[544] File Systems

Meenakshi Syamkumar

Learning Objectives

- compare the performance characteristics of different kinds of block devices (HDDs and SSDs)
- describe different kinds of file systems
- interpret the output of tools like "mount" and "df" to understand the structure of a mount namespace

Outline

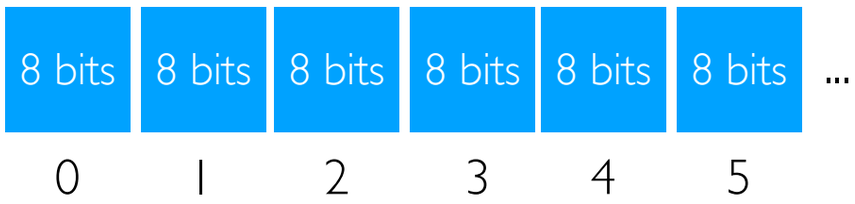
Block Devices (overview, HDD, SSD)

File Systems

Demos

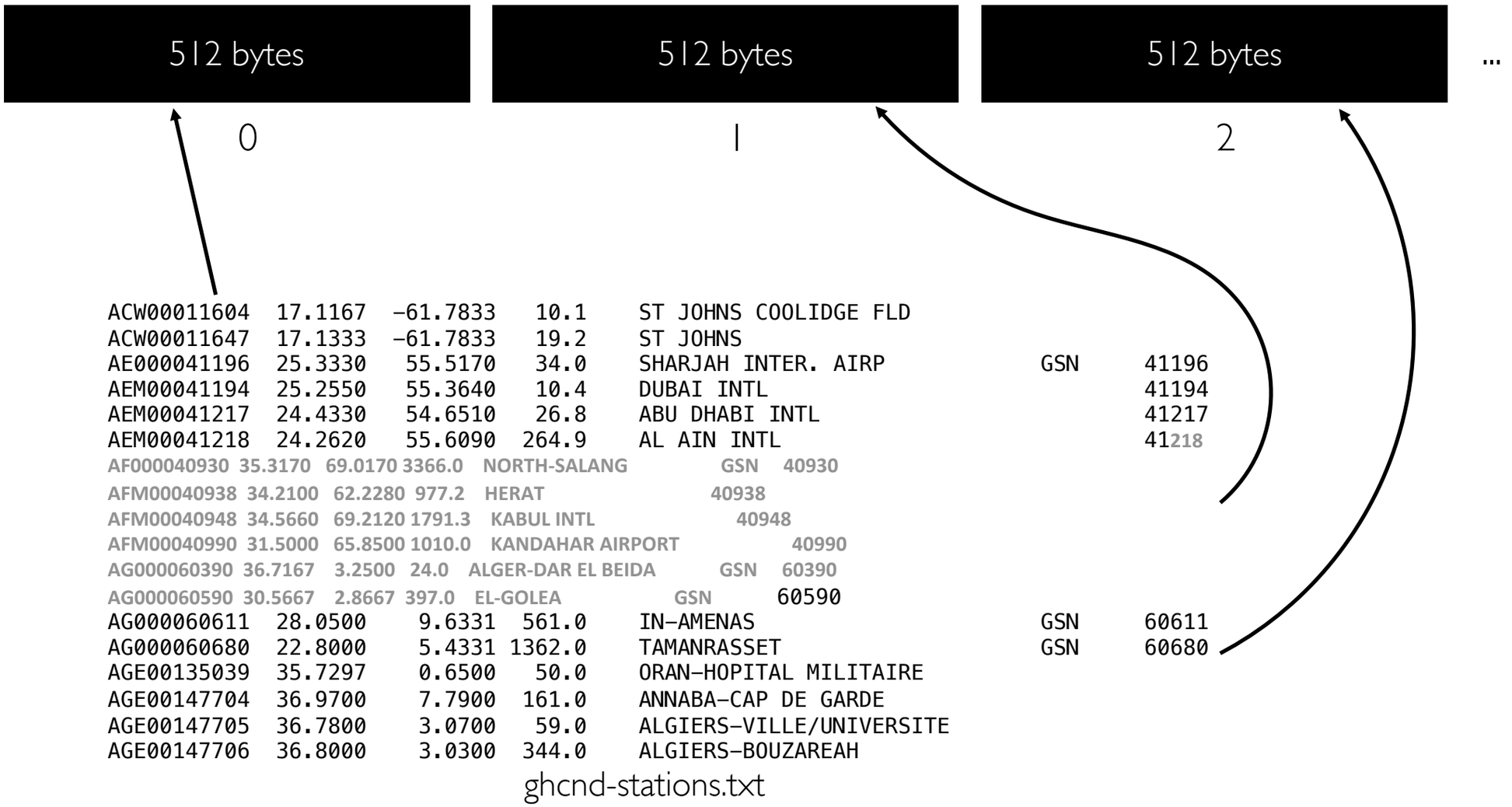
Block Devices

Memory is byte addressable



Block storage devices are accessed in units of blocks (512 bytes, few KBs, etc)

Optimizing Disk I/O with Memory: Caching and Buffering



ghcnd-stations.txt

We might want to process one line a time, but it would be wasteful to repeatedly read the same block from the device

- the Linux page cache stores pages from files in RAM (usually 4KB pages, often larger than device blocks)
- Python (and other) programs might buffer chunks of data to avoid asking Linux too many times for small pieces of data

Optimizing Disk I/O with Memory: Caching and Buffering

htop

page cache, could evict if needed

only counts non-cache memory

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- the Linux page cache stores pages from files in RAM (usually 4KB pages, often larger than device blocks)
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Small Reads (<4KB): Performance

goal: collect all station IDs

```
ACW00011604  17.1167  -61.7833   10.1    ST JOHNS COOLIDGE FLD
ACW00011647  17.1333  -61.7833   19.2    ST JOHNS
AE000041196  25.3330   55.5170   34.0    SHARJAH INTER. AIRP            GSN     41196
AEM00041194  25.2550   55.3640   10.4    DUBAI INTL                             41194
AEM00041217  24.4330   54.6510   26.8    ABU DHABI INTL                         41217
AEM00041218  24.2620   55.6090  264.9    AL AIN INTL                            41218
AF000040930  35.3170   69.0170 3366.0    NORTH-SALANG                GSN     40930
AFM00040938  34.2100   62.2280  977.2    HERAT                       40938
AFM00040948  34.5660   69.2120 1791.3    KABUL INTL                    40948
AFM00040990  31.5000   65.8500 1010.0    KANDAHAR AIRPORT                40990
AG000060390  36.7167    3.2500   24.0    ALGER-DAR EL BEIDA          GSN     60390
AG000060590  30.5667    2.8667  397.0    EL-GOLEA                  GSN       60590
AG000060611  28.0500    9.6331  561.0    IN-AMENAS                      GSN     60611
AG000060680  22.8000    5.4331 1362.0    TAMANRASSET                    GSN     60680
AGE00135039  35.7297    0.6500   50.0    ORAN-HOPITAL MILITAIRE
AGE00147704  36.9700    7.7900  161.0    ANNABA-CAP DE GARDE
AGE00147705  36.7800    3.0700   59.0    ALGIERS-VILLE/UNIVERSITE
AGE00147706  36.8000    3.0300  344.0    ALGIERS-BOUZAREAH
```

ghcnd-stations.txt

```
start = time.time()
with open("ghcnd-stations.txt") as f:
    for line in f:
        stations.append(line[:11])
print(time.time() - start)
```

simple version that reads everything: **66 ms**

format issue: no good way to ready one column without everything else

(similar to issues with bad cache line usage)

```
stations = []
line_len = 86

start = time.time()
with open("ghcnd-stations.txt",
          "rb", buffering=0) as f:
    offset = 0
    while True:
        f.seek(offset)
        station = str(f.read(11), "utf-8")
        offset += line_len

        if station:
            stations.append(station)
        else:
            break
print(time.time() - start)
```

"optimized" version that only reads stations: **171 ms**

Hard Disk Drives (HDDs)

Steps to read/write

1. move head to correct track
2. wait for spinning disk to rotate until data is under head
3. transfer the data

these steps dominate unless transferring lots of data (few MBs)

Layout

- assign block numbers to platter locations so sequential (like 5,6,7,8, ...) reads/writes will be fast
- programmers should assume random accesses (like 2, 9, 5, 1, ...) will be slow

Capacity vs. I/O and Short Stroking

Storage resources

1. capacity
2. I/O (input/output often more limited when using HDDs)

Short Stroking

- head moves over platter faster near outside track
- smaller block addrs correspond to outside tracks
- strategy: only use outside tracks
- pros: faster I/O
- cons: less space

