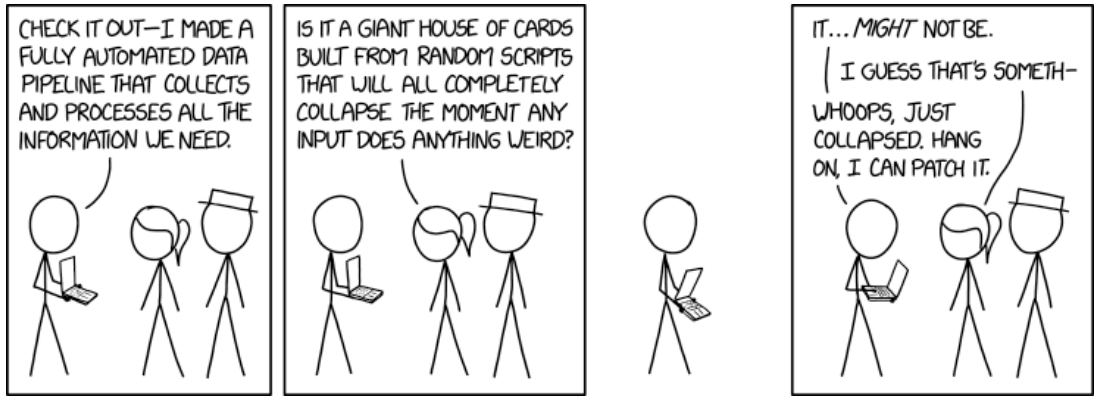
BIG DATA AND CLOUD PLATFORMS

Building data pipelines in the cloud

Data pipeline

Data pipeline

"A sequence of operations to transform and consume raw data"



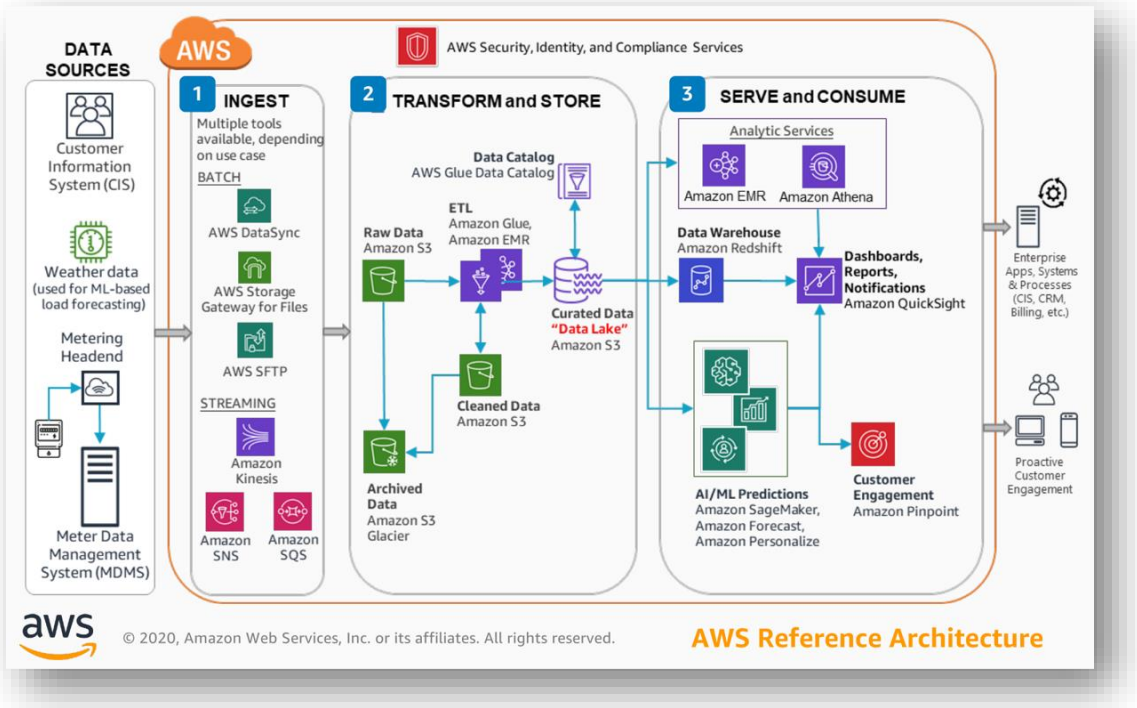
https://xkcd.com/2054/

Quemy, Alexandre. "Data Pipeline Selection and Optimization." *DOLAP*. 2019.

Data pipeline - AWS

Three main categories

- Ingest
  - Gateway, DataSync (batch)
  - Kinesis, SNS, SQS (stream)
- Transform and store
  - S3 and Glacier (storage)
  - Glue (ETL)
- Serve and consume
  - EMR (Hadoop-like cluster)
  - Athena (serverless query service to analyze data in Amazon S3)
  - (Many) Machine learning services

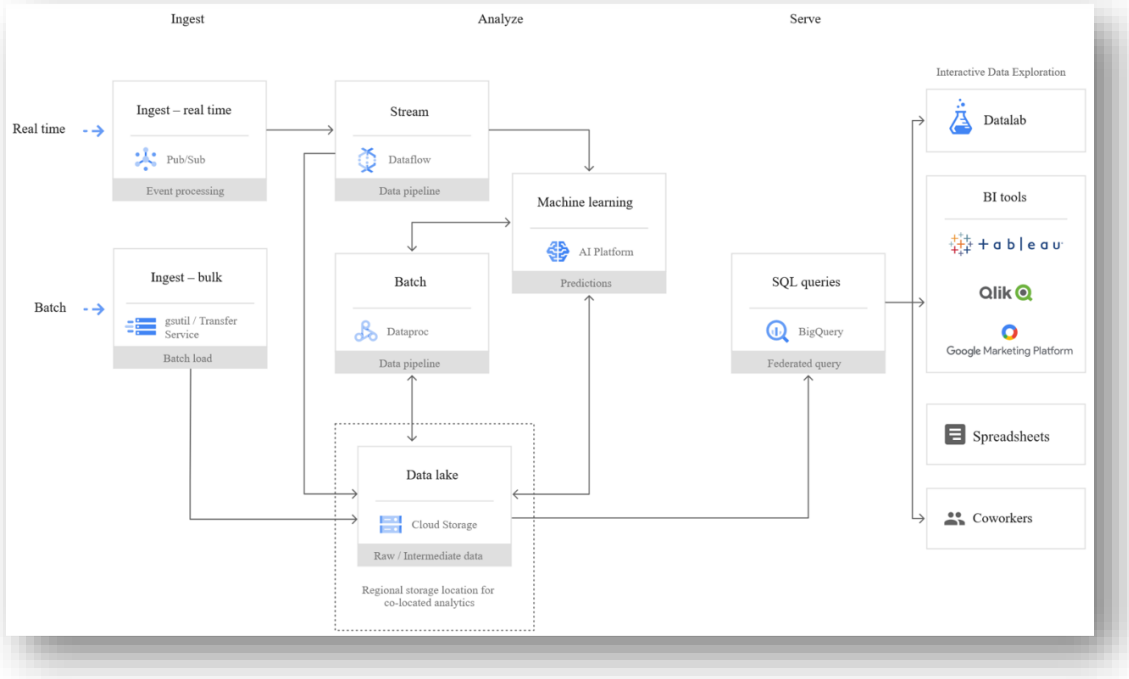


https://console.aws.amazon.com/console

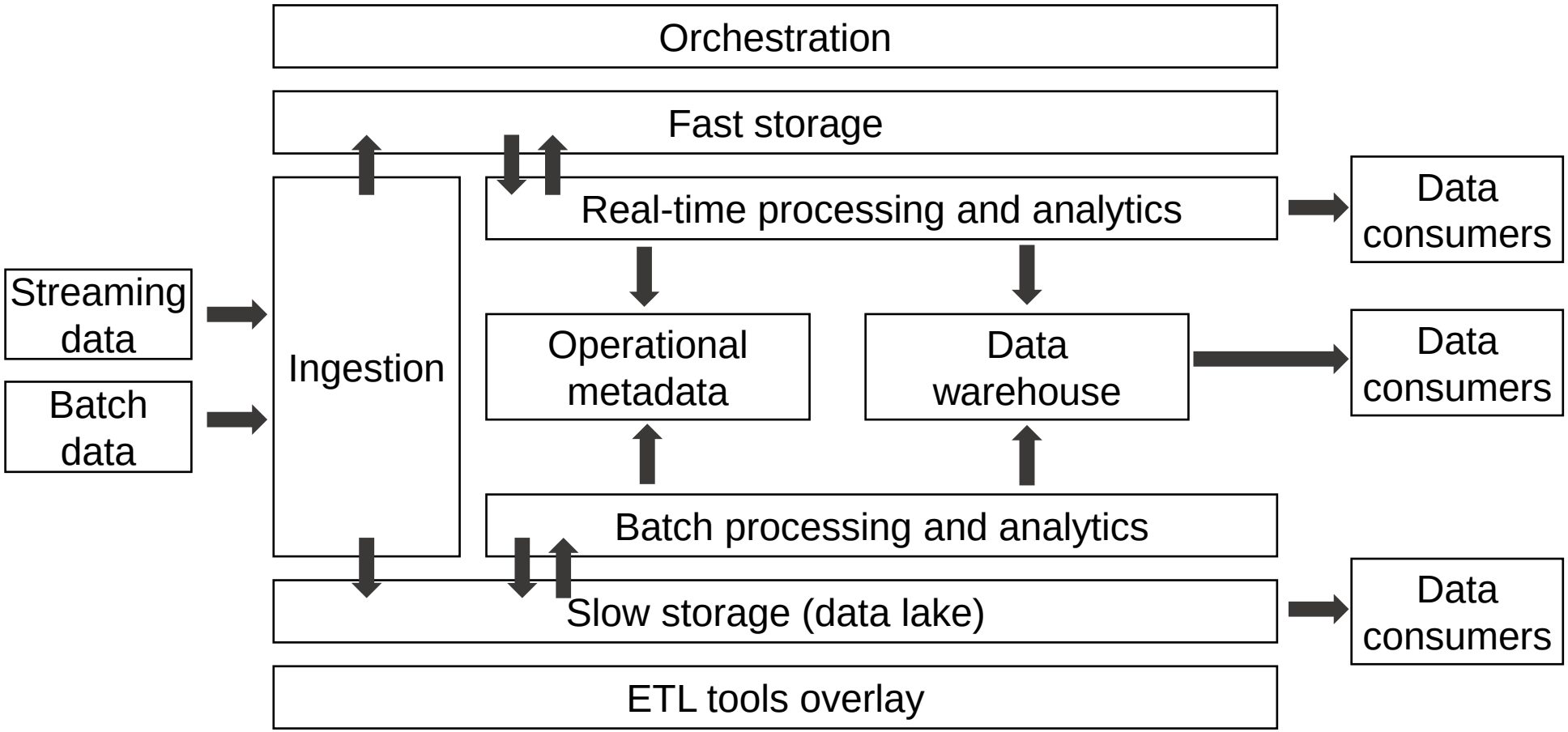
Data pipeline - Google cloud

Three main categories

- Ingest
  - Transfer service (batch)
  - Pub/Sub (stream)
- Analyze
  - Dataproc (batch)
  - Dataflow (stream)
  - Cloud storage (storage)
  - Machine learning services
- Serve
  - BigQuery (query service)



