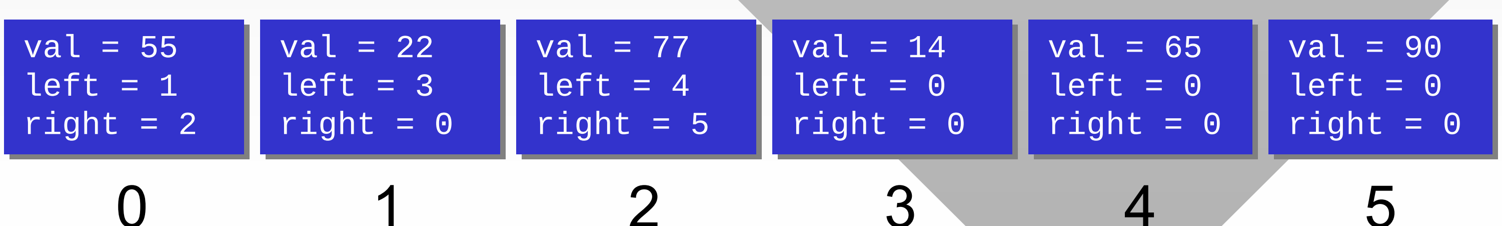
```
class LinkedListElem {
   int val;
   LinkedListElem *next;
};
```

```
class TreeElem {
   int val;
   TreeElem *left, *right;
};
```

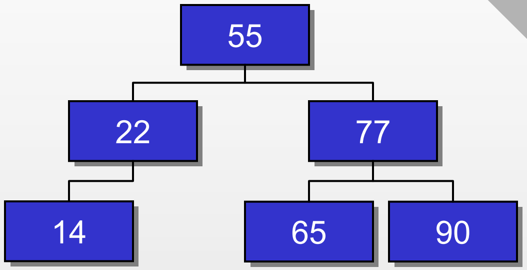
- Data structure must first be converted to an array
  - Hierarchical structure must be flattened

```
int valArray = new int [LinkedList.size()];

// traverse the list, copy into valArray
WriteFile (…, valArray,
    sizeof(int) * LinkedList.size(), …);
```

```
class TreeElem2 {
   int val;
   int left, right; // offsets
};

TreeElem2 *arr = new
          TreeElem2 [tree.size()];
```



Background on Files



- In fact, trees stored as arrays in RAM are often much faster than pointer-based trees
  - Main drawback: difficult to deal with fragmentation
- Further compaction: 2 bits to store # of children
  - Suppose 00 = none, 01 = left, 10 = right, 11 = both

0	1	2	3	4	5
`val = 55` `bits = 3`	`val = 22` `bits = 1`	`val = 77` `bits = 3`	`val = 14` `bits = 0`	`val = 65` `bits = 0`	`val = 90` `bits = 0`

- Conversion from random-access (RAM) structures to sequential arrays is called serialization
  - Similar to serial transmission over COM ports or networks