Solid State Drives (SSDs) - Flash

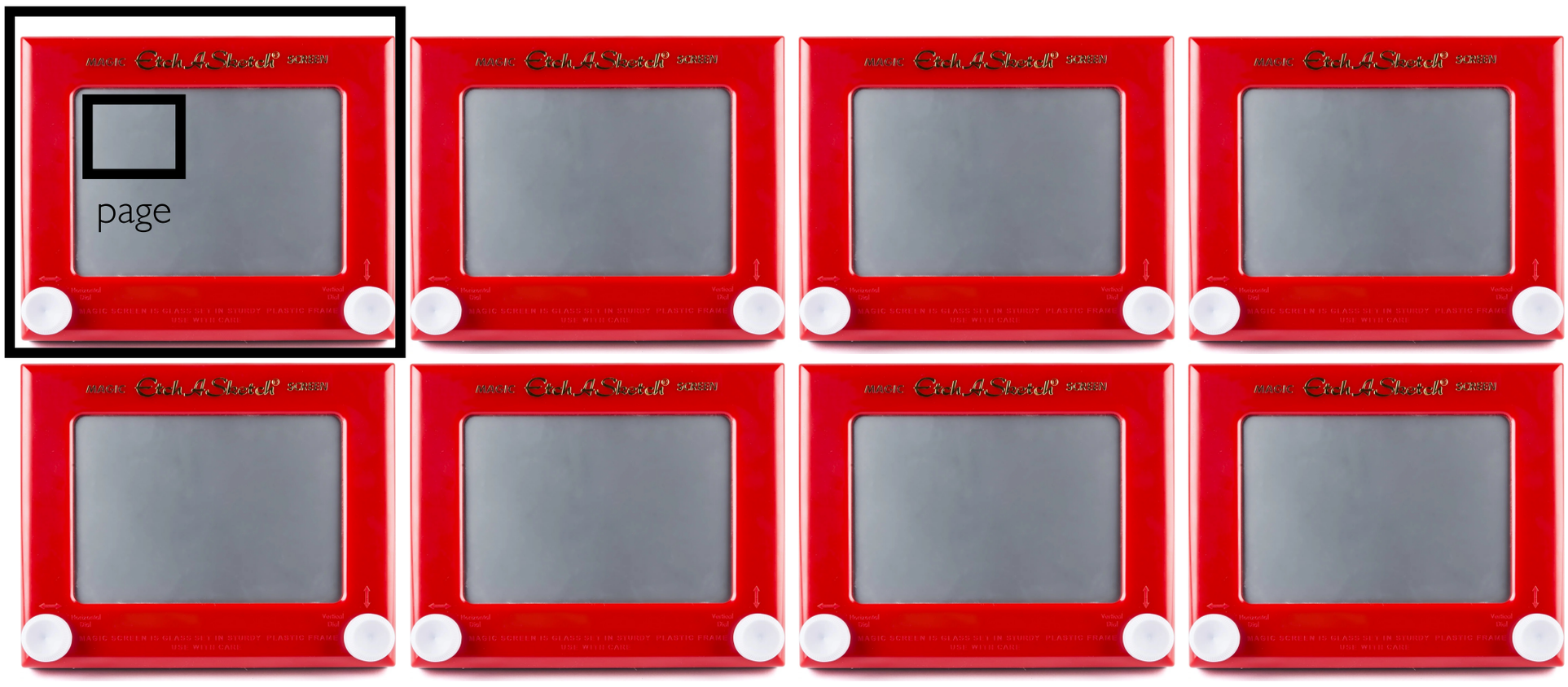
Reading and writing

- no moving parts
- inherently parallel

SSD internals:

- "block" and "page" have different meanings in this context
- "page" => unit that we can read or write (couple KBs)
- pages cannot be individually re-written
- "block" => unit that is erased together (maybe 100s of KBs)

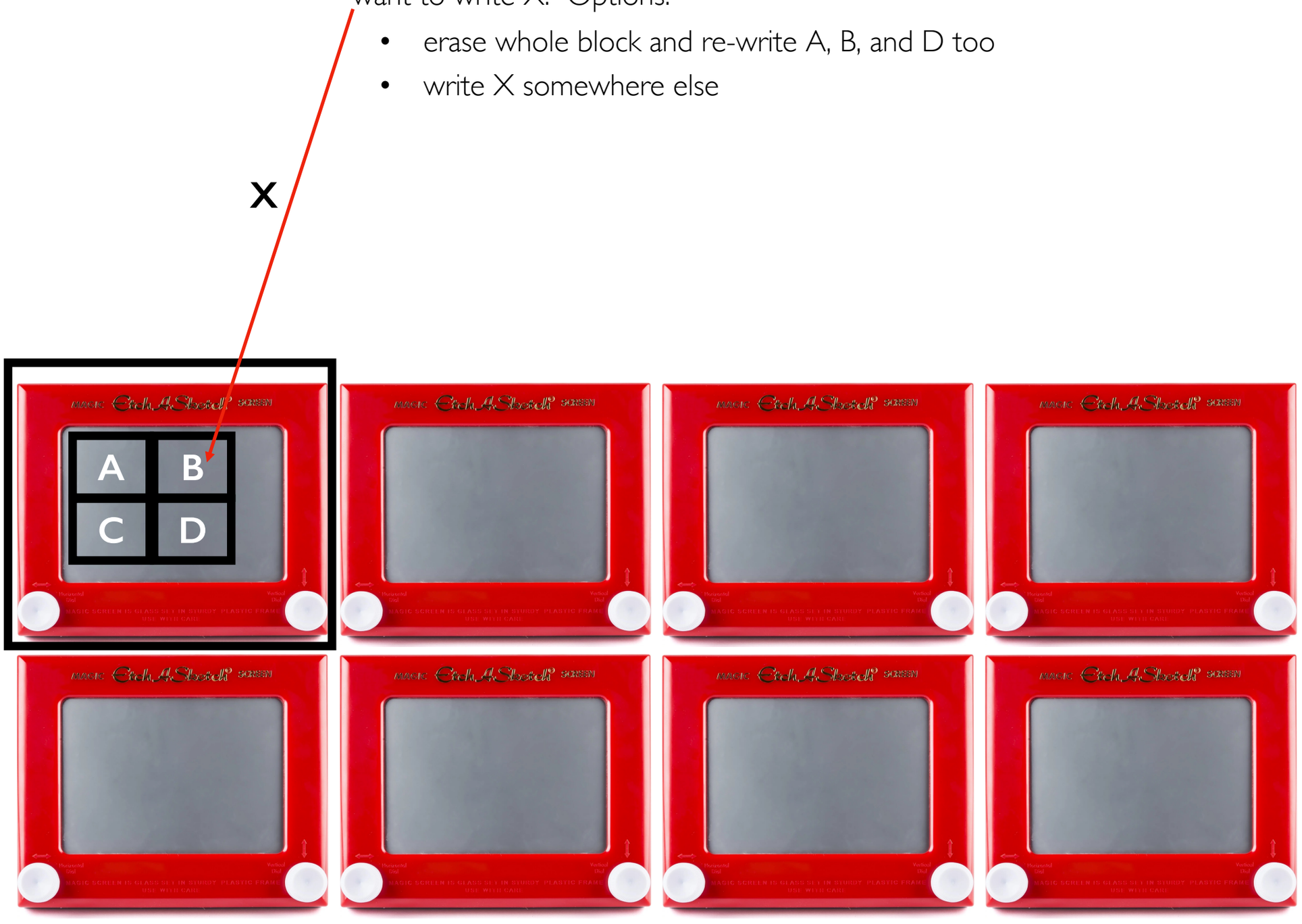
block



Solid State Drives (SSDs) - Flash

want to write X. Options:

