File System Archaeology

New techniques to help recover data from a FAT32 file system

Talk

- Data recovery
- New? Techniques
  - Reconstruct file system activity
- FAT32
  - Simple example
- Fragmented files
- Verification
- Exercise

Data Recovery

- Two main approaches
  - Use metadata
  - File carving
- Both approaches have problems with fragmentation

Data Recovery 2

- File Carving
  - Continually improving
    - New ideas to handle fragmented files
- But …
  - Slow
  - Doesn’t get metadata
    - File names, dates, length

New Techniques

- Use metadata to reconstruct file activity
  - Can reconstruct how files are laid out on disk
  - Can handle fragmentation
  - Don't need to read every cluster
    - Very efficient
- Can be used to supplement file carving techniques

New Techniques 2

- File validation strategies which don’t look at the file contents
- Reconstruction of FS data structures
- Knitting together fragmented directory clusters

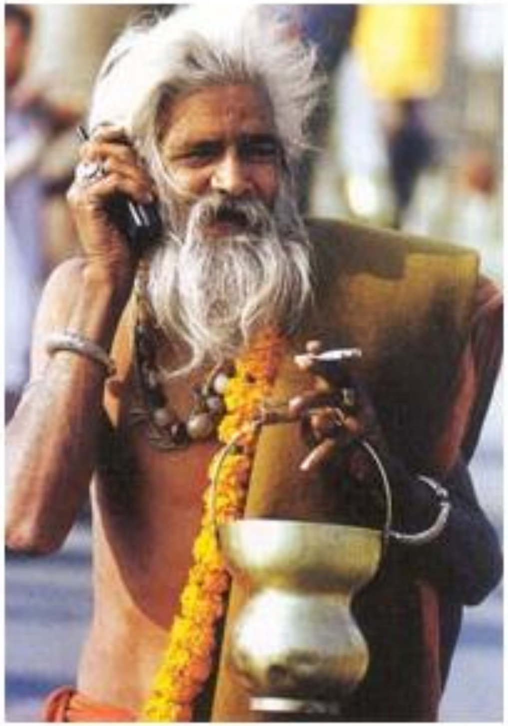
What?
Did you say FAT?
You mean that 30
year old file system.

FAT 32

- Portable and so used on
  - Phones
  - Cameras
  - USB keys

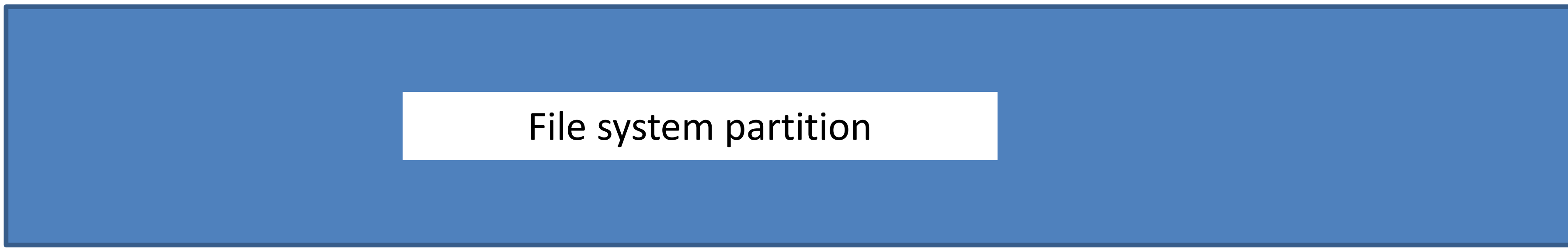
More cell phones than people

In 30 countries around the world, from Aruba to Italy to Hong Kong, mobile phone penetration has **past 100 percent**. Translation: the number of cell phone subscriptions has exceeded the size of the population. That's according to end-of-Q1-2006 data just released by London-based researcher Informa Telecom&Media. Here is the list:



Turks & Caicos Islands: 161.8%
Aruba: 150.8
Luxembourg: 140.7
Lithuania: 139.9
Cayman Islands: 136.4
Netherlands Antilles: 134.0
Grenada: 133.3
Israel: 125.9
Italy: 122.4
Cyprus: 121.5
Macau: 121.3
Bahrain: 117.8
Greece: 114.7
Czech Republic: 114.0
UAE: 113.9
Jersey: 113.6
Sweden: 112.5
Hong Kong: 110.8
UK: 110.1
Estonia: 108.6
Spain: 108.0
Austria: 107.3

FAT32 intro



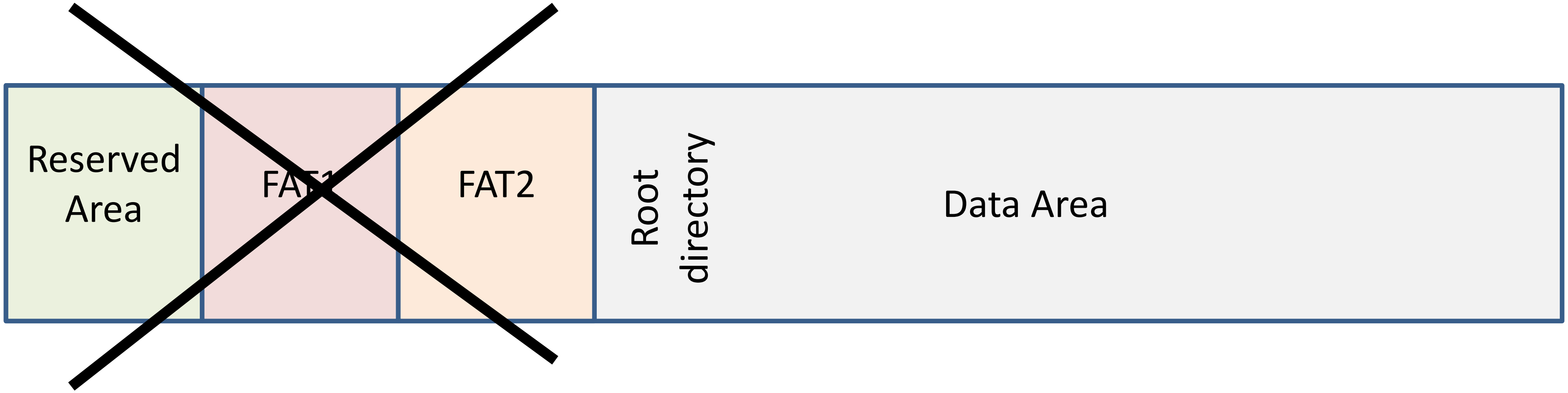
FAT32 intro

Formatting the disk initialises the data structures, creates a FAT and backup FAT and

FAT32 intro

For the purposes of this talk, we are not interested in anything other than the data area

FAT32 intro



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FAT32 intro

The Data area is where all the file data and the directory information is held.

