Bit Recovery Documentation

Release 1.2.2

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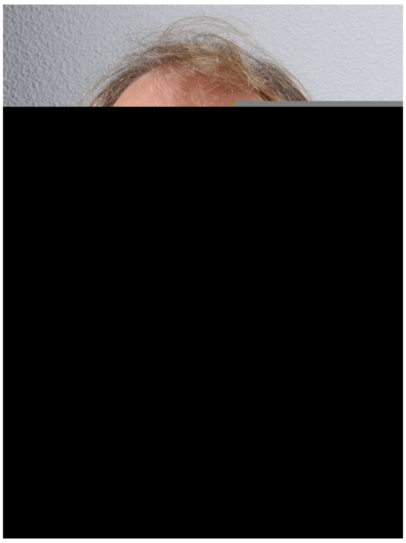
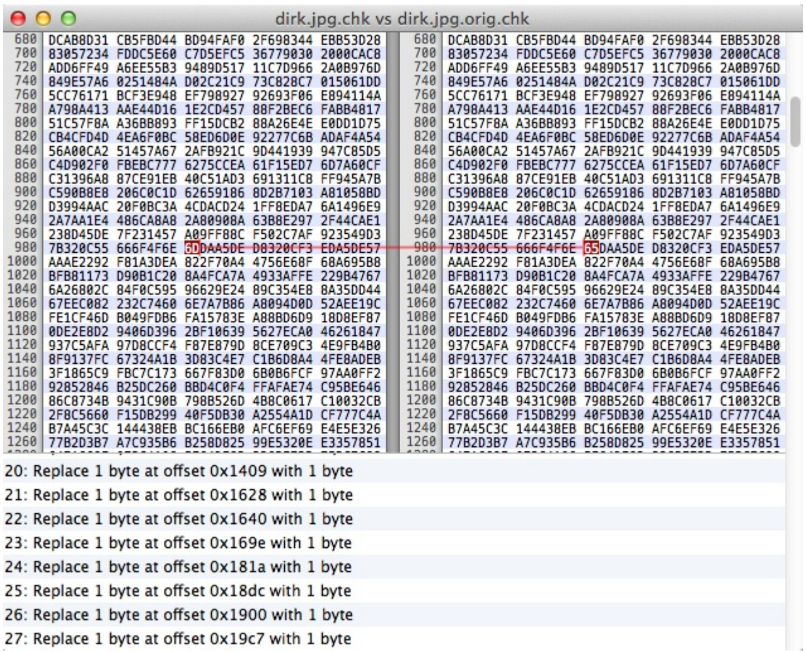
Sep 27, 2017

Contents




dirk.jpg.chk vs dirk.jpg.orig.chk
20: Replace 1 byte at offset 0x1409 with 1 byte
21: Replace 1 byte at offset 0x1628 with 1 byte
22: Replace 1 byte at offset 0x1640 with 1 byte
23: Replace 1 byte at offset 0x169e with 1 byte
24: Replace 1 byte at offset 0x181a with 1 byte
25: Replace 1 byte at offset 0x18dc with 1 byte
26: Replace 1 byte at offset 0x1900 with 1 byte
27: Replace 1 byte at offset 0x19c7 with 1 byte

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CHAPTER 1

ABOUT

Data in various stages of decay and salvation

When you store TeraBytes of data for many years, some bits in it will decay. It is hard to get figures about how much damage we can expect. But it might be in the order of a handful per TB per year.

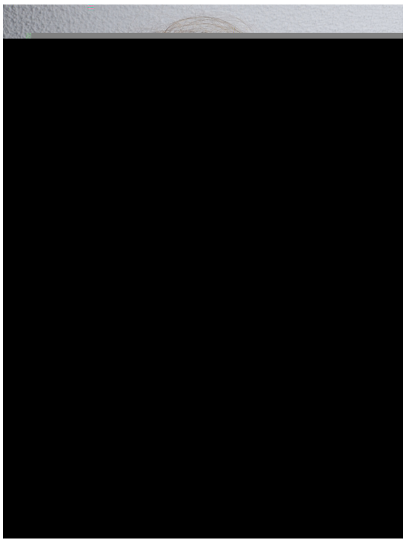
How do we recover from it? Here is an elegant method. Add some redundancy, in the form of checksums. Periodically check the checksums. When there are errors, use the checksums to correct the errors, if possible. If it is not possible, use a backup. But beware: the backup might have errors as well. Even the checksums themselves might have errors. Before we explain our strategy, here is an example that it actually works.

