

Principles of Computer Science II

Cloud Computing

Ioannis Chatzigiannakis

Sapienza University of Rome

Lecture 4



AWS: Elastic Compute Cloud (EC2)

- ▶ AWS EC2 = Elastic Compute Cloud
- ▶ Resizable compute resources in the cloud.
- ▶ Minimizes the time to provision a server.
 - ▶ Introduce a new server within minimum delay.
 - ▶ Scale capacity up very fast.
- ▶ Quickly modify the capabilities of the compute instance.
 - ▶ Introduce additional computational, memory and storage capabilities.
 - ▶ Reduce computational, memory and storage capabilities.
- ▶ Shutdown - or completely remove resources.
 - ▶ Scale down very fast.
- ▶ Pay only for the resources you need.



Typical Use Cases

- ▶ Development and Testing Environments
- ▶ Hosting of Databases
- ▶ Hosting of web services
- ▶ Data analytics
- ▶ Code repository
- ▶ GPU-assisted machine learning
- ▶ High performance computing
- ▶ Video processing
- ▶ Backup and disaster recovery
- ▶ ...



EC2 Provisioning Options

- ▶ **On Demand** – Pay for the compute capacity by the hour.
 - ▶ No up-front payment or long-term commitment.
 - ▶ Short-term, spiky, or unpredictable workloads.
 - ▶ Applications development or testing.
- ▶ **Spot Instances** – Acquire spare capacity up to 90% off the on-demand price.
 - ▶ When start/end times are flexible.
 - ▶ Applications that are only feasible at very low compute prices.
 - ▶ Urgent computing needs for large amounts of additional capacity.
- ▶ **Reserved Instances** – Significant discount (up to 75%) compared to On-Demand instance pricing.
 - ▶ For applications that have steady state or predictable usage.
 - ▶ Long term (≥ 1 year) to reduce their total computing costs.
- ▶ **Dedicated Hosts** – Physical servers dedicated for use use.



EC2 Instance Types

- ▶ **General Purpose** – balance of compute, memory and networking resources.
- ▶ **Compute Optimized** – ideal for compute bound applications that benefit from high performance processors.
- ▶ **Memory Optimized** – deliver fast performance for workloads that process large data sets in memory.
- ▶ **Accelerated computing** – use hardware accelerators, or co-processors, to perform functions, such as floating point number calculations, graphics processing, or data pattern matching, more efficiently than is possible in software running on generic CPUs.
- ▶ **Storage optimized** – for workloads that require high, sequential read and write access to very large data sets on local storage.



EC2 Instance Types & Resources

- ▶ **CPU** – 64-bit Arm, AMD EPYC 7000, Intel Xeon Platinum 8175M, Intel Xeon E5-2676.
 - ▶ 1 ... 192 virtual CPUs – 1 thread = 1 vCPU.
- ▶ **Memory** – 1 ... 512 GB.
- ▶ **Network** – up to 100 Gbps.
- ▶ **Storage**
 - ▶ Amazon Elastic Block Store (EBS) – easy to use, high performance block storage service.
 - ▶ 0 ... 60 TB NVMe SSD – ensure best IOPS (Input/Output operations per second).
- ▶ **Hardware Accelerators**
 - ▶ NVIDIA Tesla V100 GPUs, NVIDIA K80 GPUs, NVIDIA T4 Tensor Core GPUs.
 - ▶ AWS Inferentia Chips.
 - ▶ Xilinx Virtex UltraScale+ VU9P FPGAs



Available OS & Software

- ▶ **Operating Systems**
 - ▶ Linux/Unix – Amazon Linux, Debian, Ubuntu, Red Hat, CentOS, SUSE, FreeBSD, Gentoo, Mint, ...
 - ▶ Windows – Server 2019, Server 2016, Server 2012.
- ▶ **Databases** – PostgreSQL, MySQL, MongoDB, Neo4J, Oracle Enterprise, Microsoft SQL, ...
- ▶ **AWS Marketplace** – a wide selection of commercial and free software from well-known vendors.