A tentative organization



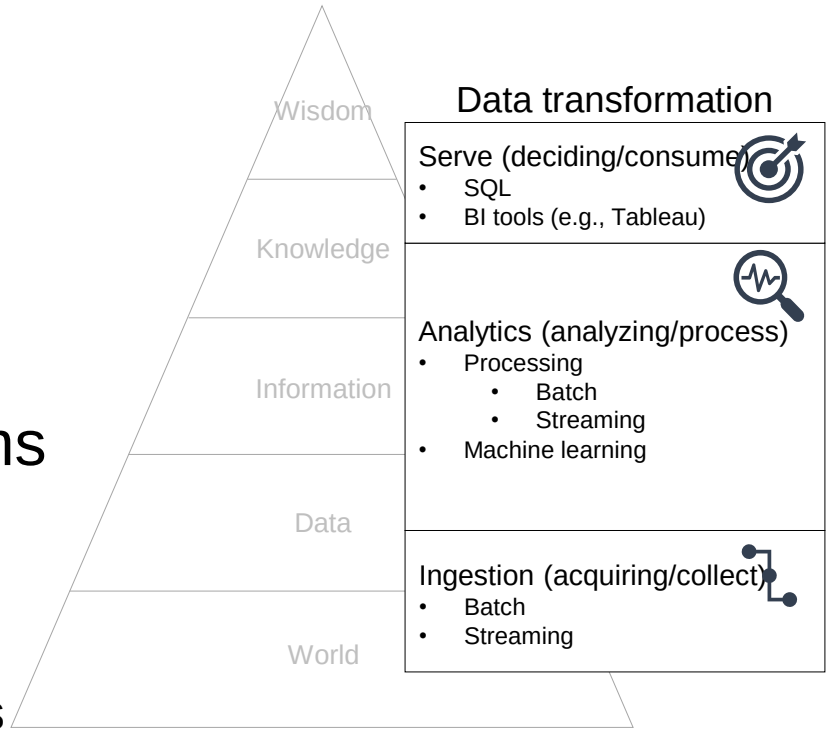
A tentative organization

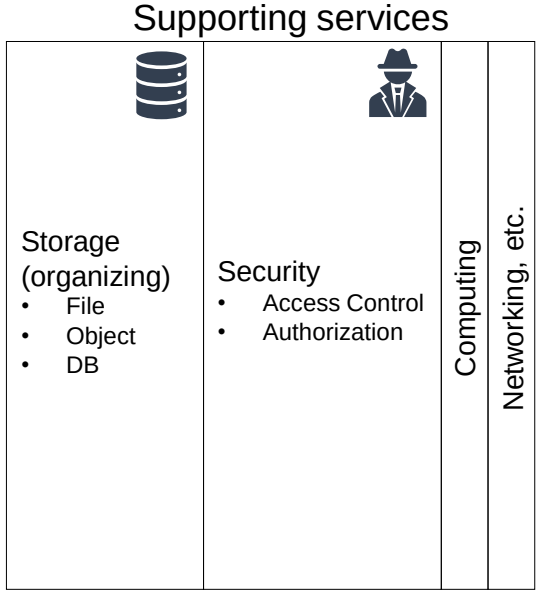
We have services

- To transform data
- To support the transformation

The (DIKW) pyramid abstracts many techniques and algorithms

- Standardization
- Integration
- Orchestration
- Accessibility through APIs



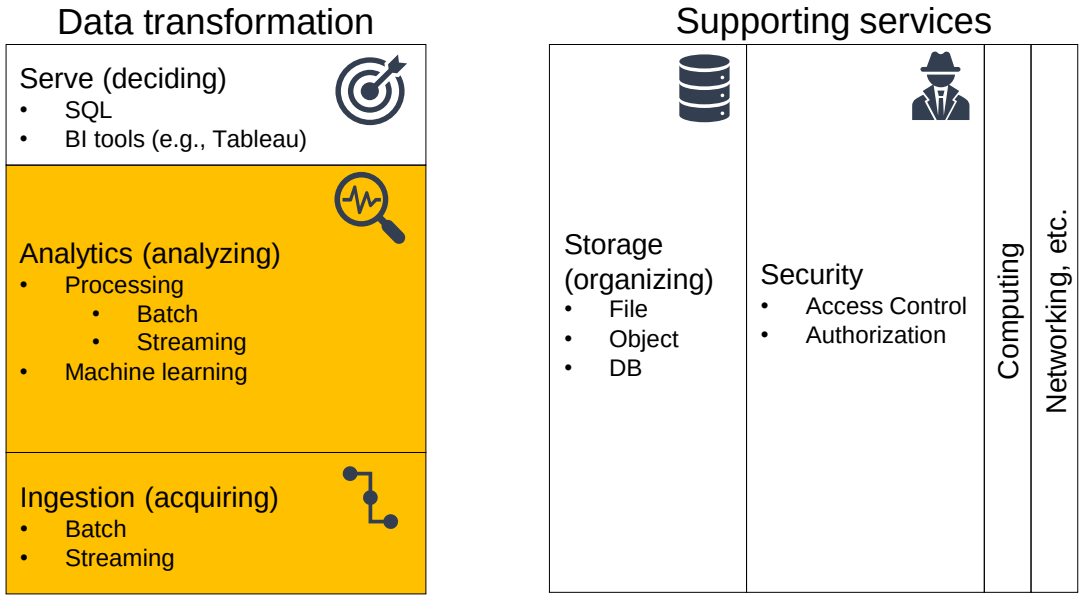


A tentative organization

This is not a sharp taxonomy

Ingestion vs Analytics

- Data streams are used for ingestion
- ... and (event) processing

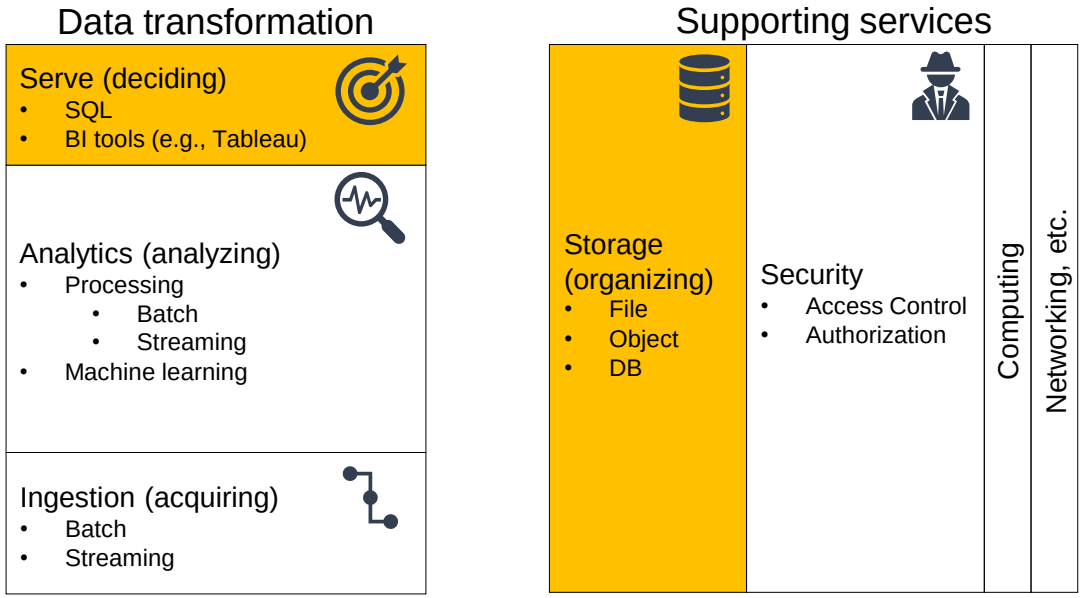


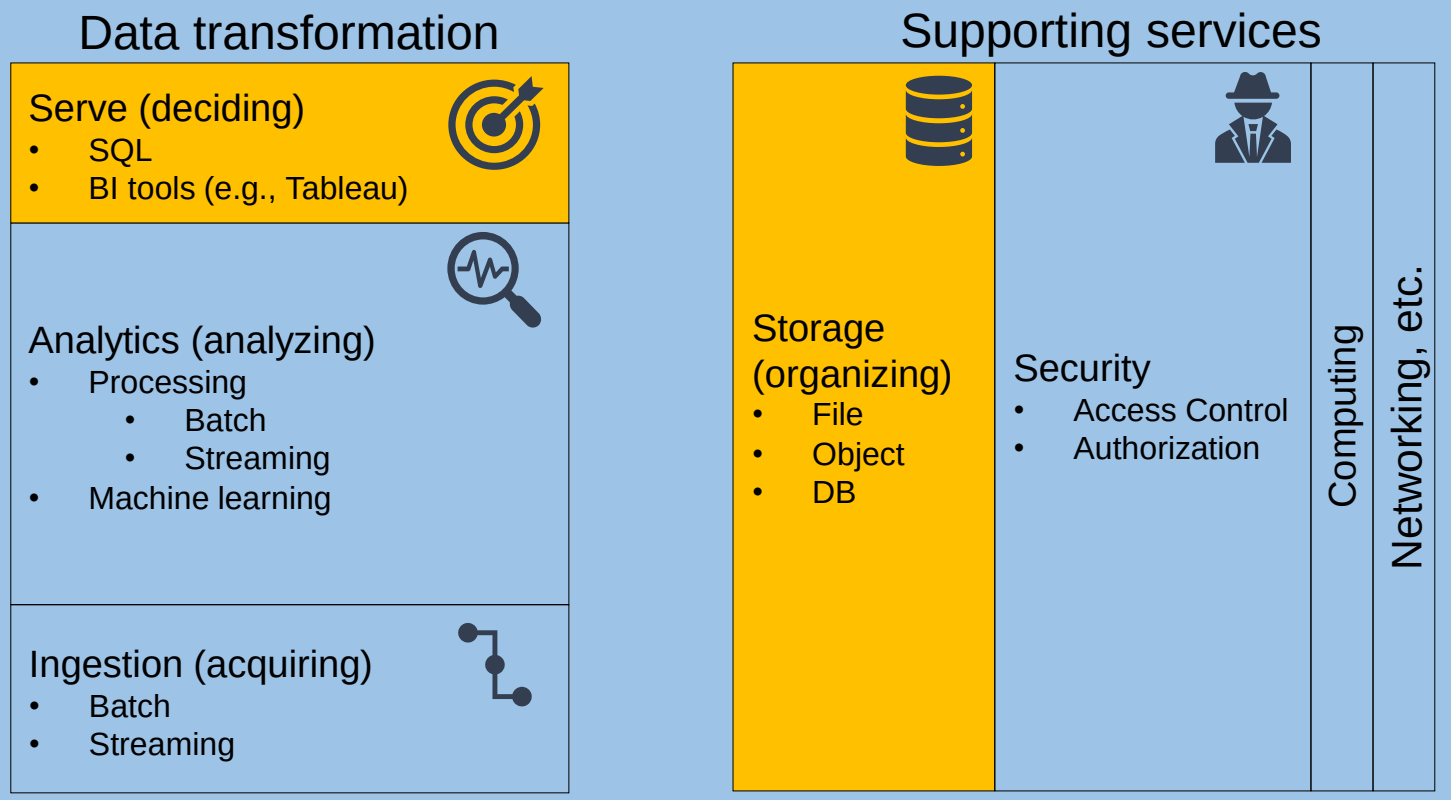
A tentative organization

This is not a sharp taxonomy

Storage vs Serving

- Databases are storage
- ... with processing capability
- ... and with serving capability




Data transformation
Serve (deciding)
• SQL
• BI tools (e.g., Tableau)
Analytics (analyzing)
• Processing
• Batch
• Streaming
• Machine learning
Ingestion (acquiring)
• Batch
• Streaming
Supporting services
Storage (organizing)
• File
• Object
• DB
Security
• Access Control
• Authorization
Computing
Networking, etc.

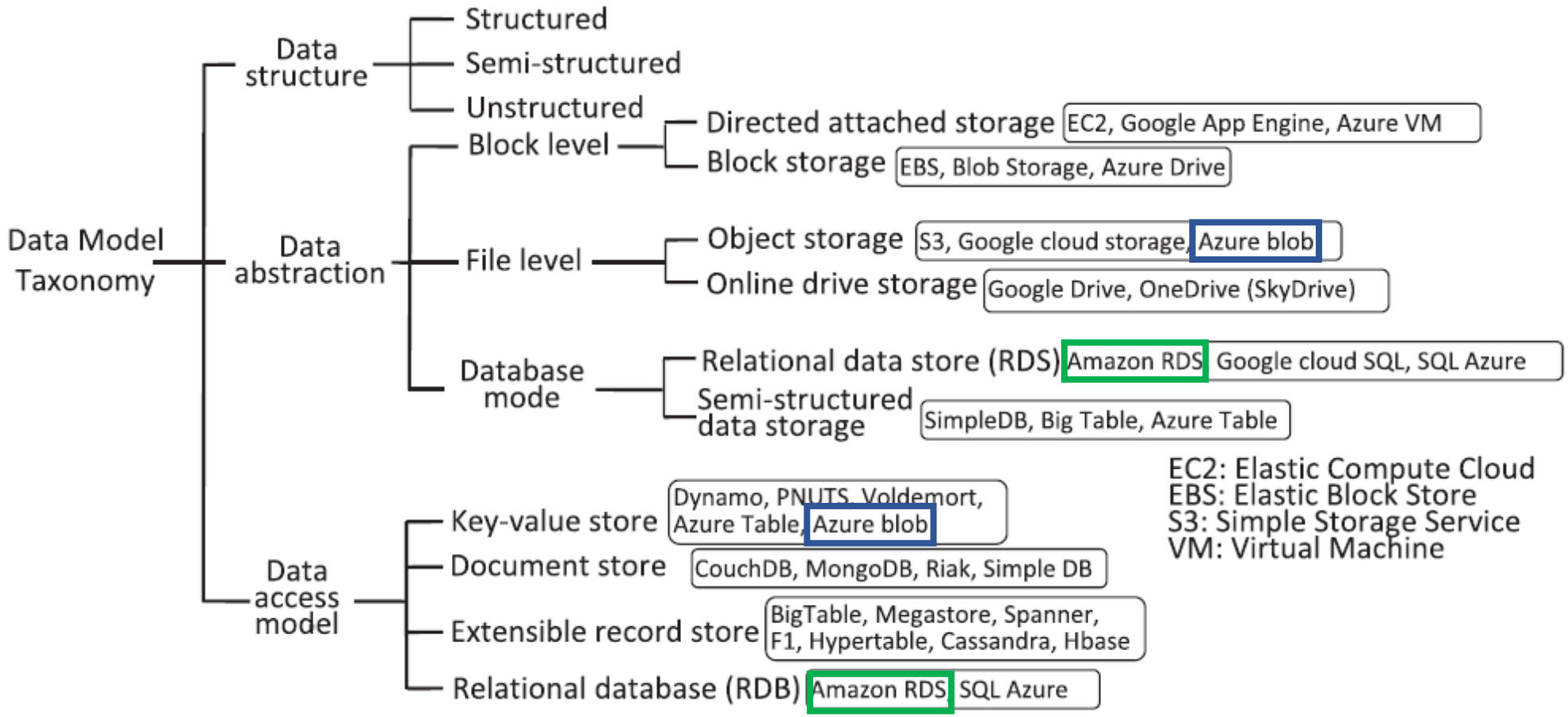
Storage

Goal: persisting data

Which storage do we choose?

- **Storage model** (or data model) ~= variety
  - How data are organized/accessed in a storage system
    - Structured vs unstructured
    - Data access model (key-value, column, etc.)
- Access **frequency**
- **Analyses** to be performed

Storage models



Mansouri, Yaser, Adel Nadjaran Toosi, and Rajkumar Buyya. "Data storage management in cloud environments: Taxonomy, survey, and future directions." ACM Computing Surveys (CSUR) 50.6 (2017): 1-51.

Storage models (AWS)

Data structure: structured

Data abstraction: database

Data access model: relational

Relational

- Store data with predefined schemas and relationships between them
- Support ACID transactions
- Maintain referential integrity

Database type	Use cases	AWS service
Relational	Traditional applications, ERP, CRM, e-commerce	Amazon Aurora, Amazon RDS, Amazon Redshift
Key-value	High-traffic web apps, e-commerce systems, gaming applications	Amazon DynamoDB
In-memory	Caching, session management, gaming leaderboards, geospatial applications	Amazon ElastiCache for Memcached, Amazon ElastiCache for Redis
Document	Content management, catalogs, user profiles	Amazon DocumentDB (with MongoDB compatibility)
Wide column	High scale industrial apps for equipment maintenance, fleet management, and route optimization	Amazon Keyspaces (for Apache Cassandra)
