bzip2 and libbzip2, version 1.0.4

A program and library for data compression

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by Julian Seward

PATENTS: To the best of my knowledge, bzip2 and libbzip2 do not use any patented algorithms. However, I do not have the resources to carry out a patent search. Therefore I cannot give any guarantee of the above statement.

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1. Introduction

`bzip2` compresses files using the Burrows-Wheeler block-sorting text compression algorithm, and Huffman coding. Compression is generally considerably better than that achieved by more conventional LZ77/LZ78-based compressors, and approaches the performance of the PPM family of statistical compressors.

`bzip2` is built on top of `libbzip2`, a flexible library for handling compressed data in the `bzip2` format. This manual describes both how to use the program and how to work with the library interface. Most of the manual is devoted to this library, not the program, which is good news if your interest is only in the program.

- How to use bzip2 [2] describes how to use `bzip2`; this is the only part you need to read if you just want to know how to operate the program.
- Programming with libbzip2 [8] describes the programming interfaces in detail, and
- Miscellanea [31] records some miscellaneous notes which I thought ought to be recorded somewhere.

2. How to use bzip2

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This chapter contains a copy of the `bzip2` man page, and nothing else.

2.1. NAME

- `bzip2`, `bunzip2` - a block-sorting file compressor, v1.0.4
- `bzcat` - decompresses files to stdout
- `bzip2recover` - recovers data from damaged bzip2 files

2.2. SYNOPSIS

- `bzip2` [-cdfkqstvzVL123456789] [filenames ...]
- `bunzip2` [-fkvsVL] [filenames ...]
- `bzcat` [-s] [filenames ...]
- `bzip2recover` filename

2.3. DESCRIPTION

bzip2 compresses files using the Burrows-Wheeler block sorting text compression algorithm, and Huffman coding. Compression is generally considerably better than that achieved by more conventional LZ77/LZ78-based compressors, and approaches the performance of the PPM family of statistical compressors.

The command-line options are deliberately very similar to those of GNU gzip, but they are not identical.

bzip2 expects a list of file names to accompany the command-line flags. Each file is replaced by a compressed version of itself, with the name original_name.bz2. Each compressed file has the same modification date, permissions, and, when possible, ownership as the corresponding original, so that these properties can be correctly restored at decompression time. File name handling is naive in the sense that there is no mechanism for preserving original file names, permissions, ownerships or dates in filesystems which lack these concepts, or have serious file name length restrictions, such as MS-DOS.

bzip2 and bunzip2 will by default not overwrite existing files. If you want this to happen, specify the -f flag.

If no file names are specified, bzip2 compresses from standard input to standard output. In this case, bzip2 will decline to write compressed output to a terminal, as this would be entirely incomprehensible and therefore pointless.

bunzip2 (or bzip2 -d) decompresses all specified files. Files which were not created by bzip2 will be detected and ignored, and a warning issued. bzip2 attempts to guess the filename for the decompressed file from that of the compressed file as follows:

- filename.bz2 becomes filename
- filename.bz becomes filename
- filename.tbz2 becomes filename.tar
- filename.tbz becomes filename.tar
- anyothername becomes anyothername.out

If the file does not end in one of the recognised endings, .bz2, .bz, .tbz2 or .tbz, bzip2 complains that it cannot guess the name of the original file, and uses the original name with .out appended.

As with compression, supplying no filenames causes decompression from standard input to standard output.

bunzip2 will correctly decompress a file which is the concatenation of two or more compressed files. The result is the concatenation of the corresponding uncompressed files. Integrity testing (-t) of concatenated compressed files is also supported.

You can also compress or decompress files to the standard output by giving the -c flag. Multiple files may be compressed and decompressed like this. The resulting outputs are fed sequentially to stdout. Compression of multiple files in this manner generates a stream containing multiple compressed file representations. Such a stream can be decompressed correctly only by bzip2 version 0.9.0 or later. Earlier versions of bzip2 will stop after decompressing the first file in the stream.

bzcat (or bzip2 -dc) decompresses all specified files to the standard output.

bzip2 will read arguments from the environment variables BZIP2 and BZIP, in that order, and will process them before any arguments read from the command line. This gives a convenient way to supply default arguments.

Compression is always performed, even if the compressed file is slightly larger than the original. Files of less than about one hundred bytes tend to get larger, since the compression mechanism has a constant overhead in the region of

50 bytes. Random data (including the output of most file compressors) is coded at about 8.05 bits per byte, giving an expansion of around 0.5%.

As a self-check for your protection, `bzip2` uses 32-bit CRCs to make sure that the decompressed version of a file is identical to the original. This guards against corruption of the compressed data, and against undetected bugs in `bzip2` (hopefully very unlikely). The chances of data corruption going undetected is microscopic, about one chance in four billion for each file processed. Be aware, though, that the check occurs upon decompression, so it can only tell you that something is wrong. It can't help you recover the original uncompressed data. You can use `bzip2recover` to try to recover data from damaged files.

Return values: 0 for a normal exit, 1 for environmental problems (file not found, invalid flags, I/O errors, etc.), 2 to indicate a corrupt compressed file, 3 for an internal consistency error (eg, bug) which caused `bzip2` to panic.

2.4. OPTIONS

`-c --stdout`
: Compress or decompress to standard output.

`-d --decompress`
: Force decompression. `bzip2`, `bunzip2` and `bzcat` are really the same program, and the decision about what actions to take is done on the basis of which name is used. This flag overrides that mechanism, and forces bzip2 to decompress.

`-z --compress`
: The complement to `-d`: forces compression, regardless of the invokation name.

`-t --test`
: Check integrity of the specified file(s), but don't decompress them. This really performs a trial decompression and throws away the result.

`-f --force`
: Force overwrite of output files. Normally, `bzip2` will not overwrite existing output files. Also forces `bzip2` to break hard links to files, which it otherwise wouldn't do.

  `bzip2` normally declines to decompress files which don't have the correct magic header bytes. If forced (`-f`), however, it will pass such files through unmodified. This is how GNU `gzip` behaves.

`-k --keep`
: Keep (don't delete) input files during compression or decompression.

`-s --small`
: Reduce memory usage, for compression, decompression and testing. Files are decompressed and tested using a modified algorithm which only requires 2.5 bytes per block byte. This means any file can be decompressed in 2300k of memory, albeit at about half the normal speed.

  During compression, `-s` selects a block size of 200k, which limits memory use to around the same figure, at the expense of your compression ratio. In short, if your machine is low on memory (8 megabytes or less), use `-s` for everything. See MEMORY MANAGEMENT [5] below.

`-q --quiet`
: Suppress non-essential warning messages. Messages pertaining to I/O errors and other critical events will not be suppressed.

`-v --verbose`

Verbose mode -- show the compression ratio for each file processed. Further `-v`'s increase the verbosity level, spewing out lots of information which is primarily of interest for diagnostic purposes.

`-L --license -V --version`

Display the software version, license terms and conditions.

`-1` (or `--fast`) to `-9` (or `-best`)

Set the block size to 100 k, 200 k ... 900 k when compressing. Has no effect when decompressing. See MEMORY MANAGEMENT [5] below. The `--fast` and `--best` aliases are primarily for GNU `gzip` compatibility. In particular, `--fast` doesn't make things significantly faster. And `--best` merely selects the default behaviour.

`--`

Treats all subsequent arguments as file names, even if they start with a dash. This is so you can handle files with names beginning with a dash, for example: `bzip2 -- -myfilename`.

`--repetitive-fast, --repetitive-best`

These flags are redundant in versions 0.9.5 and above. They provided some coarse control over the behaviour of the sorting algorithm in earlier versions, which was sometimes useful. 0.9.5 and above have an improved algorithm which renders these flags irrelevant.

2.5. MEMORY MANAGEMENT

`bzip2` compresses large files in blocks. The block size affects both the compression ratio achieved, and the amount of memory needed for compression and decompression. The flags `-1` through `-9` specify the block size to be 100,000 bytes through 900,000 bytes (the default) respectively. At decompression time, the block size used for compression is read from the header of the compressed file, and `bunzip2` then allocates itself just enough memory to decompress the file. Since block sizes are stored in compressed files, it follows that the flags `-1` to `-9` are irrelevant to and so ignored during decompression.

Compression and decompression requirements, in bytes, can be estimated as:

```
Compression:   400k + ( 8 x block size )

Decompression: 100k + ( 4 x block size ), or
               100k + ( 2.5 x block size )
```

Larger block sizes give rapidly diminishing marginal returns. Most of the compression comes from the first two or three hundred k of block size, a fact worth bearing in mind when using `bzip2` on small machines. It is also important to appreciate that the decompression memory requirement is set at compression time by the choice of block size.