Pricing Examples

- ▶ **General Purpose**
 - ▶ **t2.micro Linux or Windows** – 2 vCPUs + 4 GB – 750 hours free per month, \$0.05/h
 - ▶ **a1.xlarge Linux** – 4 64-bit ARM vCPUs + 8 GB – \$0.1152/h
 - ▶ **a1.xlarge Linux** – 4 64-bit ARM vCPUs + 8 GB – \$0.1152/h
 - ▶ **m5.24xlarge Linux** – 96 Xeon vCPUs + 337 GB – \$5.136/h
 - ▶ **m5.24xlarge Windows** – 96 Xeon vCPUs + 337 GB – \$9.552/h
- ▶ **Compute Optimized**
 - ▶ **c5.xlarge Linux** – 4 Xeon vCPUs + 8 GB – \$0.192/Hour
 - ▶ **c5.24xlarge Linux** – 96 Xeon vCPUs + 192 GB – \$4.608/Hour
- ▶ **Hardware Accelerators**
 - ▶ **p3.2xlarge Linux** – 1 NVIDIA Tesla V100 GPUs + 8 Xeon vCPUs + 61 GB – \$3.305 per Hour
 - ▶ **p3dn.24xlarge Linux** – 8 NVIDIA Tesla V100 GPUs + 96 Xeon vCPUs + 768 GB – \$33.711 per Hour



Amazon Elastic Block Store (EBS)

- ▶ Easy to use, high performance block storage service.
- ▶ Targeting both throughput and transaction intensive workloads.
 - ▶ Can be used for relational and non-relational databases.
 - ▶ Enterprise applications.
 - ▶ Big data analytics engines.
 - ▶ General purpose file systems.
 - ▶ Media workflows.
- ▶ Highly availability and durability – 99.999%
- ▶ Virtually unlimited scale – as little as a single GB of storage, or scale up to petabytes of data.
- ▶ Secure – encryption of data at-rest, data in-transit, and all volume backups.



EBS Volume Types – HDD based

- ▶ **Throughput Optimized HDD (ST1)** – ideal for frequently accessed, throughput-intensive workloads.
 - ▶ Large datasets and large I/O sizes, such as MapReduce, Kafka, log processing, data warehouse, and ETL workloads.
 - ▶ Low cost HDD volume.
 - ▶ Volume Size: 500 GB – 16 TB.
 - ▶ Max IOPS/Volume: 500
 - ▶ Max Throughput/Volume: 500 MB/s
 - ▶ Price: \$0.045/GB-month
- ▶ **Low-cost HDD (SC1)** – ideal for less frequently accessed workloads with large, cold datasets.
 - ▶ Colder data requiring fewer scans per day.
 - ▶ Volume Size: 500 GB – 16 TB.
 - ▶ Max IOPS/Volume: 250
 - ▶ Max Throughput/Volume: 250 MB/s
 - ▶ Price: \$0.025/GB-month



EBS Volume Types – SSD based

- ▶ **Provisioned IOPS SSD (IO1)** – high performance SSD volume designed for latency-sensitive transactional workloads.
 - ▶ I/O-intensive NoSQL & relational databases.
 - ▶ Volume Size: 4 GB – 16 TB.
 - ▶ Max IOPS/Volume: 64,000
 - ▶ Max Throughput/Volume: 1,000 MB/s
 - ▶ Price: \$0.125/GB-month + \$0.065/provisioned IOPS
- ▶ **Default EBS volume type (GP2)** – ideal for suitable for a broad range of transactional workloads.
 - ▶ Boot volumes, low-latency interactive apps, dev & test.
 - ▶ Volume Size: 1 TB – 16 TB.
 - ▶ Max IOPS/Volume: 16,000
 - ▶ Max Throughput/Volume: 250 MB/s
 - ▶ Price: \$0.10/GB-month



What is a Shell?