Graph	Fraud detection, social networking, recommendation engines	Amazon Neptune
Time series	IoT applications, DevOps, industrial telemetry	Amazon Timestream
Ledger	Systems of record, supply chain, registrations, banking transactions	Amazon QLDB

https://aws.amazon.com/products/databases/

Storage models (AWS)

Data structure: semi/unstructured

Data abstraction: database

Data access model: *

- **Key/value:** store and retrieve large volumes of data
- **Document :** store semi-structured data as JSON-like documents
- **Columnar:** use tables but unlike a relational database, columns can vary from row to row in the same table
- **Graph:** navigate and query relationships between highly connected datasets
- **... and more**

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Storage models (Google Cloud)

	Cloud Datastore	Bigtable	Cloud Storage	Cloud SQL	Cloud Spanner	BigQuery
Type	NoSQL document	NoSQL wide column	Blobstore	Relational SQL for OLTP	Relational SQL for OLTP	Relational SQL for OLAP
Transactions	Yes	Single-row	No	Yes	Yes	No
Complex queries	No	No	No	Yes	Yes	Yes
Capacity	Terabytes+	Petabytes+	Petabytes+	Terabytes	Petabytes	Petabytes+
Unit size	1 MB/entity	~10 MB/cell ~100 MB/row	5 TB/object	Determined by DB engine	10,240 MiB/ row	10 MB/row

	Cloud Datastore	Cloud Bigtable	Cloud Storage	Cloud SQL	Cloud Spanner	BigQuery
Type	NoSQL document	NoSQL wide column	Blobstore	Relational SQL for OLTP	Relational SQL for OLTP	Relational SQL for OLAP
Best for	Semi-structured application data, durable key-value data	"Flat" data, Heavy read/write, events, analytical data	Structured and unstructured binary or object data	Web frameworks, existing applications	Large-scale database applications (> ~2 TB)	Interactive querying, offline analytics
Use cases	Getting started, App Engine applications	AdTech, Financial and IoT data	Images, large media files, backups	User credentials, customer orders	Whenever high I/O, global consistency is needed	Data warehousing

https://cloud.google.com/products/databases

Storage models (AWS)

Data structure: unstructured

Data abstraction: file (or database)

Data access model: key-value

File system (EFS), **object storage** (S3) (or **DB K-V**; e.g., DynamoDB)

- Handle unstructured data
- ... organized as files (or blob)
- ... accessed using a key-value

Differ in the supported features

- E.g., maximum item size (DynamoDB: 400KB, S3: 5TB)
- E.g., indexes, querying mechanisms, latency, etc.

