CS6 Practical System Skills

Fall 2019 edition

Leonhard Spiegelberg
lspiegel@cs.brown.edu

Recap

Last lecture:

- bash scripting
  - exit codes / status codes / return codes ⇒ 0 success, else failure
  - `&&` and `II`
  - `[` and `test`
  - bash builtin extension: `[[ … ]]`
  - `if`
  - grouping commands via subshell `(...)` and braces `{...; }`
  - loops, arrays & functions

Recap - Quiz

Fix the following statements! Assume `x` and `y` are variables.

wrong	`z=$(x * 3)`
fixed	
wrong	`if [x > 10 || x < -10]; then echo "more than one digit"; else echo "one digit"`
fixed	
wrong	`echo "x^2 + y^2: `x ^ 2 + y ^ 2`"`
fixed	

Recap - Quiz

Fix the following statements! Assume `x` and `y` are variables.

wrong	`z=$(x * 3)`
fixed	**`z=$((x*3))`**
wrong	`if [x > 10 || x < -10]; then echo "more than one digit"; else echo "one digit"`
fixed	**`if [ $x -gt 10 ] || [ $x -lt -10 ]; then echo "more than one digit"; else echo "one digit"; fi`**
wrong	`echo "x^2 + y^2: `x ^ 2 + y ^ 2`"`
fixed	**`echo "x^2 + y^2: $((x ** 2 + y ** 2 ))"`**

08 SSH

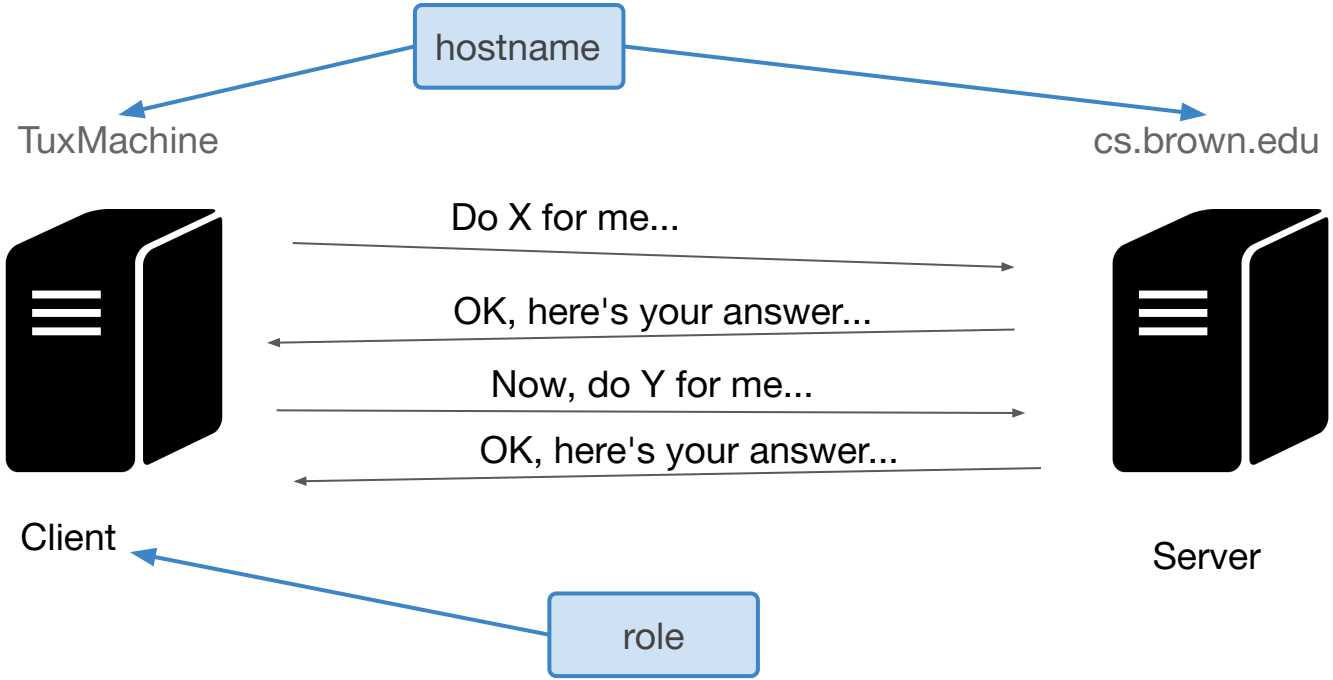
CS6 Practical System Skills

Fall 2019

Leonhard Spiegelberg *lspiegel@cs.brown.edu*

08.01 Basic networking

⇒ Networking usually follows the pattern of a client connecting to a server and performing a *request* which yields a *response*.



08.01 Basic networking

⇒ to connect to a server, we need to know its address.

⇒ in a network, each device is assigned an IP (Internet Protocol) address. Two flavours:

- ⇒ IPv4: 192.168.0.1 (32 bit integers, 4 8-bit segments)
- ⇒ IPv6: fe80::c8c:de7c:82dd:6012 (128bit, 8 16-bit segments)

⇒ a machine is also called a *host*, which has a *hostname*

⇒ you can use `hostname` to get the hostname of your machine

08.01 Basic networking

⇒ one *host* communicates with another *host* over a connection.

⇒ the outlet (or endpoint) over which the communication occurs is called a *socket*.

⇒ On a machine there are 2^{16} sockets available, identified by a 16 bit unsigned integer. Each socket binds to a unique *port* numbered 0-65536.

