An Advanced Introduction to GnuPG

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Outline

OpenPGP

- Data integrity service for messages and files
- Defined in RFC 4880
  - Published in 2007
- Focus
  - Message format
  - Message reading, writing and verification algorithms
  - Crypto algorithms to use and their parameters

Trade-offs

- Good for data at rest
  - Need to be able to decrypt data in decades
    - OpenPGP is more like tar than http/smtp/xmpp
    - Consequence: Hard to phase out old algorithms
- No interaction between encrypter and decrypter
  - Can’t negociate parameters dynamically
  - No forward secrecy

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RFC 4880bis

- IETF working group developing a new revision
- Major Goals*
  - Deprecate weak algorithms (MD5, SHA1, RIPEMD160, 3DES, IDEA)
  - Introduce new ECC curves (Ed25519, curve448)
  - New key derivation function

*http://wiki.gnupg.org/rfc4880bis

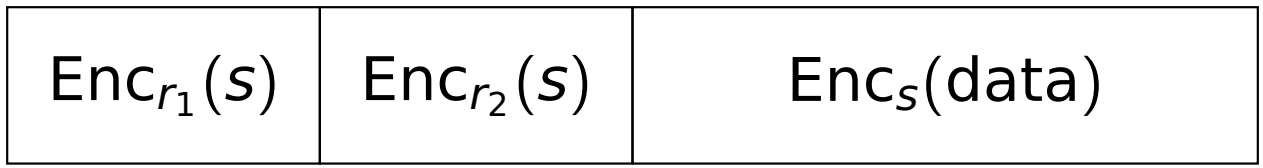
Message Format

- Packet-based
- Designed for unbuffered (single pass) processing
- 17 packet types
  - Symmetrically encrypted data
  - Public-key encrypted session key
  - Signature packet
  - Public-Key Packet
  - Public-Subkey Packet
  - Secret-Key Packet
  - User ID Packet
  - etc.

OpenPGP Algorithms

- Encryption / Decryption
- Signatures
- Key derivation function (s2k, string to key)
- Encodings (ASCII armor)

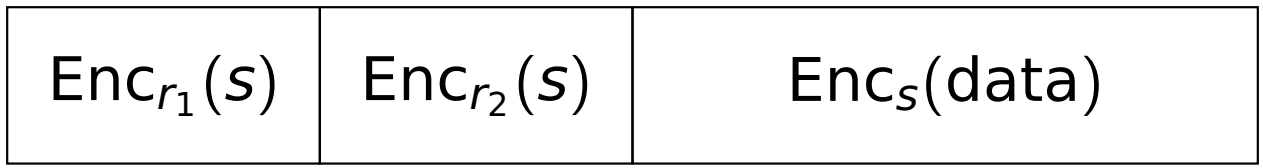
Encryption Algorithm



- **Generate** a random session key (s)
- For each recipient, **output** $\text{Enc}_{r_i}(\text{session key})$
- **Output** $\text{Enc}_s(\text{data})$

- Why a session key?
  - Symmetric crypto is fast
  - For N recipients, we encrypt plaintext once and session key N times

Encryption Algorithm



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An Encrypted Message

```
$ echo -n foo | gpg2 -e -r 630052D9 -r 8E678210 | gpg2 --list-packets
# off=0 ctb=85 tag=1 hlen=3 plen=268
:pubkey enc packet: version 3, algo 1, keyid C2B819056C652598
data: [2047 bits]
# off=271 ctb=85 tag=1 hlen=3 plen=268
:pubkey enc packet: version 3, algo 1, keyid AE19DAC58E678210
data: [2047 bits]
# off=542 ctb=d2 tag=18 hlen=2 plen=56 new-ctb
:encrypted data packet:
length: 56
mdc_method: 2
# off=563 ctb=a3 tag=8 hlen=1 plen=0 indeterminate
:compressed packet: algo=1
# off=565 ctb=cb tag=11 hlen=2 plen=9 new-ctb
:literal data packet:
mode b (62), created 1435751184, name="",
raw data: 3 bytes
```

- Two recipients
  - Self and someone else
  - (Can always encrypt to some key using `encrypt-to` in `gpg.conf`)

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- 5 packets

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- off: offset within stream
- Header
  - ctb: packet header (“cipher type byte”)
  - tag: packet type
  - hlen, plen: header and payload length (in bytes)

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- pubkey enc packet
  - Encrypted session key
  - One for each recipient
  - Encrypted using the recipient's public key

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```

- `encrypted data packet`
  - Contains the data (encapsulated)
  - Encrypted using the sesson key
- `compressed packet`
  - Nested within the encrypted data packet
- `literal data`
  - Nested within the compressed packet data packet

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- Note the order of the packets
  - Encrypted Session key precedes encrypted data
  - No buffering needed to encrypt or decrypt data