For files compressed with the default 900k block size, `bunzip2` will require about 3700 kbytes to decompress. To support decompression of any file on a 4 megabyte machine, `bunzip2` has an option to decompress using approximately half this amount of memory, about 2300 kbytes. Decompression speed is also halved, so you should use this option only where necessary. The relevant flag is `-s`.

In general, try and use the largest block size memory constraints allow, since that maximises the compression achieved. Compression and decompression speed are virtually unaffected by block size.

Another significant point applies to files which fit in a single block -- that means most files you'd encounter using a large block size. The amount of real memory touched is proportional to the size of the file, since the file is smaller than a block. For example, compressing a file 20,000 bytes long with the flag `-9` will cause the compressor to allocate around 7600k of memory, but only touch 400k + 20000 * 8 = 560 kbytes of it. Similarly, the decompressor will allocate 3700k but only touch 100k + 20000 * 4 = 180 kbytes.

Here is a table which summarises the maximum memory usage for different block sizes. Also recorded is the total compressed size for 14 files of the Calgary Text Compression Corpus totalling 3,141,622 bytes. This column gives some feel for how compression varies with block size. These figures tend to understate the advantage of larger block sizes for larger files, since the Corpus is dominated by smaller files.

```
        Compress   Decompress   Decompress   Corpus
 Flag    usage      usage       -s usage     Size

  -1    1200k       500k         350k      914704
  -2    2000k       900k         600k      877703
  -3    2800k      1300k         850k      860338
  -4    3600k      1700k        1100k      846899
  -5    4400k      2100k        1350k      845160
  -6    5200k      2500k        1600k      838626
  -7    6100k      2900k        1850k      834096
  -8    6800k      3300k        2100k      828642
  -9    7600k      3700k        2350k      828642
```

2.6. RECOVERING DATA FROM DAMAGED FILES

`bzip2` compresses files in blocks, usually 900kbytes long. Each block is handled independently. If a media or transmission error causes a multi-block `.bz2` file to become damaged, it may be possible to recover data from the undamaged blocks in the file.

The compressed representation of each block is delimited by a 48-bit pattern, which makes it possible to find the block boundaries with reasonable certainty. Each block also carries its own 32-bit CRC, so damaged blocks can be distinguished from undamaged ones.

`bzip2recover` is a simple program whose purpose is to search for blocks in `.bz2` files, and write each block out into its own `.bz2` file. You can then use `bzip2 -t` to test the integrity of the resulting files, and decompress those which are undamaged.

`bzip2recover` takes a single argument, the name of the damaged file, and writes a number of files `rec0001file.bz2`, `rec0002file.bz2`, etc, containing the extracted blocks. The output filenames are designed so that the use of wildcards in subsequent processing -- for example, `bzip2 -dc rec*file.bz2 > recovered_data` -- lists the files in the correct order.

`bzip2recover` should be of most use dealing with large `.bz2` files, as these will contain many blocks. It is clearly futile to use it on damaged single-block files, since a damaged block cannot be recovered. If you wish to minimise any potential data loss through media or transmission errors, you might consider compressing with a smaller block size.

2.7. PERFORMANCE NOTES

The sorting phase of compression gathers together similar strings in the file. Because of this, files containing very long runs of repeated symbols, like "aabaabaabaab ..." (repeated several hundred times) may compress more slowly than normal. Versions 0.9.5 and above fare much better than previous versions in this respect. The ratio between worst-case and average-case compression time is in the region of 10:1. For previous versions, this figure was more like 100:1. You can use the `-vvvv` option to monitor progress in great detail, if you want.

Decompression speed is unaffected by these phenomena.

`bzip2` usually allocates several megabytes of memory to operate in, and then charges all over it in a fairly random fashion. This means that performance, both for compressing and decompressing, is largely determined by the speed at which your machine can service cache misses. Because of this, small changes to the code to reduce the miss rate have been observed to give disproportionately large performance improvements. I imagine `bzip2` will perform best on machines with very large caches.

2.8. CAVEATS

I/O error messages are not as helpful as they could be. `bzip2` tries hard to detect I/O errors and exit cleanly, but the details of what the problem is sometimes seem rather misleading.

This manual page pertains to version 1.0.4 of `bzip2`. Compressed data created by this version is entirely forwards and backwards compatible with the previous public releases, versions 0.1pl2, 0.9.0 and 0.9.5, 1.0.0, 1.0.1, 1.0.2 and 1.0.3, but with the following exception: 0.9.0 and above can correctly decompress multiple concatenated compressed files. 0.1pl2 cannot do this; it will stop after decompressing just the first file in the stream.

`bzip2recover` versions prior to 1.0.2 used 32-bit integers to represent bit positions in compressed files, so it could not handle compressed files more than 512 megabytes long. Versions 1.0.2 and above use 64-bit ints on some platforms which support them (GNU supported targets, and Windows). To establish whether or not `bzip2recover` was built with such a limitation, run it without arguments. In any event you can build yourself an unlimited version if you can recompile it with `MaybeUInt64` set to be an unsigned 64-bit integer.

2.9. AUTHOR

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The ideas embodied in `bzip2` are due to (at least) the following people: Michael Burrows and David Wheeler (for the block sorting transformation), David Wheeler (again, for the Huffman coder), Peter Fenwick (for the structured coding model in the original `bzip`, and many refinements), and Alistair Moffat, Radford Neal and Ian Witten (for the arithmetic coder in the original `bzip`). I am much indebted for their help, support and advice. See the manual in the source distribution for pointers to sources of documentation. Christian von Roques encouraged me to look for faster sorting algorithms, so as to speed up compression. Bela Lubkin encouraged me to improve the worst-case compression performance. Donna Robinson XMLised the documentation. Many people sent patches, helped with portability problems, lent machines, gave advice and were generally helpful.

3. Programming with libbzip2

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This chapter describes the programming interface to libbzip2.

For general background information, particularly about memory use and performance aspects, you'd be well advised to read How to use bzip2 [2] as well.

3.1. Top-level structure

libbzip2 is a flexible library for compressing and decompressing data in the bzip2 data format. Although packaged as a single entity, it helps to regard the library as three separate parts: the low level interface, and the high level interface, and some utility functions.

The structure of libbzip2's interfaces is similar to that of Jean-loup Gailly's and Mark Adler's excellent zlib library.

All externally visible symbols have names beginning BZ2_. This is new in version 1.0. The intention is to minimise pollution of the namespaces of library clients.

To use any part of the library, you need to #include <bzlib.h> into your sources.

3.1.1. Low-level summary

This interface provides services for compressing and decompressing data in memory. There's no provision for dealing with files, streams or any other I/O mechanisms, just straight memory-to-memory work. In fact, this part of the library can be compiled without inclusion of stdio.h, which may be helpful for embedded applications.

The low-level part of the library has no global variables and is therefore thread-safe.

Six routines make up the low level interface: BZ2_bzCompressInit, BZ2_bzCompress, and BZ2_bzCompressEnd for compression, and a corresponding trio BZ2_bzDecompressInit, BZ2_bzDecompress and BZ2_bzDecompressEnd for decompression. The *Init functions allocate memory for compression/decompression and do other initialisations, whilst the *End functions close down operations and release memory.

The real work is done by BZ2_bzCompress and BZ2_bzDecompress. These compress and decompress data from a user-supplied input buffer to a user-supplied output buffer. These buffers can be any size; arbitrary quantities of data are handled by making repeated calls to these functions. This is a flexible mechanism allowing a consumer-pull style of activity, or producer-push, or a mixture of both.

3.1.2. High-level summary

This interface provides some handy wrappers around the low-level interface to facilitate reading and writing bzip2 format files (.bz2 files). The routines provide hooks to facilitate reading files in which the bzip2 data stream is embedded within some larger-scale file structure, or where there are multiple bzip2 data streams concatenated end-to-end.

For reading files, BZ2_bzReadOpen, BZ2_bzRead, BZ2_bzReadClose and BZ2_bzReadGetUnused are supplied. For writing files, BZ2_bzWriteOpen, BZ2_bzWrite and BZ2_bzWriteFinish are available.

As with the low-level library, no global variables are used so the library is per se thread-safe. However, if I/O errors occur whilst reading or writing the underlying compressed files, you may have to consult errno to determine the cause of the error. In that case, you'd need a C library which correctly supports errno in a multithreaded environment.

To make the library a little simpler and more portable, BZ2_bzReadOpen and BZ2_bzWriteOpen require you to pass them file handles (FILE*s) which have previously been opened for reading or writing respectively. That avoids portability problems associated with file operations and file attributes, whilst not being much of an imposition on the programmer.

