PEA

Pack, Encrypt, Authenticate

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This document refers to:
PEA file format specification version 1 revision 2 (1.2);
PEA file format specification version 2.0;
PEA 0.46 executable implementation;

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Section 1: PEA file format

Description

PEA, Pack Encrypt Authenticate, is a general purpose archiving format, featuring compression and multiple volume output, aiming to offer a flexible security model through Authenticated Encryption, that provides both privacy and authentication of the data, and redundant integrity checks ranging from checksums to cryptographically strong hashes, defining three different levels of communication to control: streams, objects, volumes.
Stream control level is actually the only level featuring Authenticated Encryption option while integrity checking can be performed at each of the three levels; each one of the three levels of control can be omitted to fit particular user's needs.
PEA archive data (except for archive header) is organized in objects; objects are organized in streams (1.1 file format allow archives containing a single stream while 2.0 allow unlimited streams), being a stream a group of objects sharing the same security constrains, satisfied by the stream level checking algorithm (checksum, hash or AE).
Stream beginning is marked by a "stream header" type of object and stream termination is marked by a "end of stream" type of object or by "end of archive" if the stream is the last one in the archive; defining PEA 1.1 file format only archives containing a single stream, it's always terminated by an "end of archive" object.
First field of an object is the object's input name size (word sized), when the field is nonzero, the archive object has an associated input name, that means the archive object maps an input object (file or dir) from the system, otherwise if the name size is zero it means the archive object is a trigger, a functional field for PEA program (as aforementioned "stream header" , "end of stream" and "end of archive" objects), and that no external data is mapped fro the system to the archive object.
Objects of "trigger" class are not checked by object level check, while archive objects with associated input object ("input object" class) are checked; both classes of objects are checked by stream level check.
If the object is a trigger, the second field is the trigger type, 4 byte sized; defined types are:

- POD (followed by $00 byte): "stream header" type of object, marks the beginning of the stream, it is followed by 4 byte-sized fields defining stream properties (compression scheme, stream control scheme, single objects control scheme, stream-specific error correcting strategy) and, if Authenticated Encryption is used for stream control, by a 16 bit field containing an header similar to the one defined for Wolfgang Ehrhardt's FCA cryptographic application:
    - 1 byte FCA sig ($FC): in PEA file format it is zeroed since file format disambiguation is performed on archive's header rather than on this field;
    - 1 byte flags field: in PEA file format it is zeroed since the information about encryption scheme is given in "stream header" area;
    - 12 byte (96 bit) pseudorandom salt;
    - 2 byte key verification field;
- EOS (followed by $00 byte): "end of stream" type, marks the end of a stream, it's followed by the stream control tag (variable sized), exists only in 2.0 file format specification;
- EOA (followed by $00 byte): "end of archive"; and marks the end of the last stream of the archive, it's followed by the stream control tag and from the last volume control tag, then the archive ends.
- MSG: triggers a message, the 4th byte define the size in byte of the message, allowing short messages up to 255 bytes; if the 4th byte is $00, the message is a long message and in this case next 4 byte field (dword) define the size in byte of the message. It may be useful to insert comments or metadata (i.e. graphic, list of stream content to improve user experience allowing faster stream content preview etc).
  MSG type exists only in 2.0 file format specification.

If the archive object is not a trigger, the second field (variable sized, with size defined by previous field) is input object's name, the qualified name of the file or dir in the system where the archive is created, followed by 4 byte (dword) sized field for object's last modification time and another 4 byte (dword) sized field for object attributes.
If the input object is a dir, no more fields are needed by PEA, next field will be the object's control tag; otherwise if the input object is a file, the next object's field is 8 byte (qword) sized file size, allowing max input size of 2^64 byte.
If the size is zero, the file is empty and next filed will be the object's control tag; otherwise next field will be the file content (structure of that data may vary due to the compression model used), and finally the object's control tag.

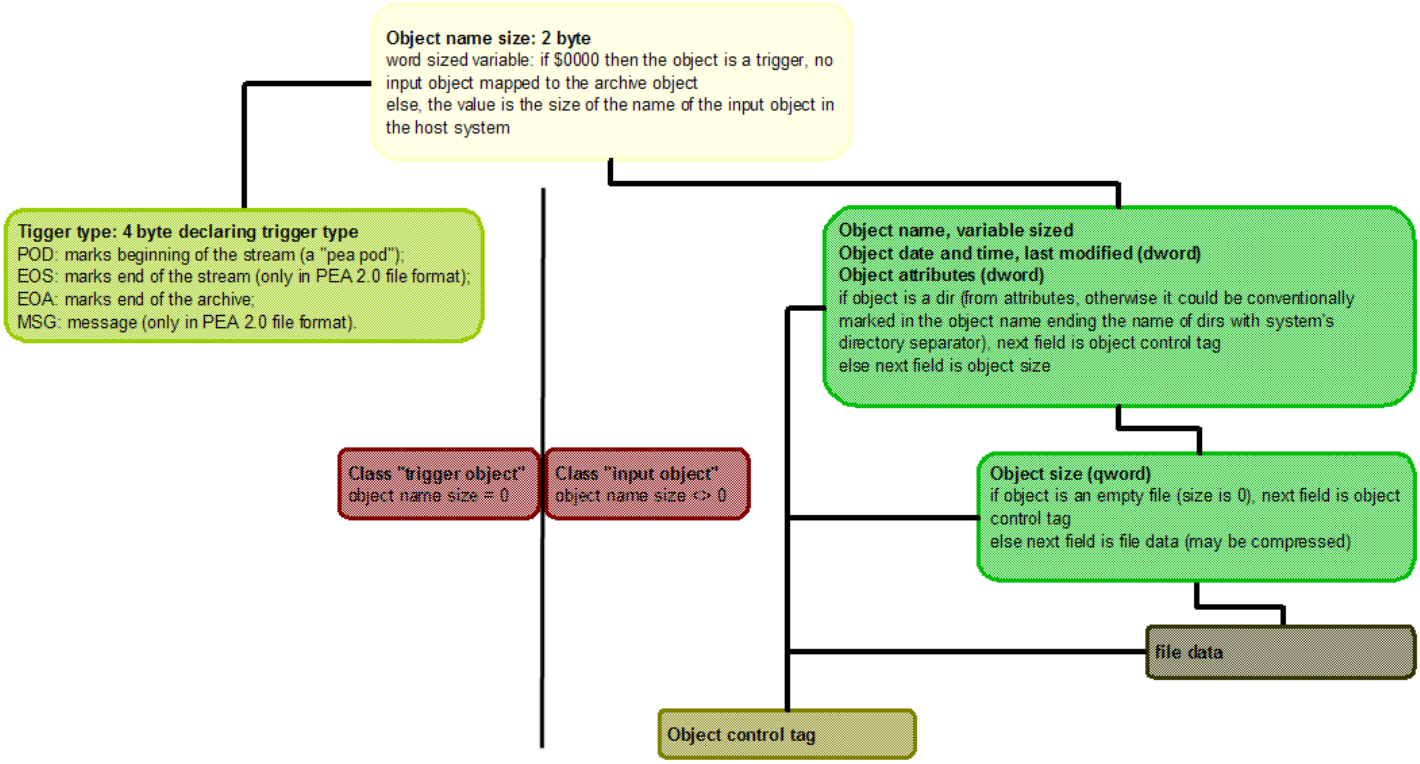


Image 1: PEA version 1 revision 1 object taxonomy flowchart

Object control is performed on all input objects, on uncompressed and unencrypted content (only if the object is a nonempty file) and all associated data (qualified name, object last modification time, object attributes and finally file size if object is a file).
Stream level control instead allow to embed different objects in different archive areas (streams) each with different control features and/or, in case of encryption, with different passwords (not mandatory different, since unique salt is used for each stream).
PEA 1.1 file format allow archives containing a single stream while PEA 2.0 format allows unlimited streams in a single archive, hypothetically even a distinct stream for each distinct object, the space overhead would be of 16 byte per object (POD and EOS objects) plus size of cryptographic subheader and authentication tag.
Streams could easily be nested (simply making the EOS tag closes the last opened stream) however this will have a bad performance impact since for each nesting level stream check and object control check would be duplicated, so PEA 2.0 format define that streams will not be nested (it's necessary to close the n-th stream with EOS trigger before opening the n-th+1 stream).
PEA stream control doesn't apply to raw input data but rather to data after compression (if used), plus all associated data including object level control tags; EOS or EOA trigger is included.
The stream level check includes also POD object (not including, if used, salt and password verifier in cryptographic subheader since are jet part of the authenticated encryption) and, for the first stream (or for the sole stream for PEA 1.1 format), the archive header; in that way all data included in the archive is subject to stream level check.
If stream level check is checksum or hash based, content of that area (POD object and archive header for first stream) is passed to the function as first block to check.
If AE is used, that area is appended to the passphrase and passed to the key derivation function, so data corruption in the area will be noticed at key verification stage, avoiding the needing to perform the full decryption process with unchecked parameters.
Using AE at stream level ckeck means also that digests of input objects are kept private, otherwise digests could be useful (for small objects, i.e. dirs, empty or small files) to cast meaningful guesses on object's content (data and associated data).
Volume level control is finalized and restarted for each volume and is performed on all volume's data after all PEA steps (so on encrypted and compressed data, if those features are used), allowing integrity check of each volume without needing to know other volumes and without needing to perform other PEA steps before volume checking, so it can be used to decide if to repudiate or accept an incoming volume due to it's integrity before starting unpacking the PEA archive, only providing that the check algorithm is known.
If the volume control algorithm is not known to the user (i.e. the parts didn't agreed on a communication standard defining a fixed volume control strategy), the first volume is needed since the check algorithm is declared in the archive header, which is not repeated in each volume.

PEA 1.2 file format details

Archive header, 10 byte:

1 byte "magic byte" field for file format disambiguation: $EA;
1 byte version number field;
1 byte revision number field; ← this byte has been changed to 2 in 1.2 revision
1 byte for volume control scheme;
1 byte for archive-wide error correcting scheme;
1 byte declaring the OS were the stream was built;
1 byte declaring OS date and time encoding;
1 byte declaring objects name character encoding;
1 byte declaring CPU type (encoded in 7 bit) and endianness (in msb);
1 byte reserved for future use

Stream header, 10 byte:

word object name size field, $0000, declaring the object is a trigger;
4 byte trigger type filed: POD$00, marking beginning of the stream;
4 byte area with declaration of stream's properties (4 1 byte fields):
compression scheme;
stream control scheme;
single objects control scheme;
stream-wide error correcting scheme.

- if Authenticated Encryption is used, the stream header is followed by a 16 byte cryptographic subheader, similar to the one defined in Wolfgang Ehrhardt's FCA cryptographic application:
  - 1 byte zeroed (was FCA sig ($FC));
  - 1 byte zeroed (was flags field);
  - 12 byte (96 bit) pseudorandom salt;
  - word key verification field

Area of objects belonging to the stream:
object name size: word;
if size is > 0, the object belong to "input object" class and following fields apply;

- object name (variable sized), last character is conventionally the DirectorySeparator if the object is a directory;
- object last modification time: 4 byte (possibility to restore this information vary between host systems);
- object attributes: 4 byte (possibility to restore them vary between host systems); if the object is a file the following fields apply:
  - file size: qword; if size is >0 the file is not empty and the following field apply:
    - file data (variable sized)
- object control tag (variable sized, depending from the single object control algorithm), generated from the all the featured fields between object name and object control tag (in other words, all object's data and associated data, uncompressed and unencrypted);

else (if name size is 0) the object belongs to "trigger object" class, the following filed apply;

- trigger type 4 byte;

In PEA 1.1 there may only be declared EOA$00, triggering end of the archive: close the stream, check or generate the stream control tag, check or generate the last volume tag and stop;
Volume control tags break the flux of aforementioned fields appearing at –n bit from the end of each volume where n is the size of volume level control tag.
At the present state of documentation please refer to the sourcecode for details about values for declaring control algorithms, compression schemes and so on.