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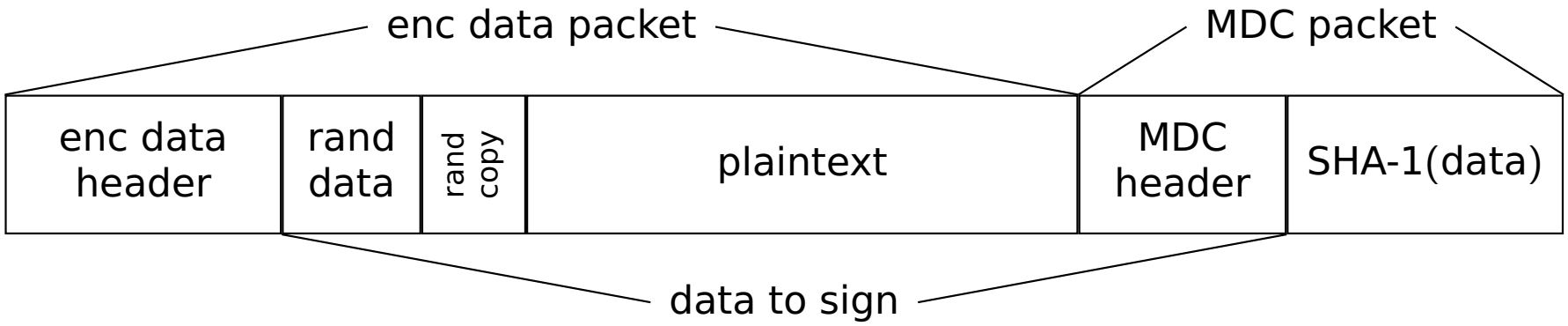
- Modification Detection System (MDS)
  - Integrity check
  - Normally done using signatures
  - But, signatures reveal the sender's identity
  - **MDS preserves integrity and anonymity**
- Modification Detection Code (MDC) packet
  - Immediately follows `encrypted data packet`
  - (Not shown by gpg for technical reasons)

Modification Detection System



- SHA-1 of:
  - Block of random data
    - AES block size is 128 bits (16 bytes)
    - $=$ 16 bytes of random data
  - Last two bytes of random data are repeated
    - Quick check for invalid key
    - No need to process TBs of data to check key
  - The plaintext
  - Header of MDC Packet
    - Included in hashed data
    - Detects data removal / extension attacks

Signing Algorithm

- **Output** hash parameters
- Simultaneously **Hash** and **Output** message
- **Sign** hash using sender's private key
- **Output** signature

A Signed Message

```
$ echo -n foo | gpg2 -s | gpg2 --list-packets
# off=0 ctb=a3 tag=8 hlen=1 plen=0 indeterminate
:compressed packet: algo=1
# off=2 ctb=90 tag=4 hlen=2 plen=13
:onepass_sig packet: keyid E149B3889E4DA08C
version 3, sigclass 0x00, digest 8, pubkey 1, last=1
# off=17 ctb=cb tag=11 hlen=2 plen=9 new-ctb
:literal data packet:
mode b (62), created 1435588610, name="",
raw data: 3 bytes
# off=28 ctb=89 tag=2 hlen=3 plen=284
:signature packet: algo 1, keyid E149B3889E4DA08C
version 4, created 1435588610, md5len 0, sigclass 0x00
digest algo 8, begin of digest 27 28
hashed subpkt 2 len 4 (sig created 2015-06-29)
subpkt 16 len 8 (issuer key ID E149B3889E4DA08C)
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- 4 packets

A Signed Message

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- Compressed packet contains other packets
  - (Logical structure not shown)

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- Signature parameters
- Parameters precede the data; no buffering required

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- Actual data to sign
- Parameters
  - `mode`: binary, text or UTF-8
  - `created`: file's last modification date
  - `name`: filename

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- The actual signature
  - Repetition of parameters from `onepass_sig` packet
  - The hash
  - Additional subpackets (included in the hash)
    - Creation time
    - Public key

Public Keys