1. original

We start with a photo of the author. It is a 436 KB jpeg image. This is indeed the uncorrupted form.

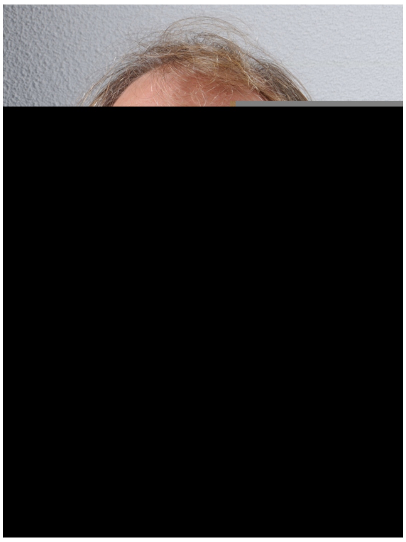
2. 174 bit errors

Now 174 bit errors are added, at random positions



3. 104 errors in the backup

We will also use a backup, but also this one is corrupted: 104 different errors



4-5. 27 + 16 bit errors in the checksum files

We also corrupt the checksums: 27 bit errors

```
Info: /Users/dirk/Scratch/dirk.jpg.chk has 55936 bits
Need to generate 27 bit errors for [/Users/dirk/Scratch/dirk.jpg.chk]
```

```
dirk.jpg.chk vs dirk.jpg.orig.chk
 680  DCAB8D31 CB5FBD44 BD94FAF0 2F698344 EBB53D28 |  680  DCAB8D31 CB5FBD44 BD94FAF0 2F698344 EBB53D28
 700  83057234 FDDC5E60 C7D5EFC5 36779030 2000CAC8 |  700  83057234 FDDC5E60 C7D5EFC5 36779030 2000CAC8
 720  ADD6FF49 A6EE55B3 9489D517 11C7D966 2A0B976D |  720  ADD6FF49 A6EE55B3 9489D517 11C7D966 2A0B976D
 740  849E57A6 0251484A D02C21C9 73C828C7 015061DD |  740  849E57A6 0251484A D02C21C9 73C828C7 015061DD
 760  5CC76171 BCF3E948 EF798927 92693F06 E894114A |  760  5CC76171 BCF3E948 EF798927 92693F06 E894114A
 780  A798A413 AAE44D16 1E2CD457 88F2BEC6 FABB4817 |  780  A798A413 AAE44D16 1E2CD457 88F2BEC6 FABB4817
 800  51C57F8A A36BB893 FF15DCB2 88A26E4E E0DD1D75 |  800  51C57F8A A36BB893 FF15DCB2 88A26E4E E0DD1D75
 820  CB4CFD4D 4EA6F0BC 58ED6D0E 92277C6B ADAF4A54 |  820  CB4CFD4D 4EA6F0BC 58ED6D0E 92277C6B ADAF4A54
 840  56A00CA2 51457A67 2AFB921C 9D441939 947C85D5 |  840  56A00CA2 51457A67 2AFB921C 9D441939 947C85D5
 860  C4D902F0 FBEBC777 6275CCEA 61F15ED7 6D7A60CF |  860  C4D902F0 FBEBC777 6275CCEA 61F15ED7 6D7A60CF
 880  C31396A8 87CE91EB 40C51AD3 691311C8 FF945A7B |  880  C31396A8 87CE91EB 40C51AD3 691311C8 FF945A7B
 900  C590B8E8 206C0C1D 62659186 8D2B7103 A81058BD |  900  C590B8E8 206C0C1D 62659186 8D2B7103 A81058BD
 920  D3994AAC 20F0BC3A 4CDACD24 1FF8EDA7 6A1496E9 |  920  D3994AAC 20F0BC3A 4CDACD24 1FF8EDA7 6A1496E9
 940  2A7AA1E4 486CA8A8 2A80908A 63B8E297 2F44CAE1 |  940  2A7AA1E4 486CA8A8 2A80908A 63B8E297 2F44CAE1
 960  238D45DE 7F231457 A09FF88C F502C7AF 923549D3 |  960  238D45DE 7F231457 A09FF88C F502C7AF 923549D3
 980  7B320C55 666F4F6E 6DDAA5DE D8320CF3 EDA5DE57 |  980  7B320C55 666F4F6E 65DAA5DE D8320CF3 EDA5DE57
1000  AAAE2292 F81A3DEA 822F70A4 4756E68F 68A695B8 | 1000  AAAE2292 F81A3DEA 822F70A4 4756E68F 68A695B8
1020  BFB81173 D90B1C20 8A4FCA7A 4933AFFE 229B4767 | 1020  BFB81173 D90B1C20 8A4FCA7A 4933AFFE 229B4767
1040  6A26802C 84F0C595 96629E24 89C354E8 8A35DD44 | 1040  6A26802C 84F0C595 96629E24 89C354E8 8A35DD44
1060  67EEC082 232C7460 6E7A7B86 A8094D0D 52AEE19C | 1060  67EEC082 232C7460 6E7A7B86 A8094D0D 52AEE19C
1080  FE1CF46D B049FDB6 FA15783E A88BD6D9 18D8EF87 | 1080  FE1CF46D B049FDB6 FA15783E A88BD6D9 18D8EF87
1100  0DE2E8D2 9406D396 2BF10639 5627ECA0 46261847 | 1100  0DE2E8D2 9406D396 2BF10639 5627ECA0 46261847
1120  937C5AFA 97D8CCF4 F87E879D 8CE709C3 4E9FB4B0 | 1120  937C5AFA 97D8CCF4 F87E879D 8CE709C3 4E9FB4B0
1140  8F9137FC 67324A1B 3D83C4E7 C1B6D8A4 4FE8ADEB | 1140  8F9137FC 67324A1B 3D83C4E7 C1B6D8A4 4FE8ADEB
1160  3F1865C9 FBC7C173 667F83D0 6B0B6FCF 97AA0FF2 | 1160  3F1865C9 FBC7C173 667F83D0 6B0B6FCF 97AA0FF2
1180  92852846 B25DC260 BBD4C0F4 FFAFAE74 C95BE646 | 1180  92852846 B25DC260 BBD4C0F4 FFAFAE74 C95BE646
1200  86C8734B 9431C90B 798B526D 4B8C0617 C10032CB | 1200  86C8734B 9431C90B 798B526D 4B8C0617 C10032CB
1220  2F8C5660 F15DB299 40F5DB30 A2554A1D CF777C4A | 1220  2F8C5660 F15DB299 40F5DB30 A2554A1D CF777C4A
1240  B7A45C3C 144438EB BC166EB0 AFC6EF69 E4E5E326 | 1240  B7A45C3C 144438EB BC166EB0 AFC6EF69 E4E5E326
1260  77B2D3B7 A7C935B6 B258D825 99E5320E E3357851 | 1260  77B2D3B7 A7C935B6 B258D825 99E5320E E3357851

20: Replace 1 byte at offset 0x1409 with 1 byte
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26: Replace 1 byte at offset 0x1900 with 1 byte
27: Replace 1 byte at offset 0x19c7 with 1 byte
```