FAT32 intro

- Divided into clusters. (Say 4k, or 4096 bytes)
- Files are stored as a sequence of clusters
- Sequence information stored in the FAT

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FAT32 intro

- Divided into clusters. (Say 4k, or 4096 bytes)
- Files are stored as a sequence of clusters
- Sequence information stored in the FAT
  - Oops … we’ve lost the FAT
    => we have to reconstruct the sequence

FAT32 intro

- Creating a file
  - Create an entry in the directory

FAT32 Typical Operations

- Creating a file (say 6k, requires 2 clusters)

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    - Holds metadata name, dates, start, len

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  - Create an entry in the directory
    - Holds metadata name, dates, start, len
  - Allocate clusters

FAT32 Typical Operations

- Creating a subdirectory
  - Create an entry in the root directory

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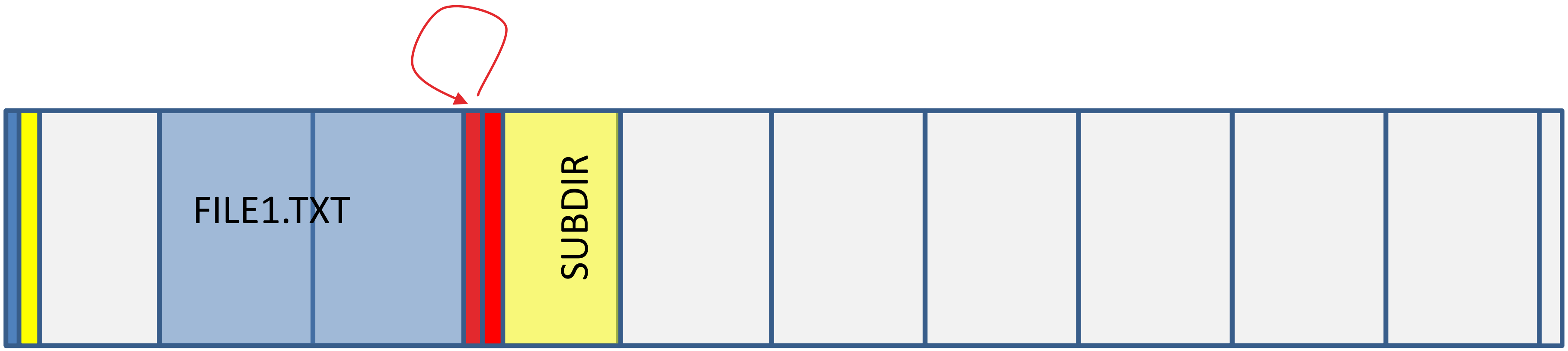
FAT32 Typical Operations

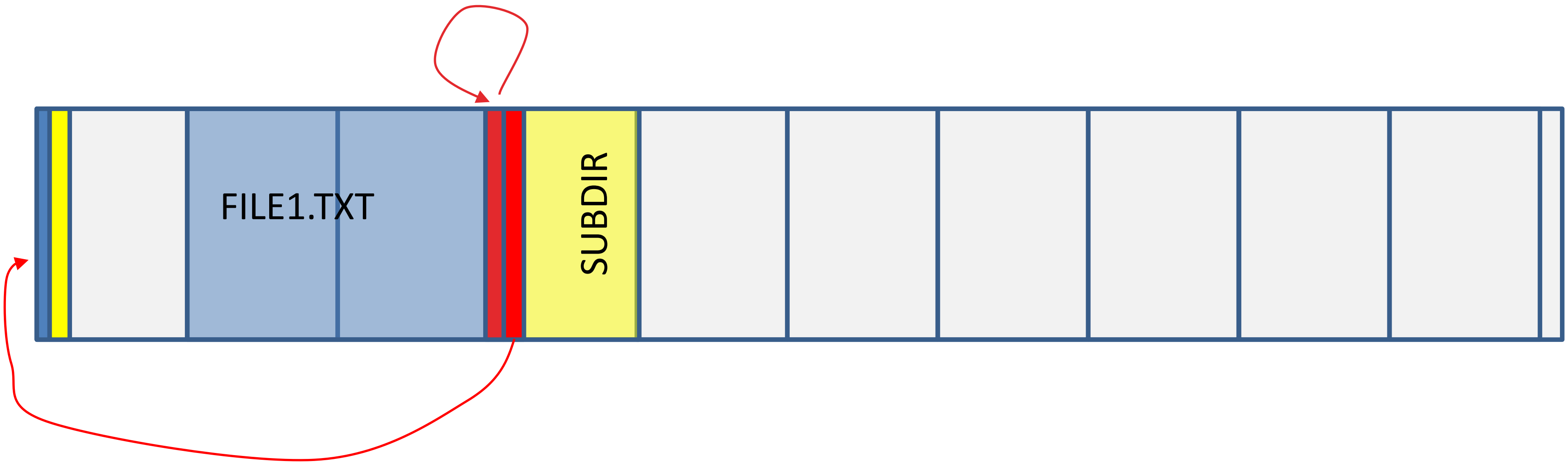
- Creating a subdirectory
  - Create an entry in the root directory
  - Allocate cluster
  - Create . and .. entries