```
$ gpg2 --export testing | gpg2 --list-packets
# off=0 ctb=99 tag=6 hlen=3 plen=269
:public key packet:
    version 4, algo 1, created 1431979963, expires 0
    keyid: E149B3889E4DA08C
# off=272 ctb=b4 tag=13 hlen=2 plen=7
:user ID packet: "Testing"
# off=281 ctb=89 tag=2 hlen=3 plen=319
:signature packet: algo 1, keyid E149B3889E4DA08C
    version 4, created 1431979963, md5len 0, sigclass 0x13
    digest algo 8, begin of digest 7b 58
    hashed subpkt 2 len 4 (sig created 2015-05-18)
    hashed subpkt 27 len 1 (key flags: 03)
    hashed subpkt 9 len 4 (key expires after 100d0h0m)
    hashed subpkt 11 len 6 (pref-sym-algos: 9 8 7 3 2 1)...
# off=603 ctb=b9 tag=14 hlen=3 plen=269
:public sub key packet:
    version 4, algo 1, created 1431979963, expires 0
    keyid: AE19DAC58E678210
# off=875 ctb=89 tag=2 hlen=3 plen=293
:signature packet: algo 1, keyid E149B3889E4DA08C
    ...
```

- Packet format also used for serializing keys
- Includes preferences and supported features
  - Upload your keys regularly!

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```

- Public key / subkey

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```

- Self-signature
  - Made using primary key
  - Links subkey to primary
    - But, not vice-versa
    - Encrypted keys can’t create signatures

Public Keys

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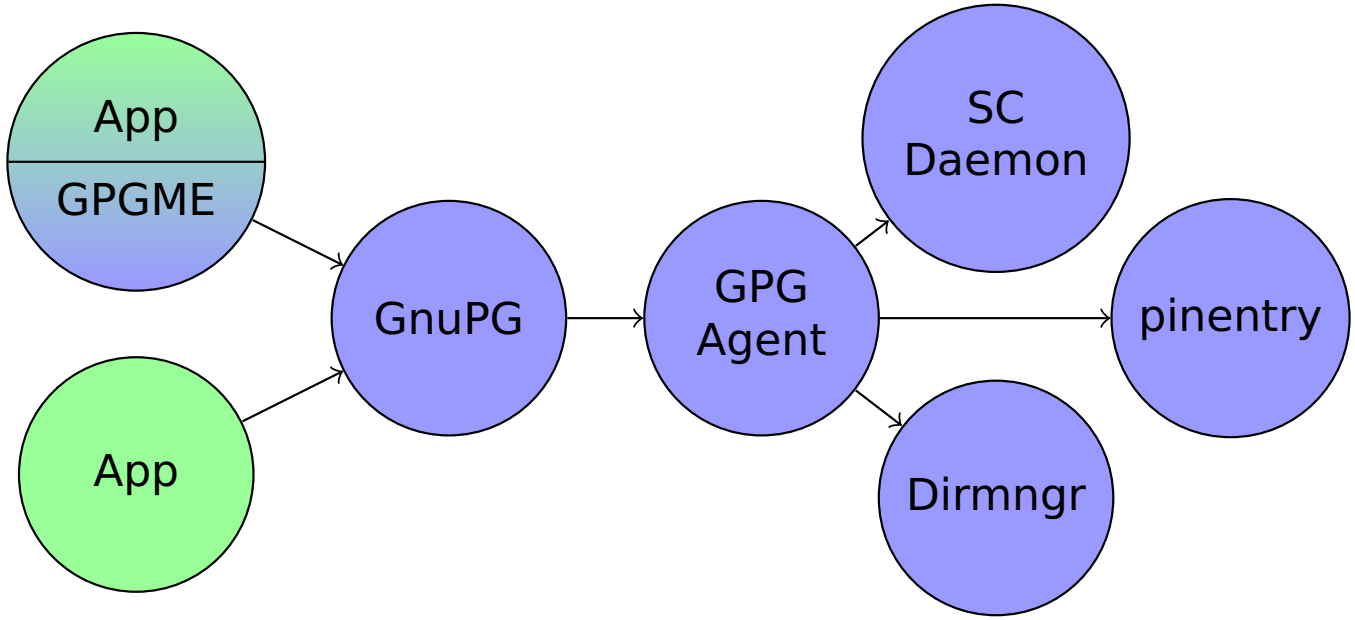
```

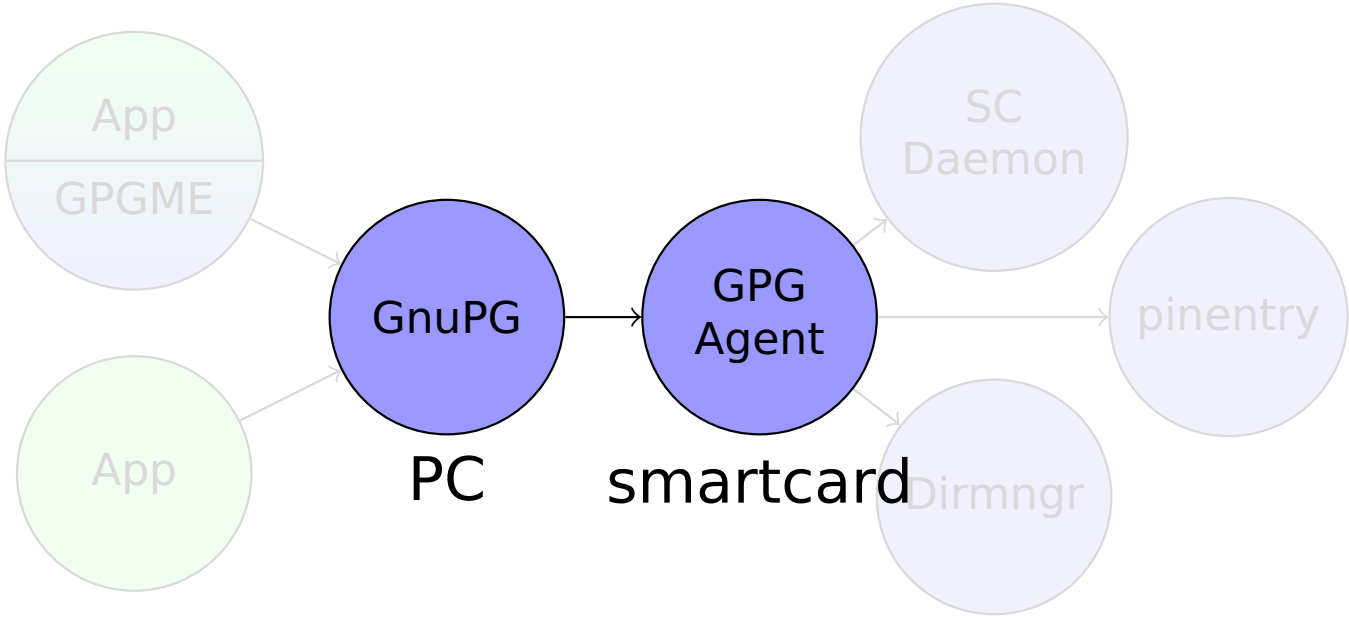
- Signature data
  - Key’s properties
  - User preference
  - Supported features