AWS S3

Simple Storage Service (S3)

- Serverless storage, save data as **objects** within **buckets**
- An **object** is composed of a file and any metadata that describes that file (e.g., **object key**)
- **Buckets** are logical containers for objects
  - You can have one or more buckets in your account
  - Control access for each bucket individually
  - Choose the geographical region where Amazon S3 will store the bucket and its contents

Benefits

- Unified data architecture
  - Build a multi-tenant environment, where many users can bring their own data
  - Improve both cost and data governance over traditional solutions
- Decoupling of storage from compute and data processing
  - You can cost-effectively store all data types in their native formats
  - Then, launch transformations as you need

Storage: access frequency (AWS)

Object storage (AWS S3) **classes**

- **Standard**: general purpose
- **Infrequent** (rapid) **access**
- **One Zone-IA**: lower-cost option for infrequently accessed data that do not require high availability and resilience
- **Glacier**: low-cost storage class for data archiving, three retrieval options that range from a few minutes to hours
- **Deep Glacier**: long-term retention for data accessed once or twice in a year. E.g., retain data sets for 10 years or longer
- **Intelligent-Tiering**: move objects between access tiers when access patterns change

	S3 Standard	S3 Intelligent-Tiering*	S3 Standard-IA	S3 One Zone-IA†	S3 Glacier	S3 Glacier Deep Archive
Designed for durability	99.999999999% (11 9's)	99.999999999% (11 9's)	99.999999999% (11 9's)	99.999999999% (11 9's)	99.999999999% (11 9's)	99.999999999% (11 9's)
Designed for availability	99.99%	99.9%	99.9%	99.5%	99.99%	99.99%
Availability SLA	99.9%	99%	99%	99%	99.9%	99.9%
Availability Zones	≥3	≥3	≥3	1	≥3	≥3
Minimum capacity charge per object	N/A	N/A	128KB	128KB	40KB	40KB
Minimum storage duration charge	N/A	30 days	30 days	30 days	90 days	180 days
Retrieval fee	N/A	N/A	per GB retrieved	per GB retrieved	per GB retrieved	per GB retrieved
First byte latency	milliseconds	milliseconds	milliseconds	milliseconds	select minutes or hours	select hours
Storage type	Object	Object	Object	Object	Object	Object
Lifecycle transitions	Yes	Yes	Yes	Yes	Yes	Yes

https://aws.amazon.com/s3/storage-classes/

Storage: access frequency (AWS)

Lifecycle configuration

- A set of rules that define actions that Amazon S3 applies to a group of objects

Two types of actions:

- **Transition:** when objects transition to another storage class. E.g., archive objects to the S3 Glacier storage class one year after creating them
- **Expiration**: when objects expire. Amazon S3 deletes expired objects on your behalf

	S3 Standard	S3 Intelligent-Tiering*	S3 Standard-IA	S3 One Zone-IA†	S3 Glacier	S3 Glacier Deep Archive
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Availability SLA	99.9%	99%	99%	99%	99.9%	99.9%
Availability Zones	≥3	≥3	≥3	1	≥3	≥3
Minimum capacity charge per object	N/A	N/A	128KB	128KB	40KB	40KB
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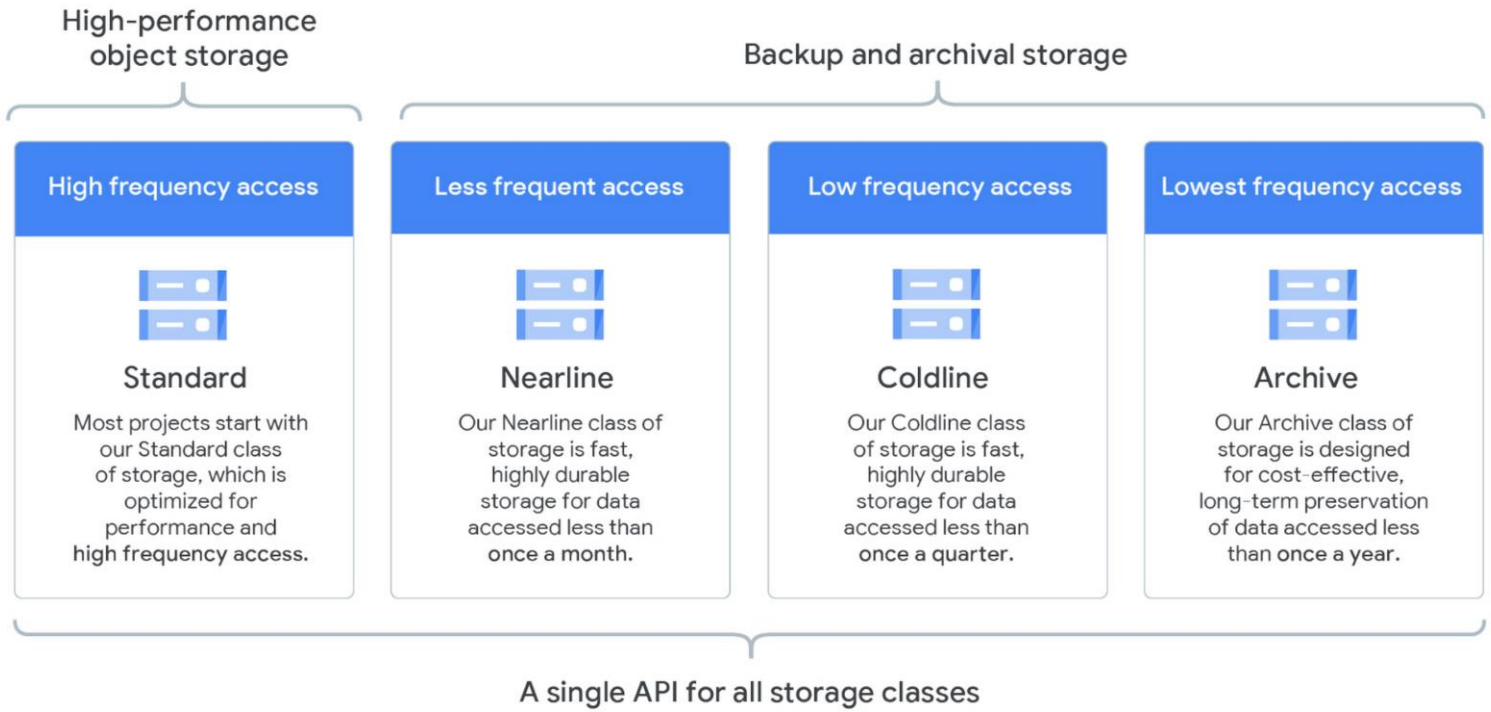
Storage type	Object	Object	Object	Object	Object	Object
Lifecycle transitions	Yes	Yes	Yes	Yes	Yes	Yes

https://docs.aws.amazon.com/AmazonS3/latest/userguide/object-lifecycle-mgmt.html

Storage: access frequency (Google Cloud)



Retention Period

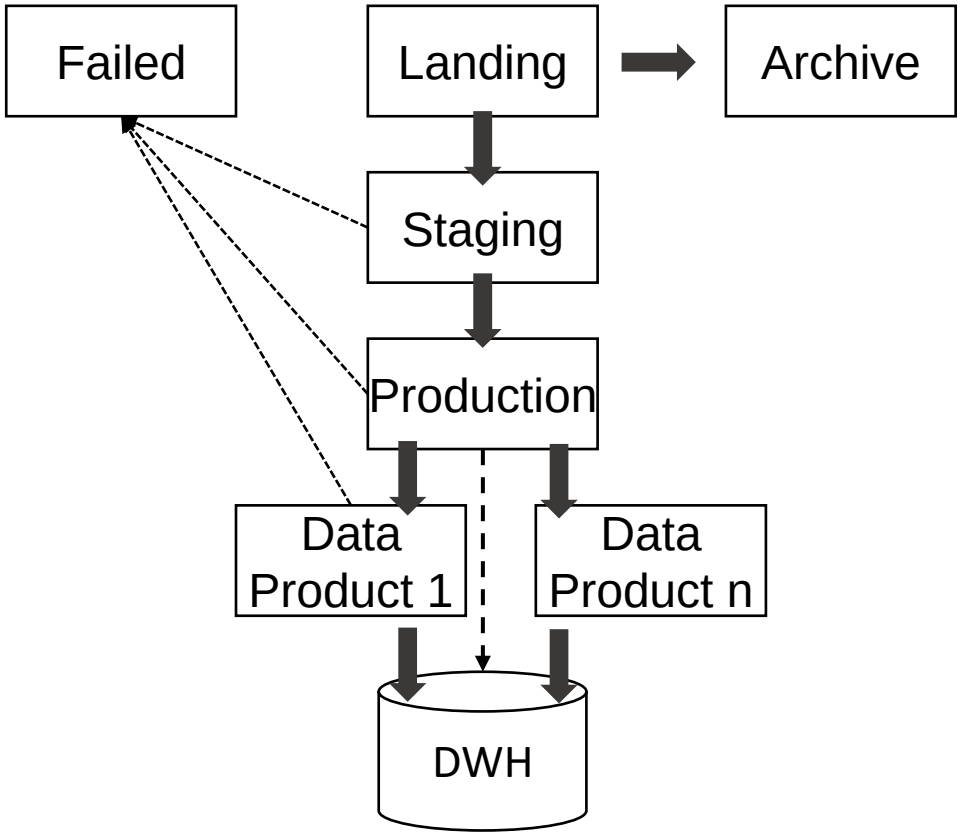
Access Frequency	<1 mo	1–3 mo	3–12 mo	>12 mo
>12/yr	Standard	Standard	Standard	Standard
4–12/yr	Standard	Nearline	Nearline	Nearline
1–4/yr	Standard	Nearline	Coldline	Coldline
<1/yr	Standard	Nearline	Coldline	Archive

https://cloud.google.com/blog/products/storage-data-transfer/archive-storage-class-for-coldest-data-now-available

Organizing the data lake

Having a consistent principles on how to organize your data is important

- To build standardized pipelines with the same design with regard to where read/write data
- Standardization makes it easier to manage your pipelines at scale
- Helps data users search for data in the storage and understand exactly to find what they need
- Decoupling storage from processing



Organizing the data lake

Landing area (LA)

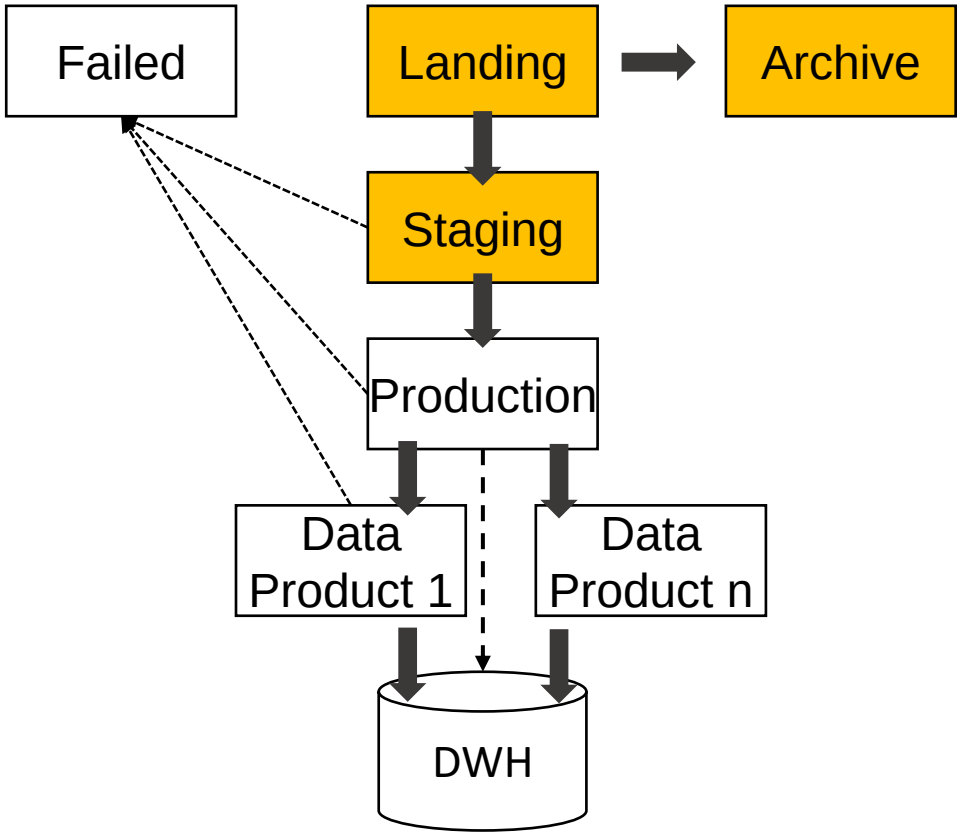
- Save raw data from ingestion
- Transient, data is not stored for long term