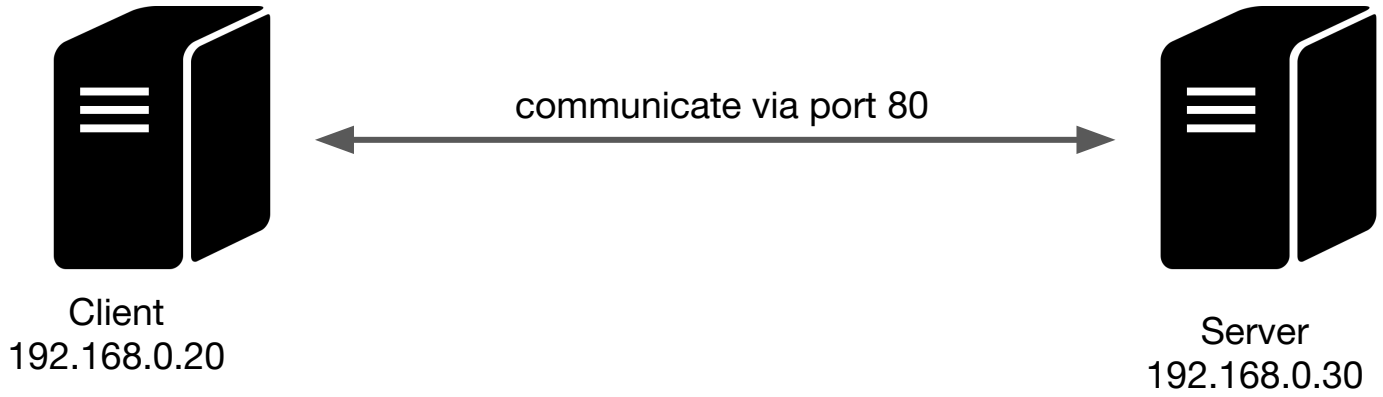
⇒ port numbers < 1024 are reserved.

08.01 Sockets

A socket is an end-point of a two-way communication link of two programs running on a network. Each socket is bound to a port number 0-65536.

08.01 Sockets and IP addresses

⇒ to specify a connection we need two IP addresses and one port



08.01 Communication layers

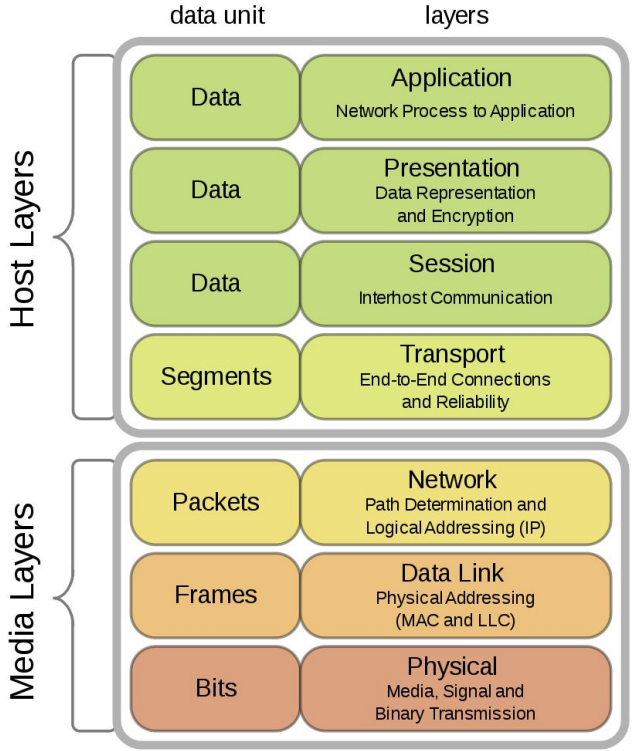
⇒ a protocol defines how two hosts/devices communicate

⇒ OSI = Open Systems Interconnection model is a model to allow different systems to communicate along clearly defined abstractions and standards

⇒ different (abstraction) layers for communication with each of them having different protocols

⇒ in CS6 we only care about host layers

⇒ more on the OSI model: https://www.cloudflare.com/learning/ddos/glossary/open-systems-interconnection-model-osi/



⇒ more on networks in CS168

08.01 Labels for IPs

⇒ IPs are hard to remember and assignment of IPs frequently changes

⇒ there are multiple ways to assign a label to an IP

⇒ depending where the machine we want to connect to is located, we can use different options to *name* it:

→ hostname i.e. a tag to a computer in a network

→ domain name i.e. a tag to use with a service which provides a final tag or address

08.01 Defining hostnames

⇒ `hostname` reveals the name under which the current machine can be reached

⇒ we can manually tag an IP, by editing `/etc/hosts` (requires root access)

/etc/hosts

```
1 ##
2 # Host Database
3 #
4 # localhost is used to configure
the loopback interface
5 # when the system is booting.
Do not change this entry.
6 ##
7 127.0.0.1   localhost
8 ::1         localhost
```

08.01 Looking up IPs via URI resolution

⇒ resources can be identified via a URI=Uniform Resource Identifier

Generic syntax:

```
URI = scheme:[//authority]path[?query][#fragment]
```

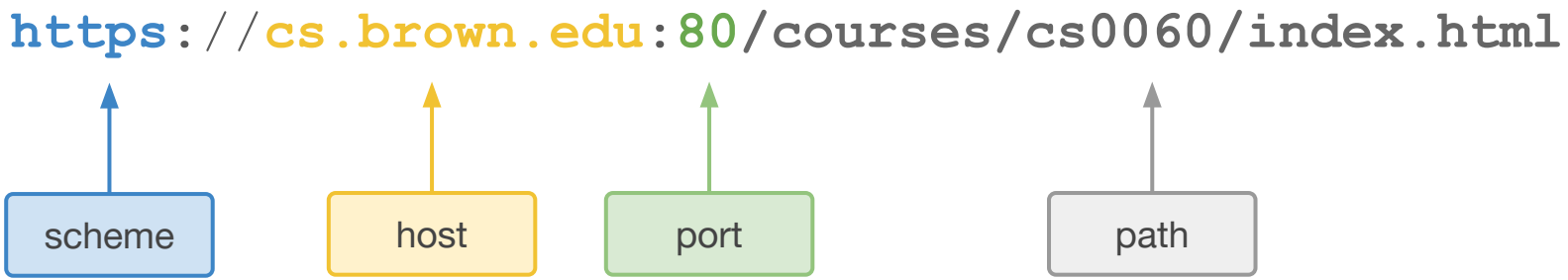
The authority itself can be split into

```
authority = [userinfo@]host[:port]
```