FAT32 Typical Operations



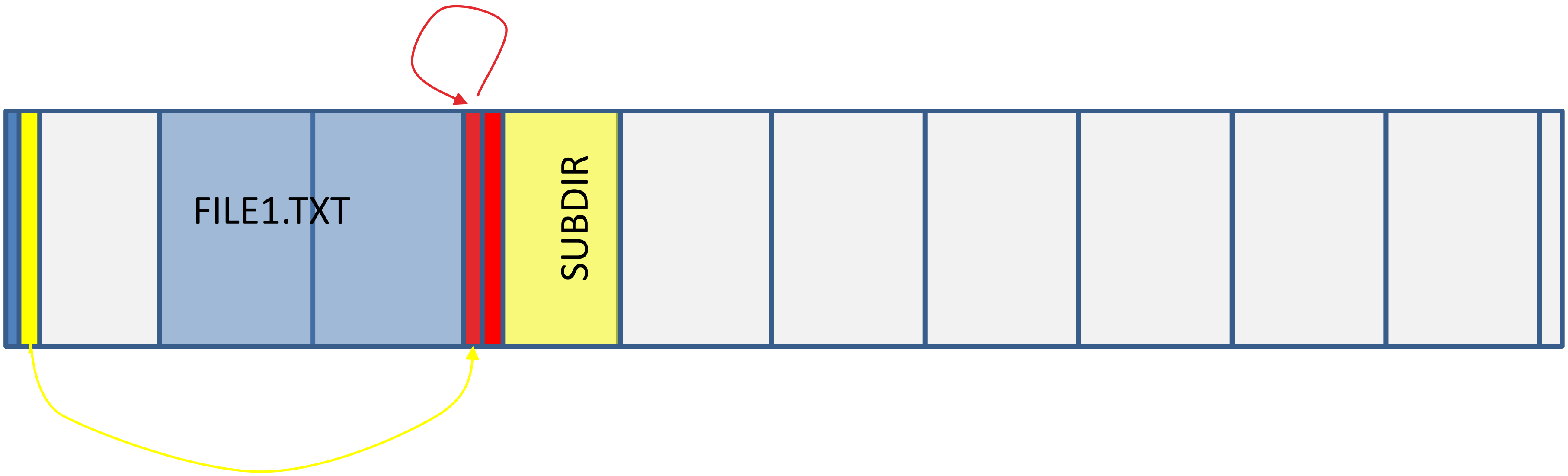
- The . entry points to itself

FAT32 Typical Operations



- The . entry points to itself
- The .. entry points to the parent directory (in this case, the root directory)

FAT32 Typical Operations

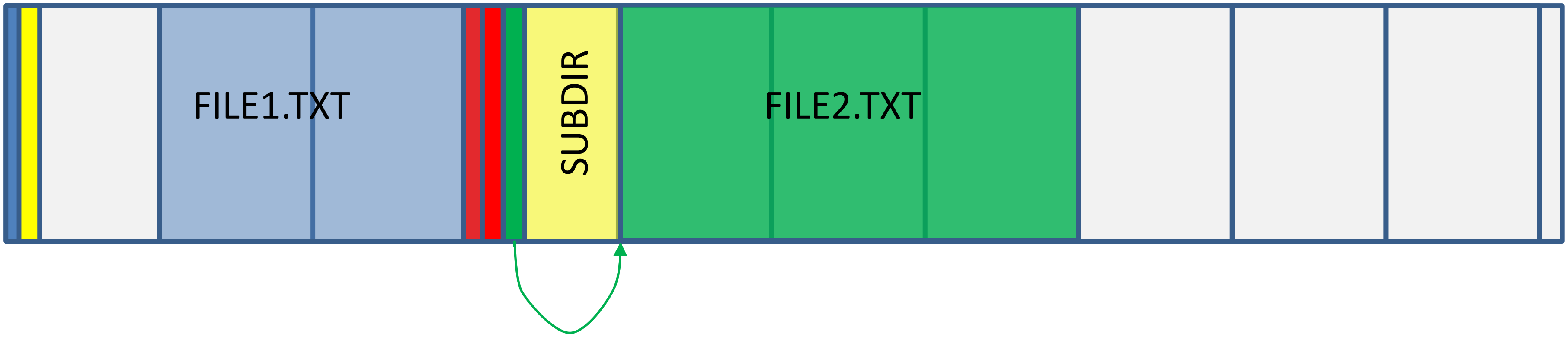


- Note that the . entry contains the same values as the subdirectory entry except for the name. Redundancy is good for forensics.

Allocation Strategy

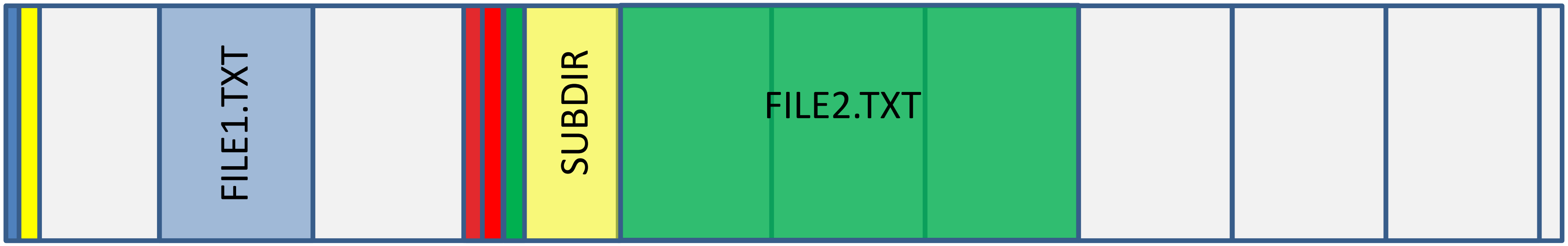
- The file system needs to allocate clusters
  - it is free to choose any free cluster
  - FAT32 supports next available
    - the next available cluster after the last one allocated

Allocation Strategy



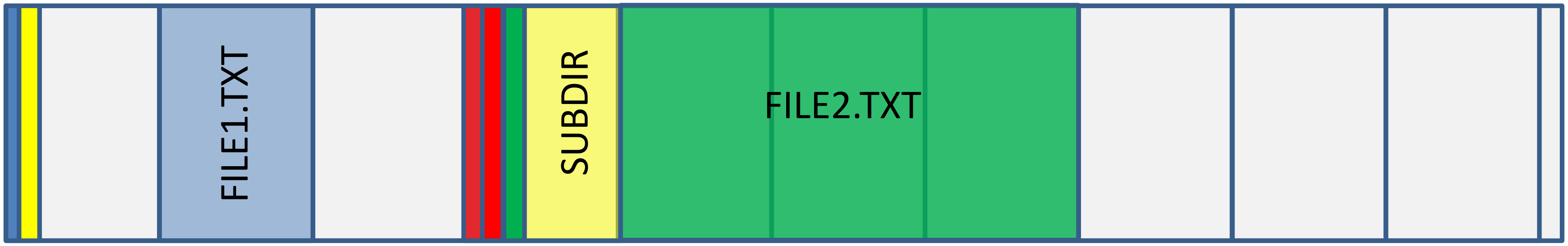
- A new file (3 clusters) is created in SUBDIR