- ▶ The user interface to the operating system
- ▶ Functionality:
 - ▶ Execute other programs
 - ▶ Manage files
 - ▶ Manage processes
- ▶ A program like any other
- ▶ Executed when you “open a Terminal”
- ▶ The shell
 - ▶ Allows the execution of command scripts
 - ▶ Enables alternative methods to carry out complex tasks
 - ▶ Provides variables



Shell Interactive Use

- ▶ The # is called the "prompt"
- ▶ In the prompt we type the name of the command and press "Enter"
- ▶ The prompt allows
 - ▶ Command history
 - ▶ Command line editing
 - ▶ File expansion (tab completion)
 - ▶ Command expansion
 - ▶ Key bindings
 - ▶ Spelling correction
 - ▶ Job control

Prompt: The Command Line

```
# date  
Sat Apr 21 16:47:30 GMT 2007
```



Error Handling

- ▶ If we type a wrong command, an error message appears

Prompt: The Command Line

```
# datee  
datee: no such file or directory
```

- ▶ The error message states that either the file or the folder (directory) was not found
 - ▶ In the prompt all commands are assumed to be connected to a file ...
- ▶ The arrow keys ↑ ↓ allow to look-up previous commands
- ▶ The arrow keys ← → allow to move within the same command line



Terminating Command Execution

- ▶ We can interrupt the execution of a command by pressing *ctrl-c*
- ▶ We can "freeze" the output of the execution of a command by pressing *ctrl-s*
 - ▶ To "un-freeze" the output of a command we use *ctrl-q*
 - ▶ **Note** – only the output is frozen not the actual execution
- ▶ To close a terminal we use *ctrl-d*
 - ▶ We may need to press multiple times *ctrl-q*
 - ▶ All programs currently running will terminate



Manual Pages

- ▶ The command *man* allows to access the manual pages
- ▶ Manual pages are organized in categories
 1. Commands – *ls*, *cp*, *grep*
 2. System Calls – *fork*, *exit*
 3. Libraries
 4. I/O Files
 5. File Encoding Types
 6. Games
 7. Miscellaneous
 8. Administrator's Commands
 9. Documents
- ▶ We can request a page from a specific category
man [category] [topic]



Manual Pages

```
FORR(2)                               Minix Programmer's Manual          FORR(2)

NAME
    fork - create a new process

SYNOPSIS
    #include <sys/types.h>
    #include <unistd.h>

    pid_t fork(void)

DESCRIPTION
    Fork causes creation of a new process. The new process (child process)
    is an exact copy of the calling process except for the following:

    The child process has a unique process ID.

    The child process has a different parent process ID (i.e., the
    process ID of the parent process).

    The child process has its own copy of the parent's descriptors.
    standard-input, 1-24 (Top)
```

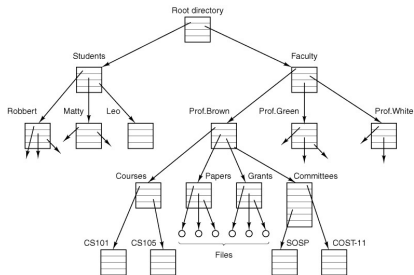


File System

- ▶ All system entities are abstracted as files
 - ▶ Folders and files
 - ▶ Commands and applications
 - ▶ I/O devices
 - ▶ Memory
 - ▶ Process communication
- ▶ The file system is hierarchical
 - ▶ Folders and files construct a tree structure
 - ▶ The root of the tree is represented using the /
- ▶ The actual structure of the tree depends on the distribution of Linux
 - ▶ Certain folders and files are standard across all Linux distributions



File System Example



Standard Folders

- ▶ /bin - Basic commands
- ▶ /etc - System settings
- ▶ /usr - Applications and Libraries
- ▶ /usr/bin - Application commands
- ▶ /usr/local - Applications installed by the local users
- ▶ /sbin - Administrator commands
- ▶ /var - Various system files
- ▶ /tmp - Temporary files
- ▶ /dev - Devices
- ▶ /boot - Files needed to start the system
- ▶ /root - Administrator's folder



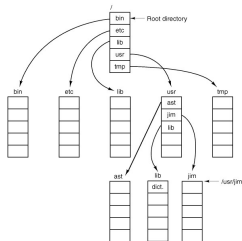
Example of File Metadata

```
# ls -la
lrwxrwxrwx 1 bin operator 2880 Jun 1 1993 bin
-r--r--r-- 1 root operator 448 Jun 1 1993 boot
drwxr-sr-x 2 root operator 11264 May 11 17:00 dev
drwxr-sr-x 10 root operator 2560 Jul 8 02:06 etc
drwxrwxrwx 1 bin bin 7 Jun 1 1993 home
lrwxrwxrwx 1 root operator 7 Jun 1 1993 lib
drwxr-sr-x 2 root operator 512 Jul 23 1992 mnt
drwx----- 2 root operator 512 Sep 26 1993 root
drwxr-sr-x 2 bin operator 512 Jun 1 1993/sbin
drwxrwxrwx 6 root operator 732 Jul 8 19:23 tmp
drwxr-xr-x 27 bin bin 1024 Jun 14 1993 usr
drwxr-sr-x 10 root operator 512 Jul 23 1992 var
```