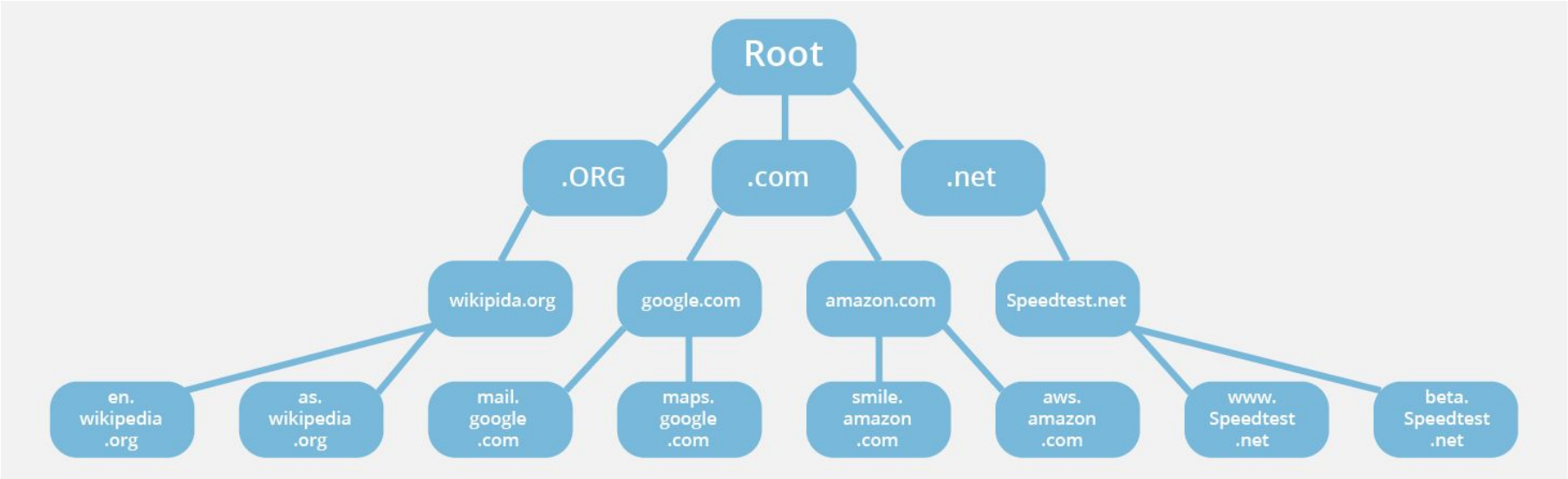
Note: `path` starts with `/`, which is considered part of the path

08.01 URLs are URIs

⇒ URL = Uniform Resource Locator
(often referred to as web address) is used to reference a web resource



08.01 DNS = Domain Name System



DNS = Domain Name System

⇒ translates URIs (incl. hostnames) through DNS servers to IP addresses

08.01 hostnames to IP

⇒ `getent hosts unix.stackexchange.com` to list addresses under which `unix.stackexchange.com` can be reached

⇒ to restrict to IPv4 only, use `getent ahostsv4 hostname`

⇒ `*NIX` tries to resolve hostname via multiple services, thus multiple IPs may be available for one URI.

getent works under Linux, use `dns-sd -q hostname` under Mac OS X

How can we access
a remote machine?

08.02 Working remotely - historic commands

⇒ as part of BSD, programs rlogin, rsh, rexec were shipped

rlogin	allows you to login into a remote machine
rsh	remote shell, allows you to open a shell without login to execute arbitrary commands
rexec	Like rsh but with login, reads username and password (unencrypted) from a socket

⇒ **Problem:** All these tools send user passwords over the network in a clear format, **without any encryption**. This is a **security risk!**

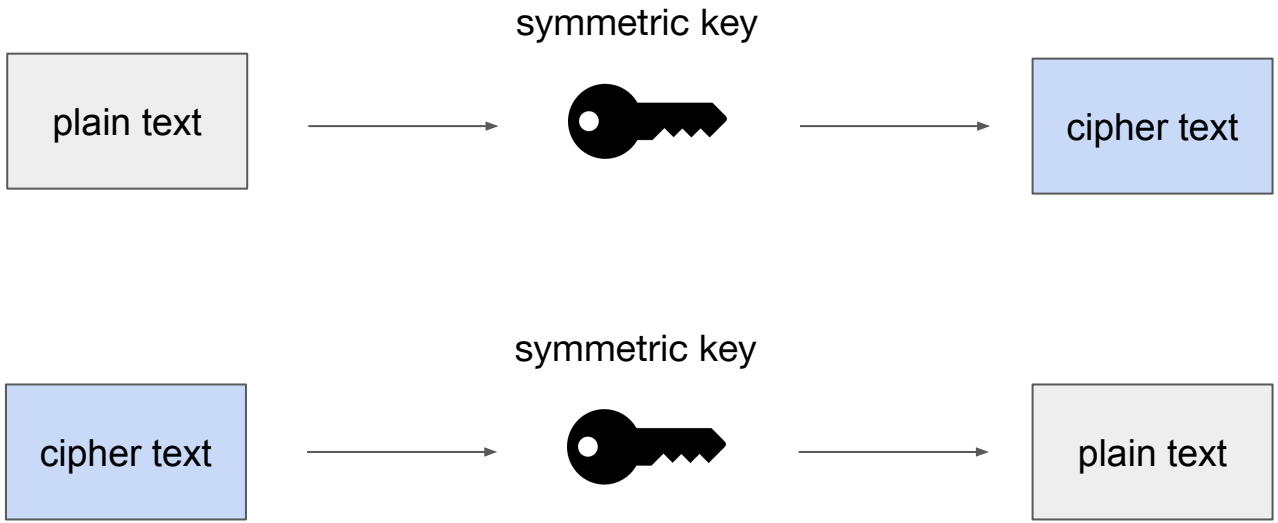
⇒ rlogin is the worst, by relying on IP addresses for authentication; but it's easy to fake an IP address and take over a remote machine!

How to encrypt data, passwords, user names to securely work with a remote machine?

08.03 Basic cryptography

Symmetric encryption:

same key is used for both encryption and decryption



08.03 Basic cryptography

Some widely used symmetric encryption algorithms are:
Blowfish, AES, RC4, DES, RC5, and RC6

⇒ widely used is AES, which can be used with 3 different key sizes: 128, 192 or 256 bit

⇒ The more bits the key has the better the encryption;
but the slower encryption/decryption

We can use `openssl` to encrypt/decrypt a file!