Allocation Strategy



- A new file (3 clusters) is created in subdir
- FILE1.TXT is edited, reduced to 1 cluster

Allocation Strategy



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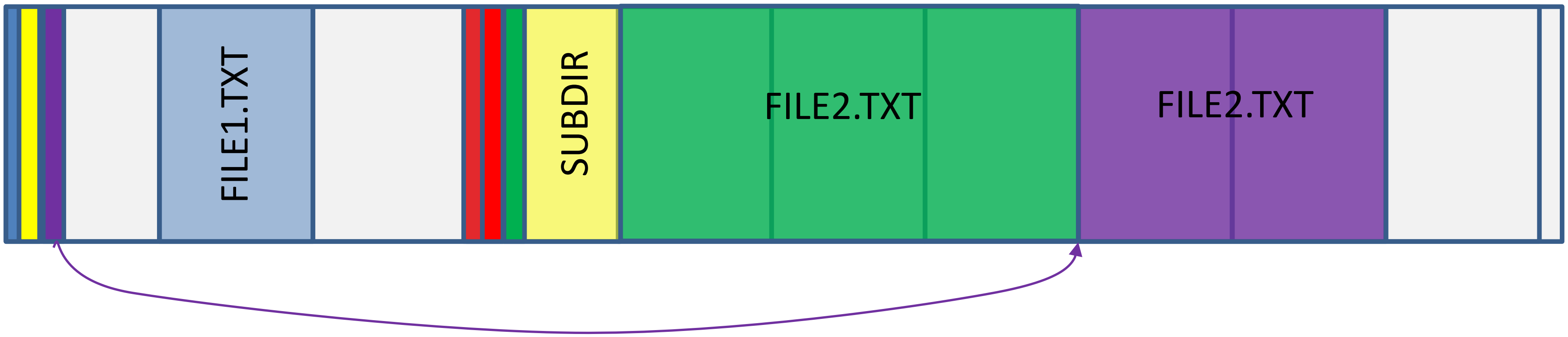

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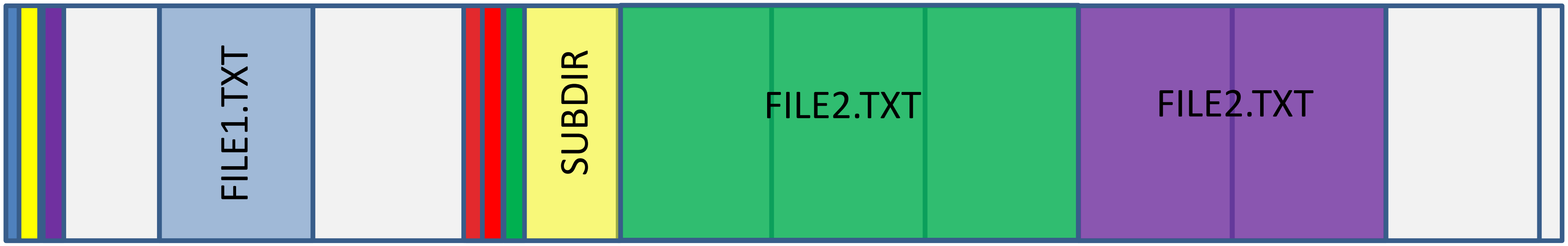

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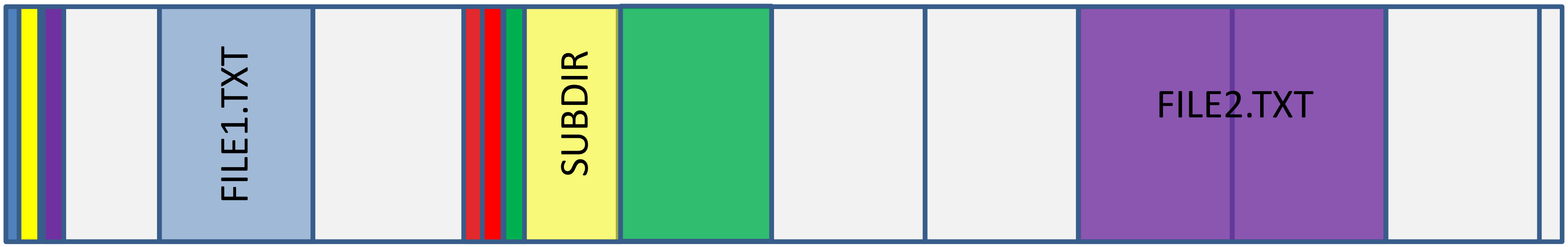

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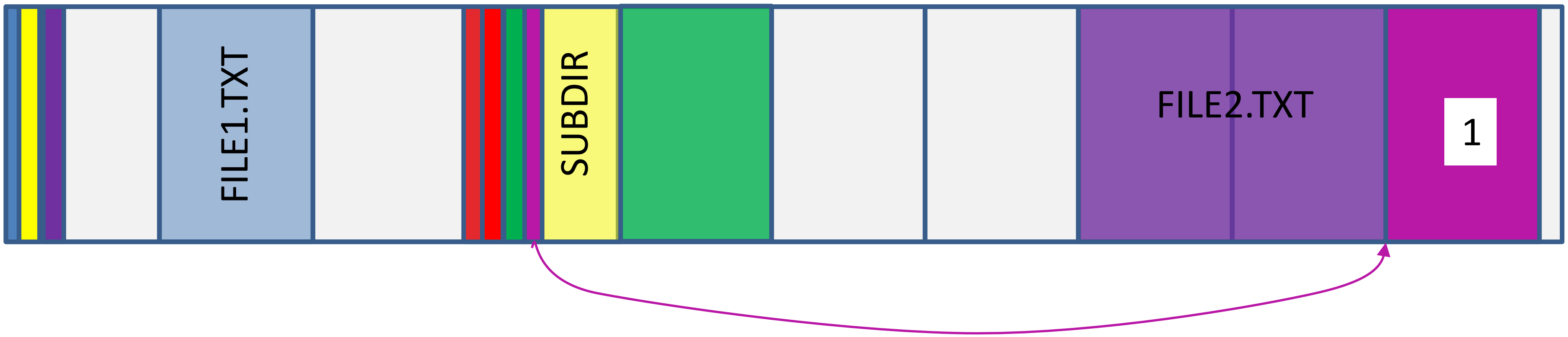