Staging area (SA)

- Raw data goes through a set of common transformations: ensuring basic quality and making sure it conforms to existing schemas for this data source and then data is saved into SA

Archive area (A)

- After saving into SA, raw data from LA should be copied into the archive to reprocess any given batch of data by simply copying it from AA into LA
- Useful for debugging and testing



Organizing the data lake

Production area (PA)

- Apply the business logic to data from SA

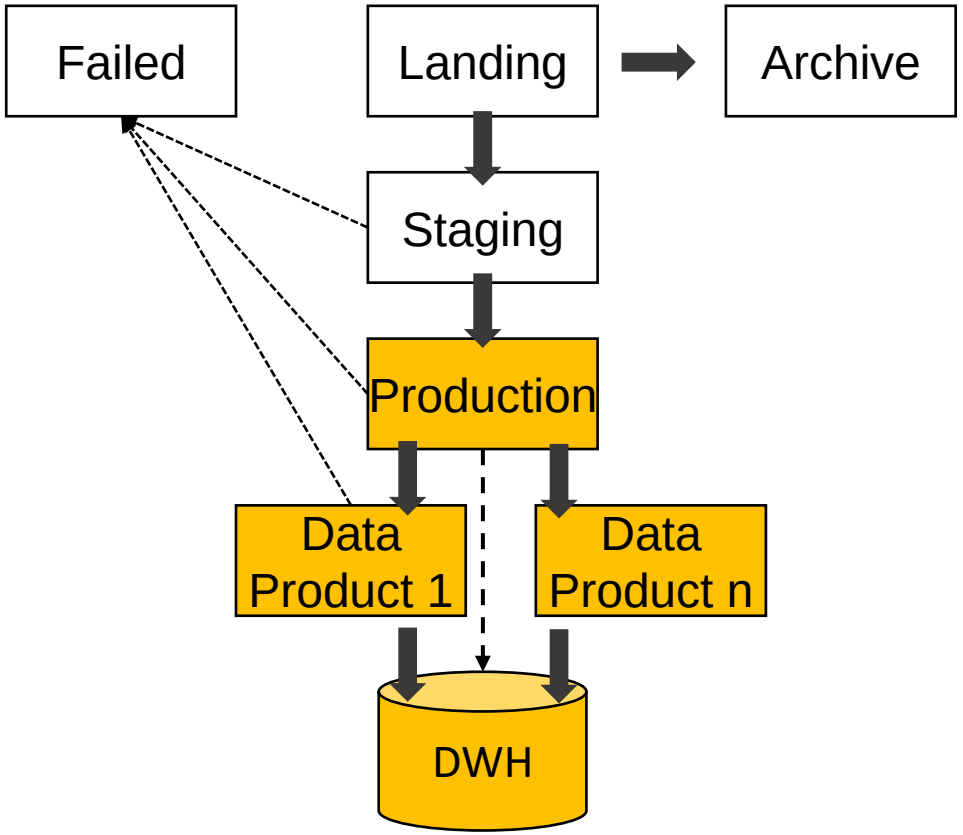
Pass-through job

- Copy data from SA to PA and then into DWH without applying any business logic
- Optional, but having a data set in the data warehouse and PA that is an exact replica can be helpful when debugging any issues with the business logic

Cloud data warehouse (DWH)

Failed area (FA)

- You need to be able to deal with all kinds of errors and failures
- There might be bugs in the pipeline code, cloud resources may fail



Organizing the data lake

Area	Permissions	Tier
Landing	Ingestion applications can write Scheduled pipelines can read Data consumers can't access	Hot
Staging	Scheduled pipelines can read/write Selected data consumers can read	Hot
Production	Scheduled pipelines can read/write Selected data consumers can read	Hot
Archive	Scheduled pipelines can write Dedicated data reprocessing pipelines can read	Cold or archive
Failed	Scheduled pipelines can write Dedicated data reprocessing pipelines can read Data consumers don't have access	Hot

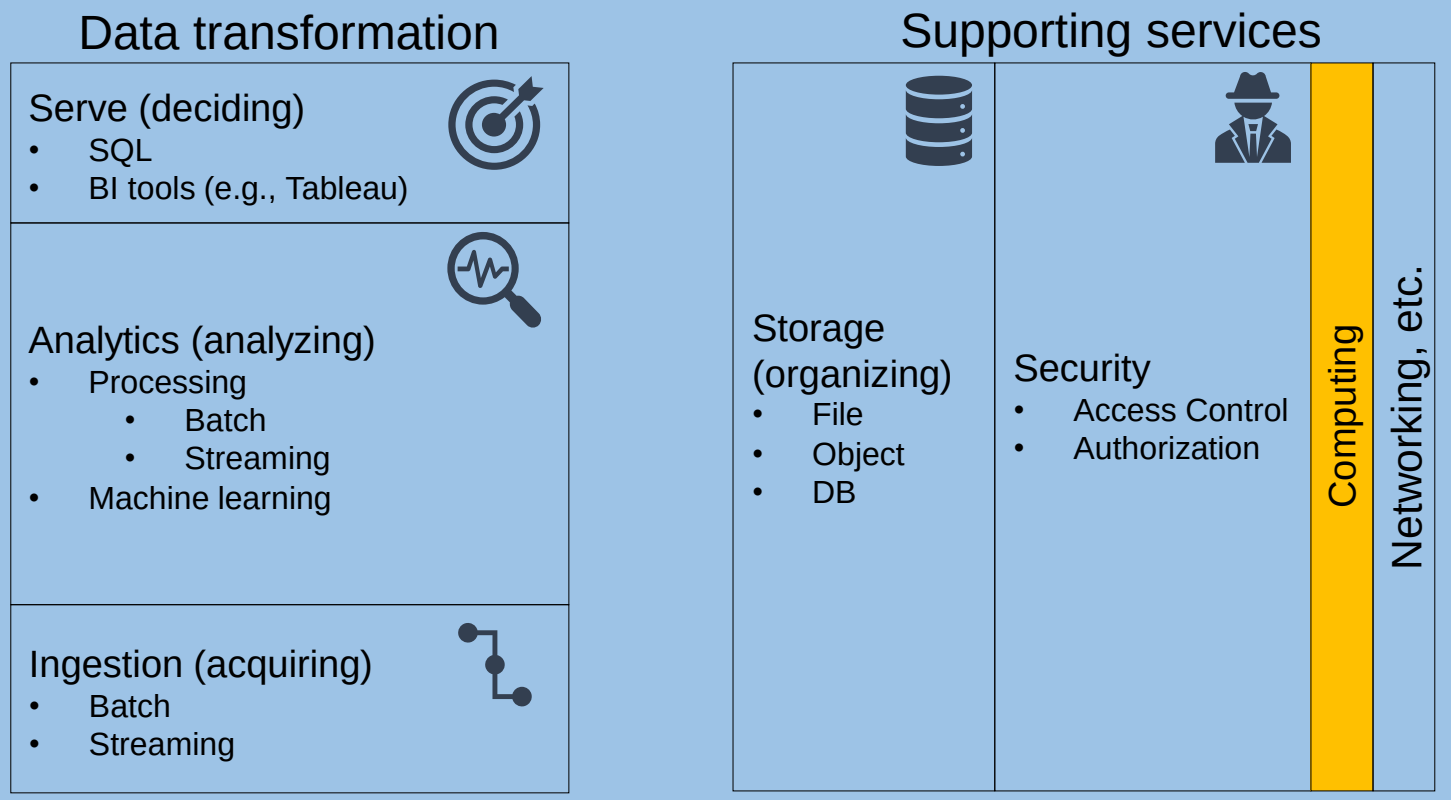
Organizing the data lake

Use folders to organize data inside areas into a logical structure

- Namespace
  - Logically group multiple pipelines together.
- Pipeline name
  - Each data pipeline should have a name that reflects its purpose. For example
    - A pipeline that takes data from the LA, applies common processing steps, and saves data into SA
    - You will also have one for archiving data into AA
- Data source name
  - Ingestion layer will assign a name to each data source you bring into the platform
- BatchId
  - Unique identifier for any batch of data that is saved into LA
  - E.g., Since only ingestion can write to LA, it is its responsibility to generate this identifier
  - A common choice for this type of an identifier is a Universally Unique Identifier (UUID)

Different areas will have slightly different folder structures

- /landing/ETL/sales_oracle_ingest/customers/01DFTFX89YDFAXREPJTR94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Analytics (analyzing)
• Processing
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• Streaming
• Machine learning
Ingestion (acquiring)
• Batch
• Streaming
Supporting services
Storage (organizing)
• File
• Object
• DB
Security
• Access Control
• Authorization
Computing
Networking, etc.