08.03 AES-128 via openssl

⇒ to encrypt a file use

Encrypt:

```
openssl aes-128-cbc -e -pass pass:secret \
-in file_to_encrypt.txt -out encrypted.txt
```

Decrypt:

```
openssl aes-128-cbc -d -pass pass:secret \
-in encrypted.txt -out decrypted.txt
```

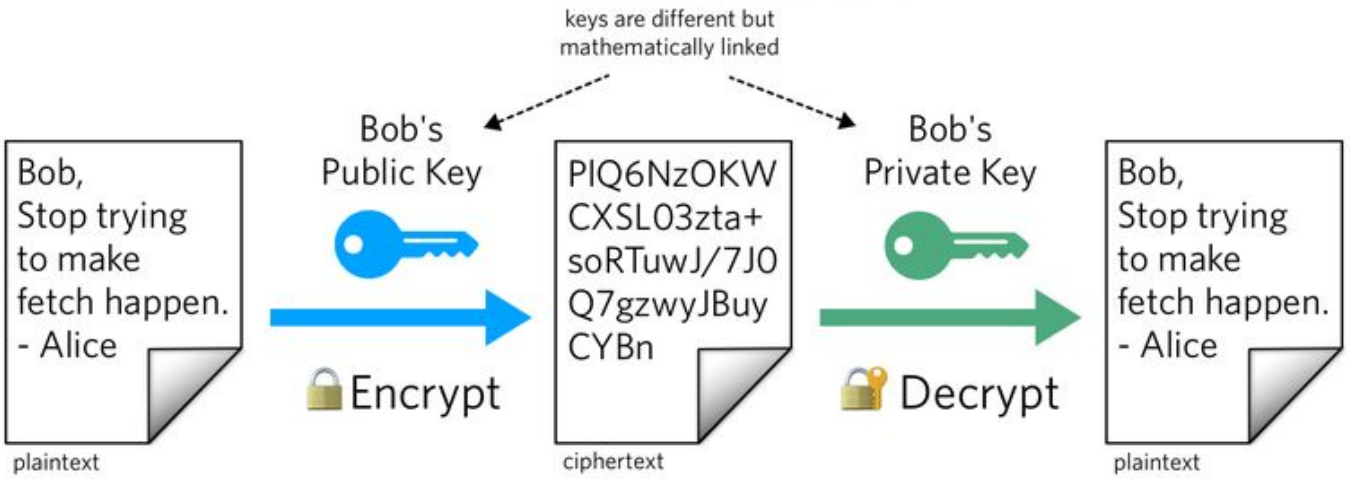
⇒ openssl provides many more features, i.e. `man openssl` or `openssl help`

Remaining problem:
How to exchange the key?

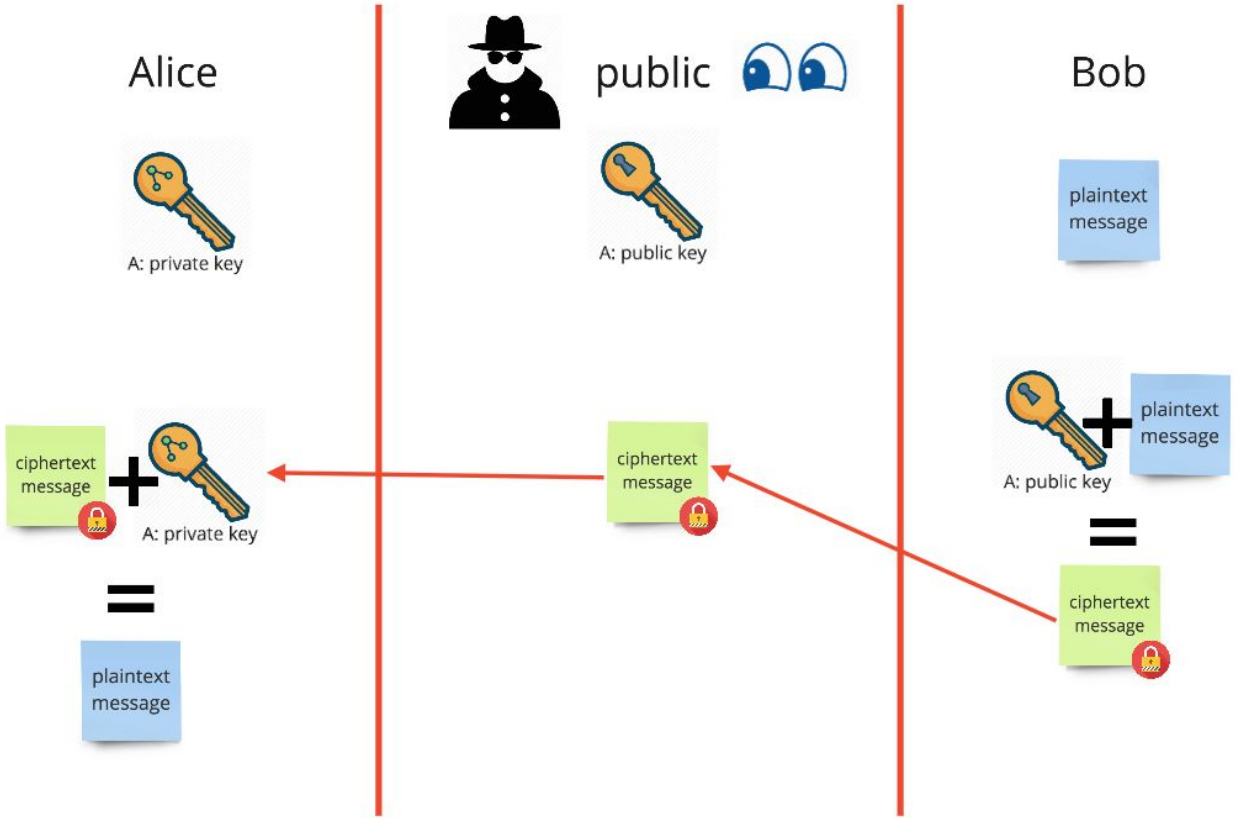
08.04 Asymmetric/public key cryptography

Generate two keys: one public key and one private key

⇒ share and use public key to encrypt message,
but **only** holder of private key can decrypt message.