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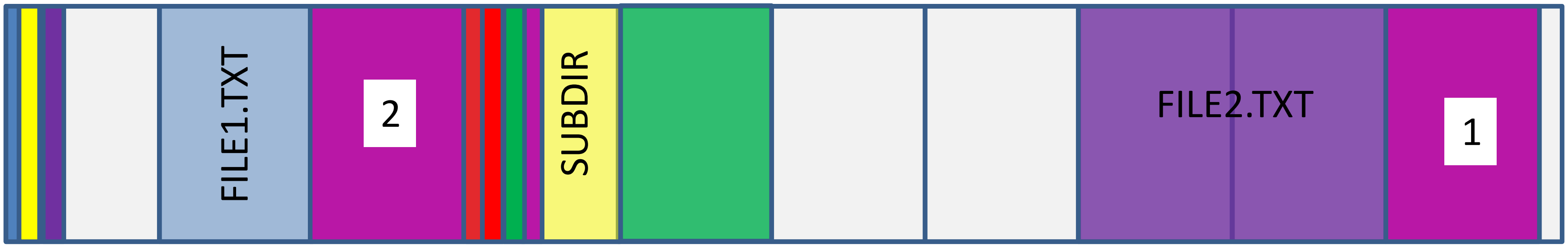

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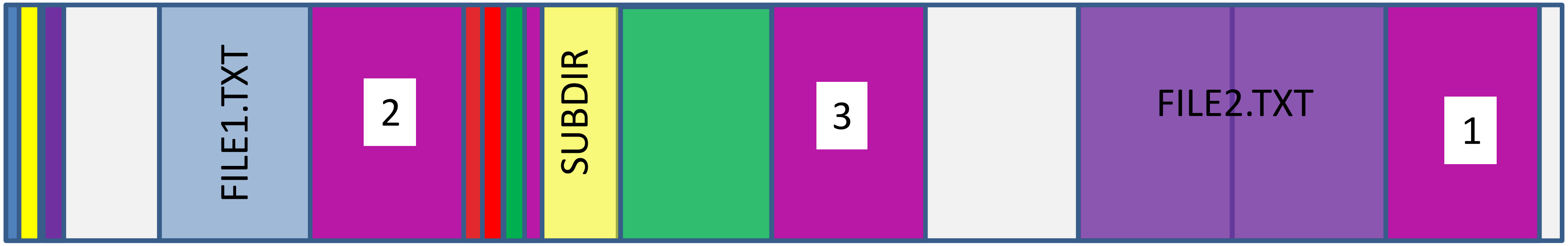

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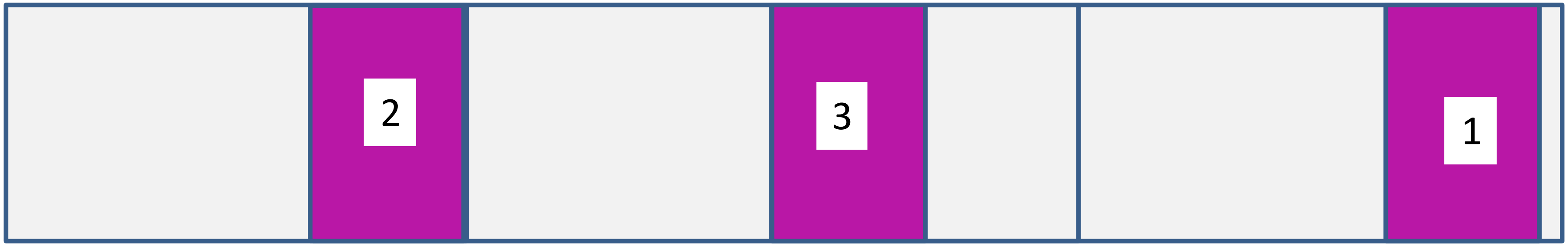
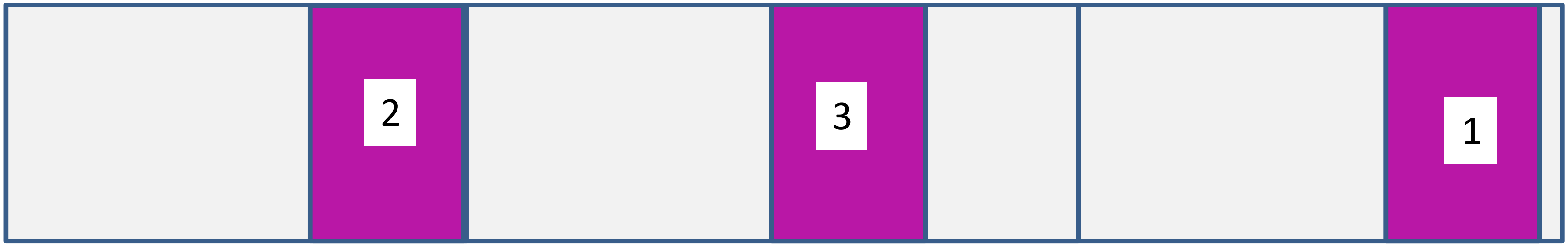


- FILE4.TXT is quite fragmented

Allocation Strategy



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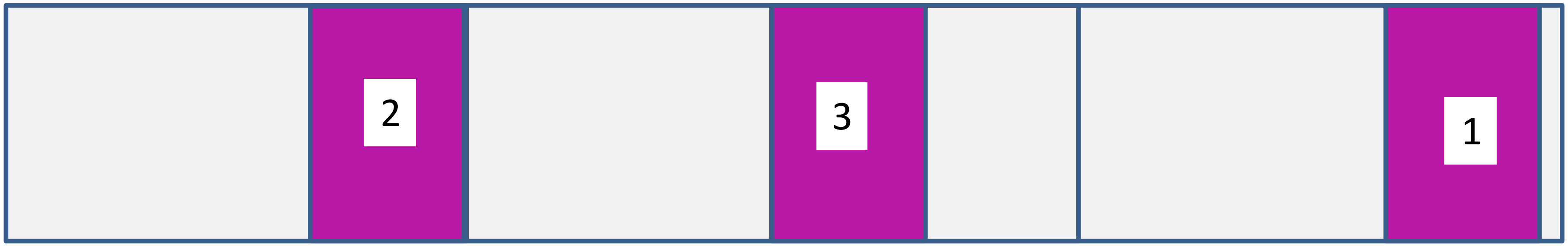
  - but ...