Supporting data pipelines

We can choose the XaaS configuration to build our pipelines

IaaS

- Outsource virtual machines to the cloud (AWS EC2)
- (You) Manage technological and business challenges

PaaS

- Outsource the data ecosystem to the cloud (e.g., AWS EMR)
- (You) Manage business challenges

https://aws.amazon.com/emr

Single instance: AWS EC2

Amazon Elastic Compute Cloud

- A web service that provides resizable compute capacity
- Complete control of computing resources
  - Processor, storage, networking, OS, and purchase model

The **instance type** determines the hardware

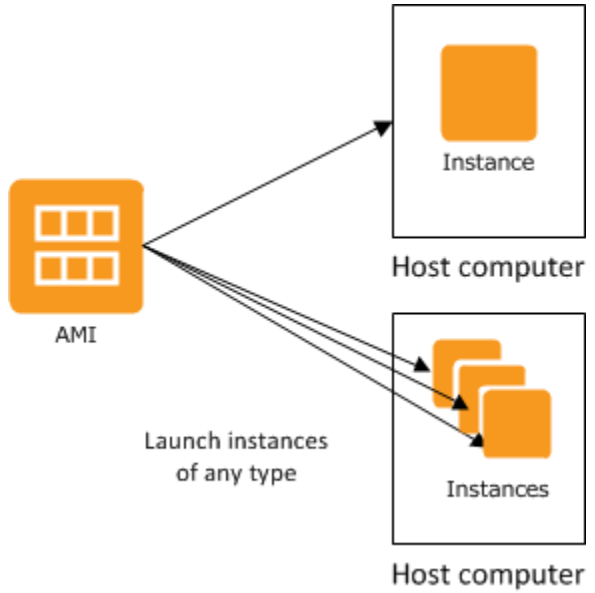
- Different compute and memory capabilities

Amazon Machine Image is a software template

- The EC2 instance is used for creating the virtual server instance
- The AMI is the EC2 virtual machines image

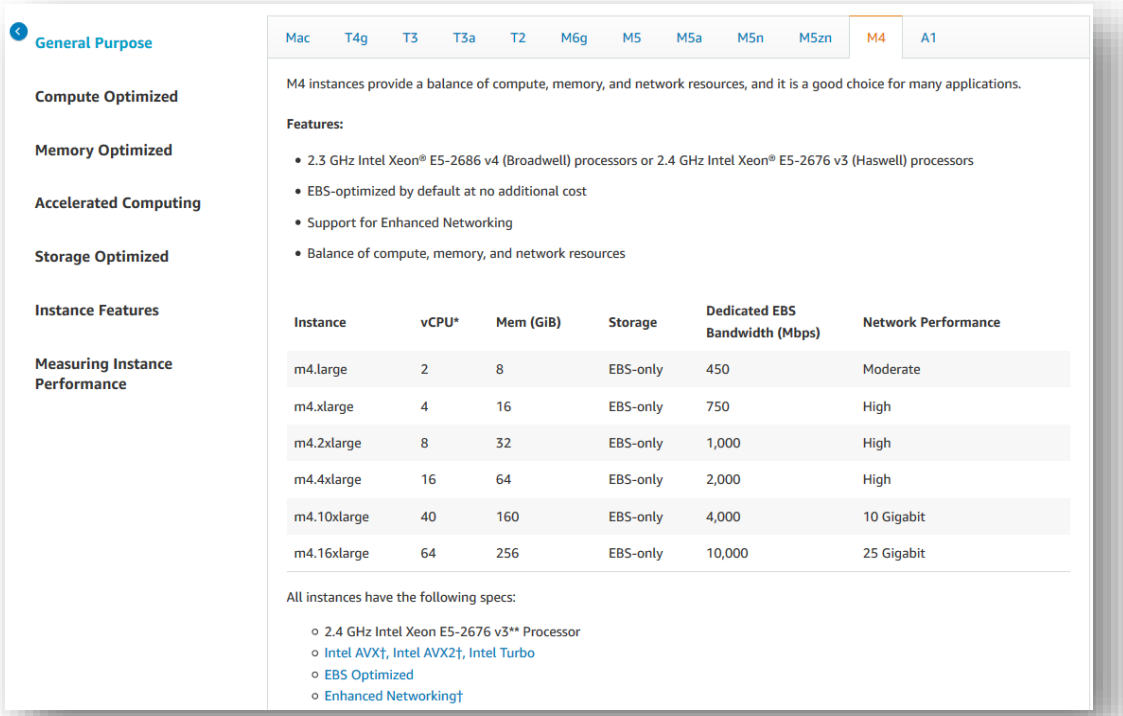
Interact with EC2 instance as with any computer

- You have complete control of your instances



https://aws.amazon.com/ec2/instance-types
https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ec2-instances-and-amis.html
https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/compute-optimized-instances.html

Single instance: AWS EC2



General Purpose
Compute Optimized
Memory Optimized
Accelerated Computing
Storage Optimized
Instance Features
Measuring Instance Performance

Mac T4g T3 T3a T2 M6g M5 M5a M5n M5zn M4 A1

M4 instances provide a balance of compute, memory, and network resources, and it is a good choice for many applications.

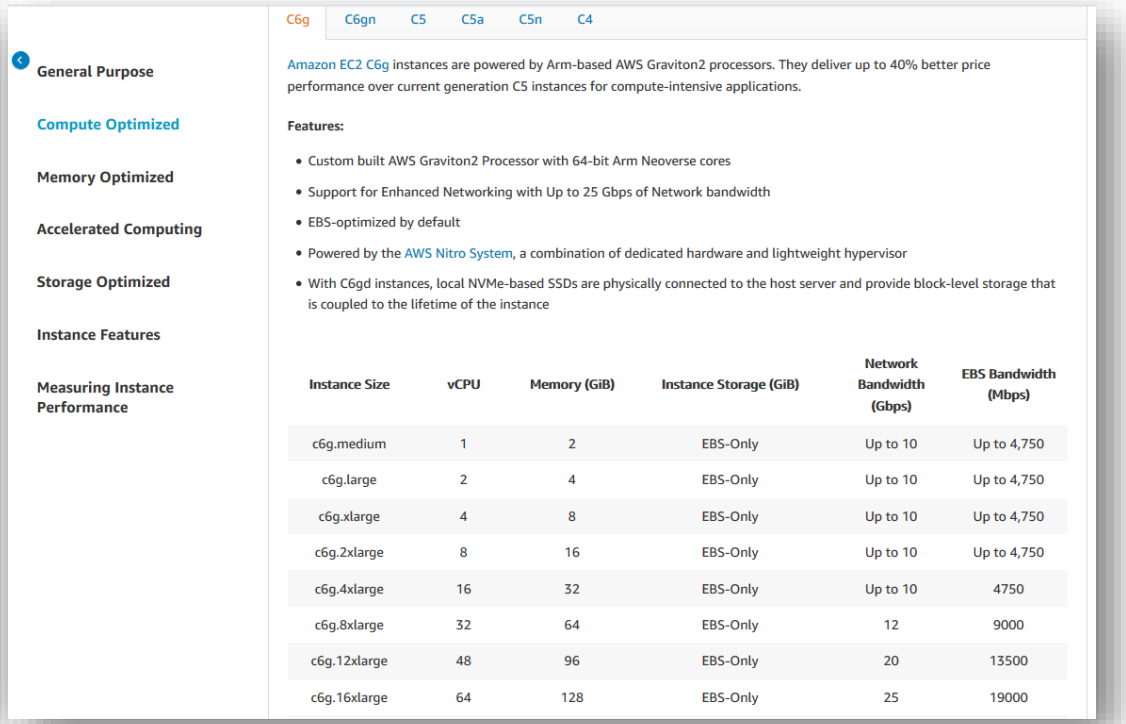
Features:

- 2.3 GHz Intel Xeon® E5-2686 v4 (Broadwell) processors or 2.4 GHz Intel Xeon® E5-2676 v3 (Haswell) processors
- EBS-optimized by default at no additional cost
- Support for Enhanced Networking
- Balance of compute, memory, and network resources

Instance	vCPU*	Mem (GiB)	Storage	Dedicated EBS Bandwidth (Mbps)	Network Performance
m4.large	2	8	EBS-only	450	Moderate
m4.xlarge	4	16	EBS-only	750	High
m4.2xlarge	8	32	EBS-only	1,000	High
m4.4xlarge	16	64	EBS-only	2,000	High
m4.10xlarge	40	160	EBS-only	4,000	10 Gigabit
m4.16xlarge	64	256	EBS-only	10,000	25 Gigabit

All instances have the following specs:

- 2.4 GHz Intel Xeon E5-2676 v3** Processor
- Intel AVX†, Intel AVX2†, Intel Turbo
- EBS Optimized
- Enhanced Networking†



General Purpose
Compute Optimized
Memory Optimized
Accelerated Computing
Storage Optimized
Instance Features
Measuring Instance Performance

C6g C6gn C5 C5a C5n C4

Amazon EC2 C6g instances are powered by Arm-based AWS Graviton2 processors. They deliver up to 40% better price performance over current generation C5 instances for compute-intensive applications.

Features:

- Custom built AWS Graviton2 Processor with 64-bit Arm Neoverse cores
- Support for Enhanced Networking with Up to 25 Gbps of Network bandwidth
- EBS-optimized by default
- Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
- With C6gd instances, local NVMe-based SSDs are physically connected to the host server and provide block-level storage that is coupled to the lifetime of the instance

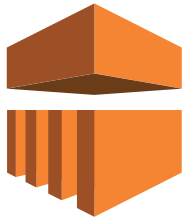
Instance Size	vCPU	Memory (GiB)	Instance Storage (GiB)	Network Bandwidth (Gbps)	EBS Bandwidth (Mbps)
c6g.medium	1	2	EBS-Only	Up to 10	Up to 4,750
c6g.large	2	4	EBS-Only	Up to 10	Up to 4,750
c6g.xlarge	4	8	EBS-Only	Up to 10	Up to 4,750
c6g.2xlarge	8	16	EBS-Only	Up to 10	Up to 4,750
c6g.4xlarge	16	32	EBS-Only	Up to 10	4750
c6g.8xlarge	32	64	EBS-Only	12	9000
c6g.12xlarge	48	96	EBS-Only	20	13500
c6g.16xlarge	64	128	EBS-Only	25	19000

https://aws.amazon.com/ec2/instance-types/

Cluster: AWS EMR

Amazon EMR is a data platform based on the Hadoop stack

- Apache Spark, Apache Hive, Apache HBase, etc.
- You can run workloads on
  - Amazon EC2 instances
  - Amazon Elastic Kubernetes Service (EKS) clusters



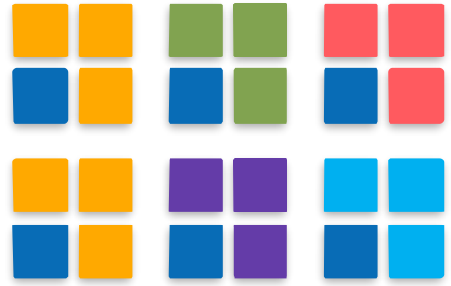
Example of workload

- Upload input data into Amazon S3
- EMR launches EC2 instances that you specified
- EMR begins the execution while pulling the input data from S3 into the launched instances
- Once the cluster is finished, EMR transfers output data to Amazon S3

