Storage

```
Module Code: ELEE1119

Module Name: Advanced Computer Engineering

Credits: 30

Module Leader: Seb Blair BEng(H) PGCAP MIET MIHEEM FHEA
```

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Byte and Bibytes

- $1000 = 10^3 \equiv 1024 = 2^{10}$
- $1000000 = 10^6 \equiv 1048576 = 2^{20}$
- ...

$\frac{SI - Bibyte}{SI} \cdot 100$

Disk Size - False Advertisement?

500GB Storage is actually $\frac{5*10^9}{1{,}073{,}741{,}824} = 465GB$

Binry Powers

```
NAME         MAJ:MIN RM   SIZE RO TYPE MOUNTPOINTS
nvme0n1      259:0    0 465.8G  0 disk
```

Denary powers

```
NAME         MAJ:MIN RM         SIZE RO TYPE MOUNTPOINTS
nvme0n1      259:0    0 500107862016  0 disk
```

Disk Size - your turn...

$$bibytes = \frac{denary}{binary}$$

1. 5 Terabytes
   - ▶ Answer
2. 32 Gigabytes
   - ▶ Answer

Storage Types

SSD: don’t rely on magnets and disks, instead they use a type of flash memory called NAND. In an SSD, semiconductors store information by changing the electrical current of circuits contained within the drive. This means that unlike HDDs, SSDs don’t require moving parts to operate.

HDD: Use magnetic technology to store data and has been around since the 1950. A hard disk drive is comprised of a stack of spinning metal disks known as platters. Each spinning disk has trillions of tiny fragments that can be magnetised in order to represent bits (1s and 0s in binary code).

Storage Types

Optical Storage: CD can store up to 700 MB of data, DVD-DL can store up to 8.5 GB, and Blu-Ray can store between 25 and 128 GB of data.

Flash Memory: A flash memory device contains trillions of interconnected flash memory cells that store data. These cells hold millions of transistors that when switched on or off represent 1s and 0s in binary code, allowing a computer to read and write information. Currently can store 2 TB of data.

Types of SSD

- Serial Advanced Technology Attachment (SATA)
- Mini SATA
- SATA M.2

Types of SSD

- Periphal Component Interconnect Express M.2 (PCIE)
- Nov-Volatile Memory Express M.2 (NVME)

SSD Architecture

- NAND flash memory chip
  - array of blocks (grid)
    - Each grid can store between 256KB and 4MB.
    - array of memory cells, (pages or sectors)
      - 1-bit cells (Single Level Cells (SLC))
      - 2-bit cells (Multi-Level Cells (MLC))
      - 3-bit cells (Triple-Level Cells (TLC))
      - 4-bit cells (Quad-Level Cells (QLC))

Comparison

	NVME SSD	M.2 SSD	SATA SSD
Speed	PCIE Gen 3 < = 3.5GB/s PCIE Gen 4 <= 7.5GB/s	<= 550MB/s	<= 550MB/s
Form Factor	M.2, U.2, PCIE	M.2	2.5" M.2
Interface Types	NVME	SATA, NVME	SATA
Adv	High Speeds	Little physical space	Good balance between affordability and speed
Dis-Adv	High Costs	More expensive 2.5"	Slower speeds

PCIE Gen

- 2.0 - 8b/10b encoding.
- 3.0 - 128b
- 4.0 - 130b encoding technique

4.0's 2 extra bits allows for reasonable clock recovery (extracting timing information from the datastream) and ensures alignment of the datastream. 16GT/s (gigatransfers) which means the maximum theoretical bandwith of PCIe 4.0 is:

$15.754Gb^{-s}$ and 1.54% overhead.

File Systems

Linux File System Structure

The file system requires an API to access the function calls to interact with file system components like files and directories.

The first two parts of the given file system are called a **Linux virtual file system**. It provides a single set of commands for the kernel and developers to access the file system. This virtual file system requires the specific system driver to give an interface to the file system.

Types of Linux File Systems

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File Systems

- **New Technology File System** - NTFS partitions can extend up to 16EiB Primarily used for Windows and Linux systems. Can't natively write to partition in MAC OS as it lacks the drives. However, third party tools can provide a way to do this.
- **File Allocation Table** - FAT is a general purpose file system that is compatible with Windows, Linux/Unix and MAC OS. Windows can't deal with anything greater than 32GB or FAT32. FAT suffers from over-fragmentation, file corruption, and limits to file names and size.