and the checksums of the backup are not spared either: 16 bit errors

```
Info: /Users/dirk/Scratch/dirk-bu.jpg.chk has 55936 bits
Need to generate 16 bit errors for [/Users/dirk/Scratch/dirk-bu.jpg.chk]
```

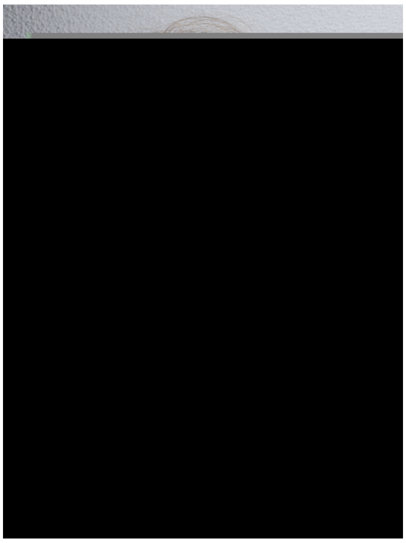
6. checking the corrupt image with the corrupt checksums

we get 163 damaged blocks

```
Info: Verification results:
        Total blocks: 436
        Good blocks: 273
        Damaged blocks: 163
```

7. after repairing 138 and leaving 25 bit errors

First we try to repair without using the backup, we can repair the majority of damaged blocks, 138.



But 25 remain unrepaired. See the result.

```
Info: Repair results:
        Repaired blocks: 138
        Unrepaired blocks: 25
        Suspicion level: 0
```

Let us again check the checksums. 50 damaged blocks! But remember that the checksums themselves were faulty!

```
Info: Verification results:
        Total blocks: 436
        Good blocks: 386
        Damaged blocks: 50
```

Yet, by a combination of restoring and repairing it is effectively possible to correct all errors.