3.1.3. Utility functions summary

For very simple needs, BZ2_bzBuffToBuffCompress and BZ2_bzBuffToBuffDecompress are provided. These compress data in memory from one buffer to another buffer in a single function call. You should assess whether these functions fulfill your memory-to-memory compression/decompression requirements before investing effort in understanding the more general but more complex low-level interface.

Yoshioka Tsuneo (tsuneo@rr.iij4u.or.jp) has contributed some functions to give better zlib compatibility. These functions are BZ2_bzopen, BZ2_bzread, BZ2_bzwrite, BZ2_bzflush, BZ2_bzclose, BZ2_bzerror and BZ2_bzlibVersion. You may find these functions more convenient for simple file reading and writing, than those in the high-level interface. These functions are not (yet) officially part of the library, and are minimally documented here. If they break, you get to keep all the pieces. I hope to document them properly when time permits.

Yoshioka also contributed modifications to allow the library to be built as a Windows DLL.

3.2. Error handling

The library is designed to recover cleanly in all situations, including the worst-case situation of decompressing random data. I'm not 100% sure that it can always do this, so you might want to add a signal handler to catch segmentation violations during decompression if you are feeling especially paranoid. I would be interested in hearing more about the robustness of the library to corrupted compressed data.

Version 1.0.3 more robust in this respect than any previous version. Investigations with Valgrind (a tool for detecting problems with memory management) indicate that, at least for the few files I tested, all single-bit errors in the decompressed data are caught properly, with no segmentation faults, no uses of uninitialised data, no out of range reads or writes, and no infinite looping in the decompressor. So it's certainly pretty robust, although I wouldn't claim it to be totally bombproof.

The file `bzlib.h` contains all definitions needed to use the library. In particular, you should definitely not include `bzlib_private.h`.

In `bzlib.h`, the various return values are defined. The following list is not intended as an exhaustive description of the circumstances in which a given value may be returned -- those descriptions are given later. Rather, it is intended to convey the rough meaning of each return value. The first five actions are normal and not intended to denote an error situation.

`BZ_OK`
: The requested action was completed successfully.

`BZ_RUN_OK, BZ_FLUSH_OK, BZ_FINISH_OK`
: In `BZ2_bzCompress`, the requested flush/finish/nothing-special action was completed successfully.

`BZ_STREAM_END`
: Compression of data was completed, or the logical stream end was detected during decompression.

The following return values indicate an error of some kind.

`BZ_CONFIG_ERROR`
: Indicates that the library has been improperly compiled on your platform -- a major configuration error. Specifically, it means that `sizeof(char)`, `sizeof(short)` and `sizeof(int)` are not 1, 2 and 4 respectively, as they should be. Note that the library should still work properly on 64-bit platforms which follow the LP64 programming model -- that is, where `sizeof(long)` and `sizeof(void*)` are 8. Under LP64, `sizeof(int)` is still 4, so `libbzip2`, which doesn't use the `long` type, is OK.

`BZ_SEQUENCE_ERROR`
: When using the library, it is important to call the functions in the correct sequence and with data structures (buffers etc) in the correct states. `libbzip2` checks as much as it can to ensure this is happening, and returns `BZ_SEQUENCE_ERROR` if not. Code which complies precisely with the function semantics, as detailed below, should never receive this value; such an event denotes buggy code which you should investigate.

`BZ_PARAM_ERROR`
: Returned when a parameter to a function call is out of range or otherwise manifestly incorrect. As with `BZ_SEQUENCE_ERROR`, this denotes a bug in the client code. The distinction between `BZ_PARAM_ERROR` and `BZ_SEQUENCE_ERROR` is a bit hazy, but still worth making.

BZ_MEM_ERROR

Returned when a request to allocate memory failed. Note that the quantity of memory needed to decompress a stream cannot be determined until the stream's header has been read. So BZ2_bzDecompress and BZ2_bzRead may return BZ_MEM_ERROR even though some of the compressed data has been read. The same is not true for compression; once BZ2_bzCompressInit or BZ2_bzWriteOpen have successfully completed, BZ_MEM_ERROR cannot occur.

BZ_DATA_ERROR

Returned when a data integrity error is detected during decompression. Most importantly, this means when stored and computed CRCs for the data do not match. This value is also returned upon detection of any other anomaly in the compressed data.

BZ_DATA_ERROR_MAGIC

As a special case of BZ_DATA_ERROR, it is sometimes useful to know when the compressed stream does not start with the correct magic bytes ('B' 'Z' 'h').

BZ_IO_ERROR

Returned by BZ2_bzRead and BZ2_bzWrite when there is an error reading or writing in the compressed file, and by BZ2_bzReadOpen and BZ2_bzWriteOpen for attempts to use a file for which the error indicator (viz, ferror(f)) is set. On receipt of BZ_IO_ERROR, the caller should consult errno and/or perror to acquire operating-system specific information about the problem.

BZ_UNEXPECTED_EOF

Returned by BZ2_bzRead when the compressed file finishes before the logical end of stream is detected.

BZ_OUTBUFF_FULL

Returned by BZ2_bzBuffToBuffCompress and BZ2_bzBuffToBuffDecompress to indicate that the output data will not fit into the output buffer provided.

3.3. Low-level interface

3.3.1. BZ2_bzCompressInit

```
typedef struct {
  char *next_in;
  unsigned int avail_in;
  unsigned int total_in_lo32;
  unsigned int total_in_hi32;

  char *next_out;
  unsigned int avail_out;
  unsigned int total_out_lo32;
  unsigned int total_out_hi32;

  void *state;

  void *(*bzalloc)(void *,int,int);
  void (*bzfree)(void *,void *);
  void *opaque;
} bz_stream;

int BZ2_bzCompressInit ( bz_stream *strm,
                         int blockSize100k,
                         int verbosity,
                         int workFactor );
```

Prepares for compression. The `bz_stream` structure holds all data pertaining to the compression activity. A `bz_stream` structure should be allocated and initialised prior to the call. The fields of `bz_stream` comprise the entirety of the user-visible data. `state` is a pointer to the private data structures required for compression.

Custom memory allocators are supported, via fields `bzalloc`, `bzfree`, and `opaque`. The value `opaque` is passed to as the first argument to all calls to `bzalloc` and `bzfree`, but is otherwise ignored by the library. The call `bzalloc ( opaque, n, m )` is expected to return a pointer `p` to `n * m` bytes of memory, and `bzfree ( opaque, p )` should free that memory.

If you don't want to use a custom memory allocator, set `bzalloc`, `bzfree` and `opaque` to `NULL`, and the library will then use the standard `malloc` / `free` routines.

Before calling `BZ2_bzCompressInit`, fields `bzalloc`, `bzfree` and `opaque` should be filled appropriately, as just described. Upon return, the internal state will have been allocated and initialised, and `total_in_lo32`, `total_in_hi32`, `total_out_lo32` and `total_out_hi32` will have been set to zero. These four fields are used by the library to inform the caller of the total amount of data passed into and out of the library, respectively. You should not try to change them. As of version 1.0, 64-bit counts are maintained, even on 32-bit platforms, using the `_hi32` fields to store the upper 32 bits of the count. So, for example, the total amount of data in is `(total_in_hi32 << 32) + total_in_lo32`.

Parameter `blockSize100k` specifies the block size to be used for compression. It should be a value between 1 and 9 inclusive, and the actual block size used is 100000 x this figure. 9 gives the best compression but takes most memory.

Parameter `verbosity` should be set to a number between 0 and 4 inclusive. 0 is silent, and greater numbers give increasingly verbose monitoring/debugging output. If the library has been compiled with `-DBZ_NO_STDIO`, no such output will appear for any verbosity setting.

Parameter `workFactor` controls how the compression phase behaves when presented with worst case, highly repetitive, input data. If compression runs into difficulties caused by repetitive data, the library switches from the standard sorting algorithm to a fallback algorithm. The fallback is slower than the standard algorithm by perhaps a factor of three, but always behaves reasonably, no matter how bad the input.

Lower values of workFactor reduce the amount of effort the standard algorithm will expend before resorting to the fallback. You should set this parameter carefully; too low, and many inputs will be handled by the fallback algorithm and so compress rather slowly, too high, and your average-to-worst case compression times can become very large. The default value of 30 gives reasonable behaviour over a wide range of circumstances.

Allowable values range from 0 to 250 inclusive. 0 is a special case, equivalent to using the default value of 30.

Note that the compressed output generated is the same regardless of whether or not the fallback algorithm is used.

Be aware also that this parameter may disappear entirely in future versions of the library. In principle it should be possible to devise a good way to automatically choose which algorithm to use. Such a mechanism would render the parameter obsolete.