File Systems

- **Extended File Allocation Table** - exFAT is a Microsoft file system with compatibility with MAC OS 10.6+. Used in TVs and portable media players. Can be 512TBs in size. Doesn't work with Linux /Unix. Suffers from defragmentation and cannot pre-allocate disk space.
- **Hierarchical File System** - Built by Apple for MAC OS X. 8EiBs. Drivers are available for Linux systems to read and write to HFS+

File Systems

- **Extended File System** - EXT4, was created for Linux Kernels. Can be up to 1 EiB a file can be 16 TB. EXT4 is backward compatible with version 2 and 3. EXT4 can pre-allocated disk space. By default Windows and MAC OS cannon read EXT.
- **Journal File System** - A high-performance journaling file system, was first developed by Silicon Graphics for the IRIX operating system in 1993. It is the default file system for IRIX version 5.3 and then it was later ported to the Linux kernel.

File Systems

- **B-Tree File System** - Btrfs (b-tree fs), was created to address the lack of pooling, snapshots, checksums, and integrated multi-device spanning in Linux file systems, particularly as the need for such features emerged when working at the petabyte scale.
- **Zettabyte File System** - Merges the traditional volume management and filesystem layers, and it uses a copy-on-write transactional mechanism—both of these mean the system is very structurally different than conventional filesystems and RAID arrays

Common Embedded Linux FS

- **ext2/ext3/ext4** - These are Linux based file systems that supports efficient and secure storage of data on hard drives.
- **VFAT** - This is a FAT file system that is commonly used in embedded Linux systems because it is compatible with a variety of operating systems.
- **JFFS2** - This is a journaling flash file system designed specifically for embedded Linux systems.
- **YAFFS** - This is a Yet Another Flash File System designed for embedded Linux systems.
- **UBIFS** - This is an Unsorted Block Image File System that is used to store data on flash memory

Small Computer System Interface Disk (scsi)

- The first hard disk detected on the SATA by the Linux port, system carries the label sda (sd => scsi disk)
- The second would be sdb
- nvme0n1 means first disk detected on the nvme port

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UUIDs

- 32 base 16 characters ([0-9][A-F])

$$128 = 32 \cdot log_2(16)$$

- 128 bit numbers

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UUID Version 1

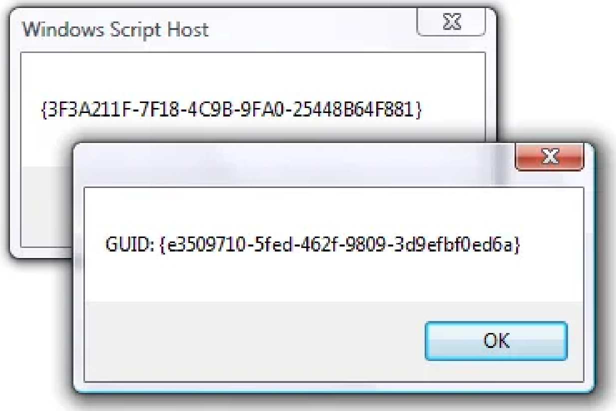
UUID Versions

There are 8 versions as of 23 June 2022

- UUID1 = Timebased + Unique or MAC [no repeats till 3603AD]
- UUID2 = Timebased(LSB) + userid
- UUID3 = Namespace+MD5 hash
- UUID4 = PRNG [1 trillion UUIDs for a chance of 2 repeats]
- UUID5 = Namespace + SHA-1 hash
- UUID6 = Timestamp and monotonic counter.
- UUID7 = UNIX Timestamp
- UUID8 - User defined Data

Who?

- Created by Microsoft but standardised by the **Internet Engineering Task Force** (IETF) and the **International Telecommunication Union** (ITU), so that each user or thing can be uniquely identifiable.
- **ITU-T X.667 | ISO/IEC 9834-8**



Where?

Combinations: UUID 4

- $0.0947mm^3$ grain of sand
- UUID4 has 122 random bits, $5.3e36$
- $5.0191e34mm^3 = 5.3e36 \cdot 0.0947mm^3$
- Volume of sand as UUID4 = $50,190,000,000,000,008km^3$

...and the volume of Jupiter

- $1,431,281,810,739,360km^3$

Uniqueness: UUID4

- In the version 4, 6 bits are fixed and the remaining 122 bits are randomly generated, for a total of 2^{122} possible UUIDs.
- $n = 2^{122}$
- So if the number of generated UUIDs exceeds $r > n$ then there must be duplicates
- If you assume perfect randomness you would expect to see collison after 2^{61}
- $2^{58} \approx 24,913,440,000,000,000 = 7.2e9 \cdot 365 \cdot 24 \cdot 60 \cdot 60$
- After a few years you would get the first collisions.