GnuPG's Architecture



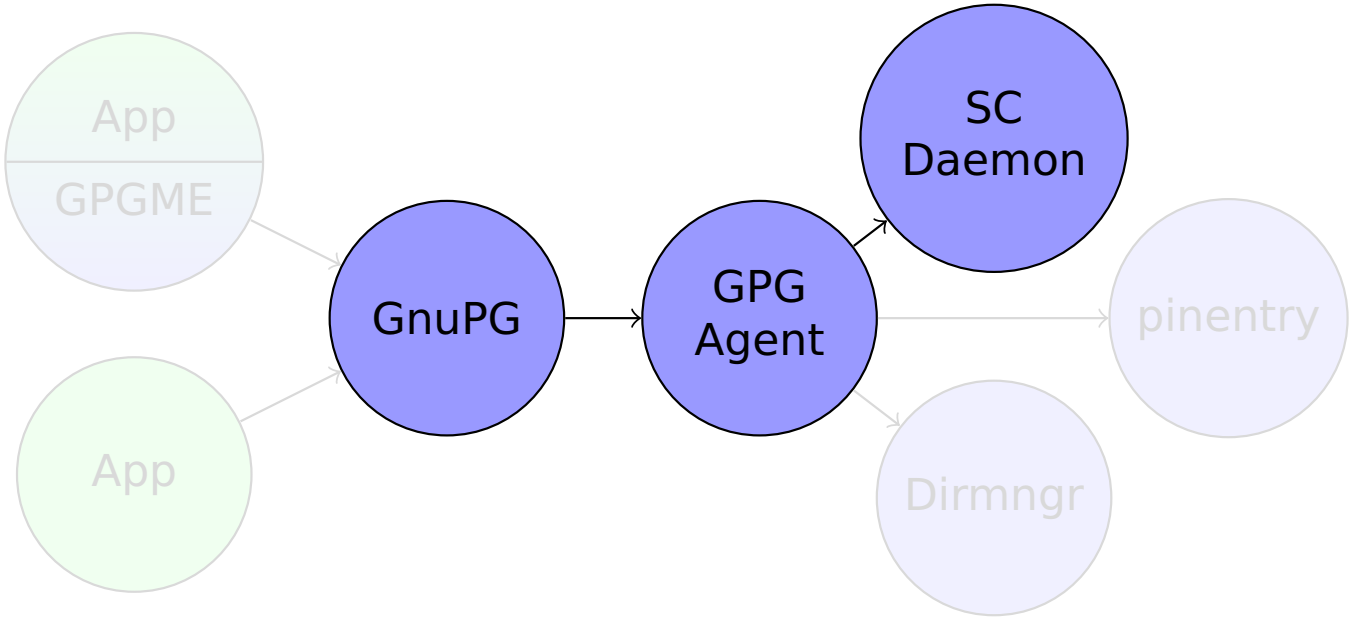
- Multi-server architecture
  - GPG is not a library!
    - GPGME *is* a library
    - Provides convenient APIs
    - Communicates with GPG
  - Components in their own address spaces
  - Reduces impact of bugs

