Package 'PKI'

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Title Public Key Infrastucture for R Based on the X.509 Standard

Author Simon Urbanek <Simon.Urbanek@r-project.org>

Maintainer Simon Urbanek <Simon.Urbanek@r-project.org>

Depends R (>= 2.9.0), base64enc

Enhances gmp

Description Public Key Infrastucture functions such as verifying certificates, RSA encription and signing which can be used to build PKI infrastructure and perform cryptographic tasks.

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SystemRequirements OpenSSL library and headers (openssl-dev or similar)

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R topics documented:

ASN1 *Functions for handling ASN.1 format (typically DER)*

Description

ASN1.decode decodes ASN.1 binary format into raw format chunks tagged with class types.

ASN1.encode converts structured objects into ASN.1 binary format.

ASN1.item creates an item - basic object in structures that can be encoded using ASN1.encode.

ASN1.type extracts the class type from an ASN.1 item

Usage

```
ASN1.decode(what)
ASN1.encode(what)
ASN1.item(what, type)
ASN1.type(what)
```

Arguments

what	object to decode/encode/query
type	class type of the item (integer value)

Details

This is a suite of low-level tools to deal with ASN.1 (Abstract Syntax Notation One) binary formats DER, BER and CER. The tools were written specifically to handle the various DER-encoded key structures so it provides only a subset of the ASN.1 specification. They are used internally by the PKI poackage.

ASN1.decode decodes the binary representation (as raw vector) into individual items. Sequences are convered into lists, all other objects are retained in their binary form and tagged with the integer class type - which can be obtained using ASN1.type function.

ASN1.encode expects item (or a list of items) either created using ASN1.decode or ASN1.item and converts them into DER binary format.

The result of ASN1.encode(ASN1.decode(x)) will be x if x was in DER format.

Value

ASN1.decode returns either one item or a list.

ASN1.encode returns a raw vector in DER format.

ASN1.type returns an integer class type

ASN1.item returns an ASN.1 item object

Note

ASN1.encode uses a fixed buffer for encoding which currently limits the total size of the resulting structure to 1MB.

Only definite length forms are supported. The validity of individual items is not checked.

Author(s)

Simon Urbanek

Examples

```
# generate a small key
key <- PKI.genRSAkey(bits = 512L)

# extract private and public parts in DER format
prv <- PKI.save.key(key, format="DER")
pub <- PKI.save.key(key, private=FALSE, format="DER")

# parse the public key
x <- ASN1.decode(pub)
x
# the second element is the actual key
# as a bit string that's itself in DER
# two integers - modulus and exponent
# Note that this is in fact the pure PKCS#1 key format
ASN1.decode(x[[2]])

# encoding it back should yield the same representation since it is DER
stopifnot(identical(ASN1.encode(x), as.raw(pub)))
```

BIGNUMint *Functions for BIGNUM representation of arbitrarily precise integers*

Description

as.BIGNUMint encodes integer in BIGNUM format as raw vector as used by ASN.1 format.

Usage

```
as.BIGNUMint(what, scalar = TRUE)
```

Arguments

what	representation of an integer or a vector thereof. Currently supported formats include "bigz" objects from the "gmp" package, integers and reals.
scalar	if TRUE then the input is expected to be scalar and only the first element will be used (zero-length vectors raise an error). Otherwise the result will be a list of all converted elements.

Details

The BIGNUM representation as used in ASN.1 is a big-endian encoding of variable length stored in a raw vector. Negative numbers are stored in two-complement's encoding, but are currently unsupported by `as.BIGNUMint`.

Value

Raw vector in BIGNUM integer representation.

Note

Unless the input is of class `"bigz"` then 32-bit platforms only support integers up to 32-bit, 64-bit platforms up to 53-bit (when real vectors are used).

Author(s)

Simon Urbanek

Examples

```
as.BIGNUMint(65537)
```

`oid` *OBJECT IDENTIFIER Functions*

Description

Object Identifiers (OIDs) are entities defined by international standards (ITU-T, ISO, IEC) used to identify objects. In the PKI context they are used for example to identify encyrption algorithms. Each root (first integer - see below) denotes the standards body governing the allocations.