AWS EMR

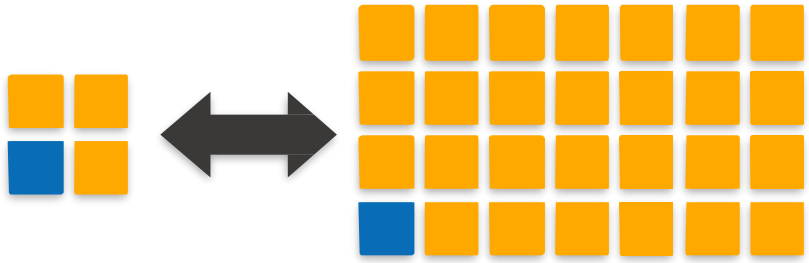
Provision as much capacity as you need

Deploy Multiple Clusters



Add or remove capacity at any time

Resize a Running Cluster



AWS EMR

EMR cluster

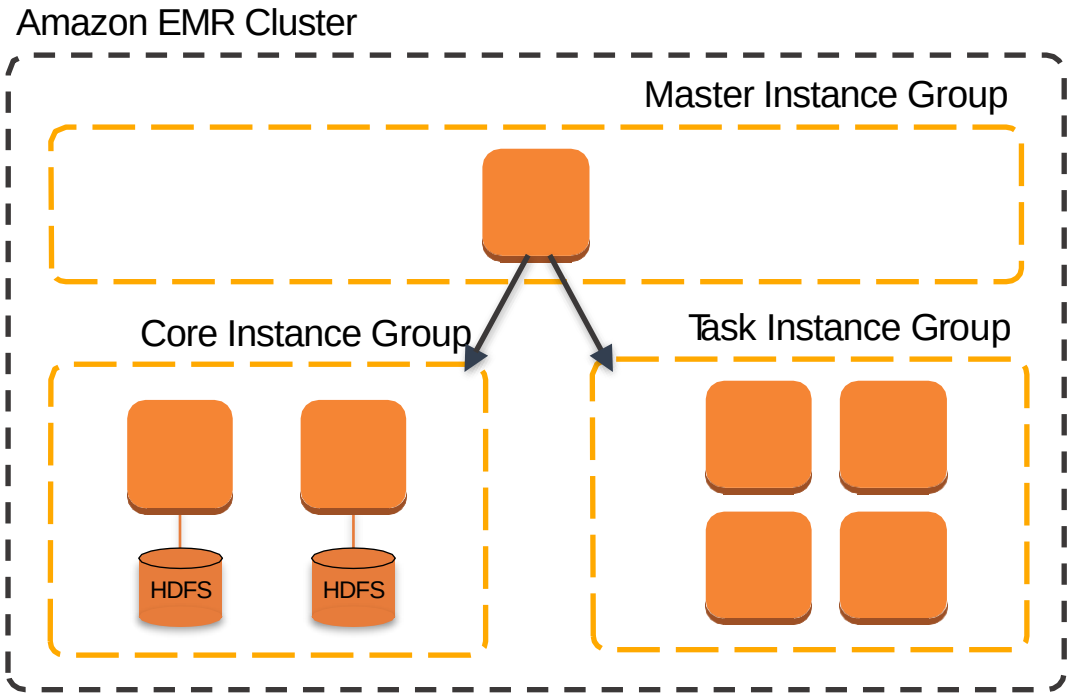
Master group controls the cluster

- Coordinate the work distribution
- Manage the cluster state

Core groups

- Core instances run Data Node daemons

(Optional) Task instances



AWS EMR

The central component of Amazon EMR is the **cluster**

- A collection of **Amazon Elastic Compute Cloud (Amazon EC2)** instances
- Each instance is called a **node**

The **node type** identifies the role within the cluster

- **Master** node coordinates the distribution of data and tasks among other nodes
  - Every cluster has (at least) a master node
  - Always active
- **Core** node runs tasks and store data in the Hadoop Distributed File System (HDFS)
  - Multi-node clusters have at least one core node
  - Always active, contains the data node daemon
- **Task** node only runs tasks
  - Task nodes are optional
  - Decoupling processing and storage, we lose data locality

AWS EMR

On-Demand Instance

- Pay for compute capacity by the hour (minimum of 60 seconds)
- No long-term commitments

Spot Instance

- Unused EC2 instance that is available for less than the on-demand price
- Hourly price is called *spot price*
  - Adjusted based on long-term supply and demand for spot instances
- Run the instance when capacity is available and price is below threshold
  - When data-center resources are low, spot instances are dropped
  - Mainly suitable for batch workloads

https://aws.amazon.com/ec2/pricing/

AWS EMR

Spot Instance cost strategies

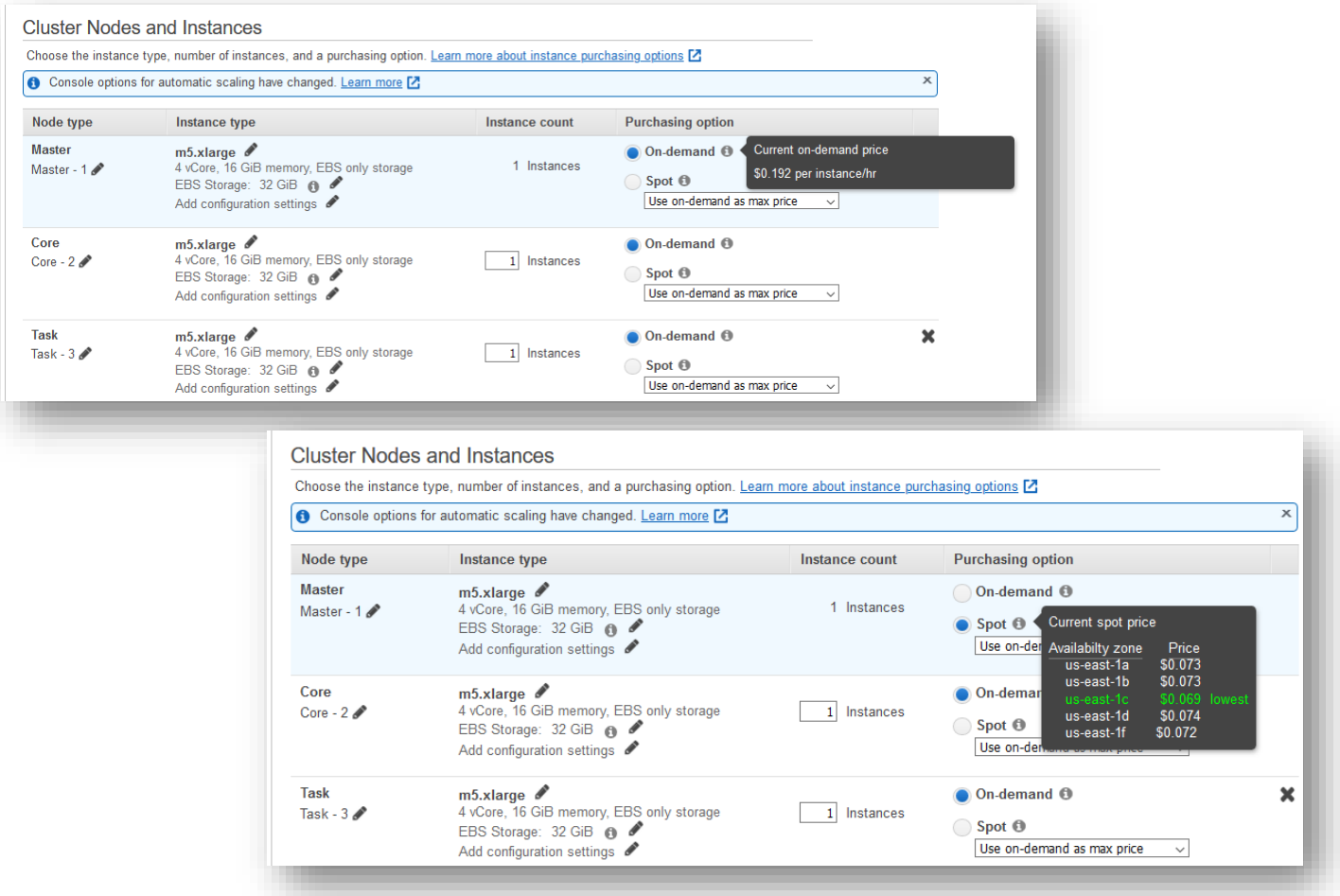
Capacity-optimized strategy

- Allocated instances into the most available pools
- Look at real-time capacity data, predict which are the most available
- Works well for workloads such as big data and analytics
- Works well when we have high cost of interruption

Lowest-price strategy

- Allocates instances in pools with lowest price at time of fulfillment

Creating the cluster



Creating the cluster

Choose to launch **master**, **core**, or **task** on Spot Instances

- The **master** node controls the cluster
  - When terminated, the cluster ends
  - Use *spot instances* if you are running a cluster where sudden termination is acceptable
- **Core** nodes process data and store information using HDFS
  - When terminated, data is lost
  - Use *spot instances* when partial HDFS data loss is tolerable
- **Task** nodes process data but do not hold persistent data in HDFS
  - When terminated, computational capacity is lost
  - The effect of spot instances on the cluster is "minimal"

https://docs.aws.amazon.com/emr/latest/ManagementGuide/emr-plan-instances-guidelines.html

Creating the cluster

Application Scenario	Master Node Purchasing Option	Core Nodes Purchasing Option	Task Nodes Purchasing Option
Long-Running Clusters and Data Warehouses	On-Demand	On-Demand or instance-fleet mix	Spot or instance-fleet mix
Cost-Driven Workloads	Spot	Spot	Spot
Data-Critical Workloads	On-Demand	On-Demand	Spot or instance-fleet mix
Application Testing	Spot	Spot	Spot