Possible return values:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if strm is NULL
  or blockSize < 1 or blockSize > 9
  or verbosity < 0 or verbosity > 4
  or workFactor < 0 or workFactor > 250
BZ_MEM_ERROR
  if not enough memory is available
BZ_OK
  otherwise
```

Allowable next actions:

```
BZ2_bzCompress
  if BZ_OK is returned
  no specific action needed in case of error
```

3.3.2. BZ2_bzCompress

```
int BZ2_bzCompress ( bz_stream *strm, int action );
```

Provides more input and/or output buffer space for the library. The caller maintains input and output buffers, and calls BZ2_bzCompress to transfer data between them.

Before each call to BZ2_bzCompress, next_in should point at the data to be compressed, and avail_in should indicate how many bytes the library may read. BZ2_bzCompress updates next_in, avail_in and total_in to reflect the number of bytes it has read.

Similarly, next_out should point to a buffer in which the compressed data is to be placed, with avail_out indicating how much output space is available. BZ2_bzCompress updates next_out, avail_out and total_out to reflect the number of bytes output.

You may provide and remove as little or as much data as you like on each call of BZ2_bzCompress. In the limit, it is acceptable to supply and remove data one byte at a time, although this would be terribly inefficient. You should always ensure that at least one byte of output space is available at each call.

A second purpose of BZ2_bzCompress is to request a change of mode of the compressed stream.

Conceptually, a compressed stream can be in one of four states: IDLE, RUNNING, FLUSHING and FINISHING. Before initialisation (BZ2_bzCompressInit) and after termination (BZ2_bzCompressEnd), a stream is regarded as IDLE.

Upon initialisation (BZ2_bzCompressInit), the stream is placed in the RUNNING state. Subsequent calls to BZ2_bzCompress should pass BZ_RUN as the requested action; other actions are illegal and will result in BZ_SEQUENCE_ERROR.

At some point, the calling program will have provided all the input data it wants to. It will then want to finish up -- in effect, asking the library to process any data it might have buffered internally. In this state, BZ2_bzCompress will no longer attempt to read data from next_in, but it will want to write data to next_out. Because the output buffer supplied by the user can be arbitrarily small, the finishing-up operation cannot necessarily be done with a single call of BZ2_bzCompress.

Instead, the calling program passes BZ_FINISH as an action to BZ2_bzCompress. This changes the stream's state to FINISHING. Any remaining input (ie, next_in[0 .. avail_in-1]) is compressed and transferred to the output buffer. To do this, BZ2_bzCompress must be called repeatedly until all the output has been consumed. At that point, BZ2_bzCompress returns BZ_STREAM_END, and the stream's state is set back to IDLE. BZ2_bzCompressEnd should then be called.

Just to make sure the calling program does not cheat, the library makes a note of avail_in at the time of the first call to BZ2_bzCompress which has BZ_FINISH as an action (ie, at the time the program has announced its intention to not supply any more input). By comparing this value with that of avail_in over subsequent calls to BZ2_bzCompress, the library can detect any attempts to slip in more data to compress. Any calls for which this is detected will return BZ_SEQUENCE_ERROR. This indicates a programming mistake which should be corrected.

Instead of asking to finish, the calling program may ask BZ2_bzCompress to take all the remaining input, compress it and terminate the current (Burrows-Wheeler) compression block. This could be useful for error control purposes. The mechanism is analogous to that for finishing: call BZ2_bzCompress with an action of BZ_FLUSH, remove output data, and persist with the BZ_FLUSH action until the value BZ_RUN is returned. As with finishing, BZ2_bzCompress detects any attempt to provide more input data once the flush has begun.

Once the flush is complete, the stream returns to the normal RUNNING state.

This all sounds pretty complex, but isn't really. Here's a table which shows which actions are allowable in each state, what action will be taken, what the next state is, and what the non-error return values are. Note that you can't explicitly ask what state the stream is in, but nor do you need to -- it can be inferred from the values returned by BZ2_bzCompress.

```
IDLE/any
  Illegal.  IDLE state only exists after BZ2_bzCompressEnd or
  before BZ2_bzCompressInit.
  Return value = BZ_SEQUENCE_ERROR

RUNNING/BZ_RUN
  Compress from next_in to next_out as much as possible.
  Next state = RUNNING
  Return value = BZ_RUN_OK

RUNNING/BZ_FLUSH
  Remember current value of next_in. Compress from next_in
  to next_out as much as possible, but do not accept any more input.
  Next state = FLUSHING
  Return value = BZ_FLUSH_OK

RUNNING/BZ_FINISH
  Remember current value of next_in. Compress from next_in
  to next_out as much as possible, but do not accept any more input.
  Next state = FINISHING
  Return value = BZ_FINISH_OK

FLUSHING/BZ_FLUSH
  Compress from next_in to next_out as much as possible,
  but do not accept any more input.
  If all the existing input has been used up and all compressed
  output has been removed
    Next state = RUNNING; Return value = BZ_RUN_OK
  else
    Next state = FLUSHING; Return value = BZ_FLUSH_OK

FLUSHING/other
  Illegal.
  Return value = BZ_SEQUENCE_ERROR

FINISHING/BZ_FINISH
  Compress from next_in to next_out as much as possible,
  but to not accept any more input.
  If all the existing input has been used up and all compressed
  output has been removed
    Next state = IDLE; Return value = BZ_STREAM_END
  else
    Next state = FINISHING; Return value = BZ_FINISH_OK

FINISHING/other
  Illegal.
  Return value = BZ_SEQUENCE_ERROR
```

That still looks complicated? Well, fair enough. The usual sequence of calls for compressing a load of data is:

1. Get started with `BZ2_bzCompressInit`.

2. Shovel data in and shlurp out its compressed form using zero or more calls of `BZ2_bzCompress` with action = `BZ_RUN`.

3. Finish up. Repeatedly call `BZ2_bzCompress` with action = `BZ_FINISH`, copying out the compressed output, until `BZ_STREAM_END` is returned.

4. Close up and go home. Call `BZ2_bzCompressEnd`.

If the data you want to compress fits into your input buffer all at once, you can skip the calls of `BZ2_bzCompress ( ..., BZ_RUN )` and just do the `BZ2_bzCompress ( ..., BZ_FINISH )` calls.

All required memory is allocated by `BZ2_bzCompressInit`. The compression library can accept any data at all (obviously). So you shouldn't get any error return values from the `BZ2_bzCompress` calls. If you do, they will be `BZ_SEQUENCE_ERROR`, and indicate a bug in your programming.

Trivial other possible return values:

```
BZ_PARAM_ERROR
  if strm is NULL, or strm->s is NULL
```

3.3.3. BZ2_bzCompressEnd

```
int BZ2_bzCompressEnd ( bz_stream *strm );
```

Releases all memory associated with a compression stream.

Possible return values:

```
BZ_PARAM_ERROR  if strm is NULL or strm->s is NULL
BZ_OK          otherwise
```

3.3.4. BZ2_bzDecompressInit

```
int BZ2_bzDecompressInit ( bz_stream *strm, int verbosity, int small );
```

Prepares for decompression. As with `BZ2_bzCompressInit`, a `bz_stream` record should be allocated and initialised before the call. Fields `bzalloc`, `bzfree` and `opaque` should be set if a custom memory allocator is required, or made `NULL` for the normal `malloc` / `free` routines. Upon return, the internal state will have been initialised, and `total_in` and `total_out` will be zero.

For the meaning of parameter `verbosity`, see `BZ2_bzCompressInit`.

If `small` is nonzero, the library will use an alternative decompression algorithm which uses less memory but at the cost of decompressing more slowly (roughly speaking, half the speed, but the maximum memory requirement drops to around 2300k). See How to use bzip2 [2] for more information on memory management.

Note that the amount of memory needed to decompress a stream cannot be determined until the stream's header has been read, so even if `BZ2_bzDecompressInit` succeeds, a subsequent `BZ2_bzDecompress` could fail with `BZ_MEM_ERROR`.

Possible return values:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if ( small != 0 && small != 1 )
  or (verbosity <; 0 || verbosity > 4)
BZ_MEM_ERROR
  if insufficient memory is available
```

Allowable next actions:

```
BZ2_bzDecompress
  if BZ_OK was returned
  no specific action required in case of error
```

3.3.5. BZ2_bzDecompress

```
int BZ2_bzDecompress ( bz_stream *strm );
```

Provides more input and/out output buffer space for the library. The caller maintains input and output buffers, and uses `BZ2_bzDecompress` to transfer data between them.

Before each call to `BZ2_bzDecompress`, `next_in` should point at the compressed data, and `avail_in` should indicate how many bytes the library may read. `BZ2_bzDecompress` updates `next_in`, `avail_in` and `total_in` to reflect the number of bytes it has read.