Differences between 1.2 and older revisions

PEA 1.2 shares all specifications with 1.0 and 1.1 format, but:

- changes third byte in header to 2 to declare new revision's specifications are used
- introduces support for BLAKE2S 256 bit and BLAKE2B 512 hash algorithms for object, volume, and stream level control

PEA 1.1 shares all specifications with 1.0 format, but:

- changes third byte in header from 0 to 1 to declare new revision's specifications are used
- introduces support to more EAX mode authenticated encryption options (AES finalists Twofish and Serpent algorithms, both 128 and 256 bit) for stream level control
- introduces support for newly designed SHA-3 256 and 512 hash algorithm (not available when PEA 1.0 specifications were published) for object, volume, and stream level control

Old Pea executable implementations built with PEA 1.0 and PEA 1.1 level specifications cannot open PEA 1.2 files if newly supported algorithms are employed, so the third byte in the header (revision filed) is set to 2 to avoid files built with new format specifications being opened by an old executable implementation - it will be raised Error parsing archive header 9: PEA_REVISION_NOT_SUPPORTED
If needed it is possible to open 1.2 files simply setting third byte in header to 1, or 0, but file will be readable only if no new algorithm was employed.

New Pea executable implementations built with PEA 1.2 level specifications can open all PEA 1.0 and all PEA 1.1 files, so updating Pea executable is strongly recommended.

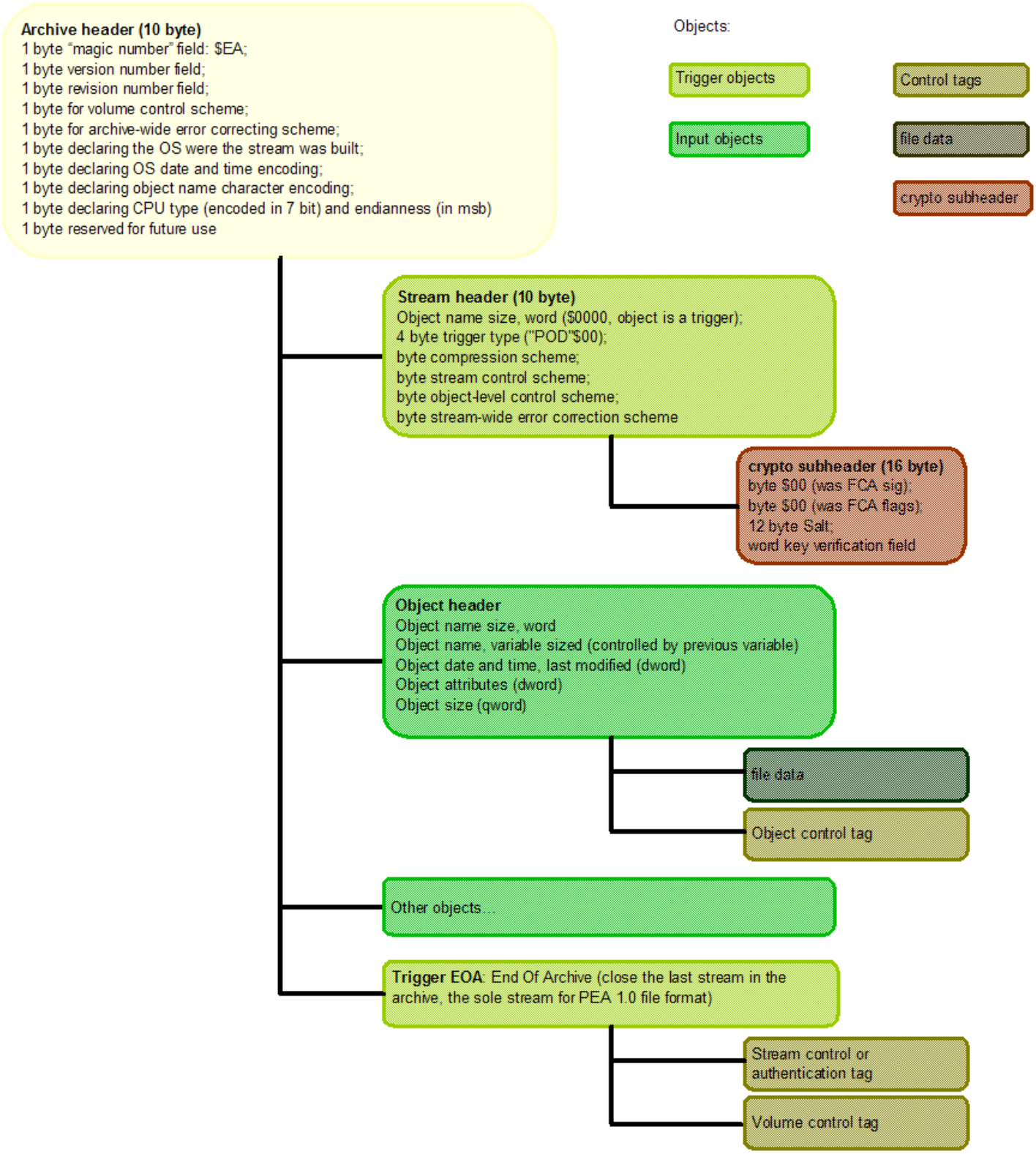


Image 2: PEA version 1 revision 1 file format flowchart (archive saved as single volume)

PEA 2.0 file format details

PEA 2.0 file format allow unlimited number of streams, not nested, each one closed by a EOS tag but the last one, closed by EOA tag. First stream authenticates also the archive's header, as in PEA 1.0.
The format allows MSG type of triggers, meant for embedding meta-information where needed in the archive.
2.* file format is aimed to be retrocompatible with 1.*, being a PEA 1.* format archive a special case of the more general 2.* format, containing a single stream and no messages.
Please note that PEA 2.0 file format specifications are actually not finalized and may undergo to further revisions before being usable and used.

PEA file format's and implementation's limitations

feature	PEA file format	Current implementation
Archive		
Max archive size	unlimited	up to 999999 volumes of 2^64-1 byte each; using 128 bit block encryption it would be safe not to encrypt more than 2^64 byte with same key, better staying one or more orders of magnitude below
Stream number	1.0: single stream; 2.0 unlimited number of streams;	Single stream (1.1 file format)
Output		
Security	Optional Authenticated Encryption, at stream level only.	
Integrity check	AE tag or hash or checksum at stream level, hash or checksum for input objects and output volumes	
Error correction	No scheme featured	
Communication recovery	Independent volume control check allow to identify corrupted volumes (first volume may be needed to know volume check algorithm)	No specific tool developed; volume check is done during extraction and then, allowing to repeat download only of corrupted volumes
Data recovery	Stream control tags allow to recognize correct streams, if better granularity is needed object control tags allow to recognize correct objects; input object names and POD trigger allow to identify objects and stream between the archive data;	No specific tool developed to try error resistant data extraction, however object check errors are reported to identify corrupted and non corrupted data if the extraction is successful
Support for multi volume output	Native, requires a single pass	
Volume number	1..unlimited	1..999999 (counter in output name)
Volume size	Volume tag size +1.. unlimited; first volume must contain at least 10 byte of data to allow parsing of the archive header, to allow unpacking application to calculate volume tag size	Volume tag size +1.. 2^64-1 (qword variable) ; first volume must contain at least 10 byte of data
Compression	Native, requires single pass; schemes: PCOMPRESS0: no compression; PCOMPRESS1..3 based on deflate using zlib's compres/uncompres, level 3, 6 and 9 respectively (see PCOMPRESS chapter)	
Solid archive	Not implemented compression modes featuring the possibility of creating solid archive	
Input		
Input types	1.0: files and dirs; 2.0: files, dirs, metadata stored as messages triggers	Files and dirs (1.0)
Input objects number	1..unlimited	Host system memory limited (input object list is stored in a dynamic array of strings)
Input object size (of single objects)	0..2^64-1	0..2^64-1
Input object qualified name size (size 0 mean that archive object is a trigger, no input object mapped to the archive object)	1..2^16-1	1..32K (exceeding needs, longer values are considered errors)
Metadata	Objects attributes and last modification time, optionally comments and any kind of meta content using messages	Save object attributes and object last modification time. Restore only object attributes (on Windows), nothing on *x

Notes on input object name character encoding
Current PEA implementation works only on ANSI-encoded object names (not support UNICODE encoding), however PEA file format allow a field in the archive header to declare the character encoding for object names.
With 16 byte-wide field for object name defined by PEA file format the room should be enough for any practical use, even with encoding using more bytes per character (bytes necessary to encode characters can be stored in an array of byte up to 64KB -1 byte); however implementing that feature would require a careful evaluation of validity of object names for the system where the archive is targeted to be restored.

Notes on volume sizes

- Volumes can be arbitrarily sized, however they need to be at least one byte wider than volume control tag, in order that at least one byte of input data is stored in the volume.
- Since the unpacking application need to know what is the volume control algorithm used, in order to be able to distinguish between input data and volume tag data, PEA file format defines mandatory that first volume of the archive must contain at least 10 bytes (so, sized 10+volume control tag size bytes) to allow all information in archive header (that contains volume control algorithms, that define volume control tag size) to be red at once.
- Volumes could have different sizes.

PCOMPRESS compression scheme

PCOMPRESS0 is a non compression scheme; it will simply copy data from the input to the output.
PCOMPRESS1..3 is a deflate-based scheme of compression that allows decompression of single blocks without need of decompressing preceding blocks: that slightly degrades compression compared to classical schemes (effect may be minimal, due to algorithm and block size chosen).
The output data structure allows fast access to arbitrary sectors knowing position in input data and makes easy to implement highly parallel compression and decompression routines (features actually not exploited in PEA file format and implementation).
Compressed data (from PCOMPRESS1..3) is organized as follows:

- buffer size field, dword; declare the size of buffer of uncompressed data to compress at once; it's needed to be declared a single time if multiple objects are compressed;
- until end of input data:
  - size of the compressed buffer (dword);
  - compressed buffer (variable sized field);
- uncompressed size of the last buffer

Each buffer is in-memory compressed with zlib's compress, level 3, 6 and 9 for PCOMPRESS 1, 2 and 3 respectively, and decompressed with zlib's uncompress, uncompressed size is equal to buffer size for all blocks but the last (declared in the last field), size of the compressed buffer is declared before each block allowing to know how much data is needed to be read for decompression.
If the compression result in expansion or no compression of the buffer, the compressed buffer is discarded and the uncompressed buffer is stored, the size of the compressed buffer will be set equal to the size of uncompressed buffer.
In decompression, finding an input buffer sized as the expected uncompressed buffer result in treating it as non compressed, no decompression is done and data is simply copied to output.
Expected uncompressed size is equal to buffer size for all blocks but the last, whose size can be calculated as residual uncompressed size (being the uncompressed size declared as file size in object header) or read from last field (uncompressed size of last buffer).
That allow to:

- spare CPU time when decompressing hard to compress files, since many buffers will simply need to be copied to the output, at the cost of simply verifying if declared compressed size = compression buffer size;
- assure that each output buffer will be at most sized as input buffer;
- for the aforementioned reason, the output will be expanded, in the worst case, by only the size needed for compression scheme's fields, not regarding the underlying compression algorithm.

The scheme would also make quite simple replacing the underlying compression strategy without changing the output data structure.

Algorithms used in PEA format

This is a quick description of algorithms allowed in PEA 1.1 file format definition; please refer to more specific publications for more detailed descriptions of the algorithm's features and performances.
Evaluations of relative algorithm's speed are taken from [6] and [7].
Algorithms available for objects, volumes and streams:

- Adler32: a very fast algorithm generating a 32 bit checksum, useful to detect casual data corruptions; it is internally called with ADLER32 string: this name is used for invoking that algorithm in command line or procedures (see "Usage" chapter).
- CRC32: 32 bit checksum through cyclic redundancy check, it's slower than Adler and have different error detection characteristics, it's useful to detect casual data corruptions; internal name: CRC32.
- CRC64: 64 bit checksum through cyclic redundancy check, slower than CRC32, useful to detect casual data corruptions; internal name: CRC64.
- MD5: 128 bit hash, slower than aforementioned checksums but faster than other featured hashes. It's no longer considered cryptographically secure, however is still useful to detect casual data corruptions and, generating a longer tag than featured checksums, minimizes the probability to have two objects with same control tag, even in an huge archive; internal name: MD5.