8. We need to use the backup

```
Info: Restore results:
        Restored blocks: 50
        Unrestored blocks: 0
        Suspicion level: 0
```

9. fully restored, thank you

10. There are absolutely no errors left

```
dirk:~/Scratch > diff -s dirk-orig.jpg dirk-restored.jpg
Files dirk-orig.jpg and dirk-restored.jpg are identical
```

Account

This story I wrote on Good Friday, 2013-03-29. All data and screenshots were directly taken from the computer when I executed the process as described above. By the way, that was a Macbook Air, and the whole process is expressed in a Perl script, which only uses the module Digest:MD5. Both Perl and this module are already present in OSX.

Contents

After that, I have tested extensively. The code for this lab is in Github. It is a tool for checksumming files in such a way that you can recover from errors. It also does the recovering. Besides, it is an environment to test various checksumming algorithms and parameters to see what performs best. You find also test data of a few dozens of experiments, summarized in an excel document. The code is here (Perl).

There is a program for checksumming files, verifying, repairing and restoring: *checksum.pl*.

Then there is a setup to do experiments: *perfset.pl* creates a pool of corrupt file and organizes tests of various checksum methods.

The question is: wich checksum methods *perform* best in the brute force search for the original byte sequence?

In order to make file corrupt, you can run *corrupt.pl* with a variety of parameters.

To gather the results of a series of experiments, use *gather.pl*. It creates a csv file, that you can use to create nice graphics in a spreadsheet program.

CHAPTER 2

checksum.pl

Description

This tool is an instrument in bit preservation of (large) files. It is estimated that if one reads 10 TB from disk, 1 bit will be in error. Also, when 1 TB is stored for a year without touching it, some bits might be damaged by random physical events such as radiation.

In order to bit-peserve large files for longer periods of time (years, decades), it becomes important to guard against data loss.

While there is no profound solution to this problem, the following stratgegy counts as best practice.

- Make several copies
- Divide the file and their copies in chuncks and compute checksums of the chunks
- periodically check checksums and restore damaged blocks from copies where the corresponding block is undamaged.

Checksum.pl is a script to compute checksums for files, to verify checksums, and to repair corrupted file by means of brute force searching, or if that is not feasible, by restoring from backup copies, even if those are corrupt themselves. It works even when the checksums themselves are corrupt.

It al depends on the damage being not too big.

Usage

Call the script like this:

```
./checksum.pl [-v] [-m method] [-t task]* [--conf kind=path]* --data kind=path
↪[backupfile] [origfile] [corruptfile]
```

where

```
-v                        verbose operation
method          key of %config_checksum
task            member of:
                                generate
                                verify
```

```
                                repair
                                restore
                                restore_ambi_no
                                restore_ambi_only
                                execute_repair
                                execute_restore
                                diag

conf:
        kind    key of %files
        path    will replace the name value in %files

data
        kind    key of %datafile
        path    path to a file on the file system
```

This script can generate checksums, verify them, and perform repair and restore from backup. The verification step produces a file with mismatches, if present. The repair and restore steps look at the file with mismatches and then try to find out how to repair those mismatches. The result is writen to a file with instructions. An execute step reads those instructions and executes them, actually changing the data file. The checksum files are not modified. They can easily be recomputed again.

All intermediate files (also those with the generated checksums) are binary: all data consists of fixed length strings, 64-bit integers, or fixed-size blocks of binary data. All these files have a header, indicating the checksum method used, as well as the data block size and the checksum length.

With arguments like *file:kind=path* you can overrule the locations and names (but not extensions) of all files that are read and written to. The kind part must occur as key in the *%files* hash.

Generating

Command:

```
./checksum.pl file
```

Generates checksums for (large) files, block by block. The size of a block is configured to 1_000 bytes. The main reason to keep it fairly small is to be able to do brute force guessing when a checksum is found not to agree anymore with a datablock.

By generating many slight bit errors in the datablock as well as the checksum, and then searching for a valid combination of datablock and checksum, we can be nearly completely sure that we have the original datablock and checksum back.

The file with checksums has the same name as the input file, but with *.chk* appended to it.

Verifying

Command:

```
./checksum.pl -v file
```

Verifies given checksums. It expects next to the input file a *file.chk* with checksums, in the format indicated above. It then extracts from file each block as specified in *file.chk*, computes its checksum and compares it to the given checksum.