- erase whole block and re-write A, B, and D too
- write X somewhere else



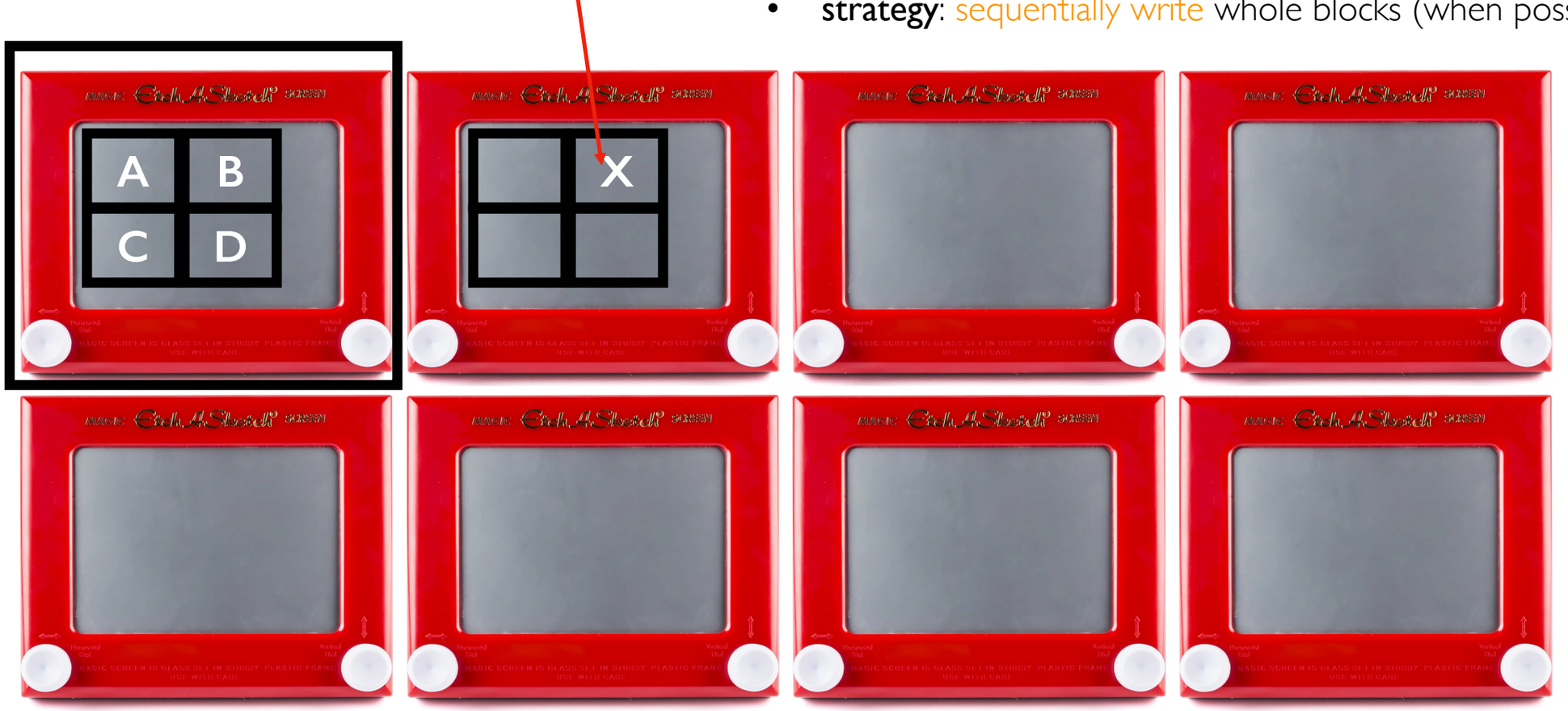
Solid State Drives (SSDs) - Flash

want to write X. Options:

- erase whole block and re-write A, B, and D too
- write X somewhere else

disadvantages

- need extra bookkeeping (in SSD) to know where data is
- need to eventually move things around to reclaim the space wasted by B
- **strategy**: sequentially write whole blocks (when possible)



HDDs vs. SSDs

Metrics

- capacity: how many bytes can we store?
- latency: how long does it take to start transferring data
- IOPS (I/O operations, of some max size, per second): how many small/random transfers can we do per second
- throughput: how many bytes can we transfer per second

Metric:	Relative to HDDS, SSDS are:
capacity	*worse*
latency	*much better (no moving parts)*
random IOPS	*even better -- low latency AND in parallel*
throughput (sequential)	*little better*
throughput (random writes)	*better (but block erase is a concern)*
throughput (random reads)	*much better*

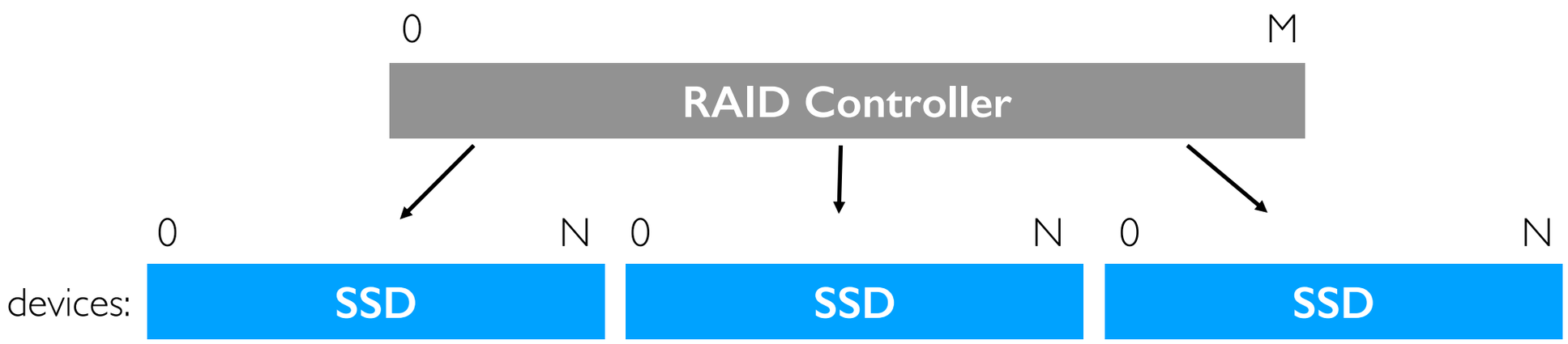
Partitions and RAID

Block devices can be divided into **partitions**:


```
root@instance-1:/home/meenakshisyamkumar# ls /dev/sd*
/dev/sda   /dev/sda1   /dev/sda14   /dev/sda15
/dev/sdb   /dev/sdb1
```

2 devices 4 partitions

RAID controllers (Redudant Array of Inexpensive Disks) can make multiple devices appear as one:



Many configs use **redundancy** (e.g., same data on >1 disk) to avoid data loss when one device dies.

Outline

Block Devices (overview, HDD, SSD)

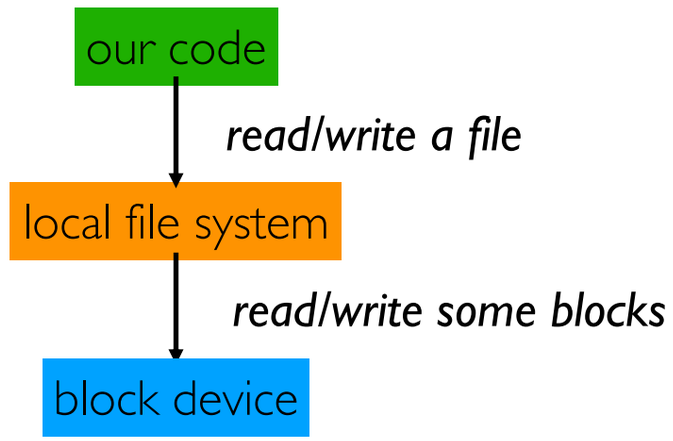
File Systems

Demos

File Systems

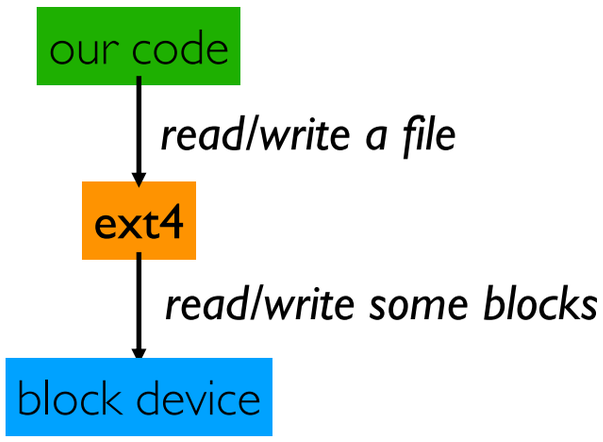
Difficult: writing code to store data in blocks
Easier: writing code to store data in files

Files systems ***abstract*** storage for us. We write to data **blocks** without thinking about it by writing data to **files** in a local file system.