Navigating the File System

- ▶ Each folder contains two "virtual" folders
ls -la
. . .
- ▶ The single dot represents the same folder
./myfile ⇒ myfile
- ▶ The two dots represent the "parent" folder in the tree



File System Security

- ▶ For each file we have 16 bit to define authorization
 - ▶ 12 bit are used by the operator
 - ▶ They are split in 4 groups of 3 bit – 1 octal – each
- ▶ The first 4 bit cannot be changed
 - ▶ They characterize the type of the file (simple file, folder, symbolic link)
 - ▶ When we list the contents of a folder the first letter is used to signify:
 - - simple files
 - d – folders
 - l – symbolic links
- ▶ The next 3 bit are known as the s-bits and t-bit
- ▶ The last three groups are used to define the access writes for read 'r', write 'w' and execute 'x'
 - ▶ For the file owner, users of the same group, and all other users.



File System Permissions Examples

Type Owner Group Anyone

d rwx r-x ---

- ▶ Folder
- ▶ The owner has full access
- ▶ All users that belong to the group defined by the file can read and execute the file – but not modify the contents
- ▶ All other users cannot access the file or execute it
- ▶ To access a folder we use the command `cd` given that we have permission to execute 'x'



Changing the File Permissions

Examples of File Permissions

Binary	Octal	Text
001	1	x
010	2	w
100	4	r
110	6	rw-
101	5	r-x
-	644	rw-r--r--

- ▶ The command `chmod` allows to modify the permissions
- ▶ There are 2 way to define the new permissions
 1. Defining the 3 Octal – e.g., `644`
 2. By using text – e.g., `a+r`



Some Examples of `chmod`

```
make read/write-able for everyone
# chmod a+w myfile
```

```
add the 'execute' flag for directory
# chmod u+x mydir/
```

```
open all files for everyone
# chmod 755 *
```

```
make file readonly for group
# chmod g-w myfile
```

```
descend recursively into directory opening all files
# chmod -R a+r mydir/
```



Changing the Owner and Group of a File

- ▶ The command `chown` allows to change the owner of a file
- ▶ The command `chgrp` allows to change the group of a file

```
give ownership to ichatz
# chown ichatz myfile
```

```
set group to students
# chgrp students mydir/
```

```
give ownership to pcs and group to students
# chgrp pcs:students myfile mydir/
```

```
descend recursively into directory opening all files
# chown -R ichatz mydir/
```



Symbolic Links

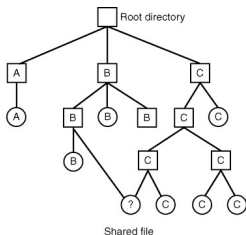
- ▶ The file system enables to create symbolic links
- ▶ Two types are provided
 - ▶ Symbolic link
 - ▶ Hard link
- ▶ The contents and metadata of the original file are used for all operations

```
create a symbolic link to a directory
# ln -s /var/log ./log
# ls -lg
lrwxrwxrwx 1 operator 8 Apr 25 10:00 log -> /var/log
```

- ▶ The contents and metadata of the original file are used for all operations
 - ▶ Except for deletion.



Examples of Symbolic Links



Access Dates

- ▶ For each file the system keeps track of
 - ▶ Date of last usage/access
 - ▶ Date of last change

check last usage time

```
# ls -lu
```

```
drwxrwxrwx 1 bin    bin      7 Apr 25 1993 home
lrwxrwxrwx 1 root   operator 7 Apr 25 1993 lib
drwx----- 2 root   operator 512 Mar 30 1993 root
```

check last change time

```
# ls -lc
```

```
drwxrwxrwx 1 bin    bin      7 Apr 25 1993 home
lrwxrwxrwx 1 root   operator 7 Oct 27 1993 lib
drwx----- 2 root   operator 512 Oct 27 1993 root
```