- SHA1: 160 bit hash whose strength is actually disputed, it's slower than MD5; it's however fit to recognize casual data corruption and may be fit in near future for detecting even malicious data tampering against low profile opponents; internal name: SHA1.
- RIPEMD-160: 160 bit hash, similar in speed to SHA1, some concerns about his strength exist however it's still well reputed; internal name: RIPEMD160.
- SHA256/512: based on a newer SHA revision and generating a 256 bit and 512 bit tag respectively, are still reputed secure up to detect malicious data tampering, it's slower than SHA1: internal names SHA256, SHA512
- SHA-3 256/512: currently reputed to be the strongest choice between available hash algorithms, generating a 256 bit and 512 bit tag respectively: internal names SHA3_256, SHA3_512
- BLAKE2S (256 bit() and BLAKE2B (512 bit): strong hash algorithm, SHA-3 finalist
- Whirlpool: based on heavily modified AES algorithm, generate a 512 bit tag, slightly speedier than SHA512; internal name WHIRLPOOL.

Please note that being the tag transmitted within the communication (the archive), all of those algorithms are meant to protect data integrity against casual data corruption rather than against malicious attacks, since the attacker could generate a new valid message/digest pair.
However, if the sender can publish the digests on a secure server the receiver can securely access, original tags can be verified, not allowing the aforementioned type of attack. Under those conditions choosing a cryptographically strong hash for generating the digest make unfeasible for the attacker to calculate a modification allowing the modified data to generate the same digest.
Algorithms available for streams:

- HMAC Authenticated Encryption using AES128 in CTR mode for the encryption: composition scheme providing the data in the stream is private and subject to authentication; internal name HMAC.
- EAX Authenticated Encryption using AES128 or AES256 in CTR and OMAC mode: a provably secure mode to provide privacy and authentication of the data relying on a single algorithm and a single key (in other word no longer two algorithms, but a single one, has to be proven secure to prove the mode is secure); internal name EAX (128 bit key size), EAX256 (256 bit key size).
- EAX AE using Twofish (128 and 256 bit) in CTR and OMAC mode; internal name: TF, TF256.
- EAX AE using Serpent (128 and 256 bit) in CTR and OMAC mode; internal name: SP, SP256.

Please note under current understandings 128 bit sized keys are commonly regarded to be probably lifetime secure (or at least secure for some decades) against bruteforce under foreseeable technology advance, 256 bit sized keys makes bruteforcing 2^(256-128)= 2^128 times harder making them probably secure forever against bruteforcing.
All Authenticated Encryption modes generate a 128 bit tag for authentication, regardless the key size.
Being the tag verification key dependent, it is possible to verify it only knowing the key, so an attacker will not be able, given the message, to recalculate the tag until the key remains secret.

PEA security model

PEA security model assumes the application to run on a trusted environment both during the archiving and unpacking stages, aiming to protect solely the data during a communication process: the protection apply when a PEA archive is sent to the receiver and end when the archive is opened by the receiver.
PEA implementation cannot assure that the system is not subject to attacks that compromise the security of the data at a lower level allowing bypassing protection (encryption, authentication error checking) provided by the application, like i.e. keylogger logging the password provided by the user, or malware as viruses or rootkits exposing directly the clear data.
The implementation doesn't save temporary data, but cannot assure that the system will not cache data used by the application to the disk.
Aim of PEA is offering a flexible security model given the three different levels for data control.
Object level integrity checking is done on raw input data to detect errors with object level granularity; if for some improbable but not negligible cases (memory banks errors, bugs etc) errors are introduced with compression or encryption steps, object level control is able to detect that event for maximum security of operation.
If encryption is used (at stream level), object level tags get encrypted, not allowing to cast guesses on object's content independently from the object's size.
Stream level check offers up to authenticated encryption feature, protecting privacy and authenticity of a group of objects with same security needs, including tags generated by object level checks. That allow to don't need a cryptographic header and authentication tag for each object transmitted (a sizeable space overhead) and to don't need to finalize and restart encryption more times than needed, since it poses serious issues to collect enough entropy to seed each encryption and costs many CPU cycles especially in the Key Derivation and seed generation phase (see [1] analysing WinZip's AE2 scheme, that is object oriented).
Volume level integrity check are communication oriented and allow to discard single corrupted volumes in order to minimize, in case of error, the overhead of resending or re-downloading the data. Volume level integrity check is performed on the data in its final form, encrypted and compressed if those features are used, that means that volume tags, independently form volume size, cannot be used to cast guesses on volume's plaintext content if encryption (at stream level) is used.
Moreover, if compression is used, the structure of the data subject to volume level check is rather different from the one subject to object level check, allowing a redundant error detection on two rather different data structures.

That mean that each of the two levels may identify kinds of errors that pass undetected in the other level, due to the different structure of the data checked, even using the same algorithm for objects and volumes; of course, chosing different algorithms may increasing furtherly the ability of error detection of the system.

Examples of use:

Alice and Bob need to exchange data as fast as possible on a wide, secure and not error-prone channel.
In those ideal condition all checking and compression features could be turned off with process speed similar to copying files from one location to another, resulting in consolidating the n input in m output volumes to fit the destination space constrains (i.e. destination is a removable archive, or destination filesystem support limited file size).

Alice and Bob need to exchange non-private data and want to be able to know if the transmission was corrupted or tampered, in which case they want simply to discard the data and repeat the communication.
All those conditions can be accomplished with the sole stream level control, all data transmitted is checked and in case of error anywere the check will fail to match.

Alice and Bob need to exchange private data at the aforementioned conditions.
It can be accomplished using authenticated encryption all data (as input data and all associated content) is kept private and checked with cryptographically strong authentication to guarantee is neither corrupted nor tampered and that it comes from the sender that decided the given password.
Multi stream archives (PEA 2.0 file format only, actually not implemented) may allow different input object group to be subject of different kind of stream level control, allowing i.e. using different password or different algorithms for different streams.

Of course, with this security model a single corrupted byte can result in needing to repeat the whole communication (or the whole stream), such model should not be used when transmitting data on channels prone to data corruption or a severe overhead for retransmitting the data will be imposed, proportional to the stream size and to the probability of data corruption.
An efficient countermeasure will be in using volume control check: in this case a corruption event will impose the need of resending only the interested volume(s) rather than the whole communication; decreasing the size of the volumes will make the event of corruption of a volume less costly.
In example Alice may publish on a ftp server m volumes, when Bob's download of a volume gets corrupted he need only to re-download the given volume rather than all the volumes; Alice can chose a volume size and nature of the checking algorithm fit to efficiently deal with corruption probability.

A severe communication problem or media failure result in the corruption most or all volumes, moreover Bob may not have the possibility to request Alice to resend the data and need to try to extract all single objects that result not corrupted.
In this critical case object level check can help Bob to recover non corrupted objects from Alice transmission, since each embedded object has its own control tag.
However see "Data Recovery" chapter below that analyse in details the practical issues in recovering data from a corrupted PEA archive (if it's not possible to resend it), since data corruption may be relevant in preventing the possibility for a program to extract data at all from an archive, altering the fields structure needed to automate the data extraction.

Examples of use against attackers, using stream level AE:

The eavesdropper Eve try to get useful information from object level tags
Object level tags are not accessible in clear, so no information can be recovered without decrypting the archive.

The eavesdropper Eve try to get useful information from volume level tags
Volume level tags are in clear, but are calculated on data in encrypted form, so no information is leaked about plaintext.

The malicious active attacker Mallory try to modify the archive's or stream's header area to see what happens if the decryption program runs with unproper parameters (control algorithms, compression scheme etc) or to mount a DOS attack on Bob.
All data in headers area, except salt and key verifier, are appended to the password and run, along with the salt, in the key derivation function; decryption is then tested with key verifier.
That makes cryptographically hard, if the key derivation function is secure (PEA uses PBKDF2, widely accepted to be secure), to find a combination of salt and password (that includes the header's data) that matches the key verification value.
Since key verifier is word sized, that means that a modification in archive's or stream header (including salt and key verifier, since used in a secure way in the verification procedure above described) has 1 /2^16 probability to pass undetected to this stage.
Moreover, only few header are possible since non valid header will make the archive to don't even be opened.
Since only one message out 2^16 will run the full decryption and authentication process, this attack has a low impact on Bob, that has two means (header validity check and key scheduling level check, the latter being cryptographically strong) to discard most of the wrong headers without spending the full decryption time.

Mallory can decide to mount a DOS attack tampering with all the communication he can intercept imposing Alice and Bob a severe overhead for repeating several communications.

Case1: private communication

Mallory could alter a volume and then substitute the volume tag with a matching one: the tampering will be reported at stream level since the altered data will not allow stream's authentication, but it will not be possible to identify the volume needed to be retransmitted.

However, if object level integrity check is used, that action will modify one of the embedded objects or related object level control tags (both protected by encryption), making them no longer match. The fact will be reported as an object level error, allowing a) to identifying tampered content b) to probably narrowing the field of possible tampered volume(s).

To avoid the detection of a tampered object Mallory should know all the content of the object and its exact position in the archive in order to be able to calculate the original control tag and the tampered one and to alter in the proper way (i.e. by difference with original values, if CTR mode encryption is used, since bit position of plaintext is not altered) the object data and related object's control tag areas.

This level of knowledge is unlikely, since object names and all related metadata, including size and control tag, are encrypted, but not impossible, since Mallory could by hypothesis have complete knowledge of all the objects need to calculate were exactly the desired object reside in the archive; this make the event non trivial but not non feasible.

If Mallory succeed in hiding both volume's and object's tampering, archive will however fail the authentication but it will not be possible to reduce the field of data to be discarded, and the DOS attack would have been successful.

The only cryptographically strong fix for this case of DOS attack is in providing authenticated encryption features for the volume level, that is actually not implemented.

Mallory could even switch the order of the volumes in the archive, since volume sequence is declared in clear (in the volume's name), however this will lead to fail the stream's authentication.

Probably the integrity checking of objects partially embedded in the volume (i.e. at the beginning and at the end), will fail, but as shown before Mallory could have enough knowledge of the objects to fix the problem of object level checks.

In both case the attacks doesn't reduce the security of the encryption nor of the authentication of the stream, but may impose to Bob the overhead to discard the whole transmission.

Case 2: publication

Issues in Case 1 becomes not meaningful when the data get published and hash values are i.e. exposed for control on a public server; if Bob can access the server securely (out of the scope for PEA security model), the hash value can verified and Mallory cannot rely on creating a new valid modified message / hash pair; the only possible attack remaining is finding a collision (modified message that generate the original hash), that is unfeasible if a cryptographically strong hash was chosen.

The volume sequence swapping attack becomes unfeasible too, unless two volumes have the same hash value, however the attacked archive will still fail at least the stream level authentication.

Cryptanalysis of PEA format

This chapter was written mainly applying to PEA file format the observations made by Tadayoshi Kono [1] on WinZip Authenticated Encryption scheme, so please note that it may be far than exhaustive since the cited study is actually focused on zip format, not on PEA format.