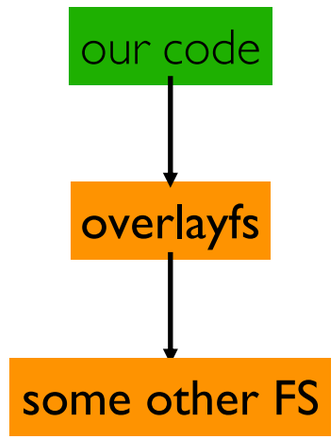


Types of File System (FS)

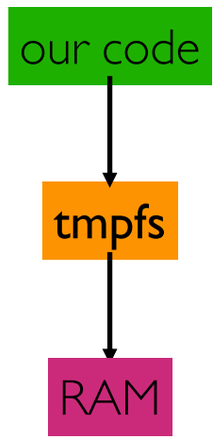
local FS



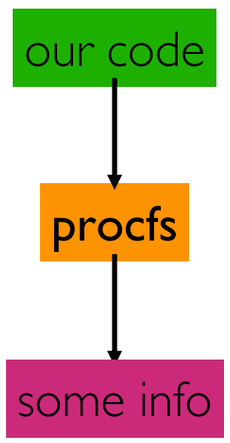
layered FS (for Docker)



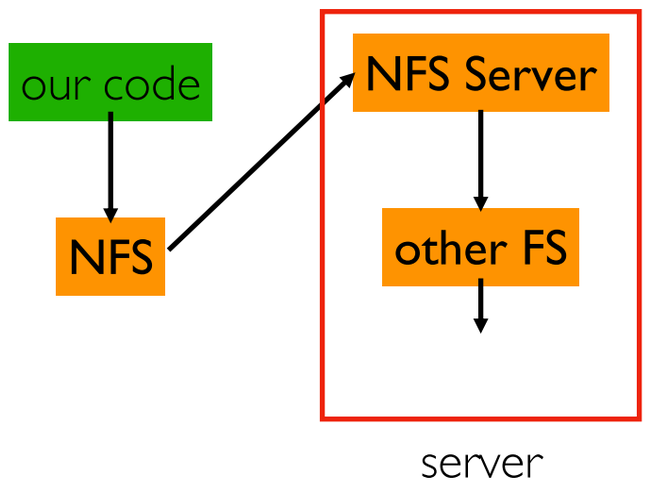
in-memory FS (Temp Files)



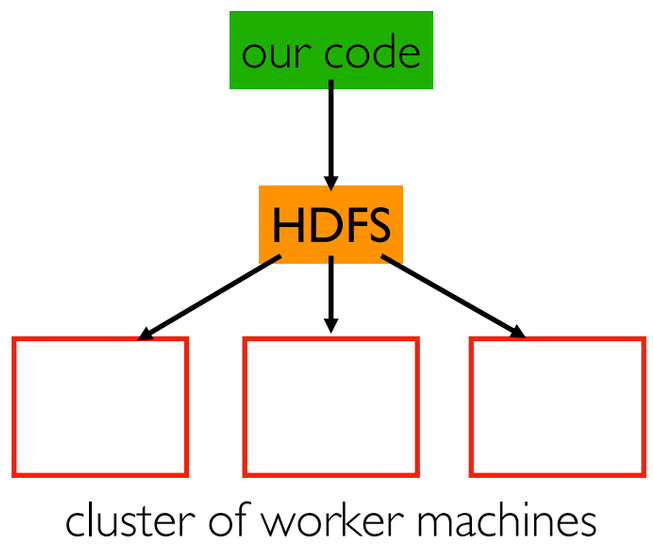
pseudo FS (Stats)



network FS



distributed FS



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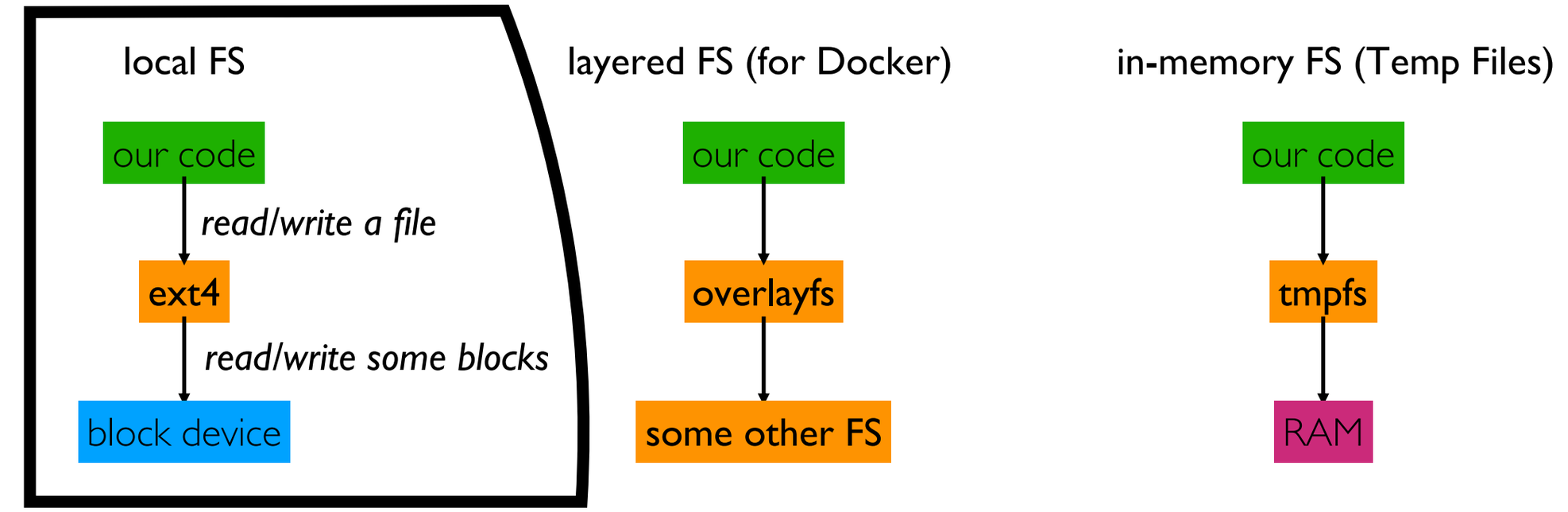
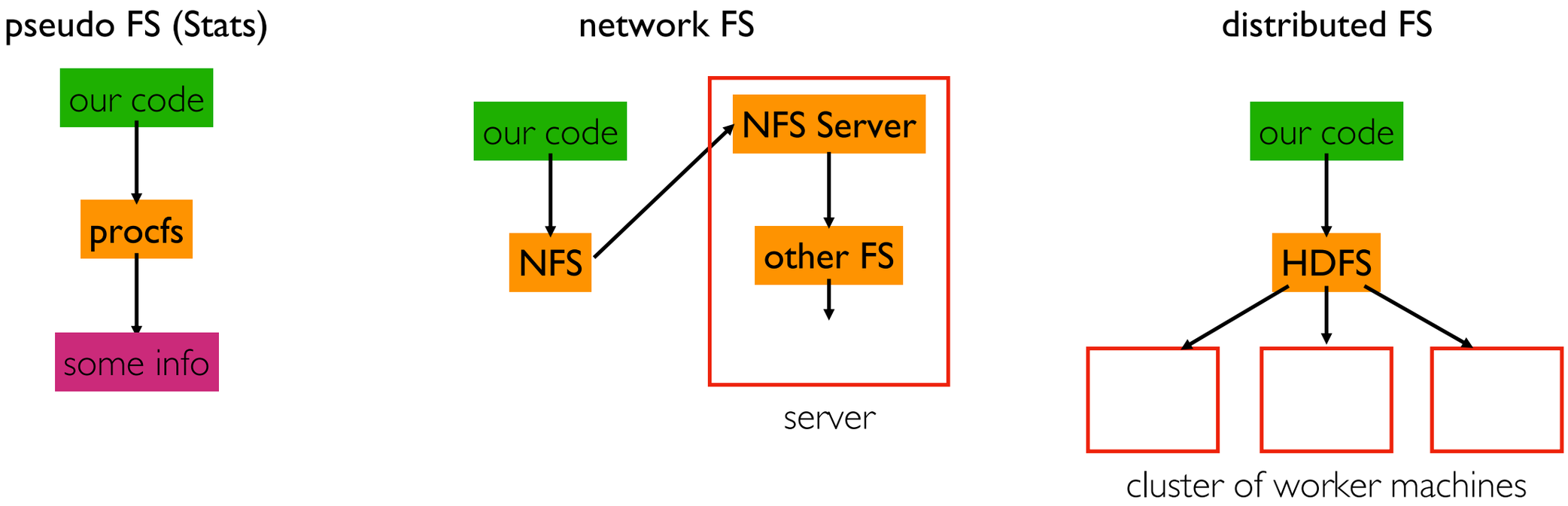
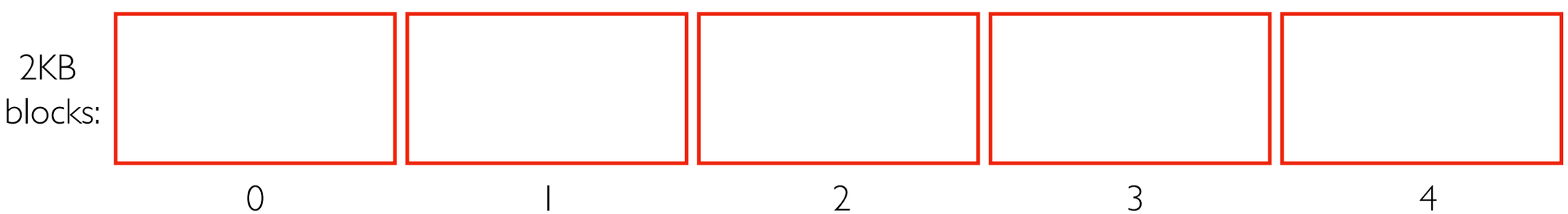