If there are checksum errors, references to the blocks in error are written to an error file, with name *file.x* . This file contains records of mismatch information. Such a record consists of just the block number, the given checksum, and the computed checksum.

If there are no errors, the *file.x* will not be present. If it existed, it will be deleted.

Repairing

Command:

```
./checksum.pl -c file
```

Looks at checksum mismatches. In every case, modifies checksum and corresponding blocks in many small ways, until the combination matches again. Both block and checksum are dithered. That means, a frame of at most n bits wide moves over the data, and inside the frame the bits are mangled in all possible ways. The dither results of the checksum are stored in a hash. The dithered blocks are not stored. They are generated on the fly, their checksum is computed, and quickly tested against the hash of checksums. If there is a hit, it will be stored. If there are no hits, repair is not possible by the current method. You might try further by increasing the frame width, or by trying other kinds of variants of the block. But maybe it is better to forget this method and try to restore from backup in such cases. If there are multiple hits, that would be a weird situation. Maybe there has been intentional tampering. The program will give clear warnings in these cases.

The repair instructions are written to *file.ri*

Restoring

Command:

```
./checksum.pl -r[a|A] file file-backup
```

Compares blocks and checksums of data and backup. The bit positions where they differ, will be varied among all possibilities. The checksums are stored in a hash for easy lookup. Then the blocks will be generated on the fly. So even if the backup is damaged, and even if the checksums are all damaged, it is still possible by brute force search to find the original data back. If data and backup differ in less than 20 bits per block, there are only a million possibilities per block to be searched. If called with -rA only the blocks for which repair found multiple hits will be restored (not the ones without hits) If called with -ra both the blocks for which repair found multiple hits and no hits will be restored

The restore instructions are written *file.rib*

Executing

Commands:

```
./checksum.pl -ec file
./checksum.pl -er file
```

Executes the repair resp. restore instructions in *file.ri* resp. *file.rib* All information needed from the backup file is already in the instruction file, so the backup file itself is not needed here. The work has been done in the previous steps, this step only performs the write actions in the file.

Diagnostics

Command:

```
./checksum.pl -dia file backupfile origfile corruptfile
```

Creates a diagnostic report of the repair and restore instructions. It takes as second argument the backup file and as third argument the original file and as fourth argument the unrestored/unrepaired corrupted file. It gives all info about the blocks which have not been restored correctly. On the basis of this information it shows which instructions helped to correctly get the original back, and which instructions were faulty.

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See also DANS Lab Bit rot and recovery

Configuration

In order to compare performance between md5 and sha256 hashing we provide two standard configurations, which can be invoked by the command line flag `-m`:

```
-m md5
-m sha256
```

invoke the md5 and the sha256 checksum algorithms respectively. The default parameter values for these methods are loaded. It remains possible to overrule these values by means of additional flags on the command line.

The default checksum mode is sha256.

Implementation details

Looking for hits

When measuring how close a "hit" is to the actual situation, the number of different bits in the checksums and in the blocks are counted. However, differences in the checksum count much more than differences in the blocks.

Bit differences in the checksums are far less probable than bit differences in the blocks, because blocks are larger. Moreover, if checksums are very different, it is an indication of tampering: a new checksum has been computed for a slightly altered block. So by default we multiply the checksum bit distance by the $data_checksum_ration. In addition, you can configure to increase or decrease this effect by multiplying with the $check_diff_penalty which is by default 1.

We compare hits with the foreground file, not with the backup. We want a hit that is closest to the foreground, since the foreground has been always under our control, and the backup has been far less in our control.

We want to keep the search effort constant for the different checksum methods. Depending on the blocksize determined by the checksum method, we can set the search parameters in such a way that the prescribed number of search operations will be used.

Binary files and headers

Every binary non-data file we read, is a file generated by this program. Such a file has a header. It will be read and written by the following two functions. It has the format:

```
a8 a8 L L L L
```

where:

```
a8 is arbitrary binary data of 8 bytes. Reserved for a string indicating the␣
↪checksum method
a8 is arbitrary binary data of 8 bytes. Reserved for a string indicating the␣
↪checksum method
L is a long integer (32 bits = 4 bytes), indicating the checksum size
L is a long integer (32 bits = 4 bytes), indicating the checksum size
L is a long integer (32 bits = 4 bytes), indicating the block size
L is a long integer (32 bits = 4 bytes), indicating the block size
```

All together the header is 32 bytes = 256 bits

The header could be damaged. We assume the checksum size and the block size are powers of two. If one of them does not appear a power of two, choose the other. If both are not powers of two, we are stuck. If both are powers of two but different, we are also stuck. Likewise, we choose between the values encountered for the checksummethod.