Allocation Strategy



- FILE4.TXT is quite fragmented …
  - but …
  - if we know the sequence of operations and the allocation strategy, we can find out which clusters the files were allocated.

Data Recovery

- Find all the directory entries (assume they all still exist … only the FATs have been destroyed)
- Sort entries by creation time
- for each entry
  - use the start cluster and number of clusters to see where it would go.
  - when we come to FILE4.TXT it has only one place to go.

Problems

- Defragmentation
  - Let’s assume it doesn’t happen
- Deleted files
  - We don’t have the time they were deleted
- Deleted directories
  - Maybe overwritten and we lose many directory entries.

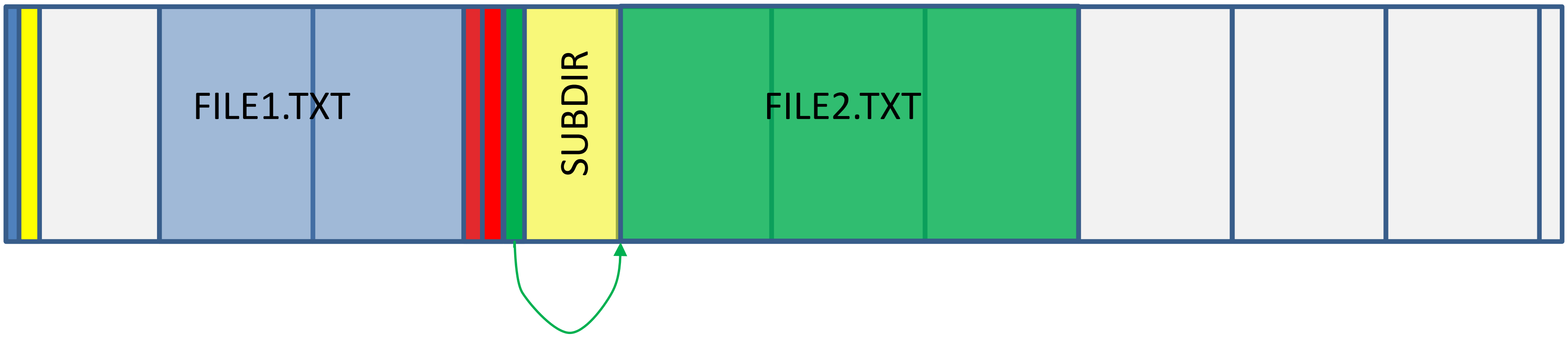
Problems 2

- Modification time
  - There’s only one and a file may be modified many times
  - It’s accurate to 2 seconds (creation time to 10ms)
  - A file may be modified and still occupy the same number of clusters
    - the last modification time is an upper bound

File Fragmentation

When a file is increased in size

Let’s go back in time



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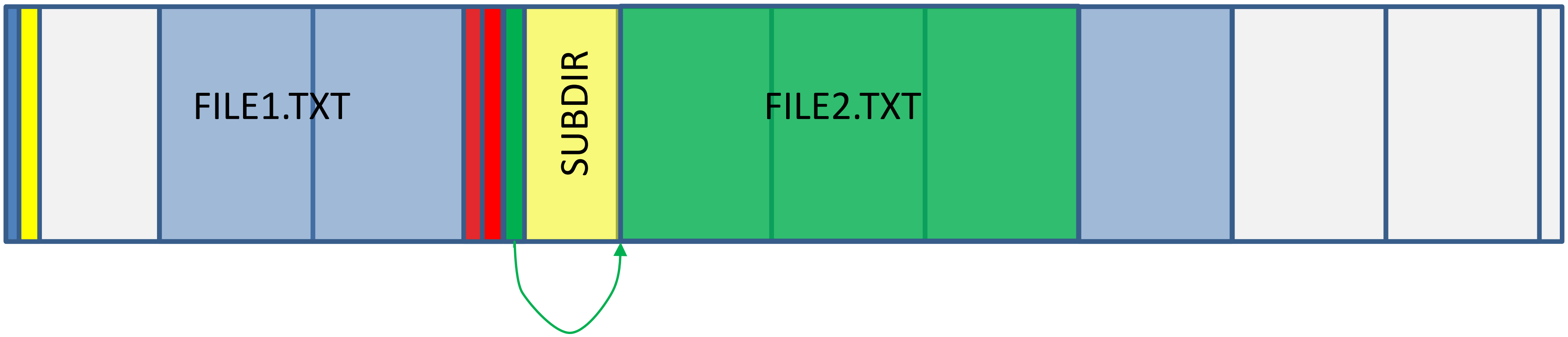

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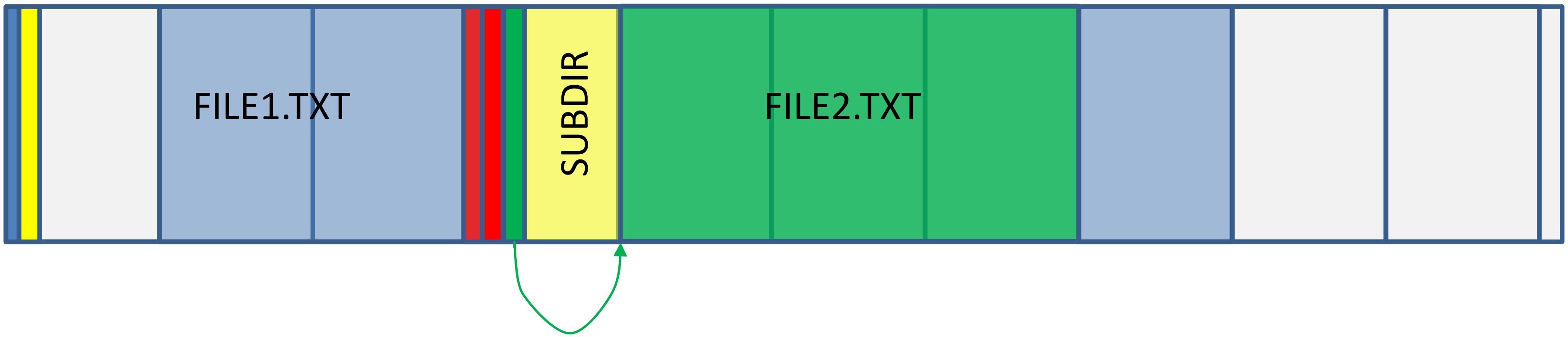