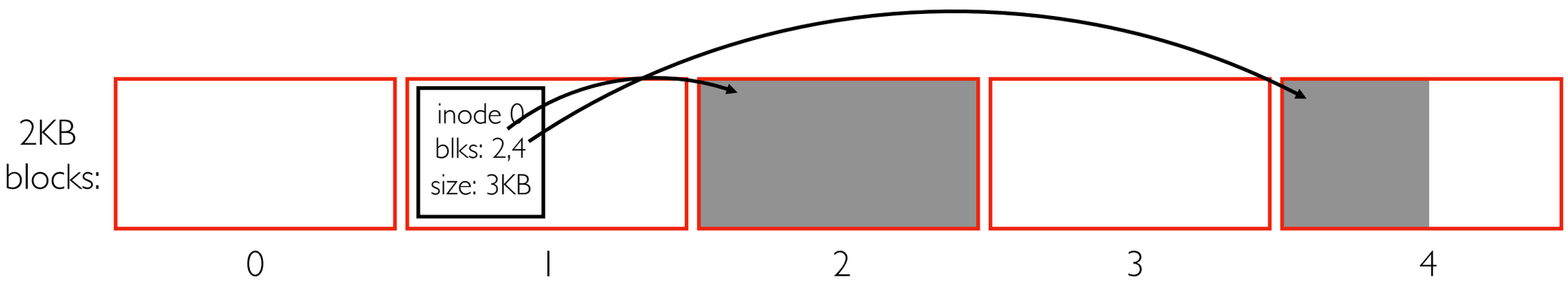


Local File Systems



How does a local FS use blocks?

Local File Systems

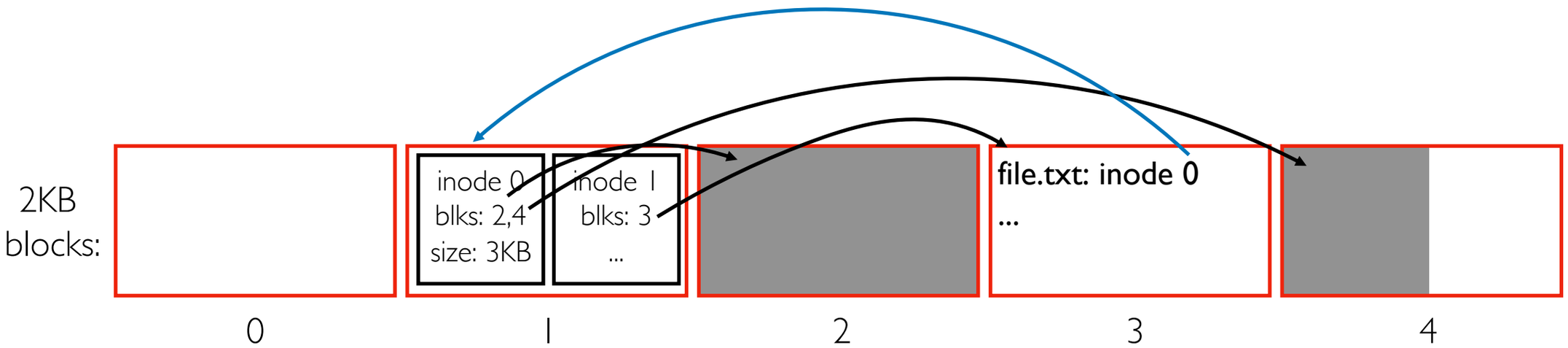


How does a local FS use blocks? Many possibilites. One example...

Files

- some metadata, like size, block locations
- each is represented by an "inode" structure (above file is fragmented)
- file extensions (like .txt) don't mean anything to the file system (just for documentation)

Local File Systems



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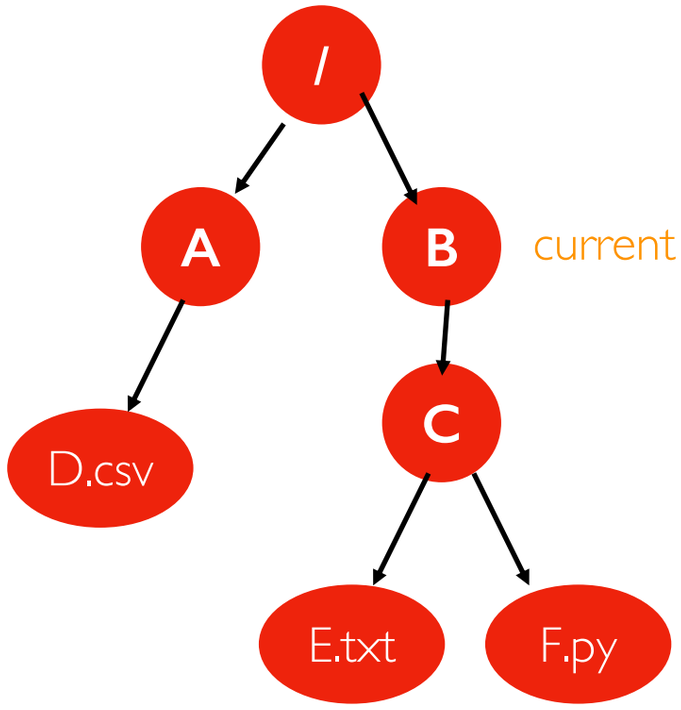
Directories

- special files containing name => inode mappings
- the same inode could be in multiple directories
- each file system has a "root" directory from which you can reach everything else recursively
- formatting creates initial structures (like the root directory)

File System Trees

Nesting of directories and files logically create "trees"

- technically DAGs (directed acyclic graphs) because the same inode number can have multiple names in different directories
- leaves: files and empty directories

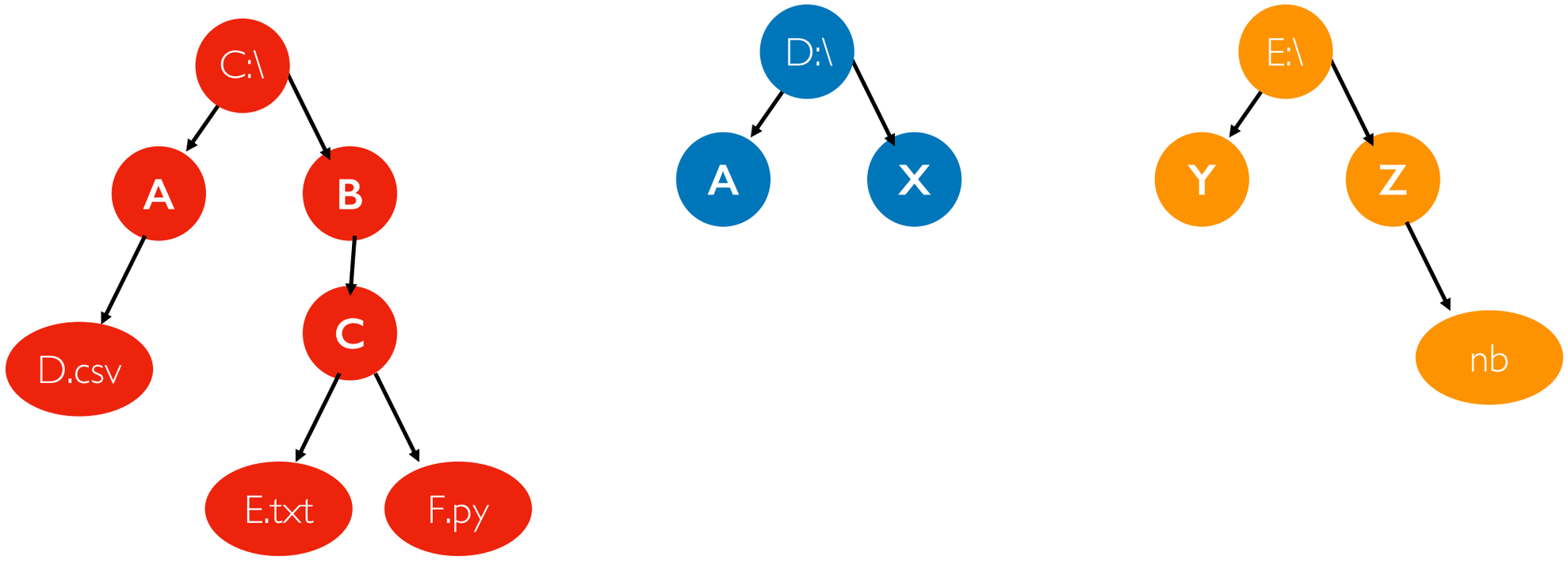


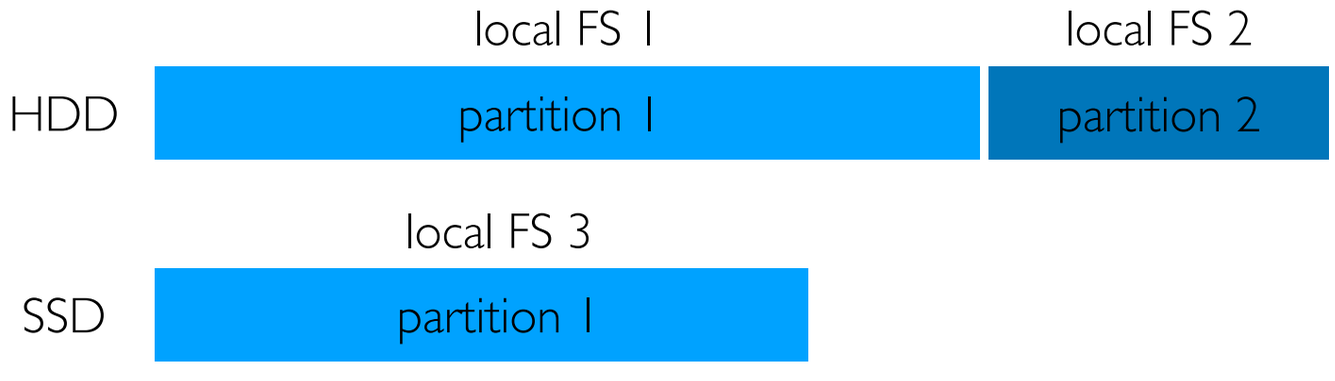
current working directory (CWD)