GnuPG's Architecture



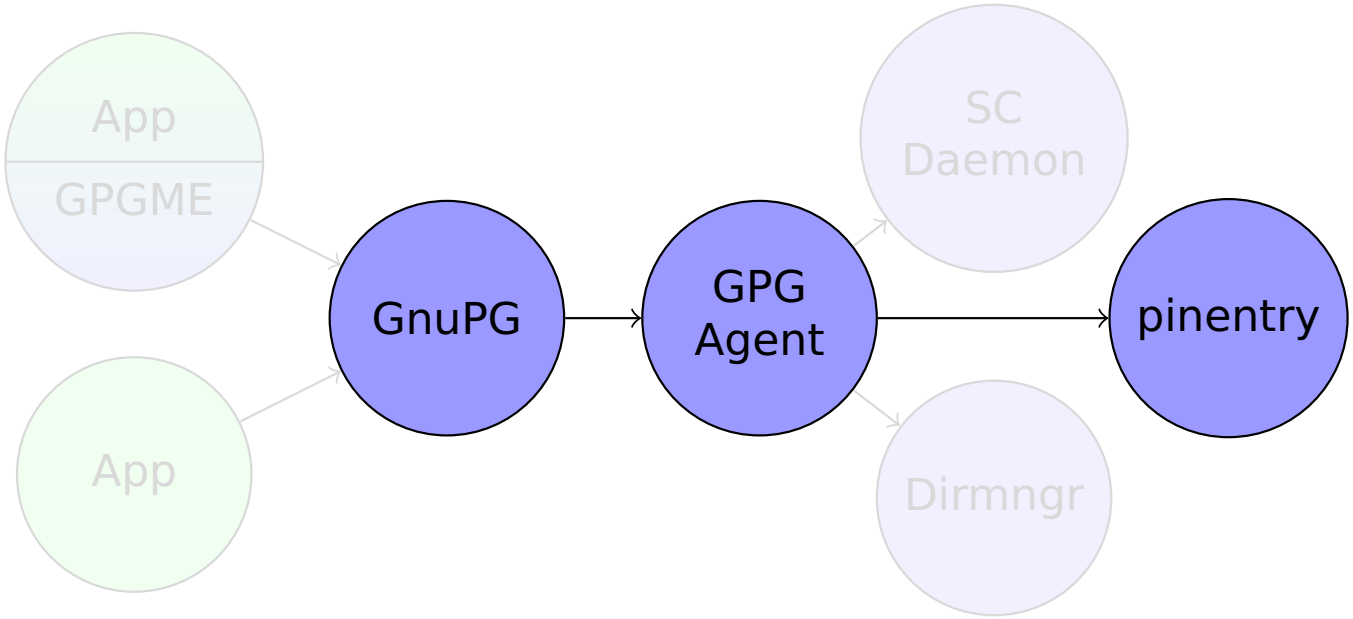
- GPG: Low security
  - Session encryption
  - Encoding, etc.
- GPG Agent: High security
  - Manages private key and passwords
  - Delegates to servers
- Separation similar to that of a PC and smartcard

GnuPG's Architecture



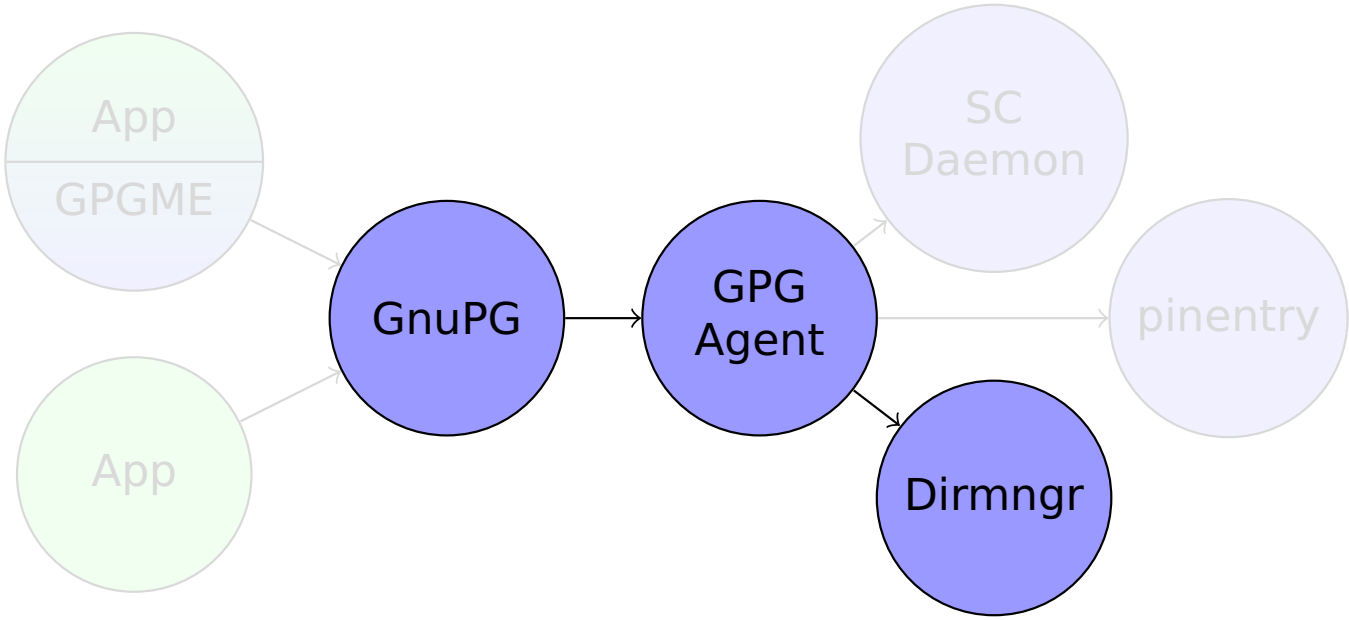
- Smartcard Daemon
  - Interacts with smartcards (directly or via PC/SC)
  - Typically packaged separately as `scdaemon`