- FILE1.TXT is increased by one cluster
- FILE5.TXT (1 cluster is created)

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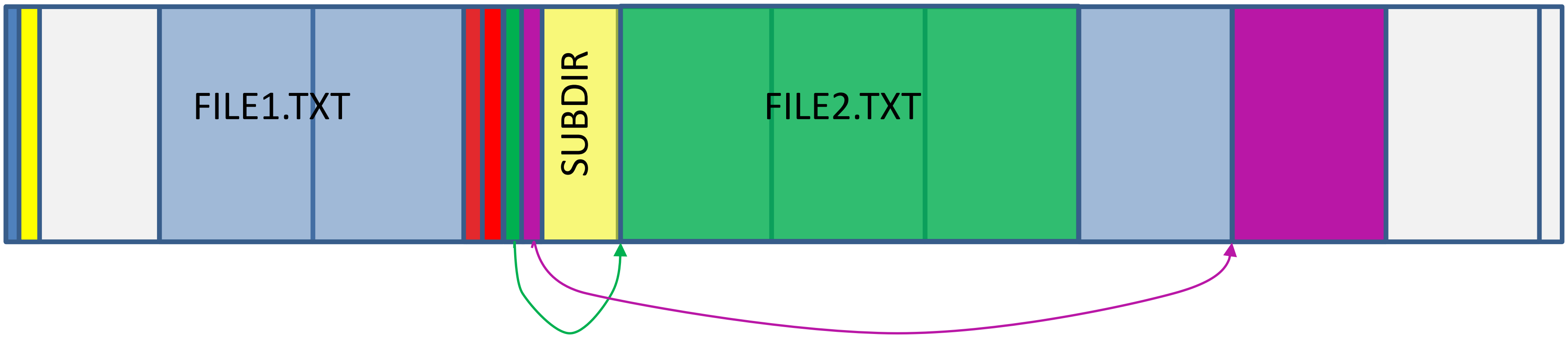


- FILE1.TXT is increased by one cluster
- FILE5.TXT (1 cluster is created)
- And it is obvious where FILE1.TXT ends up.

If only there was a way to detect the end of a file

- This would help

Techniques

- Technique Number 1
  - Recover file system activity and use in conjunction with a known allocation strategy to recover file cluster layout.

Techniques

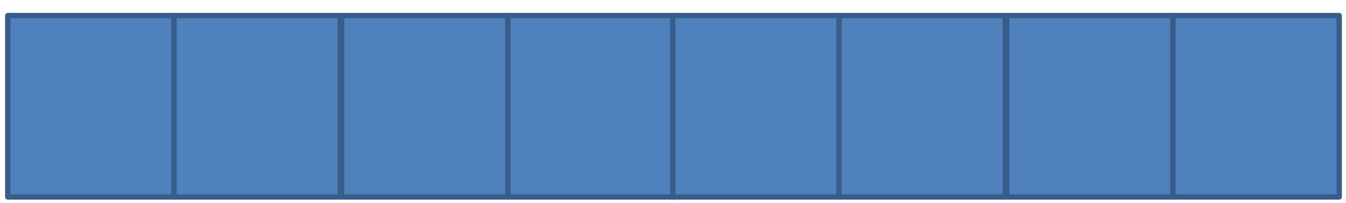
- Technique Number 2
  - We can use the redundancy of the . and .. directory entries to reliably determine cluster size and the start of the data area.
  - How?
  - we have two measures of distance. We know the byte offset where the . entry occurred and the parent entry. We also know the cluster number of each of these.
  - just divide the length by the length in clusters

Detecting the end of a file

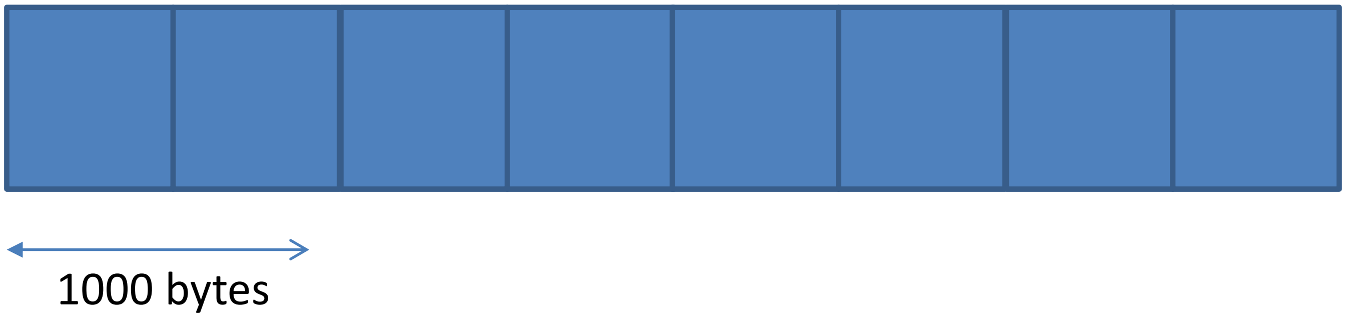
- RAM slack
  - Data written to the disk is always written in blocks of 512.
  - If a file of 1 byte is being created, just contains a single '?'
    - 512 bytes of memory is allocated
    - The first byte is set to the '?'
    - Remaining bytes are set to zero
- Idea of an ex-student (Anthony Walters)

Detecting end of file

- From the directory entry we know the length of the file
  - so we know how many bytes are in the last cluster
  - Let’s say there are 1000 bytes in the last cluster
- The cluster is, say 4K, that is 8 sectors in size

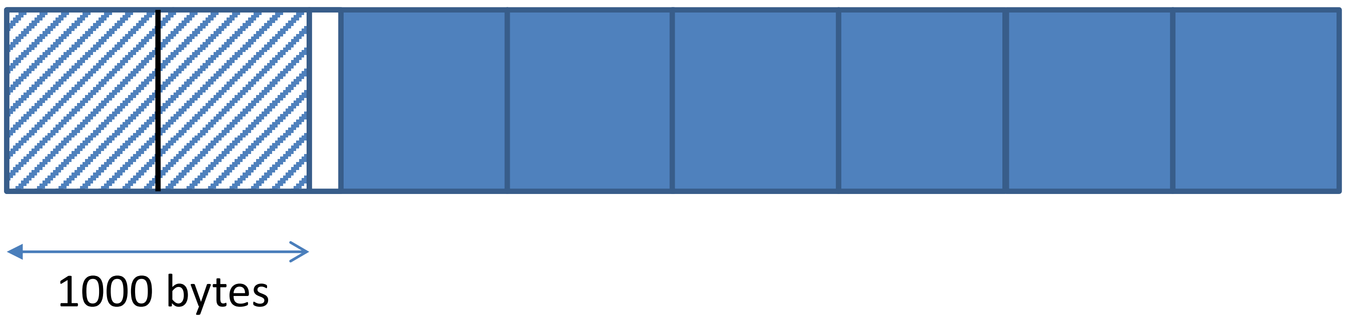


Detecting end of file



- We know that we are 1000 bytes into the last cluster
  - that is into the second sector
  - the end of that sector will contain zeros