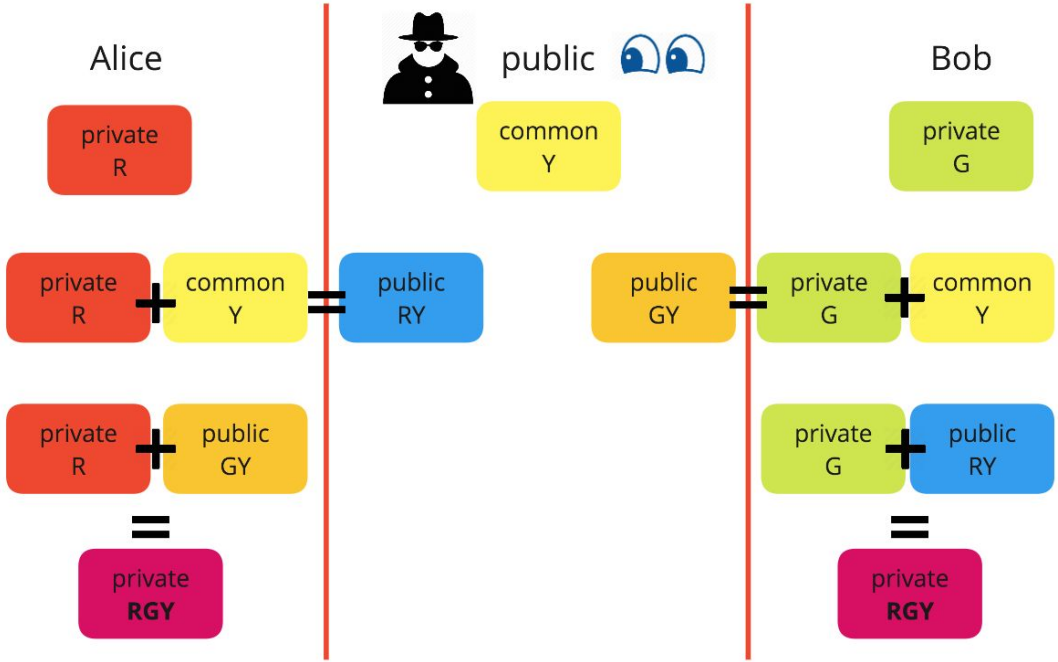


08.04 General usage



08.04 How to exchange a key?

Diffie-Hellman-Merkle key exchange

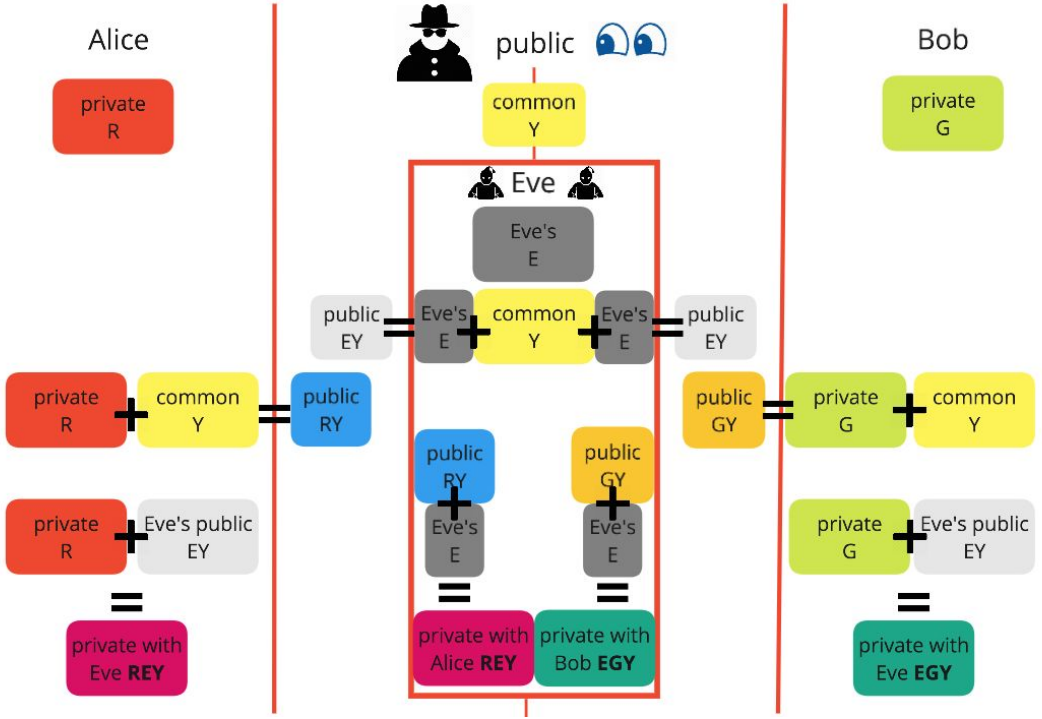


⇒ allows you to create a shared, private key! Details in a cryptography class, e.g. CS151