OIDs consist of a hierarchy of integers with each component having a meaning in the hierarchy. For example, the OID of the DER encoding is defined in the ITU-T X.680 standard as `joint-iso-itu-t(2)` `asn1(1)` `ber-derived(2)` `distinguished-encoding(1)` where the text before each integer describes its meaning in that context and the integer is the encoding of that meaning. So the OID itself would be in character form `"2.1.2.1"` (also called the dot notation introduced by IETF) and in R integer form `c(2, 1, 2, 1)`. Internally, OIDs are represented in their ASN.1 encoding as raw vectors which is the way they are typically used in files or communication payload.

The following functions are used to operate on OIDs.

`oid` creates an OID.

Coercion methods `as.integer` and `as.character` convert the OID into its numeric and textural form respectively. `as.oid` is a generic for convering objects into OIDs and is implemented for at least the above cases.

`is.oid` returns `TRUE` if the object is an OID.

Usage

```
oid(x)

as.oid(x, ...)
## Default S3 method:
as.oid(x, ...)
is.oid(x)

## S3 method for class 'oid'
Ops(e1, e2)
## S3 method for class 'oid'
print(x, ...)

## S3 method for class 'oid'
as.character(x, ...)
## S3 method for class 'oid'
as.integer(x, ...)
```

Arguments

x	object to covert/create/check
e1	left-hand side argument for binary operators
e2	right-hand side arguemnt for binary operators
...	further arguments (currently unused)

Details

The only allowed oparators on OIDs are == and != which return TRUE or FALSE.

The oid(x) constructor (and also the as.oid default method) support following types: scalar string (expected to be in dot-notation), integer vector, numeric vector (it is coerced to integer vector implicitly), raw vector (must be ASN.1 encoding of the OID).

The S3 class of OID objects is "oid". It consists of a raw vector repesenting the ASN.1 encoded OID (without the type specifier). An additional attribute "type" is set to 6L for compatiblity with ASN1.encode.

Author(s)

Simon Urbanek

See Also

ASN1.encode

Examples

```
## RSA algorithm OID:
## iso(1) member-body(2) us(840) rsadsi(113549)
## pkcs(1) pkcs-1(1) rsaEncryption(1)
```

```
o <- oid("1.2.840.113549.1.1.1")
as.raw(o)
as.integer(o)
as.character(o)
as.oid(as.integer(o)) == o
is.oid(o)
(a <- ASN1.encode(o))
as.oid(ASN1.decode(a)) == o
```

`PKI.crypt` *PKI encryption/decryption functions*

Description

`PKI.encrypt` encrypts a raw vector

`PKI.decrypt` decrypts a raw vector

Usage

```
PKI.encrypt(what, key, cipher = NULL, iv = NULL)
PKI.decrypt(what, key, cipher = NULL, iv = NULL)
```

Arguments

`what`	raw vector to encrypt/decrypt. It must not exceed the key size minus padding
`key`	key to use for encryption/decryption
`cipher`	cipher to use for encryption/decryption
`iv`	initialization vector for ciphers that use it (e.g., CBC). `NULL` corresponds to all-zeroes IV, otherwise must be either a string or a raw vector with sufficiently many bytes to match the IV length for the cipher.

Value

Raw vector (encrypted/decrypted)

Note

The cipher is optional for key objects that already contain the cipher information such as RSA keys (in fact it is ignored in that case).

Supported symmetric ciphers are AES-128, AES-256 and BF (blowfish). Each cipher can be used in CBC (default), ECB or OFB modes which are specified as suffix, so `"aes256ofb"` would specify AES-256 in OFB mode. Case and non-alphanumeric characters are ignored, so the same could be specified as `"AES-256-OFB"`. PKCS padding is used to fill up to the block size. Analogously, PKCS padding is expected when decoding.