Basically, the difference between zip's AE-2 encryption scheme and PEA's one are:

- PEA features uses EAX mode along with classic composition method; EAX mode security for both privacy and authentication was clearly proved (providing the underlying cipher is secure) in [2];
- PEA encrypt a group of objects (and authenticate them and the salt that was used) as a single encrypted stream so it's not needed to encrypt each file separately; moreover PEA 1.1 file format doesn't even allow to make archives with multiple streams: those factors makes infeasible the attacks described in [1] in chapter 7, 8 and 9:
    - 7: archives with mixed content of encrypted and unencrypted files - such case is not possible with PEA 1.1 file format since only one stream is possible;
    - 8: insufficient entropy in salt that may lead to keystream reuse; and 9: concerns in making easier dictionary attacks - becomes infeasible since salt is generated a single time, see below for implemented entropy sampling scheme in current PEA executable implementation;

  That also leads to:

  - having the encryption initialised only once means offering higher performances when encrypting many small files and allowing choosing slower key derivation and salt generation functions, if desired, with generally smaller impact on overall performances.

  - don't have the overhead of the salt and the authentication tag for each single object archived, resulting in a smaller output size overhead for cryptography related data.
- PEA encrypt all associated data of each input object (name size, name, last modification date, attributes, size and optional checksum/hash of uncompressed, unencrypted object), not only file content, making infeasible attacks described chapters 3 (leakage of data) and 5 (exploiting filenames associations)
- Attack described in chapter 4 changing compression scheme and output size to produce garbage, but unencrypted, output:

being the headers data appended to the user-provided passphrase and sent to key derivation function, only 1 /2^16 modification will pass the key verification stage, and even in this case the modification will make the authentication fail (unless finding a collision in the 2^128 authentication tag field);
moreover objects sizes are encrypted and authenticated, trying to modify them will result in stream failing the authentication;
it's possible to make this kind of attack even more unfeasible using object level integrity check, being the check tag subject to authenticated encryption:

- if the attacker try to modify the object level control tag to match with the new expected output, the stream will not authenticate and the user will be warned to don't trust it;
- if the attacker doesn't try to modify the tag, the object level check will report the error (unless the attacker can find valid PEA header settings producing a collision for the object level check algorithm and the given object, that's quite unfeasible);

it would be however a nice security policy to delete by default objects failing the authentication/integrity check in order to prevent the user to be tricked by the attacker to misuse them.

Other important details about operations for generating a .pea archive, as featured in current PEA implementation:

- PBKDF2 key derivation is used for keying; SHA1 160 bit hash is used as primitive function in the kdf for generating keys for 128 bit encryption, while Whirlpool 512 bit hash is used as primitive in kdf for generate keys for 256 bit encryption.
- Optional two factor authentication is offered: a passphrase (may contain any typeable character) is mandatory, a keyfile can be optionally used: any filetype can be specified, although it's strongly recommendable to use random generated files. Passphrase, archive header and the content of the keyfile are concatenated and sent as an array of byte to the PBKDF2 key derivation function.

Random number generation in current PEA implementation was developed trying to take in account basic concepts contained in literature, as in [8].
Please refer to pea_utils unit, in the section "functions related to keying, salting and entropy collection" for more details; in brief:

- The random number generator, from 0.11 release, uses a 2048 bit sized (256 byte) persistent randomness collector to propagate randomness collected to following sessions of use; Pea and PeaZip (a frontend for Pea executable) save that session seed as "rnd" file in "res" path.
- A "fingerprint" of the system is taken at program start, from several system- and session-specific variables, some changing slowly some others changing quickly, in example: environment variables; current disk size and free space; system timers and CPU cycle counter; memory status; PID; last OS error; list of temporary file names, attributes, file dates/times; etc… values are collected and hashed, with the fingerprint being the digest of the hash of the system's entropy pool.
- Three user dependent entropy sources can be initialised:
  - Mouse: at each mouse movement coordinates and timing (and memory status for Windows only) are used to update mouse's entropy pool;
  - Keyboard: each time a key is pressed the key and the timing (and memory status for Windows only) are used to update keyboard's entropy pool;
  - Files: when a file is opened for collection entropy purpose, content, name, timing (and memory status for Windows only) etc are used to update file's entropy pool;

  The entropy pool update process is updating the hash status with newer sampled values.
- When the generation of a random number (key, salt…) is requested, the three user dependent pools are finalized (the digest of each hash is calculated); and other two digests are created:
  - a time digest (digest of hashing of timing and CPU cycle counter;
  - a memory status digest (Windows only) generated when the random number generation is requested;

The random number generation function usually passes the values of those 6 digests (fingerprint, mouse, keyboard, files, time and memory) and the data from the persistent randomness pool through an hash and/or to seed cryptographic prng and csprng functions.

Data recovery from PEA format

Information in this chapter doesn't mean to matter for common usage of the program, becomes relevant only when rather uncommon errors or willing tampering of the data occurs.
A true data recovery mechanism with Error Correcting Code fields (i.e. like, optionally, in RAR format) is not integrated in current PEA archiver implementation, however PEA file format allow to specify an archive-specific and a stream-specific error correction scheme for future usage.
It's however possible to use PEA executable in cascade with other applications that generates ECC fields, in order to overcome this limit when data integrity is crucial, i.e. if a single copy of the archive exist and it's not possible to download it again or recover it from a backup.

On the other side, error and tampering detection is strong and can be flexibly adapted to the user's model of treat about data corruption or forgery, making extremely difficult that a casual or intentional modification get unnoticed.
As tradeoff of PEA approach it's generally not possible to partially extract and authenticate a single object from a stream since it is the whole stream the subject of authentication and all the data embedded in the stream need to be correct to obtain a positive authentication.
Volume level integrity check can help to find in which volume the problem is, otherwise object level check can allow extraction of data with object level granularity, discriminating successfully and unsuccessfully object-level integrity checked objects if it's acceptable for the user's treat model.
From the point of view of the implementation of the extraction program (UnPEA), it's critical also to understand how errors may impact with program operations:

- If encryption is used, errors in archive or stream header, in encryption salt or in the key validation field will bring to unsuccessful key validation, stopping the extraction from the encrypted archive. Generally this problem cannot be fixed, unless the user made a backup of the headers area, including cryptographic subheader (first 36 byte of the file);
- If encryption is not used errors in functional fields in the archive or stream header (fields defining archive's and stream's properties) can be detected only at stream check stage; driving UnPEA to use wrong settings in extracting the archive, they may prevent the application to work properly, not allowing to complete the extraction and the check of the content. The backup of the header material can fix that kind of errors, otherwise the header functional fields may even be rewritten manually using an hex editor and looking for reference the documentation or sourcecode to find values to write in each field.
- Errors in the file data generally allow total archive extraction (allowing further examination of the data), unless some bits are lost or added and file size is altered, making not possible to automatically find where the next file begin and so triggering errors of different kinds;
- Errors in file age and file attributes are not meaningful if UnPEA application is told to reset those attributes, otherwise incorrect date or attributes could be not accepted by the host system that may not allow to save the object;
- Errors in the declaration of the width of a variable sized field (file name size, file size, size of compressed and uncompressed block when PCOMPRESS1..3 compression is used), generally make not possible to find were next fields begin not allowing the automatic extraction process to continue, however if the data is not encrypted, or when encryption is removed, objects could be extracted using an hex editor since the object names are human readable and may help to find the desired data in the archive.

  Current implementation consider wrong input names longer than 32K characters (exceeding actual needs), warning the user and stopping; that mean that an error in input name size (word sized field) has ½ probability to pass undetected to this check, for each object in the archive.

  If PCOMPRESS1..3 compression is used, each block of compressed data is preceded by it's compressed size (4 byte field, allowing values up to 2^32-1 byte); since for PCOMPRESS* scheme output (compressed) blocks of data can have mandatory at most the same size of input (uncompressed) blocks of data, it's easy to check against most errors in those areas: if compressed size is declared bigger than the buffer size (in the current implementation 1 MB), it's certainly an error (so for the current implementation a random error in those fields has about 1/4000 probability to pass undetected).

  Moreover, the last field of a PCOMPRESS1..3 compressed files declare the uncompressed size of the last buffer (since it probably don't match the compression buffer's size), which is checked against the size of residual data expected due to the size declared for that file; if they differs a decompression error condition is raised and operation is interrupted.

Current UnPEA implementation will try to intercept error conditions and in case of unexpected types of errors will try to save an automated job report to allow further analysis.
Error checking volumes before extraction may be a way to avoid operational problems triggered by data errors to the extraction procedure; however this approach has two shortcomings:
- doing so will require the extraction procedure to run not synchronously all operations (anticipating the volume level checks), which leads to performance drawbacks;
- volume integrity check is meant to detect casual data corruption, if the volume was forged the volume tag may have been recalculated and replaced, making useless this approach (that issue doesn't apply if volume's hashes are published and safely accessible from the receiver)

Section 2: PEA implementation

Usage

PEA executable doesn't feature a way to input parameters directly into the application's graphical interface (except, when applicable, for passphrase and keyfile).
It is the "engine" performing actual work on data and can be invoked from a user-friendly GUI (i.e. PeaZip, from the same Author; for usage please refer to PeaZip's documentation), or can also be launched from command line and batch scripts. In both cases PEA executable elaborate the parameters received from calling application or script.
For using PEA features as a library, within third part software, please refer to "Notes for development" chapter.

PEA featured functions are:

- PEA: archives files and directories (even entire filesystems can be passed); compress, encrypt, authenticate, error check and split in multiple volumes the output (a .pea format archive) in a single passage, with extensive job report;
- UnPEA extract and check .pea format archive, with extensive job report;
- RFS "raw file split": byte-split an input file "as is", optionally featuring integrity checking through external control data, keeping full compatibility with other raw file splitting/joining applications (*x split, hjsplit, File Tools 1.x etc);
- RFJ "raw file join": joins raw split files (featuring also integrity checking if files were splitted with RFS);
- WIPE: securely delete files and folders;
- SANITIZE: securely delete free space;
- COMPARE: byte to byte compare two files;
- CHECK: perform selected checksum and hash algorithms on selected files;
- ENVSTR: display host system's environment variables' strings;
- LIST: list files and folders.

When the program starts, the user may be requested (if the stream control algorithm and the mode of use of the program request it) to type a passphrase (and retype it in the verification field if creating a PEA archive) and optionally select a file as key (it's strongly recommended to use a randomly generated keyfile).
The passphrase may contain spaces and any typeable char but remember that an user may have some troubles in figuring how to input some special characters specific to another language keyboard.
The user will need to remember the passphrase (and to have the key file, if used) to be able to open an encrypted archive, there is no key escrow mechanism in PEA.
PEA will try to give a rough rating about the entropy entered with the passphrase, the higher the better (until the passphrase can be memorized!) however note that PEA obviously cannot figure if the text is easily guessable or not.
When creating an archive using encryption PEA also needs to generate an unique salt, it uses system's and session's variables, timers etc for salting with unique and unpredictable values the salt generation procedure; if keying material (passphrase/keyfile) is entered interactively (i.e. as in case of PEA launched by PeaZip) mouse movements (coordinates and timings) are used to improve the amount of entropy introduced in seed generation process.