relative path to E.txt: `C/E.txt`
absolute path to E.txt: `/B/C/E.txt`
relative path to D.csv: `../A/D.csv`
absolute path to D.csv: `TopHat`

Multiple File Systems: Windows Approach

have multiple trees (each is a "drive")





Multiple File Systems: Unix Approach

mount file systems over directories of other file systems to make one big tree

https://www.brit.co/fruit-salad-tree/

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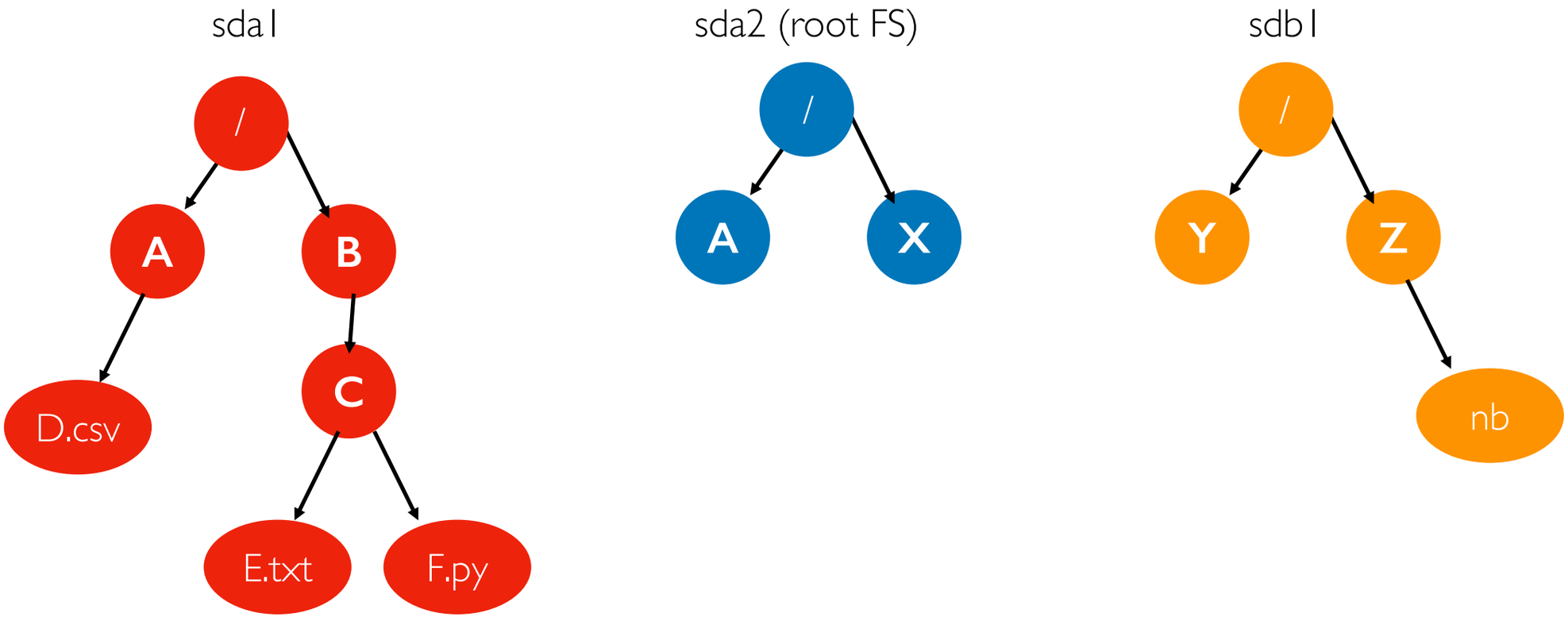
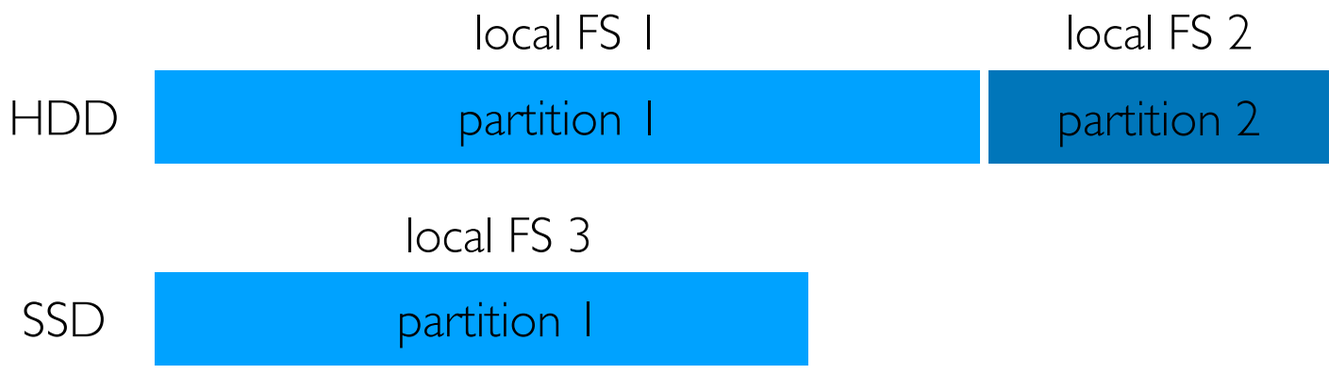
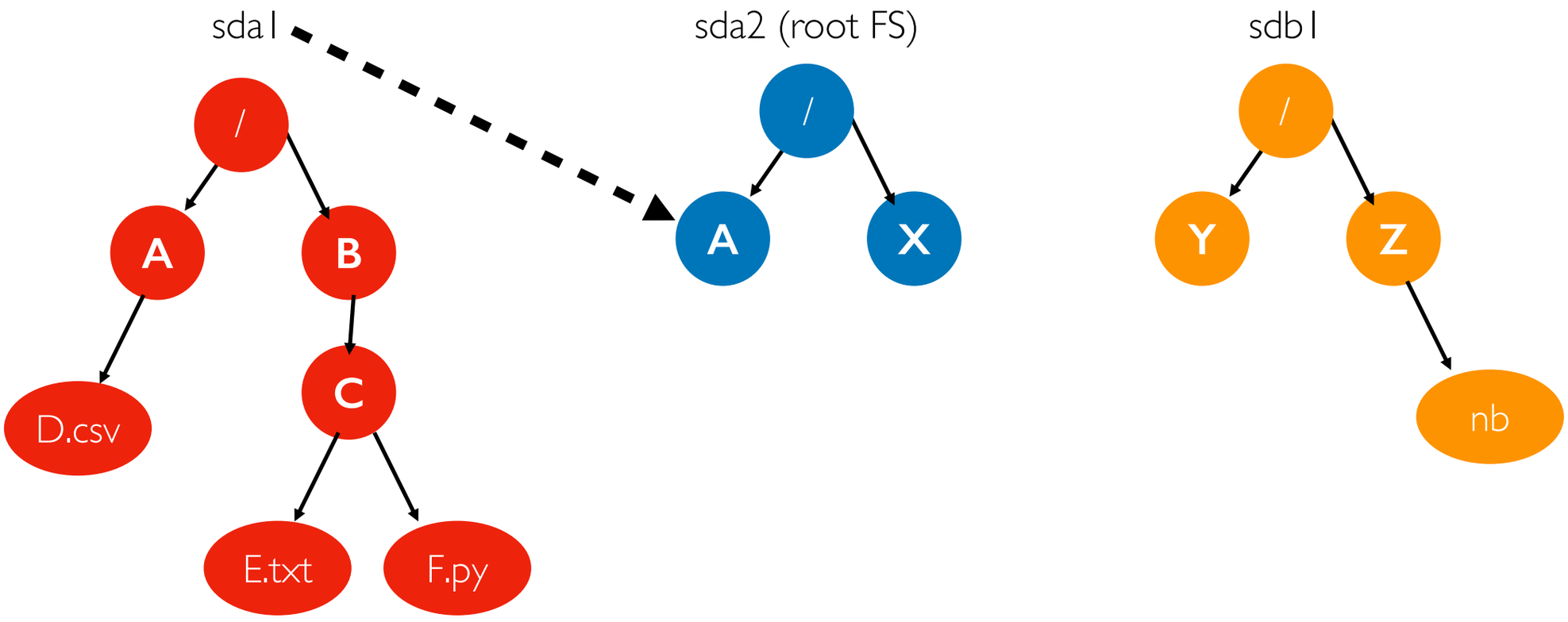