Note that the payload for RSA encryption should be very small since it must fit into the key size including padding. For example, 1024-bit key can only encrypt 87 bytes, while 2048-bit key can encrypt 215 bytes. Therefore a typical use is to use RSA to transfer a symmeric key to the peer and subsequently use symmetric ciphers like AES for encryption of larger amounts of data.

Author(s)

Simon Urbanek

See Also

PKI.genRSAkey, PKI.pubkey

Examples

```
key <- PKI.genRSAkey(2048)
x <- charToRaw("Hello, world!")
e <- PKI.encrypt(x, key)
y <- PKI.decrypt(e, key)
stopifnot(identical(x, y))
print(rawToChar(y))

## AES symmetric - use SHA256 to support arbitrarily long key strings
key <- PKI.digest(charToRaw("hello"), "SHA256")
ae <- PKI.encrypt(x, key, "aes256")
ae
ad <- PKI.decrypt(ae, key, "aes256")
stopifnot(identical(x, ad))
```

PKI.digest *Compute digest sum based on SHA1, SHA256 or MD5 hash functions*

Description

PKI.digest computes digsest sum based on the hash function specified

Usage

```
PKI.digest(what, hash = c("SHA1", "SHA256", "MD5"))
```

Arguments

what	raw vector of bytes to digest
hash	type of the hash function. Note that "MD5" should *not* be used for cryptographic purposes as it is not secure

Value

Raw vector containg the hash

Author(s)

Simon Urbanek

See Also

PKI.sign

Examples

```
PKI.digest(as.raw(1:10))
```

PKI.info *Retrieve PKI back-end information*

Description

PKI.info returns information about the engine which is providing the PKI functionality.

Usage

```
PKI.info()
```

Value

Named list:

engine	string, name of the engine, currently either "openssl" or "libressl"
version	numeric, version of the engine as a real number in the form major.minor
description	string, description of the engine, its version and any futher information that the engine may provide

Note

This function should be treated as informational only. The return value is subject to change, mainly we may extend it to possibly supply information on available ciphers etc.

Older versions of OpenSSL did not provide functional API to retrieve version inforation, so versions < 1.1 may not reflect the true version, but rather the values from the headers at compile time which may not be the same as the loaded library at run-time.

Author(s)

Simon Urbanek

Examples

```
str(PKI.info())
```

PKI.random — *Generate cryptographically strong pseudo-random bytes.*

Description

`PKI.random` generates `n` cryptographically strong pseudo-random bytes.

Usage

```
PKI.random(n)
```

Arguments

`n`	non-negative integer, number of bytes to generate

Details

`PKI.random` is the preferred way to generate cryptographically strong random content that can be used as keys, seeds etc. Not to be confused with random number generators in R, it is entirely separate for cryptographics purposes.

Value

Raw vector of `n` cryptographically strong pseudo-random bytes.

Author(s)

Simon Urbanek

Examples

```
PKI.random(10)
```

PKI.sign — *PKI: sign content or verify a signature*

Description

`PKI.sign` signs content using RSA with the specified hash function

`PKI.verify` verifies a signature of RSA-signed content

Usage

```
PKI.sign(what, key, hash = c("SHA1", "SHA256", "MD5"), digest)
PKI.verify(what, signature, key, hash = c("SHA1", "SHA256", "MD5"), digest)
```

Arguments

what	raw vector: content to sign
key	RSA private key to use for signing; RSA public key or certificate to use for verification.
hash	hash function to use. "MD5" should not be used unless absolutely needed for compatibility as it is less secure.
digest	raw vector: it is possible to supply the digest of the content directly instead of specifying what.
signature	raw vector: signature

Details

Objects are signed by computing a hash function digest (typically using SHA1 hash function) and then signing the digest with a RSA key. Verification is done by computing the digest and then comparing the signature to the digest. Private key is needed for signing whereas public key is needed for verification.

Both functions call PKI.digest on what if digest is not specified.