Similarly, `next_out` should point to a buffer in which the uncompressed output is to be placed, with `avail_out` indicating how much output space is available. `BZ2_bzCompress` updates `next_out`, `avail_out` and `total_out` to reflect the number of bytes output.

You may provide and remove as little or as much data as you like on each call of `BZ2_bzDecompress`. In the limit, it is acceptable to supply and remove data one byte at a time, although this would be terribly inefficient. You should always ensure that at least one byte of output space is available at each call.

Use of `BZ2_bzDecompress` is simpler than `BZ2_bzCompress`.

You should provide input and remove output as described above, and repeatedly call `BZ2_bzDecompress` until `BZ_STREAM_END` is returned. Appearance of `BZ_STREAM_END` denotes that `BZ2_bzDecompress` has detected the logical end of the compressed stream. `BZ2_bzDecompress` will not produce `BZ_STREAM_END` until all output data has been placed into the output buffer, so once `BZ_STREAM_END` appears, you are guaranteed to have available all the decompressed output, and `BZ2_bzDecompressEnd` can safely be called.

If case of an error return value, you should call `BZ2_bzDecompressEnd` to clean up and release memory.

Possible return values:

```
BZ_PARAM_ERROR
  if strm is NULL or strm->s is NULL
  or strm->avail_out < 1
BZ_DATA_ERROR
  if a data integrity error is detected in the compressed stream
BZ_DATA_ERROR_MAGIC
  if the compressed stream doesn't begin with the right magic bytes
BZ_MEM_ERROR
  if there wasn't enough memory available
BZ_STREAM_END
  if the logical end of the data stream was detected and all
  output in has been consumed, eg s-->avail_out > 0
BZ_OK
  otherwise
```

Allowable next actions:

```
BZ2_bzDecompress
  if BZ_OK was returned
BZ2_bzDecompressEnd
  otherwise
```

3.3.6. `BZ2_bzDecompressEnd`

```
int BZ2_bzDecompressEnd ( bz_stream *strm );
```

Releases all memory associated with a decompression stream.

Possible return values:

```
BZ_PARAM_ERROR
  if strm is NULL or strm->s is NULL
BZ_OK
  otherwise
```

Allowable next actions:

```
  None.
```

3.4. High-level interface

This interface provides functions for reading and writing `bzip2` format files. First, some general points.

- All of the functions take an `int*` first argument, `bzerror`. After each call, `bzerror` should be consulted first to determine the outcome of the call. If `bzerror` is `BZ_OK`, the call completed successfully, and only then should the return value of the function (if any) be consulted. If `bzerror` is `BZ_IO_ERROR`, there was an error reading/writing the underlying compressed file, and you should then consult `errno` / `perror` to determine the cause of the difficulty. `bzerror` may also be set to various other values; precise details are given on a per-function basis below.

- If bzerror indicates an error (ie, anything except BZ_OK and BZ_STREAM_END), you should immediately call BZ2_bzReadClose (or BZ2_bzWriteClose, depending on whether you are attempting to read or to write) to free up all resources associated with the stream. Once an error has been indicated, behaviour of all calls except BZ2_bzReadClose (BZ2_bzWriteClose) is undefined. The implication is that (1) bzerror should be checked after each call, and (2) if bzerror indicates an error, BZ2_bzReadClose (BZ2_bzWriteClose) should then be called to clean up.

- The FILE* arguments passed to BZ2_bzReadOpen / BZ2_bzWriteOpen should be set to binary mode. Most Unix systems will do this by default, but other platforms, including Windows and Mac, will not. If you omit this, you may encounter problems when moving code to new platforms.

- Memory allocation requests are handled by malloc / free. At present there is no facility for user-defined memory allocators in the file I/O functions (could easily be added, though).

3.4.1. BZ2_bzReadOpen

```
typedef void BZFILE;

BZFILE *BZ2_bzReadOpen( int *bzerror, FILE *f,
                        int verbosity, int small,
                        void *unused, int nUnused );
```

Prepare to read compressed data from file handle f. f should refer to a file which has been opened for reading, and for which the error indicator (ferror(f))is not set. If small is 1, the library will try to decompress using less memory, at the expense of speed.

For reasons explained below, BZ2_bzRead will decompress the nUnused bytes starting at unused, before starting to read from the file f. At most BZ_MAX_UNUSED bytes may be supplied like this. If this facility is not required, you should pass NULL and 0 for unused and nUnused respectively.

For the meaning of parameters small and verbosity, see BZ2_bzDecompressInit.

The amount of memory needed to decompress a file cannot be determined until the file's header has been read. So it is possible that BZ2_bzReadOpen returns BZ_OK but a subsequent call of BZ2_bzRead will return BZ_MEM_ERROR.

Possible assignments to bzerror:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if f is NULL
  or small is neither 0 nor 1
  or ( unused == NULL && nUnused != 0 )
  or ( unused != NULL && !(0 <= nUnused <= BZ_MAX_UNUSED) )
BZ_IO_ERROR
  if ferror(f) is nonzero
BZ_MEM_ERROR
  if insufficient memory is available
BZ_OK
  otherwise.
```

Possible return values:

```
Pointer to an abstract BZFILE
  if bzerror is BZ_OK
NULL
  otherwise
```

Allowable next actions:

```
BZ2_bzRead
  if bzerror is BZ_OK
BZ2_bzClose
  otherwise
```

3.4.2. BZ2_bzRead

```
int BZ2_bzRead ( int *bzerror, BZFILE *b, void *buf, int len );
```

Reads up to len (uncompressed) bytes from the compressed file b into the buffer buf. If the read was successful, bzerror is set to BZ_OK and the number of bytes read is returned. If the logical end-of-stream was detected, bzerror will be set to BZ_STREAM_END, and the number of bytes read is returned. All other bzerror values denote an error.

BZ2_bzRead will supply len bytes, unless the logical stream end is detected or an error occurs. Because of this, it is possible to detect the stream end by observing when the number of bytes returned is less than the number requested. Nevertheless, this is regarded as inadvisable; you should instead check bzerror after every call and watch out for BZ_STREAM_END.

Internally, BZ2_bzRead copies data from the compressed file in chunks of size BZ_MAX_UNUSED bytes before decompressing it. If the file contains more bytes than strictly needed to reach the logical end-of-stream, BZ2_bzRead will almost certainly read some of the trailing data before signalling BZ_SEQUENCE_END. To collect the read but unused data once BZ_SEQUENCE_END has appeared, call BZ2_bzReadGetUnused immediately before BZ2_bzReadClose.

Possible assignments to bzerror:

```
BZ_PARAM_ERROR
  if b is NULL or buf is NULL or len < 0
BZ_SEQUENCE_ERROR
  if b was opened with BZ2_bzWriteOpen
BZ_IO_ERROR
  if there is an error reading from the compressed file
BZ_UNEXPECTED_EOF
  if the compressed file ended before
  the logical end-of-stream was detected
BZ_DATA_ERROR
  if a data integrity error was detected in the compressed stream
BZ_DATA_ERROR_MAGIC
  if the stream does not begin with the requisite header bytes
  (ie, is not a bzip2 data file).  This is really
  a special case of BZ_DATA_ERROR.
BZ_MEM_ERROR
  if insufficient memory was available
BZ_STREAM_END
  if the logical end of stream was detected.
BZ_OK
  otherwise.
```

Possible return values:

```
number of bytes read
  if bzerror is BZ_OK or BZ_STREAM_END
undefined
  otherwise
```

Allowable next actions:

```
collect data from buf, then BZ2_bzRead or BZ2_bzReadClose
  if bzerror is BZ_OK
collect data from buf, then BZ2_bzReadClose or BZ2_bzReadGetUnused
  if bzerror is BZ_SEQUENCE_END
BZ2_bzReadClose
  otherwise
```

3.4.3. BZ2_bzReadGetUnused

```
void BZ2_bzReadGetUnused( int* bzerror, BZFILE *b,
                          void** unused, int* nUnused );
```

Returns data which was read from the compressed file but was not needed to get to the logical end-of-stream. `*unused` is set to the address of the data, and `*nUnused` to the number of bytes. `*nUnused` will be set to a value between `0` and `BZ_MAX_UNUSED` inclusive.

This function may only be called once `BZ2_bzRead` has signalled `BZ_STREAM_END` but before `BZ2_bzReadClose`.

Possible assignments to `bzerror`:

```
BZ_PARAM_ERROR
  if b is NULL
  or unused is NULL or nUnused is NULL
BZ_SEQUENCE_ERROR
  if BZ_STREAM_END has not been signalled
  or if b was opened with BZ2_bzWriteOpen
BZ_OK
  otherwise
```

Allowable next actions:

```
BZ2_bzReadClose
```

3.4.4. BZ2_bzReadClose

```
void BZ2_bzReadClose ( int *bzerror, BZFILE *b );
```

Releases all memory pertaining to the compressed file `b`. `BZ2_bzReadClose` does not call `fclose` on the underlying file handle, so you should do that yourself if appropriate. `BZ2_bzReadClose` should be called to clean up after all error situations.

Possible assignments to `bzerror`:

```
BZ_SEQUENCE_ERROR
  if b was opened with BZ2_bzOpenWrite
BZ_OK
  otherwise
```

Allowable next actions:

```
none
```

3.4.5. BZ2_bzWriteOpen

```
BZFILE *BZ2_bzWriteOpen( int *bzerror, FILE *f,
                         int blockSize100k, int verbosity,
                         int workFactor );
```

Prepare to write compressed data to file handle `f`. `f` should refer to a file which has been opened for writing, and for which the error indicator (`ferror(f)`)is not set.

For the meaning of parameters `blockSize100k`, `verbosity` and `workFactor`, see `BZ2_bzCompressInit`.

All required memory is allocated at this stage, so if the call completes successfully, `BZ_MEM_ERROR` cannot be signalled by a subsequent call to `BZ2_bzWrite`.

Possible assignments to `bzerror`:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if f is NULL
  or blockSize100k < 1 or blockSize100k > 9
BZ_IO_ERROR
  if ferror(f) is nonzero
BZ_MEM_ERROR
  if insufficient memory is available
BZ_OK
  otherwise
```

Possible return values:

```
Pointer to an abstract BZFILE
  if bzerror is BZ_OK
NULL
  otherwise
```

Allowable next actions:

```
BZ2_bzWrite
  if bzerror is BZ_OK
  (you could go directly to BZ2_bzWriteClose, but this would be pretty
pointless)
BZ2_bzWriteClose
  otherwise
```

3.4.6. BZ2_bzWrite

```
void BZ2_bzWrite ( int *bzerror, BZFILE *b, void *buf, int len );
```

Absorbs `len` bytes from the buffer `buf`, eventually to be compressed and written to the file.

Possible assignments to `bzerror`:

```
BZ_PARAM_ERROR
  if b is NULL or buf is NULL or len < 0
BZ_SEQUENCE_ERROR
  if b was opened with BZ2_bzReadOpen
BZ_IO_ERROR
  if there is an error writing the compressed file.
BZ_OK
  otherwise
```

3.4.7. BZ2_bzWriteClose

```
void BZ2_bzWriteClose( int *bzerror, BZFILE* f,
                       int abandon,
                       unsigned int* nbytes_in,
                       unsigned int* nbytes_out );

void BZ2_bzWriteClose64( int *bzerror, BZFILE* f,
                         int abandon,
                         unsigned int* nbytes_in_lo32,
                         unsigned int* nbytes_in_hi32,
                         unsigned int* nbytes_out_lo32,
                         unsigned int* nbytes_out_hi32 );
```

Compresses and flushes to the compressed file all data so far supplied by `BZ2_bzWrite`. The logical end-of-stream markers are also written, so subsequent calls to `BZ2_bzWrite` are illegal. All memory associated with the compressed file `b` is released. `fflush` is called on the compressed file, but it is not `fclose`'d.

If `BZ2_bzWriteClose` is called to clean up after an error, the only action is to release the memory. The library records the error codes issued by previous calls, so this situation will be detected automatically. There is no attempt to complete the compression operation, nor to `fflush` the compressed file. You can force this behaviour to happen even in the case of no error, by passing a nonzero value to `abandon`.

If `nbytes_in` is non-null, `*nbytes_in` will be set to be the total volume of uncompressed data handled. Similarly, `nbytes_out` will be set to the total volume of compressed data written. For compatibility with older versions of the library, `BZ2_bzWriteClose` only yields the lower 32 bits of these counts. Use `BZ2_bzWriteClose64` if you want the full 64 bit counts. These two functions are otherwise absolutely identical.

Possible assignments to `bzerror`:

```
BZ_SEQUENCE_ERROR
  if b was opened with BZ2_bzReadOpen
BZ_IO_ERROR
  if there is an error writing the compressed file
BZ_OK
  otherwise
```

3.4.8. Handling embedded compressed data streams

The high-level library facilitates use of `bzip2` data streams which form some part of a surrounding, larger data stream.

- For writing, the library takes an open file handle, writes compressed data to it, `fflush`es it but does not `fclose` it. The calling application can write its own data before and after the compressed data stream, using that same file handle.
- Reading is more complex, and the facilities are not as general as they could be since generality is hard to reconcile with efficiency. `BZ2_bzRead` reads from the compressed file in blocks of size `BZ_MAX_UNUSED` bytes, and in doing so probably will overshoot the logical end of compressed stream. To recover this data once decompression has ended, call `BZ2_bzReadGetUnused` after the last call of `BZ2_bzRead` (the one returning `BZ_STREAM_END`) but before calling `BZ2_bzReadClose`.

This mechanism makes it easy to decompress multiple bzip2 streams placed end-to-end. As the end of one stream, when BZ2_bzRead returns BZ_STREAM_END, call BZ2_bzReadGetUnused to collect the unused data (copy it into your own buffer somewhere). That data forms the start of the next compressed stream. To start uncompressing that next stream, call BZ2_bzReadOpen again, feeding in the unused data via the unused / nUnused parameters. Keep doing this until BZ_STREAM_END return coincides with the physical end of file (feof(f)). In this situation BZ2_bzReadGetUnused will of course return no data.

This should give some feel for how the high-level interface can be used. If you require extra flexibility, you'll have to bite the bullet and get to grips with the low-level interface.

3.4.9. Standard file-reading/writing code

Here's how you'd write data to a compressed file:

```
FILE*   f;
BZFILE* b;
int     nBuf;
char    buf[ /* whatever size you like */ ];
int     bzerror;
int     nWritten;

f = fopen ( "myfile.bz2", "w" );
if ( !f ) {
 /* handle error */
}
b = BZ2_bzWriteOpen( &bzerror, f, 9 );
if (bzerror != BZ_OK) {
 BZ2_bzWriteClose ( b );
 /* handle error */
}

while ( /* condition */ ) {
 /* get data to write into buf, and set nBuf appropriately */
 nWritten = BZ2_bzWrite ( &bzerror, b, buf, nBuf );
 if (bzerror == BZ_IO_ERROR) {
   BZ2_bzWriteClose ( &bzerror, b );
   /* handle error */
 }
}

BZ2_bzWriteClose( &bzerror, b );
if (bzerror == BZ_IO_ERROR) {
 /* handle error */
}
```

And to read from a compressed file:

```
FILE*   f;
BZFILE* b;
int     nBuf;
char    buf[ /* whatever size you like */ ];
int     bzerror;
int     nWritten;

f = fopen ( "myfile.bz2", "r" );
if ( !f ) {
  /* handle error */
}
b = BZ2_bzReadOpen ( &bzerror, f, 0, NULL, 0 );
if ( bzerror != BZ_OK ) {
  BZ2_bzReadClose ( &bzerror, b );
  /* handle error */
}

bzerror = BZ_OK;
while ( bzerror == BZ_OK && /* arbitrary other conditions */) {
  nBuf = BZ2_bzRead ( &bzerror, b, buf, /* size of buf */ );
  if ( bzerror == BZ_OK ) {
    /* do something with buf[0 .. nBuf-1] */
  }
}
if ( bzerror != BZ_STREAM_END ) {
   BZ2_bzReadClose ( &bzerror, b );
   /* handle error */
} else {
   BZ2_bzReadClose ( &bzerror, b );
}
```

3.5. Utility functions

3.5.1. BZ2_bzBuffToBuffCompress

```
int BZ2_bzBuffToBuffCompress( char*         dest,
                              unsigned int* destLen,
                              char*         source,
                              unsigned int  sourceLen,
                              int           blockSize100k,
                              int           verbosity,
                              int           workFactor );
```

Attempts to compress the data in source[0 .. sourceLen-1] into the destination buffer, dest[0 .. *destLen-1]. If the destination buffer is big enough, *destLen is set to the size of the compressed data, and BZ_OK is returned. If the compressed data won't fit, *destLen is unchanged, and BZ_OUTBUFF_FULL is returned.

Compression in this manner is a one-shot event, done with a single call to this function. The resulting compressed data is a complete bzip2 format data stream. There is no mechanism for making additional calls to provide extra input data. If you want that kind of mechanism, use the low-level interface.

For the meaning of parameters blockSize100k, verbosity and workFactor, see BZ2_bzCompressInit.

To guarantee that the compressed data will fit in its buffer, allocate an output buffer of size 1% larger than the uncompressed data, plus six hundred extra bytes.