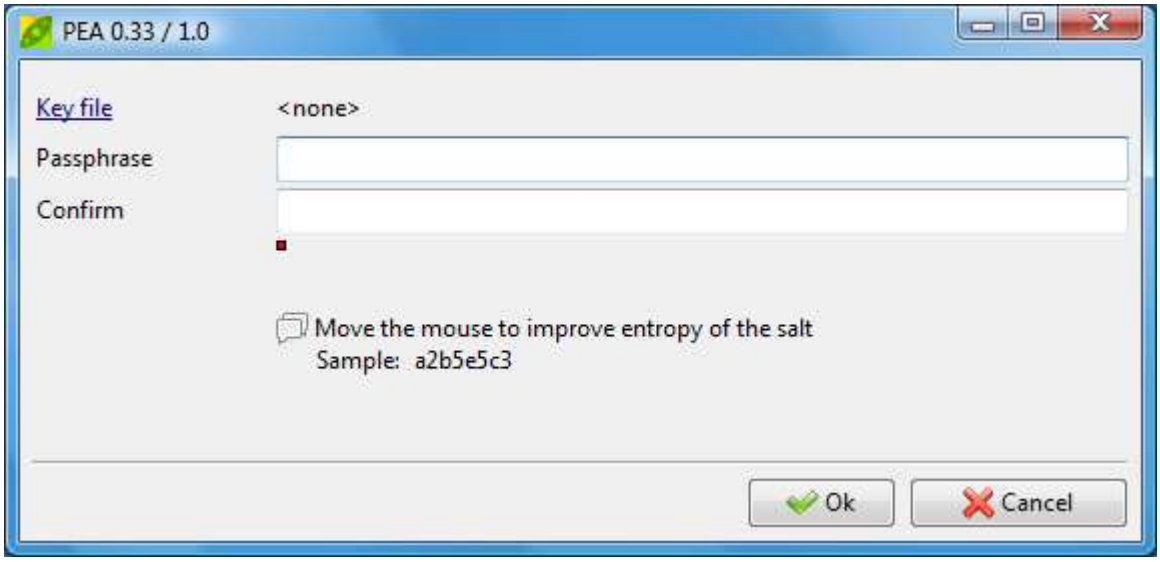


Image 3: PEA asking for password; in the form's caption is declared: the release and the PEA file format supported.
In foreground, PeaZip application that invoked Pea; in the list of input objects a disk and a folder.

PEA executable try to esteem the amount of free space needed for requested operation (that phase is usually needed to make PEA capable of correctly reporting operation's progress); if during execution of the program the free space results not sufficient the application will ask for user's intervention, i.e. clean up destination drive, or change support if output is directed to a removable drive.
When the program ends the execution, most relevant information are shown in the form and a label "job log" can be clicked, opening a second form displaying more detailed information about input, output and program settings; the job log can be saved to a plain text file as tabulated text that can be easily imported in most analysis software, i.e. a spreadsheet, for a more convenient displaying.
On Windows builds is also shown a label that allow to open the object or to explore it's path.

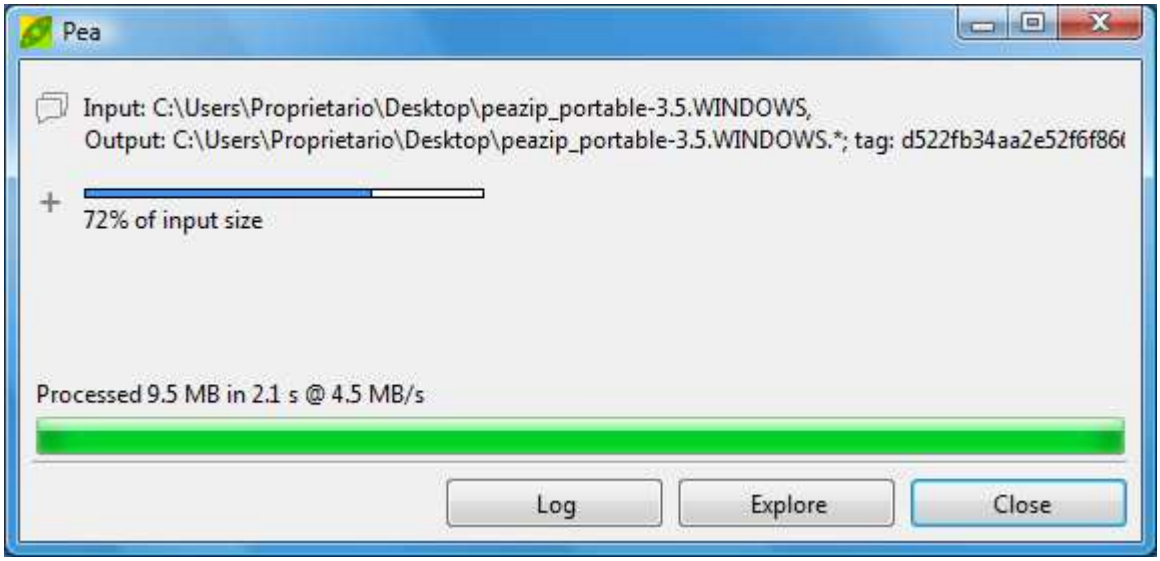


Image 4 PEA job log

Screenshots in images 3 and 4 refer to PEA executable performing "PEA" feature, the creation of archive in .pea format, however general concepts are applicable to any of the operations featured by the application
If you are interested in using PEA from command line or batch scripts, the syntax must meet the following guidelines:

PEA

Command line parameters	Example
Executable name	pea
Feature called: PEA, **create a .pea archive**	PEA
Output name, full qualified name or AUTONAME to automatically name output starting from the name of first object in input list	"c:\testdir\out"
Volume size in bytes, 0 for not creating multiple volumes; volume size must be at least 10 byte more than volume control tag size, if a lower parameter is passed the volume size will be silently adjusted (it's only relevant for very small sizes)	200001
Compression scheme to use: PCOMPRESS0..3 (see "PCOMPRESS compression scheme" chapter)	PCOMPRESS2
Algorithm to be used for volume level check (see "Algorithms used in PEA format" chapter), NOALGO for omit this level of operation (all three levels of operation can be omitted in the same way)	SHA256
Algorithm to be used for object level check	RIPEMD160
Algorithm to be used for stream level check/encryption	EAX
Mode of operation INTERACTIVE: the form is visible, user's input is requested if needed, this mode is recommended using PEA from command line since it is safer than passing secret parameters through command line (INTERACTIVE* modes can be used only for PEA and UnPEA since only those features may require keying, other modes can be used also for RFS and RFJ); BATCH: the form is visible, user's input not requested: if passphrase/keyfile are needed are got from next two parameters of the command line; HIDDEN: the form is not visible, user input not requested (as for BATCH); *_REPORT can be applied to each mode: the program operates as described for the * mode used but an automated job report is saved at the end of the operation	INTERACTIVE
Object's names input method: FROMFILE: a single object name is passed as next command line parameter, the object is a plain text file listing full qualified names of objects to archive, one per line; number of parameters that can be passed in that way is practically limited by the structure internal to the program that stores input names (a dynamic array of string, that usually cannot grow over 2 GB). FROMCL: multiple object name are passed as next command line parameters, each one is the full qualified name of an input object; number of parameter passed will be limited by the host system's command line max buffer size (usually in the order of 32KB, system dependent). When input objects don't exist, this will be recorded in the job log. Received input names are "expanded" by the program in the sense that directories passed as input object are recursively listed and each single object contained will be internally listed by the program (applying the aforementioned limitation on the size of internal structure, a dynamic array of strings). Each single input object name can be up to 32KB in size, exceeding actual needs.	FROMFILE flist.txt

UnPEA

Command line parameters	Example
Executable name	pea
Feature called: **open a .pea archive**	UNPEA
Input archive (full qualified name), first volume if volume spanning was used	“c:\testdir\out.000001.pea”
Output name, full qualified name or AUTONAME to automatically name output from the archive’s name	AUTONAME
Date and time parameter: RESETDATE use current date and time for extracted objects, ignoring date/time of archived object actually is the only option available	RESETDATE
Attributes parameter: SETATTR: restore archived object’s attributes (apply them to output object) RESETATTR: create output objects with default attributes, ignoring archived attributes	SETTATTR
Extraction mode: EXTRACT2DIR is actually the only mode available, restore archived objects in a directory with name and path as in “Output name” parameter; restored objects have the shortest possible path to preserve directory structure; if duplicate objects are found, create progressive numbered copies (position in archive determine the progressive number)	EXTRACT2DIR
Mode of operation (as in PEA)	BATCH_REPORT “This is the passphrase” NOKEYFILE

RFS

Command line parameters	Example
Executable name	pea
Feature called: RFS, **raw splitting of a file**	RFS
Output full qualified name or AUTONAME to automatically derive it from input name	AUTONAME
Volume size in bytes	123456
Volume control algorithm	WHIRLPOOL
Mode of operation	BATCH
Input full qualified name	"c:\testdir\a1.txt"

RFJ

Command line parameters	Example
Executable name	pea
Feature called: **join raw splitted files**	RFJ
Input: full qualified name of first volume	"c:\testdir\a1.txt.001"
Mode of operation	BATCH
Name of the merged filed, AUTONAME to derive it from input name	AUTONAME

WIPE

Command line parameters	Example
Executable name	pea
Feature called: **wipe files and directories**	WIPE
Level of security: NONE, ZERO, VERY_FAST, FAST, MEDIUM, SLOW, VERY_SLOW Level none performs simply a non-secure direct file delete, making the file not recoverable from recycle bin-like utilities. Level zero overwrites files with all 0, and it is intended for improving compressibility of the filesystem (i.e. disk image backup, or virtual machine optimization) rather than for secure deletion. For other levels, the wiping process is organized in following stages: 1) Overwrite file content with random data (AES256 CTR) and close file (forcing flush to disk), n times; this is the most time demanding stage, expecially for big files 2) Replace file content with random content of fake random size, (1B..4KB)*n, flush file each time 3) Rename file or folder with random name, flush file, n times Number of iteration of each step is 1 for very_fast, 2 fast, 4 medium, 8 slow, 16 very_slow	MEDIUM
Input: full qualified name of each file to be deleted	"c:\testdir\testfile.txt"

SANITIZE

Command line parameters	Example
Executable name	pea
Feature called: **sanitize free space**	SANITIZE
Level of security: ZERO, VERY_FAST, FAST, MEDIUM, SLOW, VERY_SLOW Level zero overwrites free space with all 0, and it is intended for improving compressibility of the filesystem (i.e. disk image backup, or virtual machine optimization) rather than for secure deletion of free space. Other levels overwrite free space with random data (AES256 CTR) and flush to disk multiple times; number of iteration of each step is 1 for very_fast, 2 fast, 4 medium, 8 slow, 16 very_slow	ZERO
Input: unit name	C:\

COMPARE

Command line parameters	Example
Executable name	pea
Feature called: **compare files**	COMPARE
First input file: full qualified name	"c:\testdir\testfile_a.txt"
Second input file: full qualified name	"c:\testdir\testfile_b.txt"

CHECK

Command line parameters	Example
Executable name	pea
Feature called: **checksum and hash files, show 32 byte sample of file header and EOF**	CHECK
Output coding: write checksum/hash results as HEX: hexadecimal LSBHEX: hexadecimal, Least Significant Byte first BASE64: Base64 coding	HEX
List of algorithms to be used, enter one or more by name: ADLER32, CRC16, CRC24, CRC32, CRC64, ED2K, MD4, MD5, RIPEMD160, SHA1, SHA224, SHA256, SHA384, SHA512, SHA3_256, SHA3_512, WHIRLPOOL Otherwise specify one of following options: ALL use all supported algorithms LIST listing files and folders; folders displays statistics about content ANALYZE same as list, but displays first 32 byte at file header and last 32 bytes at EOF	ALL
Stop parsing for checking algorithms/options and start parsing list of files/folders to be checked	ON
List of files to be checked	"c:\testdir\testfile1.txt" "c:\testdir\testfile2.txt" "c:\testdir\testfile3.txt"

ENVSTR

Command line parameters	Example
Executable name	pea
Feature called: **display host system's environment variables' strings**	ENVSTR

LIST (superseded by CHECK HEX LIST ON)

Command line parameters	Example
Executable name	pea
Feature called: **list files and folders**	LIST
Mode of operation INFO: list files/filders and calculate information: total size, smaller/larger object, total objects, older/newer object LIST: list files/folders only (slightly faster)	INFO
input directory/file name: full qualified name	"c:\testdir\"

HEXPREVIEW (beta)

Command line parameters	Example
Executable name	pea
Feature called: **hexadecimal preview** shows offset, hexadecimal representation of bytes and possible utf8 translation of each string of 16 bytes per row; limited to small files due to slow performances, max 16MB allowed	HEXPREVIEW
input file name (only files, dirs are not allowed): full qualified name	"c:\testfile1.txt"

Command line switches (like AUTONAME, NOALGO etc…) are here conventionally written in upcase but are not case sensitive since are internally converted in upcase.
The max length allowed for command line and for each single parameter may vary from system to system, this may be a practical problem only for invoking PEA feature with a very long list of files passed as command line parameters (FROMCL switch), however it's possible using dir names as input objects allow to pass all dir's and subdir's content to PEA as a single parameter.
The problem may be avoided using FROMFILE switch and composing a plain text file listing one input object for each line, in that case a single parameter is needed for passing to PEA all input objects.
If PEA is used within a third part application as a library, the input objects will be passed directly as a dynamic array of ansistrings, being the size of the input array memory limited.
For any of the three approaches should be however noted that in the actual implementation the list of input objects (passed as parameters or from the filelist or from input filename array) is internally parsed to recursively listing dir's content and discarding non accessible objects, and all object's names are saved into a dynamic array, whose size is memory limited; that may matter if a very huge number of input objects is internally listed to be archived, even if they are externally passed as a single filelist or under a single dir name.
As default policy PEA overwrites filetypes created by itself and don't overwrite any other kind of file, without asking for user interaction in those cases (to don't stop batch operations): in example when creating an archive the application will silently overwrite an archive with same name in same path, but on the other side it will not overwrite files extracted from an archive if the extraction operation is repeated multiple times, it will rather create a new output with progressive number appended to the name.
Pea executable automatically closes if no errors needs to be reported to the user, except if the operation is meant to generate human readable output (i.e. calculate checksum, display environment variables etc).