Value

PKI.sign signature (raw vector)

PKI.verify logical: TRUE if the digest and signature match, FALSE otherwise

Author(s)

Simon Urbanek

See Also

PKI.pubkey, PKI.genRSAkey, PKI.digest

Examples

```
key <- PKI.genRSAkey(2048)
x <- charToRaw("My message to sign")
sig <- PKI.sign(x, key)
stopifnot(PKI.verify(x, sig, key))
```

PKI.sign.tar *Functions for signing and verification of tar files*

Description

PKI.sign.tar appends a signature to a tar file

PKI.verify.tar verifies the signature in a tar file

Usage

```
PKI.sign.tar(tarfile, key, certificate, output = tarfile)
PKI.verify.tar(tarfile, key, silent = FALSE, enforce.cert = FALSE)
```

Arguments

tarfile	string, file name of the file to sign
key	PKI.sign.tar: private key to use for signing; PKI.verify.tar: optional, public key to use for verification
certificate	optional, certificate to embed in the signature with the public key matching key. If not present the signature will only contain the public key.
output	file name, connection or raw vector determining how to store the signed tar file
silent	if TRUE then no warning are generatod, otherwise a warning is issues for failed verification describing the reason for failure
enforce.cert	if TRUE then a certificate is required in the signature. It can be also set to a valid certificate in which case the public key of the certificate in the signature must also match the public key in the supplied certificate.

Details

PKI.tar.sign adds extra entry .signature with the signature based on the contents of the tarfile. Note that any existing signatures are retained. key is a mandatory private key used to sign the content. certificate is optional but if present, it will be embedded in the signature.

The tarfile can be in compressed form (gzip, bzip2 or xz) in which case it is decompressed internally before the signature is applied. If output is a file name then the same compression is applied to the output, otherwise the output is uncompressed.

PKI.verify.tar retrieves the last .signature entry from the tar file (if tarfile is a file name then the same compression auto-detection is applied as above) and verifies the signature against either the supplied (public) key or against the key or certificate stored in the signature. The result is TRUE or FALSE except when enforce.cert is set. In that case the result is the certificate contained in the signature if the validation succeeded (and thus it can be further verified against a chain of trust), otherwise FALSE.

Note

The signature format is ASN.1 DER encoded as follows:

`SEQ(signature BITSTRING, subjectPublicKeyInfo, Certificate[opt])`

The `subjectPublicKeyInfo` can be `NULL` in which case the certificate must be present (in X.509 DER format).

The signature is appended as tar entry named `.signature`. However, terminating blocks are not removed from the file, so the signature is placed after the EOF blocks and thus doesn't affect extraction.

Author(s)

Simon Urbanek

`raw2hex` *Convert raw vector to string hex representation*

Description

`raw2hex` convers a raw vector into hexadecimal representation

Usage

```
raw2hex(what, sep, upper = FALSE)
```

Arguments

`what`	raw vector
`sep`	optional separator string
`upper`	logical, if `TRUE` then upper case letters are used, otherwise any letters will be lower case.

Details

If `sep` is omitted or `NULL` then the resulting character vector will have as many elements as the raw vector. Otherwise the elements are concatenated using the specified separator into one character string. This is much more efficient than using `paste(raw2hex(x), collapse=sep)`, but has the same effect.

Value

Character vector with the hexadecimal representation of the raw vector.

Author(s)

Simon Urbanek

Examples

```
raw2hex(PKI.digest(raw(), "SHA1"), "")
raw2hex(PKI.digest(raw(), "MD5"), ":")

## this is jsut a performance comparison and a test that
## raw2hex can handle long strings
x <- as.raw(runif(1e5) * 255.9)
system.time(h1 <- raw2hex(x, " "))
system.time(h2 <- paste(raw2hex(x), collapse=" "))
stopifnot(identical(h1, h2))
```

RSA *PKI functions handling RSA keys*

Description

`PKI.load.key` loads an RSA key in PKCS#1/8 PEM or DER format.

`PKI.save.key` creates a PEM or DER representation of a RSA key.

`PKI.genRSAkey` generates RSA public/private key pair.