Multiple File Systems: Unix Approach

mount file systems over directories of other file systems to make one big tree




```
mount /dev/sda1 /A
```

Multiple File Systems: Unix Approach

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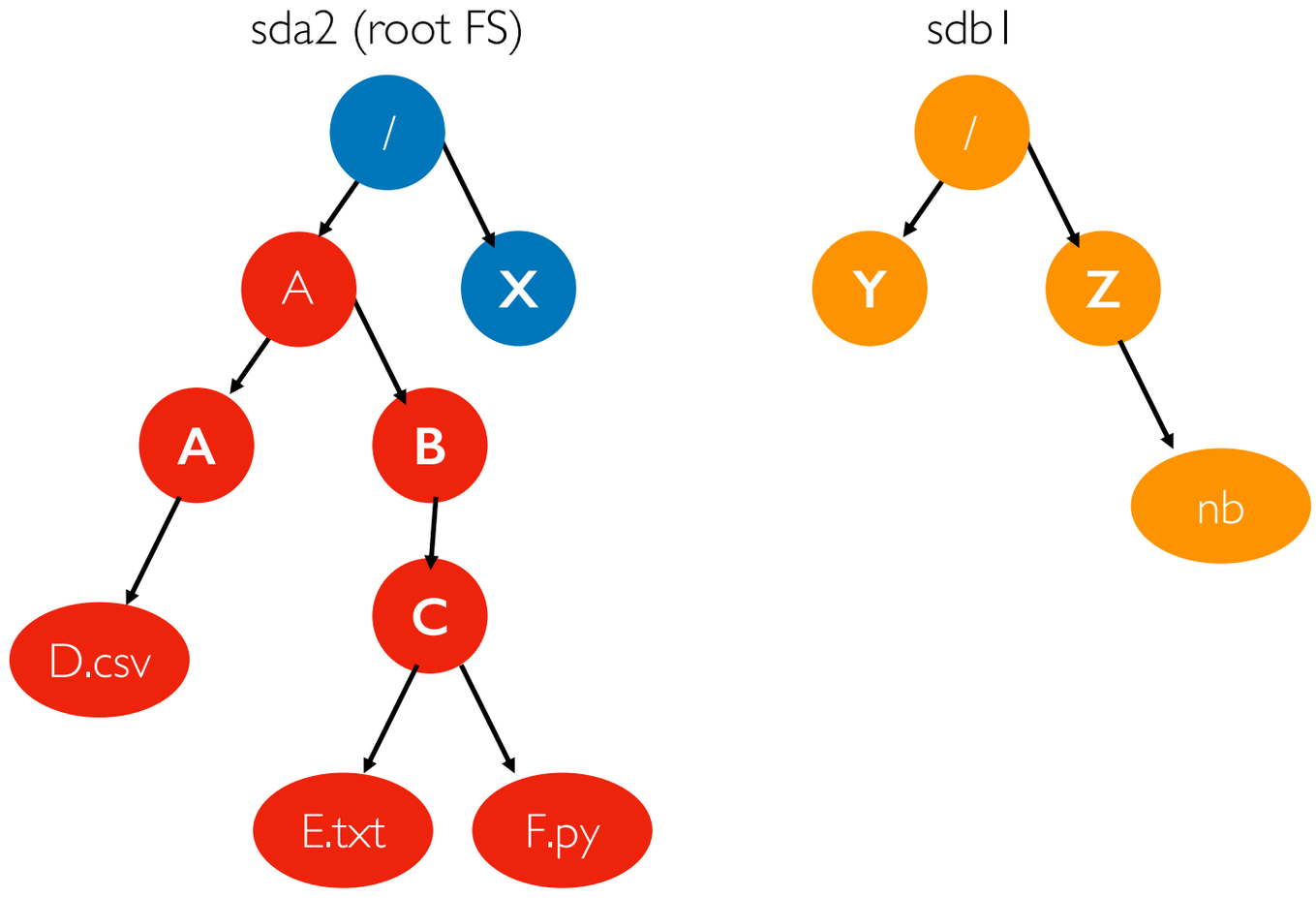


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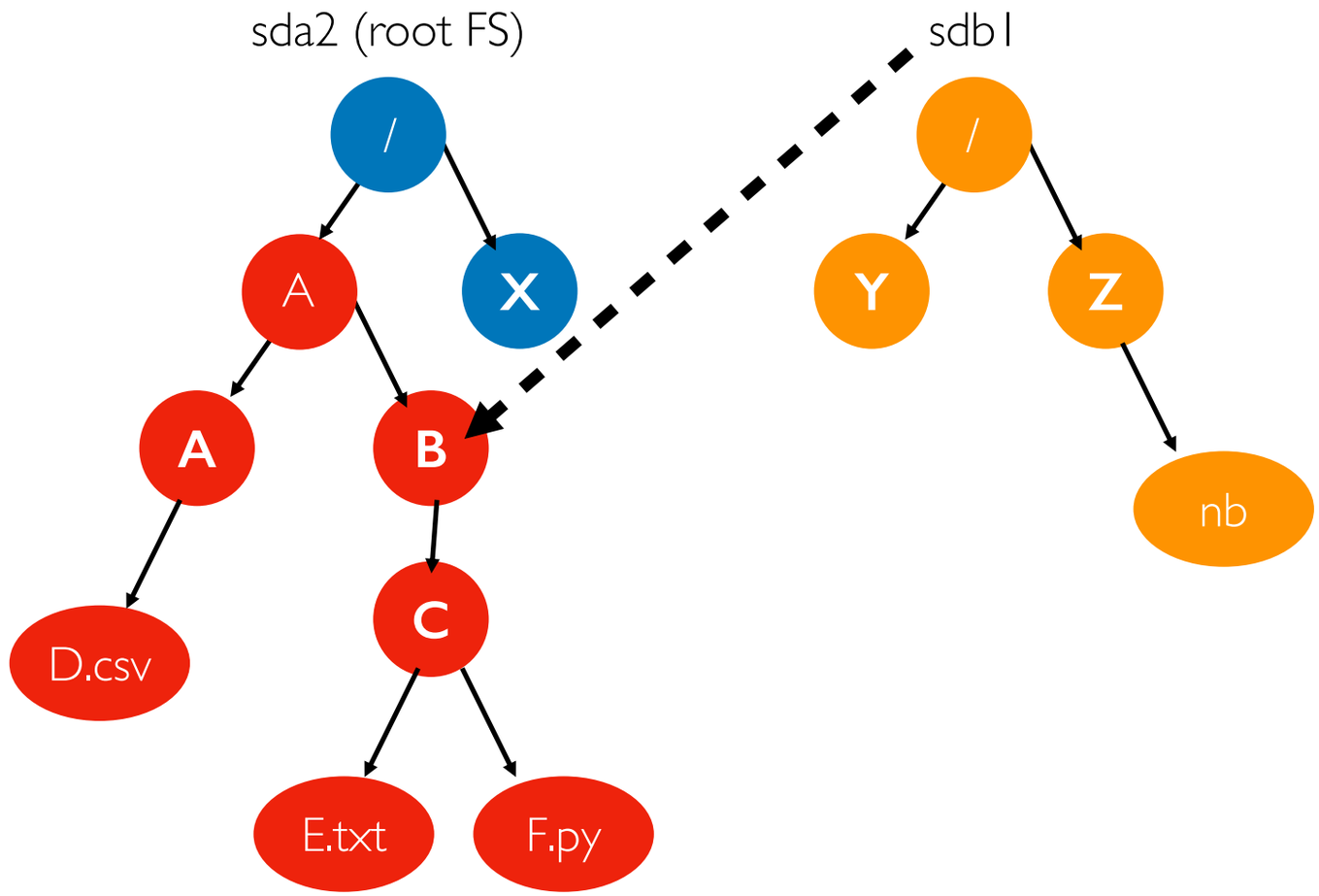