GnuPG's Architecture



- Pinentry
  - For user interactions
    - Request passphrase
    - Ask questions
  - Multiple implementations
    - Tighter integration
    - Different security properties

GnuPG's Architecture



- Directory manager
  - Interacts with keyservers (HKP, ldap, http)
    - `gpg2 --search-keys email@example.org`
    - `gpg2 --recv-key keyid`
    - etc.
  - Certificate and CRL cache

Assuan

- Components communicate using Assuan protocol
  - IPC protocol
  - Pipe / socket based
  - Very simple, text-based interface
  - No interface definition language (IDL)
  - Example:

```
$ pinentry
OK Your orders please
setprompt Enter your password:
OK
getpin
D 123abc
OK
```

  - Use `gpg-connect-agent` to connect to the running GPG Agent or dirmngr

watchgnupg

- Tool for gathering log entries
  - In `gpg-agent.conf`, add:
    - `log-file socket:///home/USER/.gnupg/S.log`
    - `debug-level basic` # (or advanced or expert)
  - Run:

    ```
    $ watchgnupg --force /home/USER/.gnupg/S.log
    ```

Private Key Management

- Online
  - `gpg2 --gen-key`
  - Key stored locally
  - Low security: must trust all local software
- Offline
  - Key stored on a smartcard (GnuK, Nitro, etc.)
  - Should use subkeys
    - Setup slightly more complicated
  - Should store backups on a USB stick
    - Can't export private key from smartcard
  - Much higher security
    - Crypto can only be done when key is inserted
    - But, often not obvious what the operation is
- Note: easier to explain crypto when using a smartcard

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Offline Keys

- Use Tails!!!
  - Hardened
  - Wipes memory on shutdown
- Managing the key:
  - Boot from a USB stick
    - Medium Security
    - BIOS might be infected, etc.
  - Use a dedicated offline computer
    - Old IBM x40 or x60 costs <50 Euros on ebay
    - Remove wireless network card!
    - High security
    - But, still susceptible to Bad USB!

Generating a *Secure* Passphrase

- Generating a secure passphrase is hard
  - "Assume your adversary is capable of one trillion guesses per second." -Snowden
  - To withstand one year, need 65 bits of entropy!
  - How to measure a password's entropy?
  - Need a random password
  - But that's impossible to memorize
  - Unless we encode it smartly!

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Diceware

- Encode using a simple word list
  - /dev/random? 1k words (10-bits entropy per word)
  - dice? $6^4 = 1296$ words (10.3-bits entropy)
- Secure even if adversary knows the word list!
- Examples:
  - 1. able
  - 2. about
  - 3. above
  - ...
- Required length:
  - 80 bits = good = 8 words
  - 120 bits = strong = 12 words
- Examples:
  - percent burst able smash opposite ready blind stab
  - pipe after harm person split seize radar about

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Word Lists

- Diceware (8k)
- PGP Biometric word list (512)
- Voice of America's simple English word list (1.5k)

Avoiding Man in the Middle Attacks

- Key signing parties are for geeks
- Exchanging fingerprints in person is inconvenient
- Use the telephone!

```
$ gpg2 --recv-key 630052D9
$ gpg2 --with-icao-spelling --fingerprint 630052D9
pub   rsa3744/630052D9 2015-04-07 [expires: 2025-04-04]
      Key fingerprint = 8F17 7771 18A3 3DDA 9BA4  8E62 AACB 3243 (
                        "Eight Foxtrot One Seven  Seven Seven Sev(
...
$ gpg2 --sign-key 630052D9 # or --lsign-key
```

- Secure enough for all but the most paranoid
- Much more secure than no check

Trust on First Use (TOFU)

- New trust model (since v2.1.10, Dec. 2015)
- Checks identity / key consistency
  - Model used by `ssh`
- No user support required

`gpg.conf:`

```
trust-model tofu+pgp
```

Key Management

- When you get a signed message, fetch the key
- Refresh keys regularly
  - Why?
    - New preferences
    - Revocation certificates
  - How?
    - Don't use `gpg2 --refresh-keys`
    - Install parcimonie
    - Uses tor
    - Random intervals between each key refresh

Key Disclosure

- You have to disclose the encryption key for a message?
- Don’t disclose your private key!
- This allows decryption of all messages
- Just disclose the session key.

```
$ echo | gpg2 -e -r keyid | gpg2 --show-session-key
...
gpg: session key: ’9:576EE31...’
```

Don’t backup the RNG’s seed!

- Exclude `.gnupg/random_seed` from backups!