08.04 Diffie-Hellman-Merkle exchange

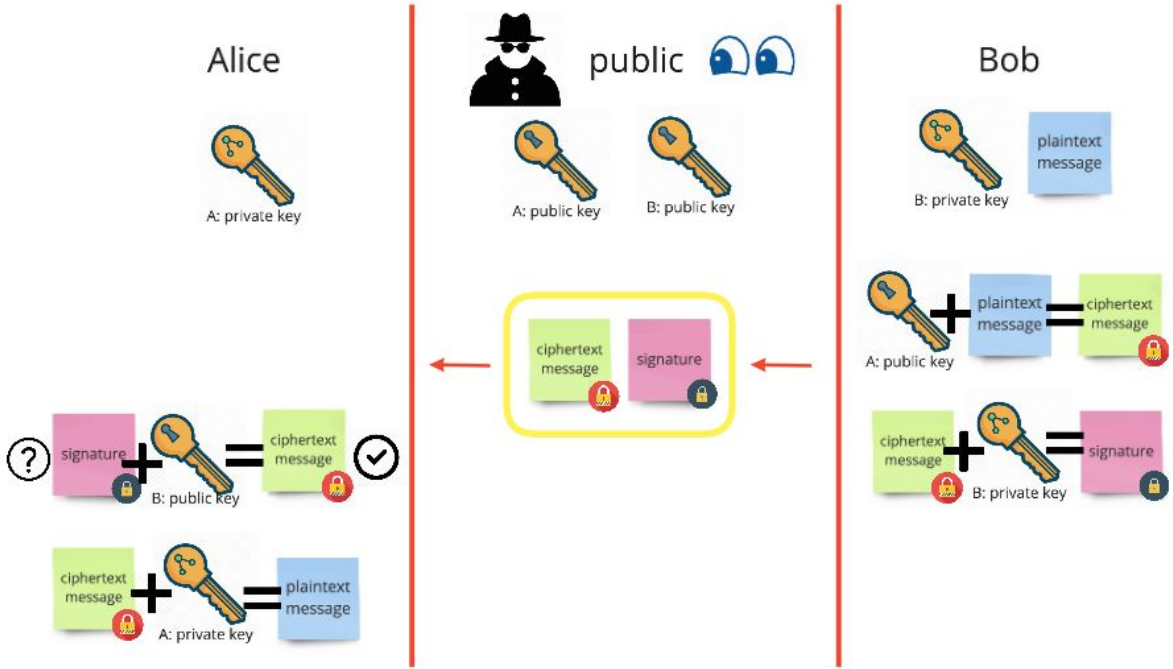
⇒ can be used to share a secret key, which then may be used for following *symmetric encryption*

⇒ Problem:
Man-in-the-middle attack possible because no authentication that public keys are from actual Alice/Bob respectively.



08.04 RSA key exchange

RSA is a true public cryptography algorithm named after Rivest-Shamir-Adleman



08.04 RSA vs. Diffie-Hellman-Merkle

⇒ RSA can be used for both exchanging a key OR direct, asymmetric encryption.

⇒ Also DHM can be used for both exchanging a key OR direct encryption

⇒ they use different underlying principles and are vulnerable to different attacks

⇒ symmetric cryptography is usually faster than asymmetric cryptography

⇒ Details in Cryptography class

08.04 Public key cryptography

Summary:

Generate a key pair, **ONLY** share the public key.
NEVER share the private key.

⇒ for additional security, private key is often protected by a passphrase. I.e. the private key for asymmetric encryption is encrypted using a symmetric encryption (per default AES-128).

⇒ Advantage: If someone gains access to your system, private key still somehow encrypted.

Practical public key cryptography...

...thanks to SSH!

08.05 SSH

SSH = Secure Shell

⇒ invented 1995 at Helsinki University of Technology, Finland

⇒ cryptographic network protocol to allow safe remote login

⇒ replaced previously used standards such as rlogin, rsh, rexec and telnet

⇒ defacto standard way to work with other machines over a network today

⇒ uses port 22 per default

08.05 SSH protocol

⇒ ssh handles the set up and generation of an encrypted TCP connection

⇒ allows to login securely remotely (ssh)

⇒ allows to copy files securely (scp)

08.05 SSH programs

⇒ there are two programs:

Client:	ssh	
Server:	sshd	⇐ runs in the background

⇒ if sshd is not running, you can not login

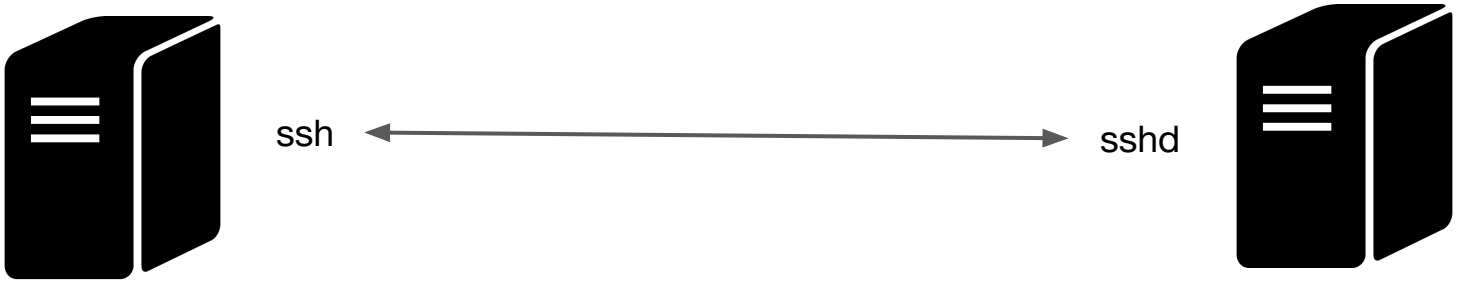
⇒ different implementations for ssh/sshd
most popular one: OpenSSH

08.05 SSH authentication options

⇒ SSH provides 4 different authentication methods

1. Password
2. **Public/private keypair** ⇐ this is the one you should use
3. Host-based authentication
4. Kerberos

08.05 SSH - Password authentication




```
tux@server $: ssh remote-machine
password:

remote-machine $:
```

This is the authentication used when you login to department machines via `ssh user@ssh.cs.brown.edu`

08.05 Public/Key Cryptography

Using public/key cryptography to login:

1. Generate keys via `ssh-keygen`
   (generates private and public key)
2. Copy public key to remote machine and
   append it to `~/.ssh/authorized_keys`
3. login via `ssh -i <private-key-file> remote-machine`

08.05 Step1 - Key generation

⇒ you can generate a key pair using `ssh-keygen`

⇒ keys should be stored by default in `~/.ssh/id_rsa` (private) and `~/.ssh/id_rsa.pub` (public)

⇒ ssh uses default names, i.e. if `id_rsa.pub` and `id_rsa` exist in `~/.ssh`, you can login without specifying a key explicitly.

⇒ you can protect your key with a passhrase (recommended!)