Quick benchmarks

How does PEA implementation compares with existing state of art archivers, i.e. 7zip, WinZip, WinACE, WinRAR…?

Comparing different software that offers different features, saves different metadata, offers different interaction and reporting to the user, performs different runtime error checks etc… it's not unlikely to comparing apples and oranges.
However, most users would like to know what to expect from an archiver software, at least for most evident and immediate factors: speed and compression ratio.
About speed, I need to make two premises:
First, PEA is still a young project, don't expect it to be jet optimised for best performances, actually I focused more on giving pervasive and detailed error reporting and job logging.
Second, PEA file format offers strong multilevel integrity check and strong authenticated encryption; those are computing intensive tasks and will heavily weight on overall performances even if it uses a very fast underlying cryptographic library, written and maintained by Wolfgang Ehrhardt [6].
About compression, PEA uses a deflate based compression format (PCOMPRESS*), so compression ratio is expected to be quite similar to other deflate-based compression software.
So, let's do some benchmarks!
System 1 is a 2003 desktop PC: P4 (f15m2) 2,66 GHz 256MB RAM HD 40GB 7200 rpm
System 2 is a 2006 MacBook Pro: CoreDuo fixed @2GHz 512MB RAM HD 80GB 5400 rpm
Both machines are running WinXP Pro SP2 with latest patches (august 2006), system, program and input data are on the same partition, that uses NTFS filesystem and was just defragmented.
Input 1 is dev-pas 1.92 folder, just installed, 557 files 37 folders, 26.145.641 B
Input 2 is enwik8, 1 file, 100000000 B
Each single test runs 4 times, first time discarded, the reported time is an average between other 3 times, when the system had jet cached files needed by the program (in order to be less disk limited as possible), each time the output archive is deleted.
Software is almost used in default configuration and output archive is not splitted in multiple volumes.

application and settings	Input 1			Input 2		
	sec sys1	sec sys2	out size (B)	sec sys1	sec sys2	out size (B)
PEA pcompress2, no encryption, obj CRC32, volume MD5	4,4	4,9	8.463.268	19,5	23,5	36.652.296
PEA pcompress2, no encryption, obj CRC64, volume SHA256	4,6	5,1	8.465.664	19,9	24,1	36.652.316
PEA pcompress2, stream AES128 EAX, obj CRC64, volume SHA256	4,8	5,5	8.465.696	21,3	25,8	36.652.348
PEA pcompress2, stream AES256 EAX, obj CRC64, volume SHA256	4,9	5,6	8.465.696	21,6	26,4	36.652.348
PEA pcompress2, stream AES256 EAX, obj CRC64, volume Whirlpool	5,3	6,1	8.465.728	23,3	28,5	36.652.380
7z 4.42 .zip normal (algorithm optimized for best compression)	9,0	10,0	8.320.900	38,0	35,0	35.176.610
7z 4.42 .7z normal	23,0	11,0	6.545.794	211,0	96,0	27.195.501
7z 4.42 .7z normal, using encryption defaults (AES256)	23,0	11,0	6.545.825	212,0	96,0	27.195.519
WinACE 2.61 .zip normal compression (not default)	4,0	3,0	9.209.048	11,0	12,0	42.298.878
WinACE 2.61 .zip normal compression (not default), AES128	13,0	13,0	9.232.442	12,0	13,0	42.298.920
WinACE 2.61 .ACE (defaults)	20,0	11,0	7.184.402	123,0	71,0	30.875.330
WinACE 2.61 .ACE (defaults), using encryption defaults (Blowfish 128)	20,0	12,0	7.185.558	125,0	73,0	30.875.334
WinRAR 3.51 .zip (defaults)	3,0	2,0	8.488.192	15,0	13,0	36.496.168
WinRAR 3.51 .RAR (defaults)	12,0	7,0	7.565.393	132,0	70,0	29.778.994
WinRAR 3.51 .RAR (defaults), using encryption defaults (AES128, not encrypt filenames)	12,0	7,0	7.583.924	133,0	71,0	29.779.006
WinZip 10.0 trial build 6698 normal (default)	4,0	2,0	8.556.276	14,0	10,0	36.810.059
WinZip 10.0 trial build 6698 normal (default), AES128	7,0	6,0	8.579.670	15,0	11,0	36.810.101
WinXP integrated compression utility	3,0	3,0	8.577.683	13,0	10,0	36.936.694

Table 1: times and output sizes (lower, better); in grey, archivers using non deflate based compression

application and settings	size ratio		time ratio sys 1 *		time ratio sys 2 *	
	Input 1	Input 2	Input 1	Input 2	Input 1	Input 2
PEA pcompress2, no encryption, obj and volume CRC32	98,913%	99,571%	110,000%	139,286%	245,000%	235,000%
PEA pcompress2, no encryption, obj and volume SHA256	98,941%	99,571%	115,000%	142,143%	255,000%	241,000%
PEA pcompress2, stream AES128 EAX, obj and volume SHA256	98,941%	99,572%	68,571%	142,000%	91,667%	234,545%
PEA pcompress2, stream AES256 EAX, obj and volume SHA256	98,941%	99,572%	70,000%	144,000%	93,333%	240,000%
PEA pcompress2, stream AES256 EAX, obj and volume Whirlpool 512	98,942%	99,572%	75,714%	155,333%	101,667%	259,091%
7z 4.42 .zip normal (algorithm optimized for best compression)	97,249%	95,562%	225,000%	271,429%	500,000%	350,000%
7z 4.42 .7z normal	76,503%	73,881%	575,000%	1507,143%	550,000%	960,000%
7z 4.42 .7z normal, using encryption defaults (AES256)	76,503%	73,881%	328,571%	1413,333%	183,333%	872,727%
WinACE 2.61 .zip normal compression (not default)	107,629%	114,911%	100,000%	78,571%	150,000%	120,000%

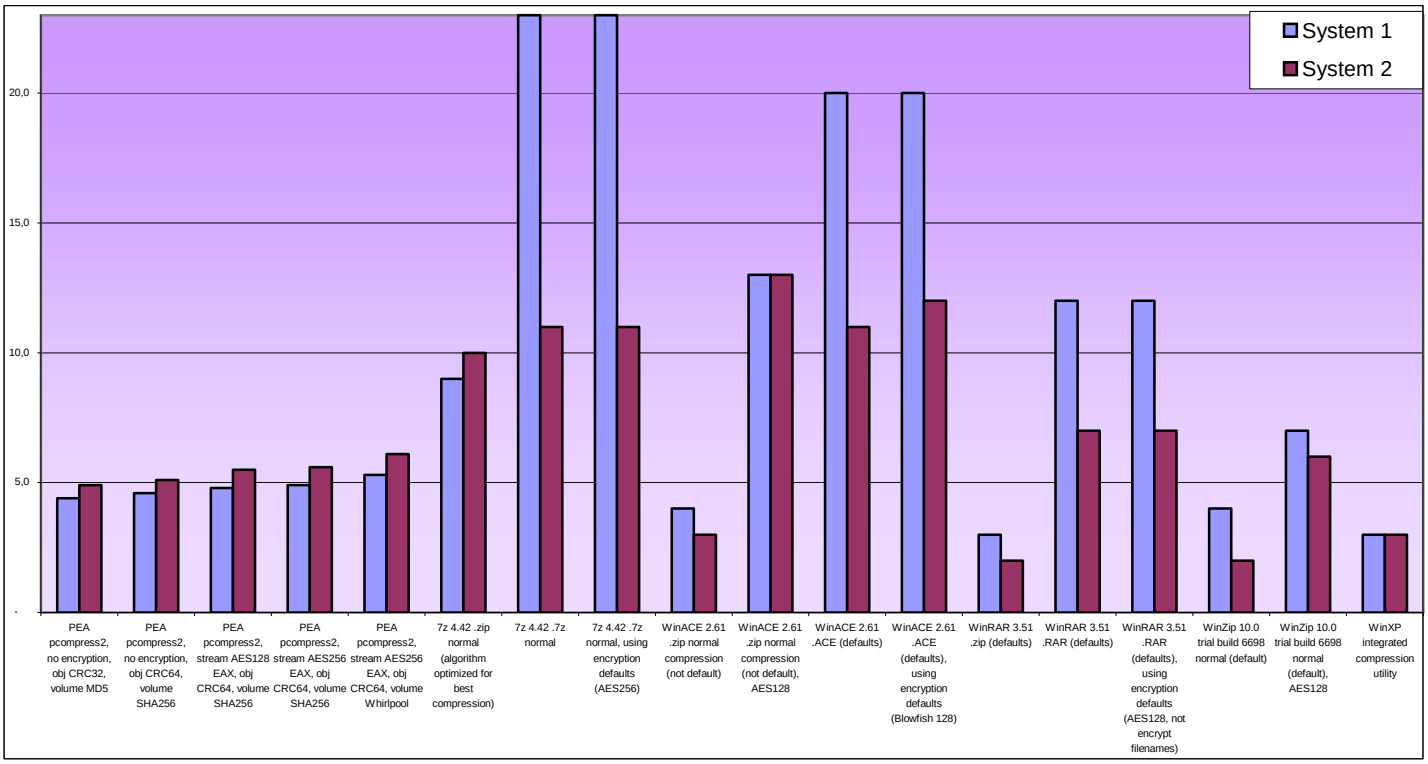
WinACE 2.61 .zip normal compression (not default), AES128	107,903%	114,911%	185,714%	80,000%	216,667%	118,182%
WinACE 2.61 .ACE (defaults)	83,966%	83,877%	500,000%	878,571%	550,000%	710,000%
WinACE 2.61 .ACE (defaults), using encryption defaults (Blowfish 128)	83,980%	83,877%	285,714%	833,333%	200,000%	663,636%
WinRAR 3.51 .zip (defaults)	99,204%	99,147%	75,000%	107,143%	100,000%	130,000%
WinRAR 3.51 .RAR (defaults)	88,419%	80,899%	300,000%	942,857%	350,000%	700,000%
WinRAR 3.51 .RAR (defaults), using encryption defaults (AES128, not encrypt filenames)	88,636%	80,899%	171,429%	886,667%	116,667%	645,455%
WinZip 10.0 trial build 6698 normal (default)	100,000%	100,000%	100,000%	100,000%	100,000%	100,000%
WinZip 10.0 trial build 6698 normal (default), AES128	100,273%	100,000%	100,000%	100,000%	100,000%	100,000%
WinXP integrated compression utility	100,250%	100,344%	75,000%	92,857%	150,000%	100,000%

Table 2: times and output sizes % compared to WinZip10 (lower, better); in grey, archivers using non deflate based compression
*Times are compared with WinZip times for creating a non encrypted archive if compared archiver doesn't use encryption, and are compared with times of WinZip creating an AES128 encrypted archive if compared archiver uses encryption.
Sizes are always compared to non encrypted WinZip10 archive

As expected PEA gives a compression ratio similar to other deflate based archivers (similar to RAR using .zip format, marginally better (0,5-1%) than WinZip10.0 and XP integrated compression tool) except for 7z that uses an algorithm optimised for getting better compression (3-5% smaller) at a seizeable expense of speed.