UUID 1

- combination of:
    - current time and date.
        - RFC 4122 60-bit count of $100ns$ since 00:00:00:00 15 October 1582 to 01/01/1970
        - $122192928000000000ns$
        - Current date time since 00:00:00:00 01 January 1970

$$179968452060779520 0ns = 16774915926077952 00 + 122192928000000000$$

- 48-bit MAC address of the host machine

Epochs/Time

- 01/01/1970
  - Unix engineers set the arbitrary datetime stamp because... it was convenient...
- 19/01/2038 03:14:07 the storage for 32-bit will become obsolete, as the value will be too large
  - Will need to migrate to 64-bit or just deal with the timestamp showing:
    - 19/01/1901 03:14:08

UUID 1: Time format

Name	Bytes	Hex	Bits	Comments
time_low	4	8	32	integer giving the low 32-bits of time
time_high	2	4	16	integer giving the middle 16-bits of time
time_hi_version	2	4	16	4-bits representing the "version" and the followinghigh 12 bits of time
clock_seq_hi_and_res clock_seq_low	2	4	16	1 to 3-bit "variant" in the most significant bits, followed by the 13 to 15-bit clock sequence

Example

```
$ date +"%s.%N" | awk -F "." '{print "(nano seconds = )", (($1*1000000000)+122192928000000000+$2)}'
> (nano seconds = ) 1799602340604762112
```

- Time Low = 04762112 -> 0048AA00

```
$ printf "%016X" 04762112 | awk -F "%" '{print $1}'
> 000000000048AA00
```

- Time High = 0fe0 -> 0F29
- Time High+Version = 1179 -> 049B
- Clock_seq = is random bits say a number between 1000-9999 and replace the MSB with the variant number 0x10xx.
- 0048AA00-0F29-049B-25D9-[MAC|random 48-bits]

UUID 2

- Distributed Computing Environment (DCE)
- combination of:
  - Current time and date.
  - The local identifier replaces the lower 32 bits of the timestamp.48-bit MAC address of the host machine
    - Domain Name or Hostname

      ```
      $ id -u; id -g; whoami;
      ```

  - MacAddress or random generated Hex

    ```
    cat -A /dev/urandom | less
    ```

UUID 3

- namespace could be website, DNS information, plain text, etc
- the namespace value is hashed using the `md5hash` alogrithm

MD5 Algorithm

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MD5 Alogrithm

- Round 1: (b AND c) OR ((NOT b) AND (d))
- Round 2: (b AND d) OR (c AND (NOT d))
- Round 3: b XOR c XOR d
- Round 4: c XOR (b OR (NOT d))

UUID4

1. Generate 128 random bits:

```
dd if=/dev/random count=16 bs=1 2> /dev/null | xxd -ps
> 567D61C2EE3B2391414110256D2385
```

00000101 01100111 11010110 00011100 00101110 11100011 **10110010** 00111001 **00010100** 00010100 00010001 00010000 00100101 01101101 00100011 10000101

2. Take the 7th byte and perform an AND operation with `0x0F` to clear out the high nibble. Then, OR it with `0x40` to set the version number to 4.

00000010 = **10110010** & 00001111 (0x0f)

01000010 = **00000010** | 01000000 (0x40)

UUID4 Example

3. Next, take the 9th byte and perform an AND operation with `0x3F` and then OR it with `0x80`.

   00010100 = **00010100** & 00111111 (0x3f)

   10010100 = **00010100** | 10000000 (0x80)

4. Convert the 128 bits to hexadecimal representation and insert the hyphens to achieve the canonical text representation.

   567D61C2-EE30-4299-4141-110256D2385

Your Turn

10101110 00100001 10110100 11111100 01101111 01110010 **10100011** 00110010 **10111010** 10000110 11010010 00001001 11010001 11100000 10101111 01101001

2. Take the 7th byte and perform an AND operation with `0x0F` to clear out the high nibble. Then, OR it with `0x40` to set the version number to 4.
3. Next, take the 9th byte and perform an AND operation with `0x3F` and then OR it with `0x80`.
4. Convert the 128 bits to hexadecimal representation and insert the hyphens to achieve the canonical text representation.

▶ Answer

UUID 5

- namespace could be website, DNS information, plain text, etc
- the namespace value is hashed using the `sha1sum` alogrithm

Everything is a File...

Inodes

- It is used to record the metadata of the file, such as the inode number, file size, access rights, modification date, data location, etc. One file has one associated inode, and like file content, inode stores on disk.

Directories

- D(d)entry for short, is used to record the name of the file, the inode pointer, and the association with other directory entries.
- Multiple associated directory entries constitute the directory structure of the file system.
- However, unlike inodes, a directory entry is an in-memory data structure maintained by the kernel, so it is often called a directory entry cache.

Superblock Information

File, Inode, Address_Space

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```
struct address_space_operations{
    int (*writepage)(struct page *page, struct writeback_control *wbc);
    int (*readpage)(struct file *, struct page *);
    /* write back some dirty pages from this mapping */
    int (*writepages)(struct address_space *, struct writebackcontrol *);
    /* set a page dirty. Return true if this dirited it */
    int (*set_page_dirty)(stuct page *page)
    int (*readpages)(struct, file *filp, struct address_space *mapping,
                                            struct list_head *pages, unsigned nr_pages);
    …
}
```

Strace

Tracing system calls and signals