08.05 Step1 - Key generation

`ssh-keygen`

useful options	meaning
`-t rsa`	select rsa for key generation
`-b bits`	how many bits to use for key, anything larger than 1024 is good
`-N new_passphrase`	specify passphrase on the fly to protect key
`-f output_keyfile`	creates private key under output_keyfile and public key under output_keyfile.pub

08.05 Step1 - Key generation

Example:

```
tux@server:~$ ssh-keygen -b 2048 -t rsa -f tuxkey
Generating public/private rsa key pair.
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in tuxkey.
Your public key has been saved in tuxkey.pub.
The key fingerprint is:
SHA256:RozagpJ2mW8gki9MvVHTypZldp1DsIkof1vx3L8rLcc tux@server
The key's randomart image is:
+---[RSA 2048]----+
|         ...     |
|      oo. = .    |
|   . +.*o= +     |
| o..BoB.. + o    |
|=+.Bo*..S. o .   |
|=oo *...o     .  |
|.... o .      o. |
| .  .        o E.|
|              +o.|
+----[SHA256]-----+
```

08.05 Key files

private key

```
-----BEGIN RSA PRIVATE KEY-----
MIIEpQIBAAKCAQEAyrPwcbd48cOIQZNvZMkUozPlAR4mBW47PxjD1LXQtzZRYkAe
E/5k7cEBNU4tCHbEAiWw9jE3wi610mInV/nYQ/jEbHnWJ8QVHpyhUC5QKuAPhdY3
+Mp2HFDbHMA2tY7m7wuOg27QghiG6QCDFMOaG678QI71970l5LOgsL7/lC2/MV4I
pLZQXaONSstIMoP7zLKeEoMp7BgoTnArRWu2V2U4DECERoTSdK+HOph5hpl2vLWC
Ut/wJ/4K98kiCDrOfPEagWYJf0U14WOU4jXOYFJkG7kc8xPyvBqRKScrcv0uscCX
2tG+wHO3BzM1zUozQ6pEPA4T/6TAej4OxOEBrwIDAQABAoIBAHzSg50zMzoFg5GG
HdF9dcTuPvYKP7WWZMt9D5KcB5Pa0hDjlOIRBMvXz0upAVg18ouz9B4WvtRH+VU9
dibZxtBMj4CRIkxIlgzMvRVn/5v3b/elq7/7xPG45MT2pHn3LsRDZJYRFjsWqXUw
CIgvz2V+wv1qS5MsGfqUlr5gT3hJ/uJp8I2kFrLsc8/BhsxixCpVFd4HKiv1WRQW
AmzJRC3Ew1sSp9fNFrRF5O6IJvfC7KRn3eDe7MW6SamiEpHcYZxHkXbUF4sHRKAS
hyZEPCP16j4MNZYhvrxXEa6HBYMZIfCpBpIl4JE1bkRRygvzhhcDiDv7b/hfkrF/
04FdAgECgYEA5dgUaje/0YIGemnYW7CIFnB6NTWn+UHag3UE7AJ3pLNJt/qPXlTq
WifPFK8TkIjPlXeJ6HR4K4QQRbItkisWNCc99dcbF+6rcKrUNcY0eLrt8VsUPYQN
Hx8PpqLRN0c68lQ3U+iq1G3uNeaGTvXrykcDcXwWIdlzKloIlNc2GwECgYEA4cUr
r0N9+bQrYGf/WNc0KiQUbb10zN0eJ7eIMfEUzq4Xn6kDbCZCoT6bT0EI3K+MymTT
sU8qpuEfgBDqMxrdSzwigmLeecgtH4CxuDQbjjcS/3YzmE2bjFHRUwp6COM+T+rA
uwKY+kAC8ruf+llNllHW4RBKYoRiGAgTSrAgjK8CgYEA0qu6Gpm64ifSFEYMIA6w
zhCOk1L5AcjQpwmNV13zmC0VduLcolQm8jfm4UiQIDymOJP2/fAzbX+BAsEMcBu6
IFePvVRK6ybCUWTjWd6wnbCJBF69MJ1nAY2Q5OX76jUJ3LBAflKWsluIqjMADEPw
udlZWJ2qE6CipMEdeH/CggECgYEAuqVqrAY8C0dr5NOVQjkHox8Y1HCgMw1KdMNC
ESehcAx080Wi0rH+u5cqhqbZULjAyEH60McGF9hdVl6lf4JiGGSqkuhxzHQ0+apH
QmWxsizNw+xQU0U1pxes2d37bYWQajlFBFXtalWpGksKwsk5X2BhKMdy92dCQWPL
rx9UiXkCgYEAkcvhOec0kO9NTuFfzqaYWEsbxFM8eA/TR6P9MrfJX4z8yvJ0zkxl
ptFAn5nbZSdCPCJHof/FTnslpfMS80Pw0Xrp/FLVBiT6ynObIaFJUsKQLxcgEOu5
CeIOtVliGfIJcCDlNatY3gpuRC7qzYnWK08HjZ+c95WdP8GzUryAn3U=
-----END RSA PRIVATE KEY-----
```

public key

```
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAABAQDKs/B
xt3jxw4hBk29kyRSjM+UBHiYFbjs/GMPUtdC3NlFiQB
4T/mTtwQE1Ti0IdsQCJbD2MTfCLrXSYidX+dhD+MRse
dYnxBUenKFQLlAq4A+F1jf4ynYcUNscwDa1jubvC46D
btCCGIbpAIMUw5obrvxAjvX3vSXks6Cwvv+ULb8xXgi
ktlBdo41Ky0gyg/vMsp4SgynsGChOcCtFa7ZXZTgMQI
RGhNJ0r4c6mHmGmXa8tYJS3/An/gr3ySIIOs588RqBZ
gl/RTXhY5TiNc5gUmQbuRzzE/K8GpEpJyty/S6xwJfa
0b7Ac7cHMzXNSjNDqkQ8DhP/pMB6Pg7E4QGv
tux@server
```

08.05 Step2 - copying ssh keys

⇒ append them to `~user/.ssh/authorized_keys` on the machine where you want to login to authorize login as `user`

⇒ Tip: use `>>` to append to `~user/.ssh/authorized_keys`

⇒ On Linux, there is also a command to copy keys to a remote machine: `ssh-copy-id`

private key, public key will be only copied though!