Input 1 (hundreds of objects, <25 MB)

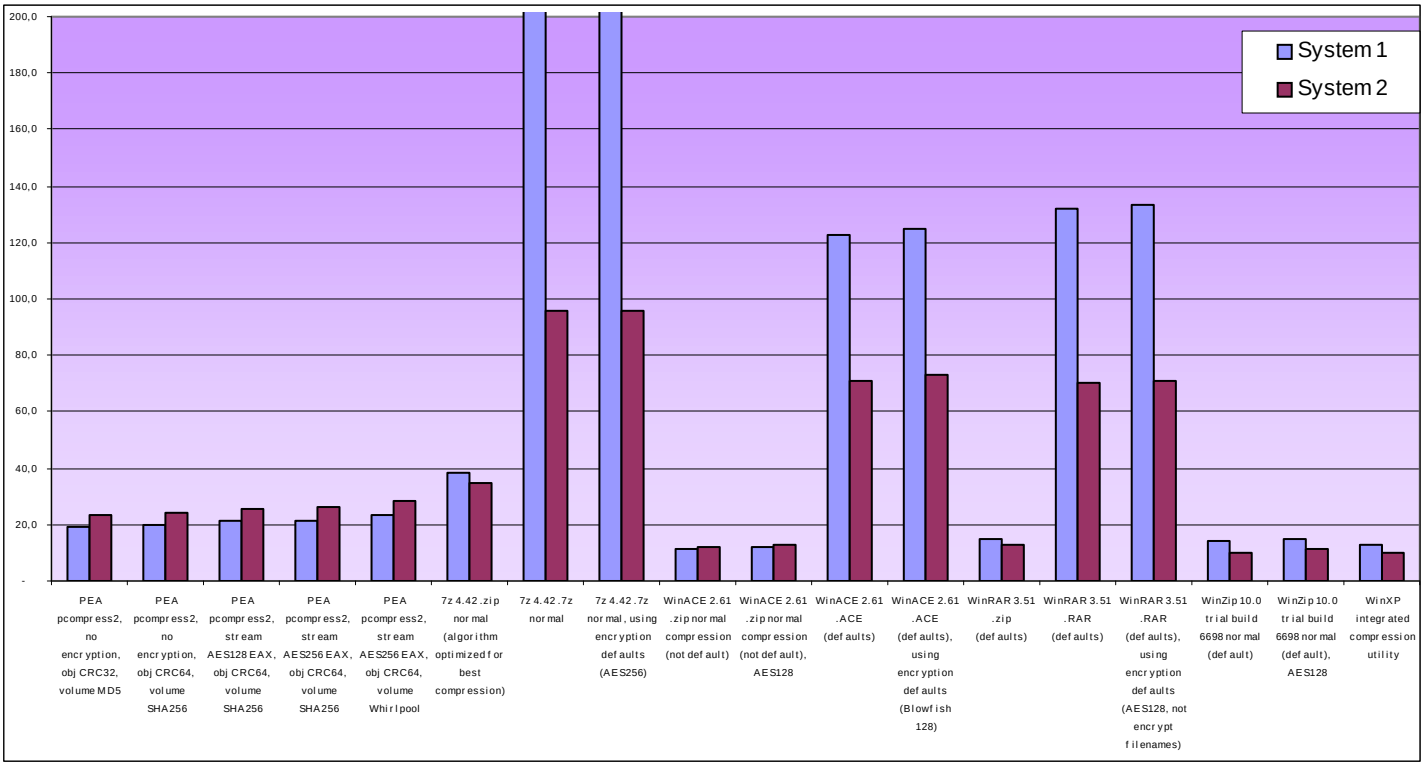
When encryption is not involved PEA is roughly 1,1 / 1,4x slower than WinZip10 on single core system, 2,4 / 2,5x slower on dual core system, giving similar compression ratio (about 0,5-1% better for .pea).
Non deflate based compressed formats (.ace, .7z, .rar) are generally slower, especially running under single core system 1, but shows to be able to significantly reduce the gap on system 2 that with two cores allow better multithreading performances.
Using encryption has a dramatic impact on .zip format: since encryption must be stopped and restarted for each object and this, as explained in "PEA security model", an huge computational overhead is introduced, especially due to seed generation and key derivation; this also introduces a little overhead in output size (0,2-0,3%) for .zip format and, what's more important, raises serious security concerns as briefly introduced in "Cryptanalysis of PEA format" chapter.
.pea format, instead, can offer encryption at stream level introducing a low computing time overhead over creation of non encrypted .pea, closing the speed gap with WinZip creating encrypted .zip and being substantially faster than WinACE's encrypted .zip (the two archivers in the set supporting .zip authenticated encryption with AES).
Comparing WinZip and PEA times when using encryption, PEA times are 0,7 / 0,75x (depending on security settings) on single core system and 0,9 / 1x on dual core system.
Other compression formats use a similar approach, introducing a low computing time overhead for offering encryption, however since they offers also more powerful (and time costly) compression algorithms, they are generally quite slower than PEA an Winzip in this test (1,2 / 2x slower than WinZip on system 2, 1,7 / 3,3 on system 1).



Graph1: times (sec) for Input 1, shorter, better

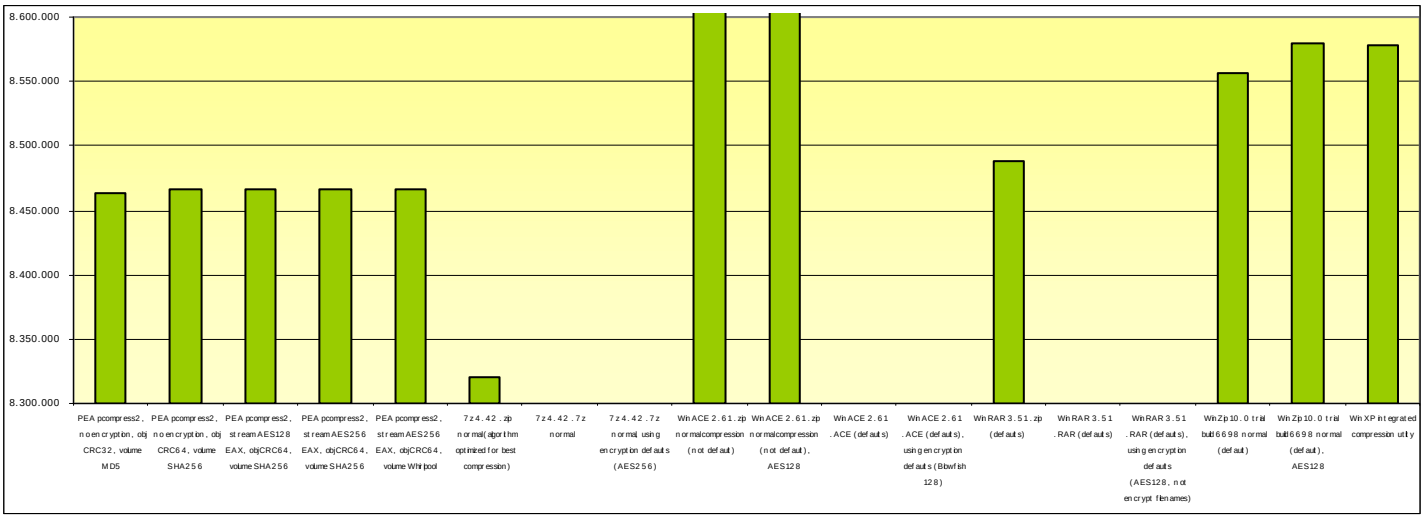
Input 2 (single file <100MB)

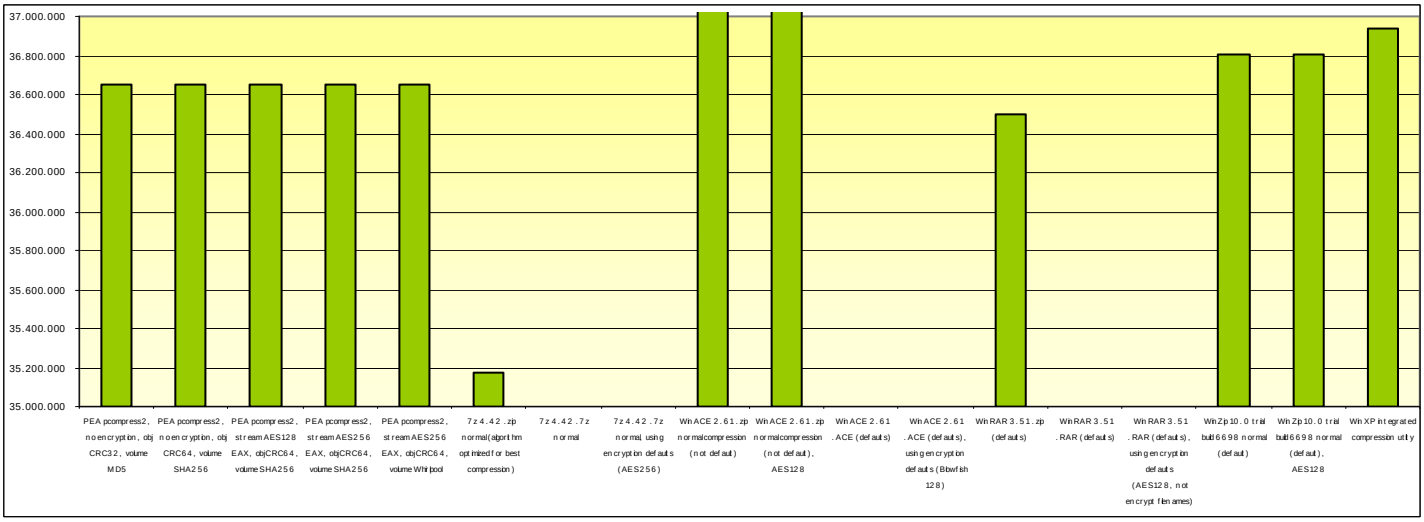
With this kind of input .zip format can offer encryption at a reasonable overhead; .pea times are 1,4 / 1,6x on system 1 and 2,3 / 2,6x on system 2 than WinZip times, refleting closely the performance ratio for non encrypted archives.
Non-deflate based formats takes 6,5 / 15x longer times of creation than WinZip's .zip (they are especially disadvantaged on single core system) due to the more powerful compression algorithms involved, with encryption changing very little in this scenario, as a tradeoff they generally offers a even more improved compression ratio against deflate based compression than in the first test.



Graph2: times (sec) for Input 2, shorter, better

PEA performance profiling (stub)
Built the demo application minigzip using the same libraries used by PEA (Lazarus's paszlib), with the same FPC version, it takes 24 seconds to compress with parameter –6 the enwik8 file on system 2.
The entry time for PEA (no encryption, CRC32 on objects and MD5 on volumes, PCOMPRESS2 compression equivalent to deflating with –6 parameter) is 23,5 second, and turning off al checks in PEA, the times can be reduced up to 23 sec.
That means that PCOMPRESS* compression scheme and other operations to create .pea format output doesn't introduce too bad overheads over gzip scheme; the little gain in speed while instead complexity of operation increases (minigzip does only CRC32) may be due to high speed of CRC32 and MD5 code used by PEA, that comes from W.Ehrhardt crypto library, that may be significanlty fast than the CRC32 version in paszlib.
Both application are single threaded.
The speed of compression allowed by the compression libraries seem quite low compared to state of art archivers performing analogous compression, so it seem to be an important bottleneck for overall PEA performances.