Detecting end of file



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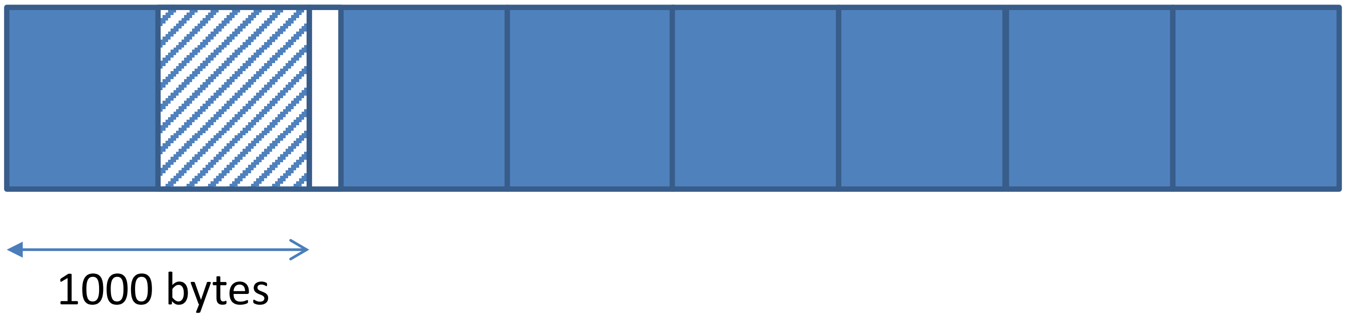


- So, we search for a cluster which has a second sector which contains the end of the file and 24 zeros

Problems

- Microsoft Common Document Format (CDF) files seem to occupy a whole number of sectors and so this technique won’t work with them.
- We get most confidence if the file ends with a non zero value.

Techniques

- Technique 1
  – Recover file system activity to identify file cluster layout.
- Technique 2
  – Reliably determine cluster size and the data area.
- Technique 3
  – Identify the end of files which do not occupy a whole number of sectors

Joining Directory Clusters

- A 4k cluster has room for 32 directory entries.
- A file usually requires more than 1 entry, in fact, tests show that typically a file requires 3.4 entries and so one cluster can hold 9 of these typical files.
- When a file is created and there isn't enough room in the directory a new cluster is added.

Long FileName entries

- Every file needs a base directory entry
- When a file is created which requires a long file name, then special entries are created (Long FileName or LFN entries).
- Tests show that 2.4 LFN entries are required for every file. Add the base directory entry to get 3.4
- The LFN entries have a checksum to tie them to the base directory entry.

Joining Directory Clusters

- The file directory entries may straddle a cluster.
  - We can then use the checksum to join the clusters together.
- We can also use common parent entries
- Failing that, we can use the file times in the directory to match

4 Techniques

- Technique 1
  - Recover file activity to identify file cluster layout.
- Technique 2
  - Reliably determine cluster size and the data area.
- Technique 3
  - Identify the end of files
- Technique 4
  - Joining up directory clusters

In Practice

Most files are not fragmented

- Simson Garfinkel used his huge corpus to determine that only 6% of files were fragmented. (http://simson.net/clips/academic/2007.DFRWS.pdf)
- We can quickly run through these and validate them and remove that part of the disk from further consideration
  - spend more time on the fragmented files.

Tying it all together

An Actual Example

- 4G FAT32 Flash key
- Originally formatted using XP
- ¾ filled with files
  - backed up, so mostly created
- Then formatted with OS X
  - same cluster size, but different data area
- A small number of file created occupying about 0.1% of the disk

Recovery

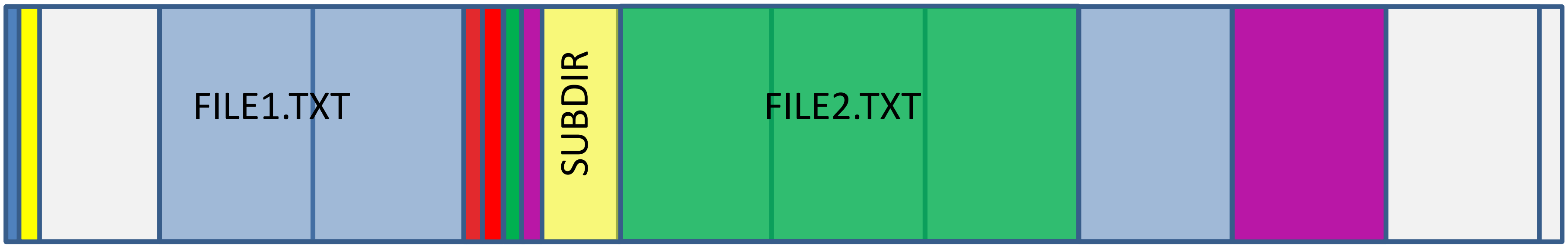
- We consider a block of files to be a set of files which are laid out sequentially
  - we can have more confidence that these files are not fragmented
- We recovered 2856 files occupying 1.6 GB bytes. The system found 65 file blocks with an average size of 61 files in a block. The largest block contained 424 files.
- Only the directories were fragmented

Efficiency

- This approach could be made very efficient. If you can verify a file by examining the last cluster, then you don’t need to examine every cluster on the disk.
- Every unfragmented file is an opportunity to avoid examining its clusters.

Exercise

Let’s go back in time



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Let’s go back in time

- FILE1.TXT is increased by one cluster
- FILE5.TXT (1 cluster is created)
- FILE2 is deleted
- When we look only at directory entries can we be sure that FILE1.TXT occupies those clusters

This?

Or this?

Code

- Code is at http://code.google.com/p/comebackfat/
- It is exploratory
- It is not efficient

Thank You