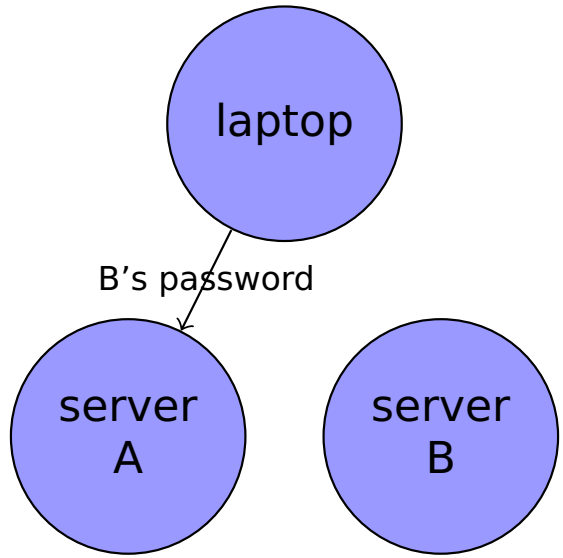
Key Expiry

- Always use an expiration
  - Guarantees an eventual revocation
- Can easily extend expiration
- Bonus: forces people to refresh keys

Key Rotation

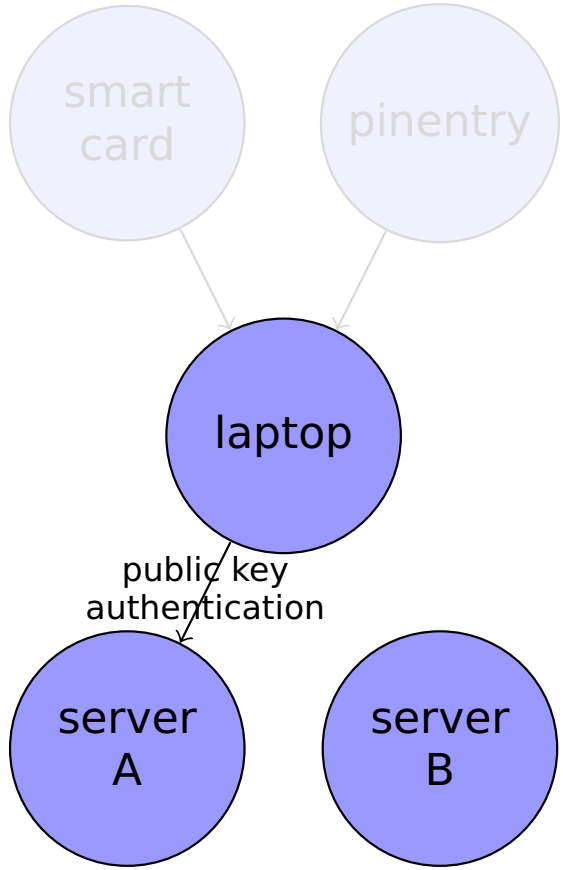
- When generating a new key, cross sign the keys
- revocation message is just for humans

ssh: Keys Instead of Passwords



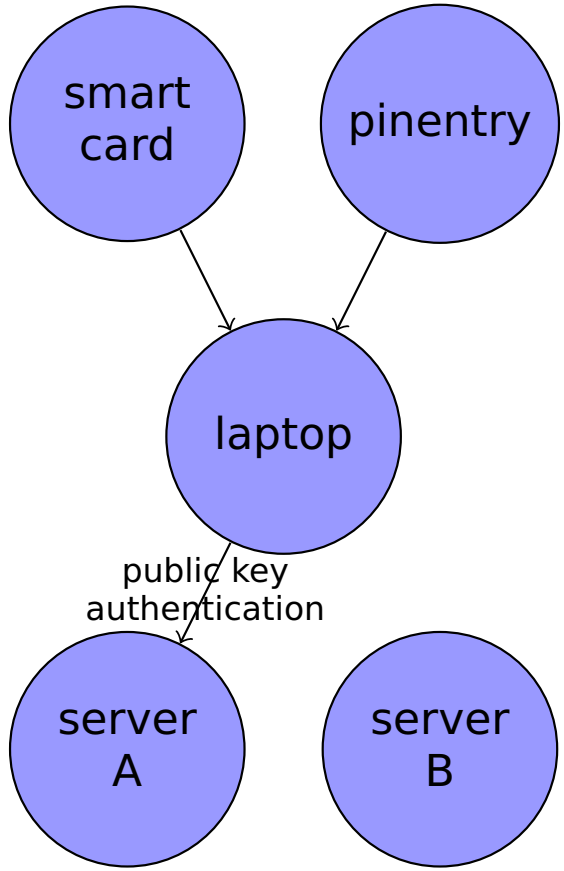
- Using keys means password is not sent to server
  - Ever enter password for a different server?
  - You've just disclosed your password!

ssh keys



- OpenSSH stores private keys on hard drive
- Keys are protected by a passphrase
- Passphrase is cached by ssh agent

ssh keys



- GnuPG implements the ssh agent protocol
- GnuPG can use keys stored on a smart card