Graph 3 and 4: archive size for Input 1 and 2, close up to interval populated by most of deflate based archivers. Shorter, better.

Conclusions

PEA is a single threaded application at early stage of development, however if compared to state of art solutions it shows to be in the range of usability for what concerns speed/compression/features tradeoff; of course, the benchmarks reported here are far than exhaustive, since i.e. unpacking speed was not even taken in account.

PEA implementation offers a compression level similar to .zip format and a speed intermediate between 7z's .zip and faster .zip archivers; it also offers authenticated encryption feature (and strong multi level integrity check) at the expense of a reasonable overhead.

Due to the approach to encryption involving encryption of whole streams rather than single objects, and due to the use of quite fast deflate based compression algorithm it becomes the best choice when it's needed to quickly encrypt archives containing a great number of files.

As for compression, PEA format gives a little advantage over classic .zip compression (about 1%) when archiving many small files; the advantage reduces to about 0,5% when encrypting a single big file.

For a more standard compression benchmark, taking as reference values published in [9], PEA using highest compression (with CRC32 at object level and SHA256 at volume level, without encryption) compress enwik8 to 36,580,568 bytes and enwik9 to 323,884,338 bytes (with a compressor/decompressor compressed size of about 540 KB, that includes graphical interface etc), that places PEA between Gzip (36,445,248 / 322,591,995) and Pkzip (36,934,712 / 327,607,376).

After that benchmark and after having analysed the different additional features of various mainstream formats I'll recommend:

.zip format for archiving few large object as fast as possible, if compression ratio is not an issue or when archiving files that will however compress a few, like most multimedia formats;

.7z, when compression ratio is more important than speed, i.e. when compressing moderate quantity of well compressible data;

.rar, due to the advanced error correction features, for backup;

.pea, for archiving and securing many small or medium sized files, i.e. document or mixed content folders, suitable even for big amount of data due to the reasonably quick compression algorithm used.

Implementation notes

(global):

- When a directory is provided as input object, the content of the dir and all subdirs is listed and added to the archive; arbitrary level of nesting is supported.
- When a hardlink is provided as input object, the pointed data is archived; when a symlink file (i.e., a Windows link) is provided as input object, only the link file, containing references to the actual data, is archived.
- Empty files and empty dirs are supported.
- There is no separate thread controlling the application and allowing aborting operation while running, the only way to stop a PEA instance is to kill the process.
- Unattended operations (BATCH and HIDDEN operation modes) are interrupted due to need of operator's feedback when one of the following conditions is encountered:
    - PEA output path is full;
    - output path seem to not have enough free space for requested operation;
    - parsing parameters, a critical error is encountered such that operation cannot continue;
    - elaborating the input data (UnPEA), a critical error is encountered such that operation cannot continue: the user will be prompted an error message; if the error type is unexpected a job log will be autosaved.

- Esteem of requested space (and number of volumes involved) for a given operation may be not accurate when: compression/decompression is involved (PEA, UnPEA); some objects get deleted or moved by other processes while PEA is archiving them; not all volumes are accessible in the same path (UnPEA, RFJ), this generally doesn't impact on other operations but may not allow to PEA to give accurate report of job progress.
- INTERACTIVE operation mode cannot be used when calling *_lib_procedure procedures (not calling from command line the pea application generated compiling project_pea as a standalone executable), al parameters must be passed from the main application;
- HIDDEN mode can be used even calling pea standalone executable from command line but the process will remain hidden and will not display a graphic tool for terminating it; that may be an undesirable behaviour under most circumstances.

PEA:
- If from command line, file list or procedure parameters are passed names with wrong cases as objects to save, it will work on case-insensitive systems (the objects with wrong cases in names will be found), but it will not work on case-sensitive systems (objects will not be found and will be listed as skipped in job log). It may lead to problems, on a case-sensitive system, using objects restored from an archive created giving wrong cases in names on a case-insensitive system;
- the application will silently switch to a volume size of at least 10 byte + volume tag size

RawFileSplit:
- .check file is saved to disk as a whole object, not taking in account the given volume size, that usually has no impact unless volumes space constrains are meaningful for the order of magnitude of .check file.

RawFileJoin:
- The application needs all the volumes to be accessible and in the same path, unlike UnPEA that can understand what volumes are needed and can ask the user for providing them if they are not found.

Known issues

UnPEA:
- Restore file attributes supported only on Win32.
- Doesn't restore file last modification date.

Notes for development

It's possible to compile pea_unit to obtain a standalone PEA executable, as in PEA executable implementation.
When launching PEA executable, form create parse paramstr(1) to determine what call_* procedure is being requested; call_* procedures allow interaction for entering passphrase/keyfile (if needed) and let time to the application to draw the appropriate form.
If no interaction is needed, or after pressing passphrase/keyfile confirmation button, "interacting" boolean variable is set to false, allowing a timer to call parse_action procedure that calls the procedure * (i.e. pea, unpea, rfs, frj) as requested in paramstr(1); after that, another boolean variable is set to true in order to prevent the timer to re-trigger the action again.
When the procedure * is called, it parses and error check the command line and, if no error is found, it calls the operative procedure *_procedure, passing appropriate parameters as translated from command line arguments.
When pea_procedure is called, the input list will be "expanded" by an internal procedure that recursively list dirs content and trim not found object from the input list; a detailed report is done listing found and not found objects (either missing while expanding input list or at any further point in pea_procedure invoking the object).

To use PEA features as library from another application, you can call *_lib_procedure procedures; refer to the code for parameter description, however those procedures aims to offer a syntax as close as possible to command line usage.
You could also directly call *_procedure procedures, that points directly to execution of requested features, however *_lib_procedure procedures aims to offer a more developer-friendly interface performing checks on passed parameters and autocompleting some of the parameters (most of the less intuitive ones) required by *_procedure procedures.
Mode of operation is declared as opmode in *_lib_procedure, then passed to *_procedure as pw_param; INTERACTIVE* modes of use cannot be used from *_lib_procedure, keying material (passphrase and, if used, keyfile) must be provided as parameters from the main application calling PEA or UnPEA features.

Section 3: Question & Answers

1) Why should I use PEA?
There are many well known archiving software, even free ones, either more mature than PEA, or more feature rich, or that support more formats.
However, PEA file format has interesting features explained in the present document, if you get interested in those characteristics, then PEA is today the only program supporting that format.
If you are interested in Delphi/Pascal programming, PEA comes with sources under LGPL, so you could be interested in seeing how it works or contributing to the PEA project.
Or, if you just want to try jet another archiver, or encryption tool, or compression tool, or splitting tool, you should give PEA a try since it's free, open source, handy and easy to use through PeaZip interface.
Finally, if you simply need a raw file splitter/joiner, PEA is a good choice, keeping compatibility with other applications of that kind (like *x split, hjsplit, File Tools 1.x) and offering also wide choice of integrity checking algorithms… then you may consider giving a try to PEA fromat for archiving and splitting multiple files and folders rather than a single file.

2) Why should I NOT use PEA?
PEA executable only support PEA file format and raw splitted files, that's only two formats, so if you are searching for a solution to manage various common archive/compression formats (zip, 7z, rar, ace, tar etc…) PEA executable is not that kind of solution.
At present days, PEA format is just beginning to being used and only PEA support it, so if you send a PEA file to someone you should be sure that the receiver knows what it is; this usually is not an issue using more known format.
Auto extracting PEA files could be a solution for this start up situation, but generally the auto extracting solution is a wrong and dangerous paradigm for many reasons (the user executes code without verifying it, the code add sizeable overhead, the auto extractor should be targeted to a specific host system etc…) so since security is one of the main focus of PEA format the development is actually not targeted toward this solution.

3) Where should use or not use PEA?
PEA format possible field of use may be:

- general purpose archiving: consolidation of more files into a single one, with fast compression scheme to spare disk space, offering robust and flexible error checking and security features;
- basic backup tool, when it's simply needed to consolidate and keep private the data;
- send or publish multi-volume archives since volume oriented error checking allow to efficiently discard only wrong volumes in case of download error;
- the same, but involving keeping data private during the communication;

Fields of use where PEA is not very fit are:

- advanced backup tool, since it doesn't feature partial archive update and extraction, error correcting scheme and is not focused on some advanced archiving features like scheduling, differential backup, system-specific ways to save metadata (attributes, security attributes) and dismounting open files, rule-driven restore strategies etc: use a specific backup tool instead, otherwise an acceptable choice could be RAR;
- publishing of multi volume archive when data resending it's not possible or highly unpractical, since it doesn't feature a native ECC scheme and will not allow to rebuild corrupted archives without re-downloading the wrong volume(s): use RAR or PAR instead if you know the channel/ the media is very prone to errors.

4) Why should I use PEA instead of tar, gzip, split?
The approach of cascading different programs to accomplish a single task often makes sense, in example firstly archive and then compress allow to exploit redundancies between files to obtain better compression ratio (solid archive) and to compress heading material (if the archive contains several small files it can effectively improve compression ratio).
However the downside of this approach is that for each passage (three in the example, that doesn't take encryption/authentication in account) the data must be read and written, that obviously impacts on performances, especially if data size is too big to be kept in memory, resulting in multiple reading from temporary files on the disk, that requires free space and poses a severe performance bottleneck.
PEA works in a single passage, which means that data is read and written a single time, allowing better performances and to not be subject to IPC (inter-process communication) limitations inherent in cascading different processes to accomplish a single task.
However nothing prevent you in using PEA in cascade to get the benefit of this approach, in example firstly archive the data with PEA, then compress, encrypt/authenticate and split the resulting archive with a second passage of PEA. In this example you need only two passages and a single program.
Or otherwise you can freely combine PEA with any other program that provide, as PEA, a full usage from command line, in example you may make the archive with tar (or a mirror program, or a backup program), compress it with your favourite compressor and then encrypt/authenticate and split it with PEA…
In few words, PEA is developed to be used either as a single pass program (likewise popular archiving programs like WinZip, WinRAR, WinACE, 7zip, etc) or in a cascade of programs, with other programs or even alone, featuring itself all the functions needed

to start with n input files and ending with m output volumes of desired size, compressed, encrypted, authenticated and integrity checked.

5) Why is so difficult obtaining a good passphrase rating?
Passphrase's rating given by PEA is based on entropy evaluation according criteria and observations in [3] [4] [5]; no dictionary test is featured in the entropy calculation; entropy evaluation is restarted for each word.
It's quite established that is not easy introducing great amount of entropy typing easy to remember strings of characters, even using mixed cases, numbers and special characters.
Moreover, the entropy rating is not a strength rating, since it's not easy (if feasible at all) to automate an algorithm to understand if a passphrase is easily guessable or not i.e. can be guessed using social engineering, factor that can decrease by orders of magnitude the effort in guessing the passphrase.
As a general role of thumb, an entropy poor passphrase will generally be weak, but an entropy rich passphrase will not automatically be strong.
In order to fully exploit the keyspace of a 256 or even a 128 bit cipher is more suited a randomly generated keyfile containing sufficient entropy, sampled from more entropy-rich sources than written sentences; however that leads to entirely different kinds of problem, focused in managing the key file in a secure way to neither have it exposed nor lose it (that will make the encrypted data no longer accessible).

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[9] http://www.cs.fit.edu/~mmahoney/compression/text.html

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- Wolfgang Ehrhardt who written and maintains a very good Delphi/Pascal crypto library, used in PeaZip project, you can find his works on [6]; please refer to Wolfgang Ehrhardt for all what concerns those units, (collected in "we" path in pea-peach source package);
- All people on sci.crypt.* and comp.compression, for the useful answers and information provided;
- Wikipedia, for the quality of the articles and links provided;
- FreePascal and Lazarus teams, for developing and maintaining such a good development environment and related documentation.