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mount /dev/sdb1 /A/B
```

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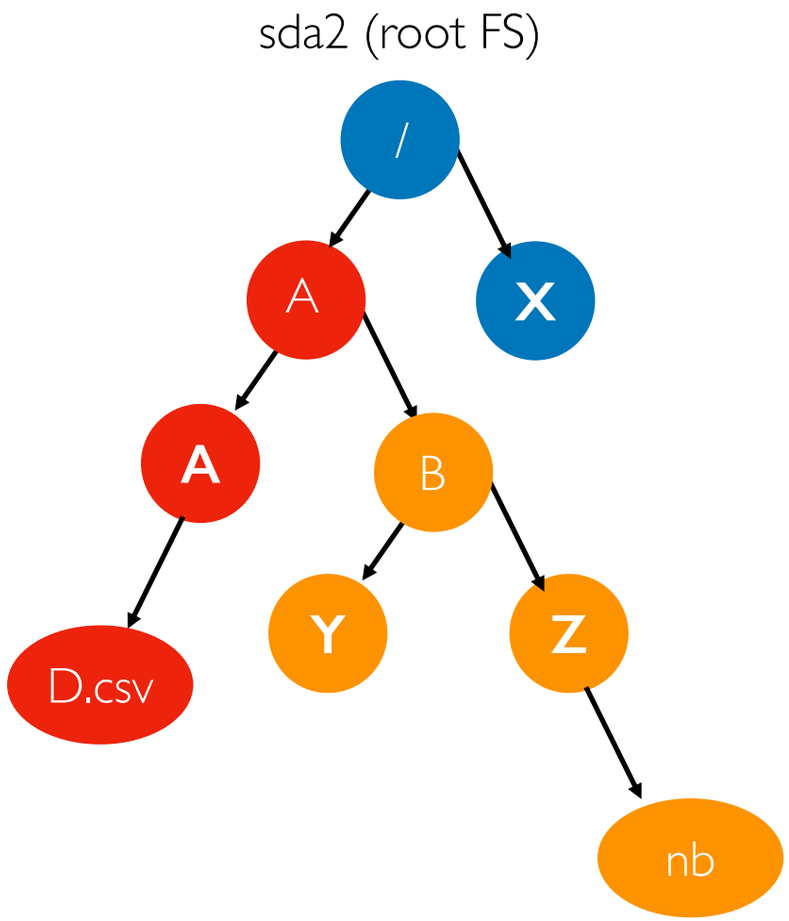


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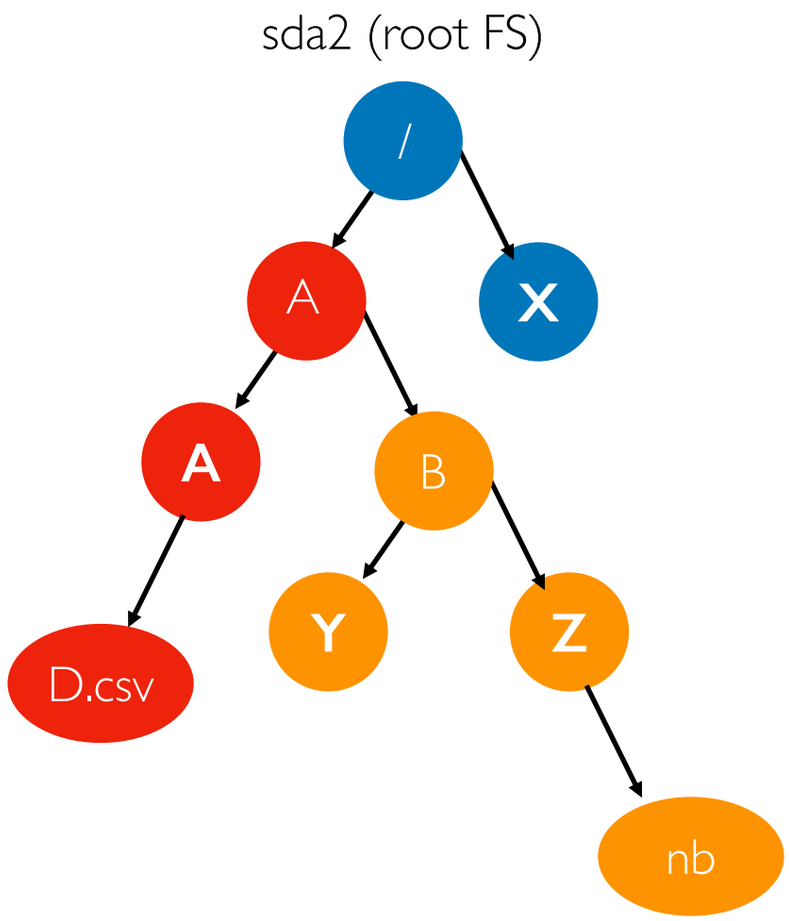
Multiple File Systems: Unix Approach

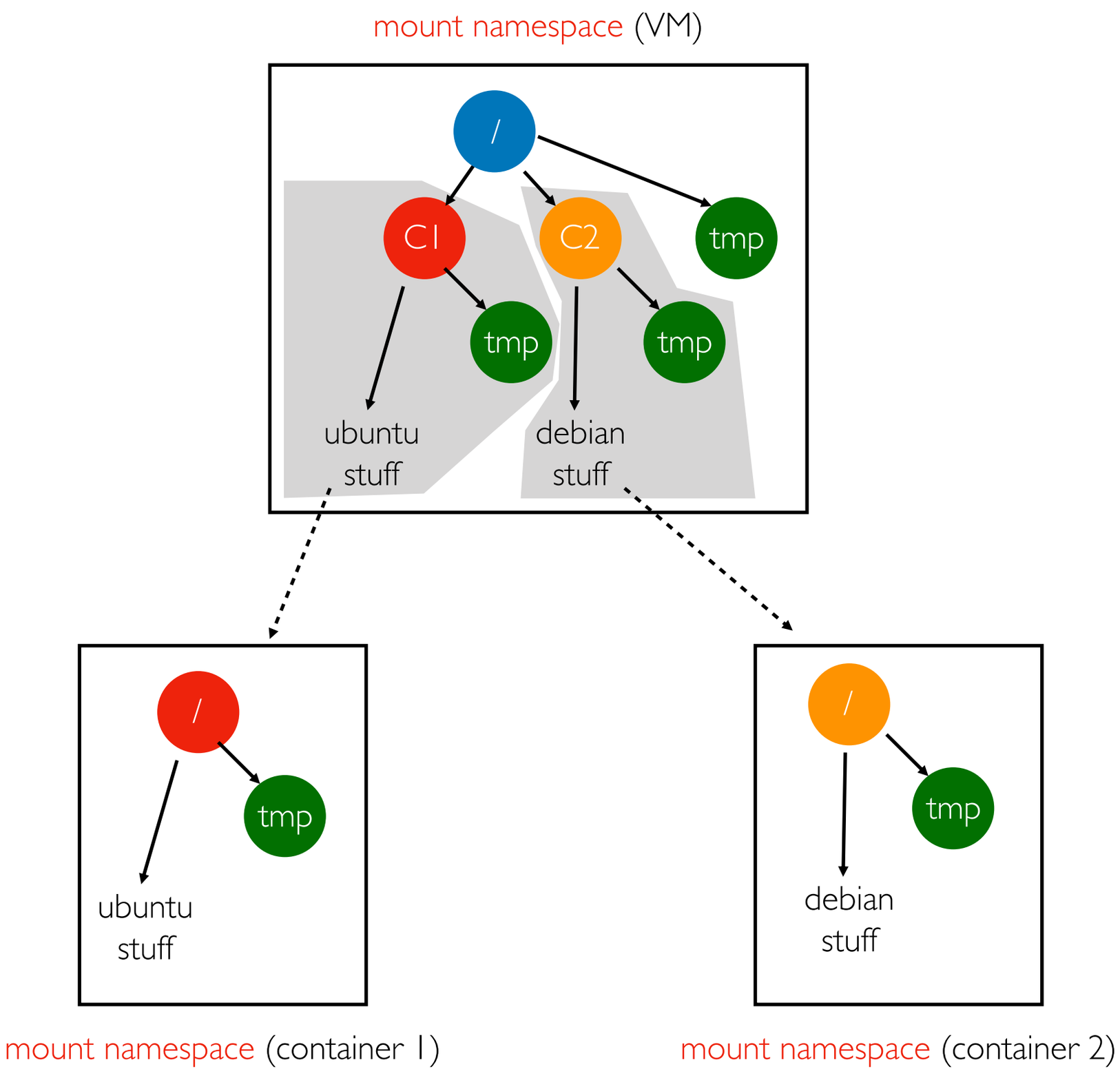
mount file systems over directories of other file systems to make one big tree



Note: each container has it's own root file system and mount namespace

```
mount /dev/sda1 /A
mount /dev/sdb1 /A/B
```

Container File Systems (Simplified)



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