Reading and Writing files

Opens files for reading, writing, and read-writing. Uses the specification created in the init() function. Returns a file handle in case of succes. The file handle is meant to be stored in global variables. So more than one routine can easily read and write the same file.

Repair block

This function implements a main step: Repair a single block We apply ditherings progressively, in rounds corresponding to the frame length n of the dithering. We start with n = 0, then n = 1 and so on. So the smaller disturbances will be checked first, and we assume that bigger disturbances do not compete with smaller ones. If there are hits in a round, the next rounds will be skipped.

Restore block

now generate the set by creating all possible bit values at the positions where $str1 and $str2 differ in order to optimize the search process, we want to search in such a way that we do cases first where bits are taken consecutively from the data version or the backup version. The reason is that errors come in bursts. Hence, if backup and data differ in bit i and bit i+1, both bits are likely to be correct in either backup or in data. It is much less likely that bit i is correct in data and bit i+1 in backup, or vice versa. So if the max number of brute force operations does not permit full traversal, we do a partial traversal with the most likely suspects first. This will increase the change of finding a good restore.

So we generate all possibile bit strings for the difference mask. We will xor the bits in the mask with the corresponding bits in the data. So we should try bitstrings first with minimal alterations between 1s and 0s.

Dithering

This is the technique used for repairing blocks.

Dithering is subtly mangling a bit string, by introducing a limitied amount of bit errors. We let an imaginary frame of fixed width slide over the bitstring, and inside the frame we generate all possible bit errors.

More precisely, n-dithering is dithering with a frame of exactly width n. And <=n-dithering is dithering with frames of width 1 to n.

If we do n-dithering, we generate bitstrings of length n, and x-or the input bitstring with it, at a reference position that slides throughout the input.

Bit 0 and bit n-1 of an n-frame are always 1. If one or of them would be 0, we would have an n-1 frame, or an n-2 frame, or even less. We would be doing double work then.

Bits 1 up to and including n-2 range over the full set of possible bitstrings of length n-2.

n-ditherings and m ditherings are mutually exclusive when n <> m. This is precisely because the end points are always one, and the endpoints change the input bitstring.

So the number of ditherings with frame length <= n is: 2 ^ (n-1)

Masking

This is the technique used for restoring blocks. When the corresponding block from the backup is fetched, and we have the data block, then in the most general case we do not know which block is right. They could be both wrong. Even the checksums could be all wrong.

We assume however, that the bits in which they agree are correct.

So me make a mask of the differing bits, and we create all bit variations in that mask.

We try them all out by brute force.

So there is good chance that we find a hit, even if all initial data is corrupted.

CHAPTER 3

perfset.pl

Description

Generates a test sets from a base file called dataname-orig in a root directory. The root directory and some other parameters are defined by the experiment. There are several experiments spelled out below, the first argument selects a specific one. An original data file is corrupted and copied to form the starting point of several parts of the test set. Each part correspondes to a checksum method such as md5 or sha256. Corruption is pseudo random, no two corruptions will be the same. From then on both parts will be subjected to checksum tests and error correcting.

Usage

Command:

```
./perfset.sh [-v] [-v] [-d] -e experiment [-tm timestamp]
```

where

```
-v                              verbose rsync, if twice: verbose all
-d                              debug mode when calling perl scripts
-f                              force fresh corruption
-c                              execute the changes and perform final check
-e experiment   key of %experiment
```

CHAPTER 4

corrupt.pl

Description

Corrupts the file with (burst)bit errors. If level is given, it is the desired number of (burst)bit errors per TB. If number is given, it is the desired absolute number of bit errors.

The bit errors are generated at independently randomly chosen positions.

It is also possible to generate burst errors of length at most nbits. A burst error is a sequence of identical bits that will overwrite a sequence of equal length in the input file. The length of the burst is determined randomly and independently but stays below the maximum length. The value of the burst (zeroes or ones) will be determined randomly.

Usage

Command:

```
./corrupt.pl [-s] [-b nbits] [-l level | -n number] --data file*
```

CHAPTER 5

gather.pl

Description

Gather data from experiments

Usage

Command:

```
./gather.pl [-v] [--base reportbasedir]
```

where

```
-v                      verbose rsync, if twice: verbose all
--base          base directory of the reports
```

CHAPTER 6

Indices and tables

- genindex
- modindex
- search