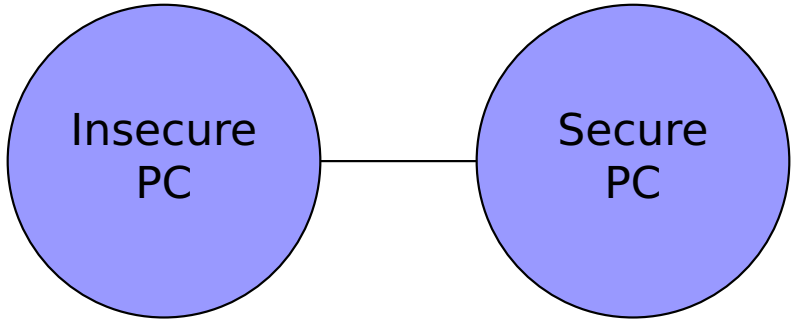
GnuPG's ssh agent: configuration

- Set `SSH_AUTH_SOCK` in `.bashrc`:
  ```
  $ export SSH_AUTH_SOCK=$HOME/.gnupg/S.gpg-agent.ssh
  ```
- Add `enable-ssh-support` to `.gnupg/gpg-agent.conf`
- Restart gpg agent
- Add public key to `.ssh/authorized_keys` file
- public key obtained by doing:
  ```
  $ ssh-add -L
  ssh-rsa AAAAB3NzaC1...zyt cardno:000603016636
  ```

Remote gpg-agent

- gpg can use a remote gpg-agent
  - Running on another computer
  - Running as a different user

How it works



- Create a new user, gpg
- On secure pc, add the following to `.gnupg/gpg-agent.conf`:

```
extra-socket /home/gpg/.gnupg/S.gpg-agent-remote
```

- On insecure pc, run the following to forward the port:

```
$ ssh -f -o ExitOnForwardFailure=yes -o StreamLocalBindUnlink=yes \
> -L /home/neal/.gnupg/S.gpg-agent:/home/gpg/.gnupg/S.gpg-agent-remote  \
> gpg@localhost bash -c ' while sleep 5; do echo NOP; done  | gpg-connect-agent'
```

- Requires OpenSSH $\geq$ 6.7 (Unix Domain Sockets)

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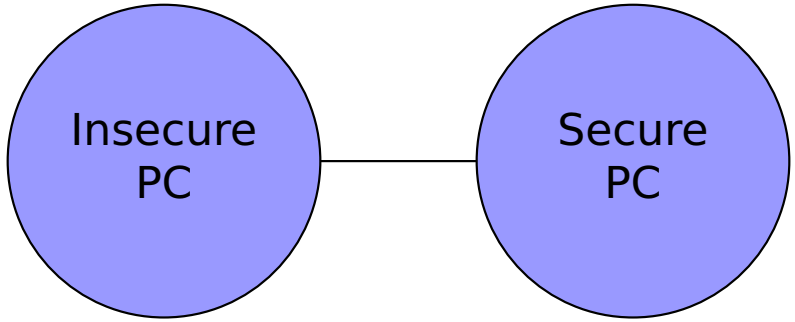

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  - If forwarding fails, exit
  - If the socket to be forwarded already exists, remove it first

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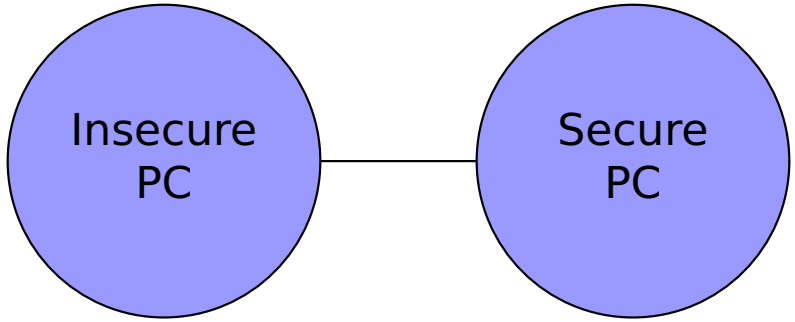

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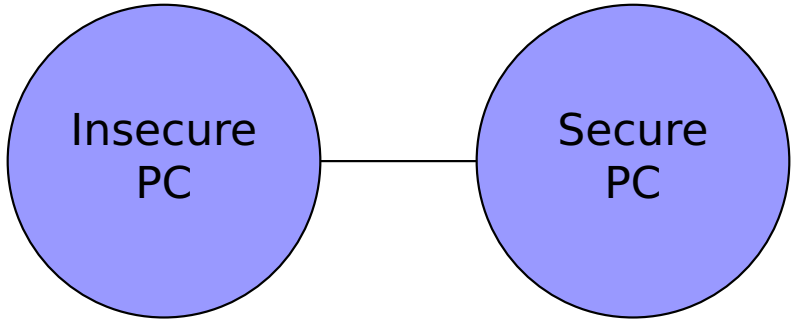
  - Forwards the file `.../S.gpg-agent` on insecure
  - To the file `.../S.gpg-agent-remote` on secure
  - ssh won't expand tildes

How it works



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  - Loop keeps connection opened and port forwarded
  - Exits when gpg-agent exits

Thanks!

- Slides are online at `www.gnupg.org`
- More resources:
  - Riseup: `https://help.riseup.net/en/security/message-security/openpgp/best-practices`
  - The grugq (for the truly paranoid): `https://gist.github.com/grugq/03167bed45e774551155`

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