⇒ Example: `ssh-copy-id -i ~/.ssh/id_rsa user@host`

08.05 Step3 - Logging in

To login into the remote machine use

```
ssh -i <private-key-file> user@host
```

or

```
ssh -i <private-key-file> host -l user
```

⇒ can be cumbersome to write login details always, to save default edit `~/.ssh/config`!

08.06 Configuration via ~/.ssh/config

⇒ can store details for a host there

~/.ssh/config

```
Host cs6demo
     HostName 18.206.152.69
     User tux
     IdentityFile ~/.ssh/tux.key
```

⇒ i.e. after adding tux.key.pub tp ~tux/.ssh/authorized_keys

on remote machine, login is as simple as ssh cs6demo!

08.06 ~/.ssh/known_hosts

⇒ SSH uses a (RSA) fingerprint to verify the identity of the server/remote. When connecting the first time, usually a prompt ask whether to accept the server's fingerprint.

⇒ If ssh warns about mismatch of the fingerprint, the following scenarios might have happened:

1. the key used to generate the fingerprint changed on the server (SSH or OS update)
2. hostname or IP belongs to different server now
3. Malicious man-in-the-middle attack

08.06 ~/.ssh/known_hosts

⇒ use `ssh-keygen -R hostname` to remove entry for hostname from known_hosts

⇒ you can add a fingerprint using ssh-keyscan via

```
ssh-keyscan -H hostname >> ~/.ssh/known_hosts
```

08.06 Summary

`~/.ssh/known_hosts`

⇒ used to verify the identity of remote hosts

`~/.ssh/authorized_keys`

⇒ keys authorized to login on this machine

`~/.ssh/config`

⇒ login configuration

08.07 More on SSH - Tracing SSH

use `-v` to see what's happening under the hood!

```
tux@server:~$ ssh -v user@ssh.cs.brown.edu
OpenSSH_7.6p1 Ubuntu-4ubuntu0.3, OpenSSL 1.0.2n  7 Dec 2017
debug1: Reading configuration data /etc/ssh/ssh_config
debug1: /etc/ssh/ssh_config line 19: Applying options for *
debug1: Connecting to ssh.cs.brown.edu [128.148.31.18] port 22.
debug1: Connection established.
debug1: SELinux support disabled
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_rsa type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_rsa-cert type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_dsa type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_dsa-cert type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_ecdsa type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_ecdsa-cert type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_ed25519 type -1
debug1: key_load_public: No such file or directory
debug1: identity file /home/tux/.ssh/id_ed25519-cert type -1
debug1: Local version string SSH-2.0-OpenSSH_7.6p1 Ubuntu-4ubuntu0.3
debug1: Remote protocol version 2.0, remote software version OpenSSH_7.9p1 Debian-10
debug1: match: OpenSSH_7.9p1 Debian-10 pat OpenSSH* compat 0x04000000
debug1: Authenticating to ssh.cs.brown.edu:22 as 'lspiegel'
debug1: SSH2_MSG_KEXINIT sent
debug1: SSH2_MSG_KEXINIT received
debug1: kex: algorithm: curve25519-sha256
debug1: kex: host key algorithm: rsa-sha2-512
debug1: kex: server->client cipher: chacha20-poly1305@openssh.com MAC: <implicit> compression: none
debug1: kex: client->server cipher: chacha20-poly1305@openssh.com MAC: <implicit> compression: none
debug1: expecting SSH2_MSG_KEX_ECDH_REPLY
debug1: Server host key: ssh-rsa SHA256:P4ZsteVHDJ1nFV6UfH1VTK0RgRjXvBMti6IhLS+EeoI
The authenticity of host 'ssh.cs.brown.edu (128.148.31.18)' can't be established.
RSA key fingerprint is SHA256:P4ZsteVHDJ1nFV6UfH1VTK0RgRjXvBMti6IhLS+EeoI.
Are you sure you want to continue connecting (yes/no)?
```

08.07 More on SSH

ssh can be used to run arbitrary commands remotely

⇒ `ssh cmd [param1 …]`

Example:

```
ssh cs6server ls /home/tux
```

⇒ helpful to install things remotely, execute scripts, …

⇒ can use this with all the other bash tools!

08.07 More on SSH

⇒ X Server provides (one way for a) graphical user interface (GUI) on Linux

⇒ we can start programs remotely and display their GUI via X-Server forwarding ssh -X

Example:

```
ssh cs6server firefox library.brown.edu
```

⇒ Further application: SSH can be used to tunnel ports, i.e. exposing a secured port of a remote locally.

08.08 Transferring files: scp

```
scp [-r] [-i identity_file] [[user@]host1:]file1 ... [[user@]host2:]file2
```

⇒ there are many more options, however -i to specify private key is the most useful.

⇒ `scp` copies files between hosts using SSH protocol

Example:

```
scp -r folder tux@cs6demo:/home/tux/
```

copies folder recursively to /home/tux/.

08.08 scp examples

local file to remote host

```
scp file.txt user@host:/remote/directory
```

remote file to local cwd

```
scp user@host:/remote/directory/file.txt .
```

remote host to remote host

```
scp tux@from_host:/home/tux/file.txt sealion@to_host:/home/sealion/
```

08.08 scp limits

⇒ `scp` can be slow for large files as it performs a plain copy, i.e. read/writes all files and encrypts data via SSH

⇒ use `scp -c cipher` for faster encryption by selecting a fast cipher explicitly (`ssh -Q cipher` to list available algorithms)

⇒ `scp` is not able to resume copying, show progress, ...

Is there another tool?

08.08 rsync

rsync = remote sync

⇒ can be used to sync directories, download files,
resume transfers, show progress, ...

⇒ similar syntax to scp, use `-e ssh` to use SSH as protocol

⇒ more powerful options, e.g

`--progress`	shows progress on transfers
`--include '*.csv'`	include only csv files
`--exclude '*.tmp'`	exclude tmp files
`--max-size='1m'`	maximum size of files to be transferred
`--dry-run`	perform dry-run, i.e. no materialization

End of lecture.

Next class: Thu, 4pm-5:20pm @ CIT 477