`PKI.mkRSApubkey` creates a RSA public key with the supplied modulus and exponent.

`PKI.load.OpenSSH.pubkey` loads public key in OpenSSH format (as used in `.ssh/authorized_keys` file)

Usage

```
PKI.load.key(what, format = c("PEM", "DER"), private, file, password="")
PKI.save.key(key, format = c("PEM", "DER"), private, target)
PKI.genRSAkey(bits = 2048L)
PKI.mkRSApubkey(modulus, exponent=65537L, format = c("DER", "PEM", "key"))
PKI.load.OpenSSH.pubkey(what, first=TRUE, format = c("DER", "PEM", "key"))
```

Arguments

`what`	string, raw vector or connection to load the key from
`key`	RSA key object
`format`	format - PEM is ASCII (essentially base64-encoded DER with header/footer), DER is binary and key means an acutal key object
`private`	logical, whether to use the private key (`TRUE`), public key (`FALSE`) or whichever is available (`NA` or missing).
`file`	filename to load the key from - `what` and `file` are mutually exclusive
`password`	string, used only if `what` is an encrypted private key as the password to decrypt the key
`target`	optional connection or a file name to store the result in. If missing, the result is just returned form the function as either a character vector (PEM) or a raw vector (DER).

bits	size of the generated key in bits. Must be 2 ^ n with integer n > 8.
modulus	modulus either as a raw vector (see as.BIGNUMint) or bigz object (from gmp package) or an integer.
exponent	exponent either as a raw vector (see as.BIGNUMint) or bigz object (from gmp package) or an integer.
first	logical, if TRUE only the first key will be used, otherwise the result is a list of keys.

Value

PKI.load.key: private or public key object

PKI.save.key: raw vector (DER format) or character vector (PEM format).

PKI.genRSAkey: private + public key object

PKI.mkRSApubkey, PKI.load.OpenSSH.pubkey: raw vector (DER format) or character vector (PEM format) or a "public.key" object.

Note

The output format for private keys in PEM is PKCS#1, but for public keys it is X.509 SubjectPublicKeyInfo (certificate public key). This is consistent with OpenSSL RSA command line tool which uses the same convention.

PKI.load.key can auto-detect the contained format based on the header if 'PEM' format is used. In that case it supports PKCS#1 (naked RSA key), PKCS#8 (wrapped key with identifier - for public keys X.509 SubjectPublicKeyInfo) and encrypted private key in PKCS#8 (password must be passed to decrypt). 'DER' format provides no way to define the type so 'private' cannot be 'NA' and only the default format (PKCS#1 for private keys and X.509 SubjectPublicKeyInfo for public keys) is supported.

The OpenSSH format is one line beginning with "ssh-rsa ". SSH2 PEM public keys (rfc4716) are supported in PKI.load.key and the binary payload is the same as the OpenSSH, only with different wrapping.

Author(s)

Simon Urbanek

See Also

PKI.encrypt, PKI.decrypt, PKI.pubkey

Examples

```
# generate 2048-bit RSA key
key <- PKI.genRSAkey(bits = 2048L)

# extract private and public parts as PEM
priv.pem <- PKI.save.key(key)
pub.pem <- PKI.save.key(key, private=FALSE)
# load back the public key separately
```

```
pub.k <- PKI.load.key(pub.pem)

# encrypt with the public key
x <- PKI.encrypt(charToRaw("Hello, world!"), pub.k)
# decrypt with private key
rawToChar(PKI.decrypt(x, key))

# compute SHA1 hash (fingerprint) of the public key
PKI.digest(PKI.save.key(key, "DER", private=FALSE))

# convert OpenSSH public key to PEM format
# (the example is split into multiple lines just
#  so it is readable in the documentation, in reality you can
#  simply use the full line from is_rsa.pub without gsub)
PKI.load.OpenSSH.pubkey(gsub("\n","",
  "ssh-rsa AAAAB3NzaC1yc2EAAAABIwAAAIEAuvOXqfZ3pJeWeqyQOIXZwmg
M1RBqPUmVx3XgntpA+YtOZjKfuoJSpg3LhBuI/wXx8L2QZXNFibvX4qX2qoYsb
Hvkz2uonA3F7HRhCR/BJURR5nT135znVqALZo328v86HDsVWYR2/JzY1X8GI2R
2iKUMGXF0hVuRphdwLB735CU= foo@mycomputer"), format="PEM")
```

X509 *Public Key Instraftructure (X509) functions*

Description

`PKI.load.cert` creates a certificate object from a string, connection or file.