BZ2_bzBuffToBuffDecompress will not write data at or beyond dest[*destLen], even in case of buffer overflow.

Possible return values:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if dest is NULL or destLen is NULL
  or blockSize100k < 1 or blockSize100k > 9
  or verbosity < 0 or verbosity > 4
  or workFactor < 0 or workFactor > 250
BZ_MEM_ERROR
  if insufficient memory is available
BZ_OUTBUFF_FULL
  if the size of the compressed data exceeds *destLen
BZ_OK
  otherwise
```

3.5.2. BZ2_bzBuffToBuffDecompress

```
int BZ2_bzBuffToBuffDecompress( char*         dest,
                                unsigned int* destLen,
                                char*         source,
                                unsigned int  sourceLen,
                                int           small,
                                int           verbosity );
```

Attempts to decompress the data in source[0 .. sourceLen-1] into the destination buffer, dest[0 .. *destLen-1]. If the destination buffer is big enough, *destLen is set to the size of the uncompressed data, and BZ_OK is returned. If the compressed data won't fit, *destLen is unchanged, and BZ_OUTBUFF_FULL is returned.

source is assumed to hold a complete bzip2 format data stream. BZ2_bzBuffToBuffDecompress tries to decompress the entirety of the stream into the output buffer.

For the meaning of parameters small and verbosity, see BZ2_bzDecompressInit.

Because the compression ratio of the compressed data cannot be known in advance, there is no easy way to guarantee that the output buffer will be big enough. You may of course make arrangements in your code to record the size of the uncompressed data, but such a mechanism is beyond the scope of this library.

BZ2_bzBuffToBuffDecompress will not write data at or beyond dest[*destLen], even in case of buffer overflow.

Possible return values:

```
BZ_CONFIG_ERROR
  if the library has been mis-compiled
BZ_PARAM_ERROR
  if dest is NULL or destLen is NULL
  or small != 0 && small != 1
  or verbosity < 0 or verbosity > 4
BZ_MEM_ERROR
  if insufficient memory is available
BZ_OUTBUFF_FULL
  if the size of the compressed data exceeds *destLen
BZ_DATA_ERROR
  if a data integrity error was detected in the compressed data
BZ_DATA_ERROR_MAGIC
  if the compressed data doesn't begin with the right magic bytes
BZ_UNEXPECTED_EOF
  if the compressed data ends unexpectedly
BZ_OK
  otherwise
```

3.6. `zlib` compatibility functions

Yoshioka Tsuneo has contributed some functions to give better `zlib` compatibility. These functions are `BZ2_bzopen`, `BZ2_bzread`, `BZ2_bzwrite`, `BZ2_bzflush`, `BZ2_bzclose`, `BZ2_bzerror` and `BZ2_bzlibVersion`. These functions are not (yet) officially part of the library. If they break, you get to keep all the pieces. Nevertheless, I think they work ok.

```
typedef void BZFILE;

const char * BZ2_bzlibVersion ( void );
```

Returns a string indicating the library version.

```
BZFILE * BZ2_bzopen  ( const char *path, const char *mode );
BZFILE * BZ2_bzdopen ( int      fd,   const char *mode );
```

Opens a `.bz2` file for reading or writing, using either its name or a pre-existing file descriptor. Analogous to `fopen` and `fdopen`.

```
int BZ2_bzread  ( BZFILE* b, void* buf, int len );
int BZ2_bzwrite ( BZFILE* b, void* buf, int len );
```

Reads/writes data from/to a previously opened `BZFILE`. Analogous to `fread` and `fwrite`.

```
int  BZ2_bzflush ( BZFILE* b );
void BZ2_bzclose ( BZFILE* b );
```

Flushes/closes a `BZFILE`. `BZ2_bzflush` doesn't actually do anything. Analogous to `fflush` and `fclose`.

```
const char * BZ2_bzerror ( BZFILE *b, int *errnum )
```

Returns a string describing the more recent error status of `b`, and also sets `*errnum` to its numerical value.

3.7. Using the library in a stdio-free environment

3.7.1. Getting rid of stdio

In a deeply embedded application, you might want to use just the memory-to-memory functions. You can do this conveniently by compiling the library with preprocessor symbol BZ_NO_STDIO defined. Doing this gives you a library containing only the following eight functions:

BZ2_bzCompressInit, BZ2_bzCompress, BZ2_bzCompressEnd BZ2_bzDecompressInit, BZ2_bzDecompress, BZ2_bzDecompressEnd BZ2_bzBuffToBuffCompress, BZ2_bzBuffToBuffDecompress

When compiled like this, all functions will ignore verbosity settings.

3.7.2. Critical error handling

libbzip2 contains a number of internal assertion checks which should, needless to say, never be activated. Nevertheless, if an assertion should fail, behaviour depends on whether or not the library was compiled with BZ_NO_STDIO set.

For a normal compile, an assertion failure yields the message:

bzip2/libbzip2: internal error number N.

This is a bug in bzip2/libbzip2, 1.0.4 of 20 December 2006. Please report it to me at: jseward@bzip.org. If this happened when you were using some program which uses libbzip2 as a component, you should also report this bug to the author(s) of that program. Please make an effort to report this bug; timely and accurate bug reports eventually lead to higher quality software. Thanks. Julian Seward, 20 December 2006.

where N is some error code number. If N == 1007, it also prints some extra text advising the reader that unreliable memory is often associated with internal error 1007. (This is a frequently-observed-phenomenon with versions 1.0.0/1.0.1).

exit(3) is then called.

For a stdio-free library, assertion failures result in a call to a function declared as:

```
extern void bz_internal_error ( int errcode );
```

The relevant code is passed as a parameter. You should supply such a function.

In either case, once an assertion failure has occurred, any bz_stream records involved can be regarded as invalid. You should not attempt to resume normal operation with them.

You may, of course, change critical error handling to suit your needs. As I said above, critical errors indicate bugs in the library and should not occur. All "normal" error situations are indicated via error return codes from functions, and can be recovered from.

3.8. Making a Windows DLL

Everything related to Windows has been contributed by Yoshioka Tsuneo (tsuneo@rr.iij4u.or.jp), so you should send your queries to him (but perhaps Cc: me, jseward@bzip.org).

My vague understanding of what to do is: using Visual C++ 5.0, open the project file libbz2.dsp, and build. That's all.

If you can't open the project file for some reason, make a new one, naming these files: blocksort.c, bzlib.c, compress.c, crctable.c, decompress.c, huffman.c, randtable.c and libbz2.def. You will also need to name the header files bzlib.h and bzlib_private.h.

If you don't use VC++, you may need to define the proprocessor symbol _WIN32.

Finally, dlltest.c is a sample program using the DLL. It has a project file, dlltest.dsp.

If you just want a makefile for Visual C, have a look at makefile.msc.

Be aware that if you compile bzip2 itself on Win32, you must set BZ_UNIX to 0 and BZ_LCCWIN32 to 1, in the file bzip2.c, before compiling. Otherwise the resulting binary won't work correctly.

I haven't tried any of this stuff myself, but it all looks plausible.

4. Miscellanea

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These are just some random thoughts of mine. Your mileage may vary.

4.1. Limitations of the compressed file format

`bzip2-1.0.X`, `0.9.5` and `0.9.0` use exactly the same file format as the original version, `bzip2-0.1`. This decision was made in the interests of stability. Creating yet another incompatible compressed file format would create further confusion and disruption for users.

Nevertheless, this is not a painless decision. Development work since the release of `bzip2-0.1` in August 1997 has shown complexities in the file format which slow down decompression and, in retrospect, are unnecessary. These are:

- The run-length encoder, which is the first of the compression transformations, is entirely irrelevant. The original purpose was to protect the sorting algorithm from the very worst case input: a string of repeated symbols. But algorithm steps Q6a and Q6b in the original Burrows-Wheeler technical report (SRC-124) show how repeats can be handled without difficulty in block sorting.
- The randomisation mechanism doesn't really need to be there. Udi Manber and Gene Myers published a suffix array construction algorithm a few years back, which can be employed to sort any block, no matter how repetitive, in O(N log N) time. Subsequent work by Kunihiko Sadakane has produced a derivative O(N (log N)^2) algorithm which usually outperforms the Manber-Myers algorithm.

  I could have changed to Sadakane's algorithm, but I find it to be slower than `bzip2`'s existing algorithm for most inputs, and the randomisation mechanism protects adequately against bad cases. I didn't think it was a good tradeoff to make. Partly this is due to the fact that I was not flooded with email complaints about `bzip2-0.1`'s performance on repetitive data, so perhaps it isn't a problem for real inputs.

  Probably the best long-term solution, and the one I have incorporated into 0.9.5 and above, is to use the existing sorting algorithm initially, and fall back to a O(N (log N)^2) algorithm if the standard algorithm gets into difficulties.
- The compressed file format was never designed to be handled by a library, and I have had to jump though some hoops to produce an efficient implementation of decompression. It's a bit hairy. Try passing `decompress.c` through the C preprocessor and you'll see what I mean. Much of this complexity could have been avoided if the compressed size of each block of data was recorded in the data stream.
- An Adler-32 checksum, rather than a CRC32 checksum, would be faster to compute.

It would be fair to say that the `bzip2` format was frozen before I properly and fully understood the performance consequences of doing so.

Improvements which I was able to incorporate into 0.9.0, despite using the same file format, are:

- Single array implementation of the inverse BWT. This significantly speeds up decompression, presumably because it reduces the number of cache misses.
- Faster inverse MTF transform for large MTF values. The new implementation is based on the notion of sliding blocks of values.
- `bzip2-0.9.0` now reads and writes files with `fread` and `fwrite`; version 0.1 used `putc` and `getc`. Duh! Well, you live and learn.

Further ahead, it would be nice to be able to do random access into files. This will require some careful design of compressed file formats.

4.2. Portability issues

After some consideration, I have decided not to use GNU `autoconf` to configure 0.9.5 or 1.0.

`autoconf`, admirable and wonderful though it is, mainly assists with portability problems between Unix-like platforms. But `bzip2` doesn't have much in the way of portability problems on Unix; most of the difficulties appear when porting to the Mac, or to Microsoft's operating systems. `autoconf` doesn't help in those cases, and brings in a whole load of new complexity.

Most people should be able to compile the library and program under Unix straight out-of-the-box, so to speak, especially if you have a version of GNU C available.

There are a couple of `__inline__` directives in the code. GNU C (`gcc`) should be able to handle them. If you're not using GNU C, your C compiler shouldn't see them at all. If your compiler does, for some reason, see them and doesn't like them, just `#define __inline__` to be `/* */`. One easy way to do this is to compile with the flag `-D__inline__=`, which should be understood by most Unix compilers.

If you still have difficulties, try compiling with the macro `BZ_STRICT_ANSI` defined. This should enable you to build the library in a strictly ANSI compliant environment. Building the program itself like this is dangerous and not supported, since you remove `bzip2`'s checks against compressing directories, symbolic links, devices, and other not-really-a-file entities. This could cause filesystem corruption!

One other thing: if you create a `bzip2` binary for public distribution, please consider linking it statically (`gcc -static`). This avoids all sorts of library-version issues that others may encounter later on.

If you build `bzip2` on Win32, you must set `BZ_UNIX` to 0 and `BZ_LCCWIN32` to 1, in the file `bzip2.c`, before compiling. Otherwise the resulting binary won't work correctly.

4.3. Reporting bugs

I tried pretty hard to make sure `bzip2` is bug free, both by design and by testing. Hopefully you'll never need to read this section for real.

Nevertheless, if `bzip2` dies with a segmentation fault, a bus error or an internal assertion failure, it will ask you to email me a bug report. Experience from years of feedback of bzip2 users indicates that almost all these problems can be traced to either compiler bugs or hardware problems.

- Recompile the program with no optimisation, and see if it works. And/or try a different compiler. I heard all sorts of stories about various flavours of GNU C (and other compilers) generating bad code for `bzip2`, and I've run across two such examples myself.

  2.7.X versions of GNU C are known to generate bad code from time to time, at high optimisation levels. If you get problems, try using the flags `-O2 -fomit-frame-pointer -fno-strength-reduce`. You should specifically *not* use `-funroll-loops`.

  You may notice that the Makefile runs six tests as part of the build process. If the program passes all of these, it's a pretty good (but not 100%) indication that the compiler has done its job correctly.

- If `bzip2` crashes randomly, and the crashes are not repeatable, you may have a flaky memory subsystem. `bzip2` really hammers your memory hierarchy, and if it's a bit marginal, you may get these problems. Ditto if your disk or I/O subsystem is slowly failing. Yup, this really does happen.

  Try using a different machine of the same type, and see if you can repeat the problem.

- This isn't really a bug, but ... If `bzip2` tells you your file is corrupted on decompression, and you obtained the file via FTP, there is a possibility that you forgot to tell FTP to do a binary mode transfer. That absolutely will cause the file to be non-decompressible. You'll have to transfer it again.

If you've incorporated `libbzip2` into your own program and are getting problems, please, please, please, check that the parameters you are passing in calls to the library, are correct, and in accordance with what the documentation says is allowable. I have tried to make the library robust against such problems, but I'm sure I haven't succeeded.

Finally, if the above comments don't help, you'll have to send me a bug report. Now, it's just amazing how many people will send me a bug report saying something like:

```
bzip2 crashed with segmentation fault on my machine
```

and absolutely nothing else. Needless to say, a such a report is *totally, utterly, completely and comprehensively 100% useless; a waste of your time, my time, and net bandwidth*. With no details at all, there's no way I can possibly begin to figure out what the problem is.

The rules of the game are: facts, facts, facts. Don't omit them because "oh, they won't be relevant". At the bare minimum:

```
Machine type.  Operating system version.
Exact version of bzip2 (do bzip2 -V).
Exact version of the compiler used.
Flags passed to the compiler.
```

However, the most important single thing that will help me is the file that you were trying to compress or decompress at the time the problem happened. Without that, my ability to do anything more than speculate about the cause, is limited.

4.4. Did you get the right package?

`bzip2` is a resource hog. It soaks up large amounts of CPU cycles and memory. Also, it gives very large latencies. In the worst case, you can feed many megabytes of uncompressed data into the library before getting any compressed output, so this probably rules out applications requiring interactive behaviour.

These aren't faults of my implementation, I hope, but more an intrinsic property of the Burrows-Wheeler transform (unfortunately). Maybe this isn't what you want.

If you want a compressor and/or library which is faster, uses less memory but gets pretty good compression, and has minimal latency, consider Jean-loup Gailly's and Mark Adler's work, `zlib-1.2.1` and `gzip-1.2.4`. Look for them at http://www.zlib.org and http://www.gzip.org respectively.

For something faster and lighter still, you might try Markus F X J Oberhumer's `LZO` real-time compression/decompression library, at http://www.oberhumer.com/opensource.

4.5. Further Reading

`bzip2` is not research work, in the sense that it doesn't present any new ideas. Rather, it's an engineering exercise based on existing ideas.

Four documents describe essentially all the ideas behind `bzip2`:

```
Michael Burrows and D. J. Wheeler:
  "A block-sorting lossless data compression algorithm"
   10th May 1994.
   Digital SRC Research Report 124.
   ftp://ftp.digital.com/pub/DEC/SRC/research-reports/SRC-124.ps.gz
   If you have trouble finding it, try searching at the
   New Zealand Digital Library, http://www.nzdl.org.

Daniel S. Hirschberg and Debra A. LeLewer
  "Efficient Decoding of Prefix Codes"
   Communications of the ACM, April 1990, Vol 33, Number 4.
   You might be able to get an electronic copy of this
   from the ACM Digital Library.

David J. Wheeler
   Program bred3.c and accompanying document bred3.ps.
   This contains the idea behind the multi-table Huffman coding scheme.
   ftp://ftp.cl.cam.ac.uk/users/djw3/

Jon L. Bentley and Robert Sedgewick
  "Fast Algorithms for Sorting and Searching Strings"
   Available from Sedgewick's web page,
   www.cs.princeton.edu/~rs
```

The following paper gives valuable additional insights into the algorithm, but is not immediately the basis of any code used in bzip2.

```
Peter Fenwick:
   Block Sorting Text Compression
   Proceedings of the 19th Australasian Computer Science Conference,
     Melbourne, Australia.  Jan 31 - Feb 2, 1996.
   ftp://ftp.cs.auckland.ac.nz/pub/peter-f/ACSC96paper.ps
```

Kunihiko Sadakane's sorting algorithm, mentioned above, is available from:

```
http://naomi.is.s.u-tokyo.ac.jp/~sada/papers/Sada98b.ps.gz
```

The Manber-Myers suffix array construction algorithm is described in a paper available from:

```
http://www.cs.arizona.edu/people/gene/PAPERS/suffix.ps
```

Finally, the following papers document some investigations I made into the performance of sorting and decompression algorithms:


```
Julian Seward
   On the Performance of BWT Sorting Algorithms
   Proceedings of the IEEE Data Compression Conference 2000
     Snowbird, Utah.  28-30 March 2000.

Julian Seward
   Space-time Tradeoffs in the Inverse B-W Transform
   Proceedings of the IEEE Data Compression Conference 2001
     Snowbird, Utah.  27-29 March 2001.
```