`PKI.verifyCA` verifies a certificate against a given chain of trust.

`PKI.pubkey` extracts public key from a certificate.

`PKI.get.subject` extracts the subject name from the certificate.

`PKI.get.cert.info` decodes information from the certificate.

Usage

```
PKI.load.cert(what, format = c("PEM", "DER"), file)
PKI.verifyCA(certificate, ca, default = FALSE, partial = FALSE)
PKI.pubkey(certificate)
PKI.get.subject(certificate)
PKI.get.cert.info(certificate)
```

Arguments

`what`	string, raw vector or connection to load the certificate from
`format`	format used to encode the certificate
`file`	filename to load the certificate from - `what` and `file` are mutually exclusive
`certificate`	a certificate object (as returned by `PKI.load.cert`)
`ca`	a certificate object of the Certificate Authority (CA) or a list of such objects if a chain of certificates is involved

default	logical, if TRUE then root CAs known to OpenSSL will be added to the trust store. In that case ca can also be NULL if the certificate is directly signed by the root CA (very uncommon).
partial	logical, if TRUE then the CAs listed in ca are trusted even if they are neither root nor self-signed CAs.

Details

PKI.verifyCA is used to verify the validity of a certificate by following a chain of trust. In the most simple case the certificate was issued by a certificate authority (CA) directly, which has a self-signed certificate. This is typically the case when you (or your organization) have created your own CA for internal use. In that case you only need to supply that CA's certificate to ca and that's it. It is also possible that your self-signed CA issued an intermediate certificate - if that is the case then pass a list of both certificates (order doesn't matter) to ca.

Another use case is that you have a certificate which has been issued by publicly trusted CA - this is commonly the case with SSL certificates used by web servers. In that case, the chain doesn't end with an internal self-signed certificate, but instead it will end with a publicly known root CA. OpenSSL manages a list of such trusted CAs and you can check against them with default=TRUE. However, in most cases your certificate won't be issued directly by a root CA, but by an intermetiate authority so you have to pass the intermediate certificate(s) in the ca argument.

Finally, it is sometimes possible that the default list of trusted certificates does not include the root CA that you need. If that is the case, and you still want to trust that chain, you can set partial=TRUE and then PKI.verifyCA will trust the certificates provided in ca unconditinally, even if they don't lead to a trusted root or are not self-signed. Note, however, that this is the least secure option and you should only use it if the certificates are supplied by you and not the user. If you want to support user-supplied intermediate certificates then you can use PKI.verifyCA first to verify the integrity of the user-supplied chain with partial=TRUE and then verify just the intermediate certificate against your trusted certificate. That way you won't trust the intermediate certificate inadvertently.

Value

PKI.load.cert: a certificate object

PKI.verifyCA: TRUE is the certificate can be trusted, FALSE otherwise

PKI.pubkey: public key object

PKI.get.subject: string containing the subject information in one-line RFC2253 format but in UTF8 encoding instead of MBS escapes. NOTE: this is experimantal, we may choose to parse the contents and return it in native R form as a named vector instead.

Author(s)

Simon Urbanek

Examples

```
(ca <- PKI.load.cert(file=system.file("certs", "RForge-ca.crt", package="PKI")))
(my.cert <- PKI.load.cert(readLines(system.file("certs", "demo.crt", package="PKI"))))
PKI.verifyCA(my.cert, ca)
PKI.pubkey(my.cert)
```

```
PKI.get.subject(my.cert)
PKI.get.cert.info(my.cert)
```

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