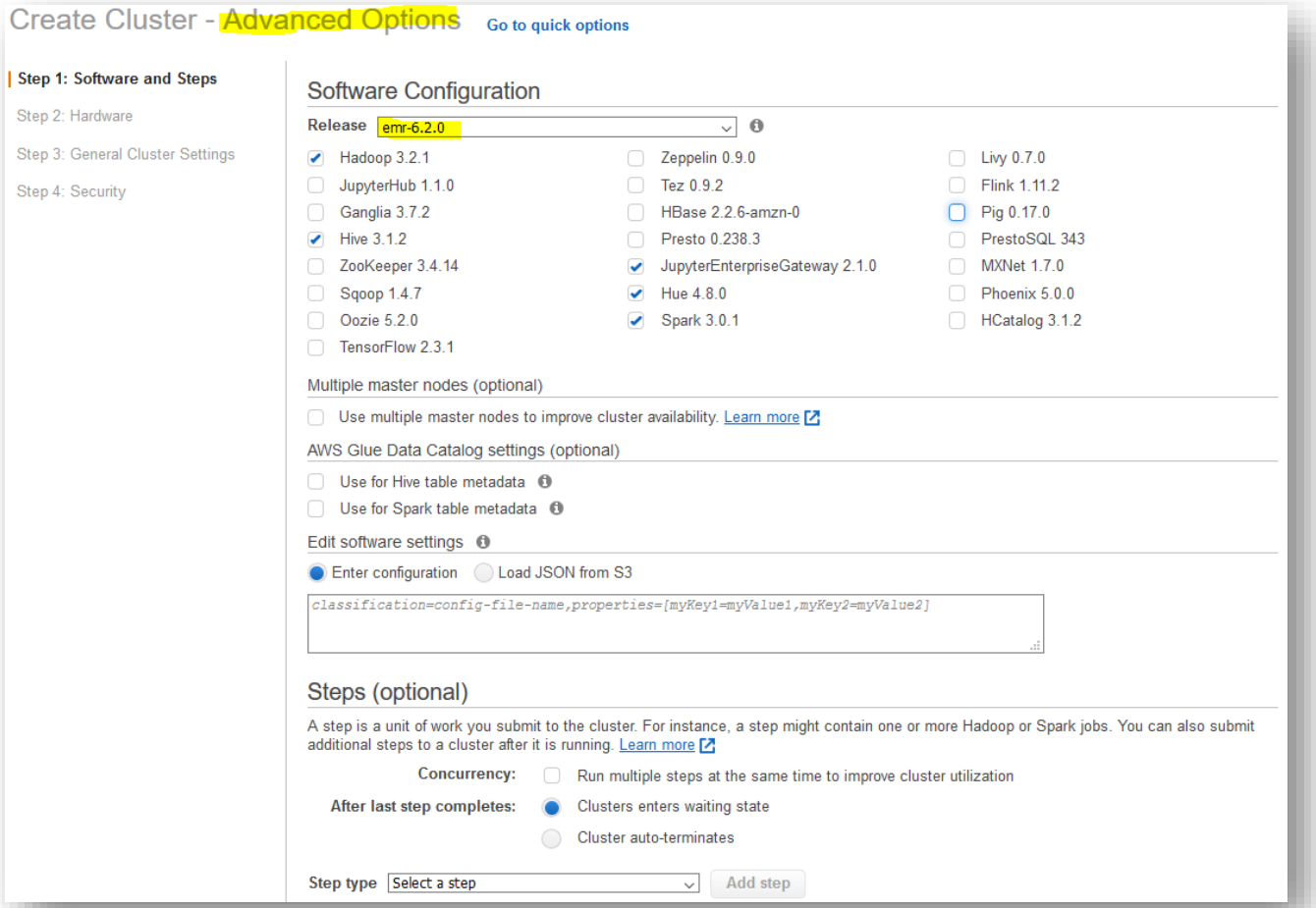
Creating the cluster

Amazon EMR provides two main file systems

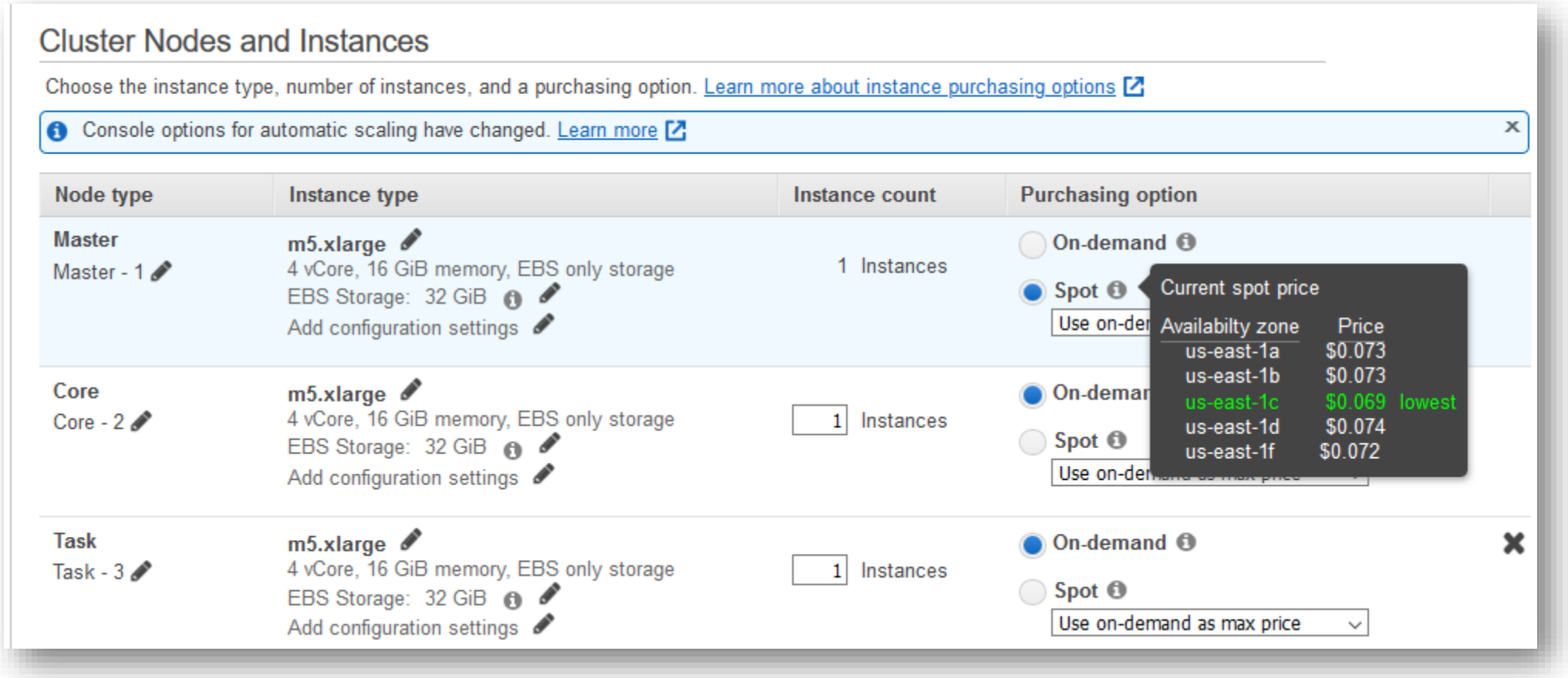
- **HDFS** and **EMRFS**, specify which file system to use by the prefix
- `hdfs://path (or just `path`)`
  - HDFS is used by the master and core nodes
  - AWS EBS volume storage is used for HDFS data
  - Is fast, best used for caching the results produced by intermediate job-flow steps, why?
  - It's ephemeral storage which is reclaimed when the cluster ends
- `s3://DOC-EXAMPLE-BUCKET1/path` (EMRFS)
  - An implementation of the Hadoop file system atop Amazon S3
  - We can avoid EBS storage

https://docs.aws.amazon.com/emr/latest/ManagementGuide/emr-plan-storage.html

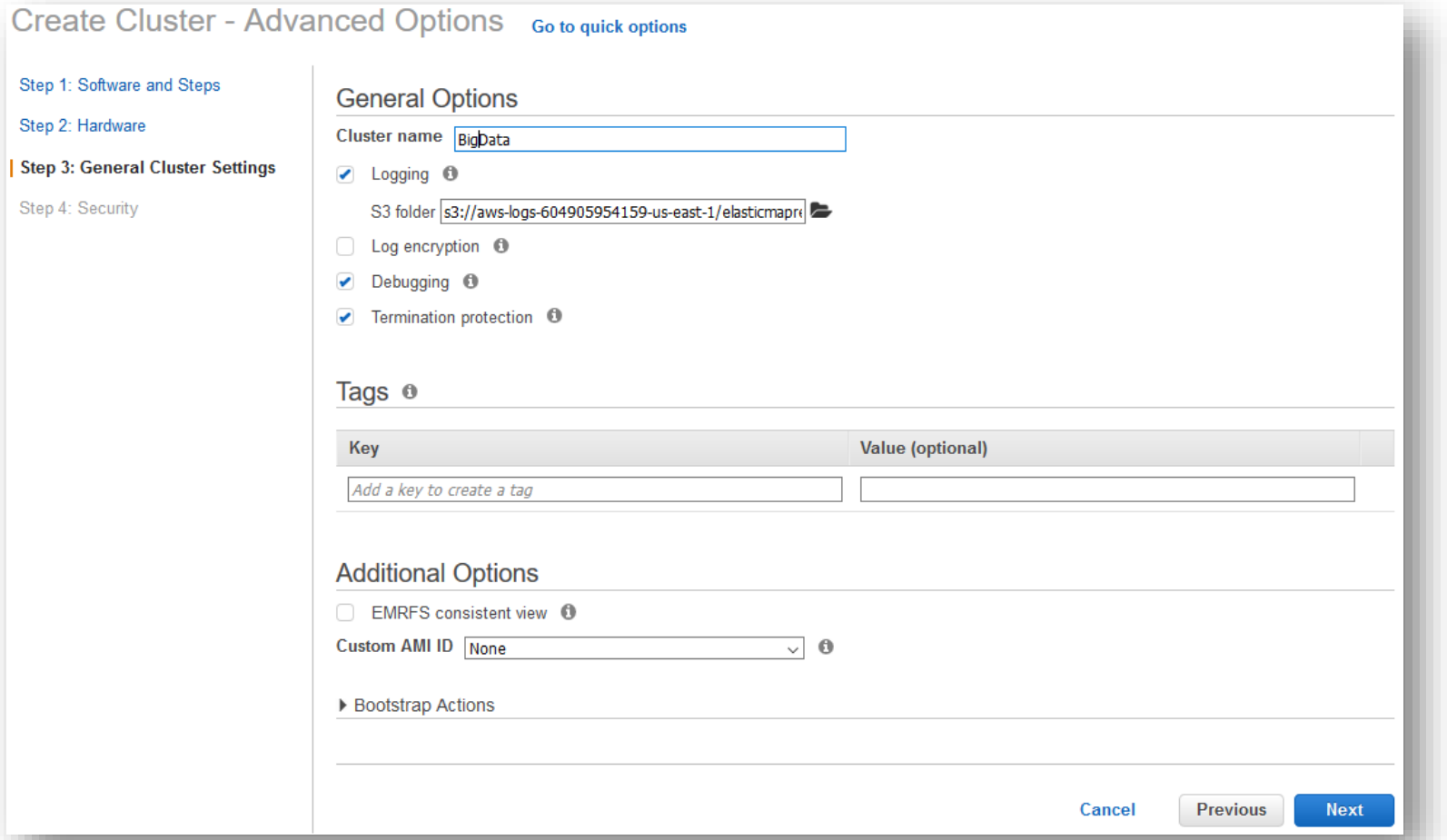
Creating the cluster



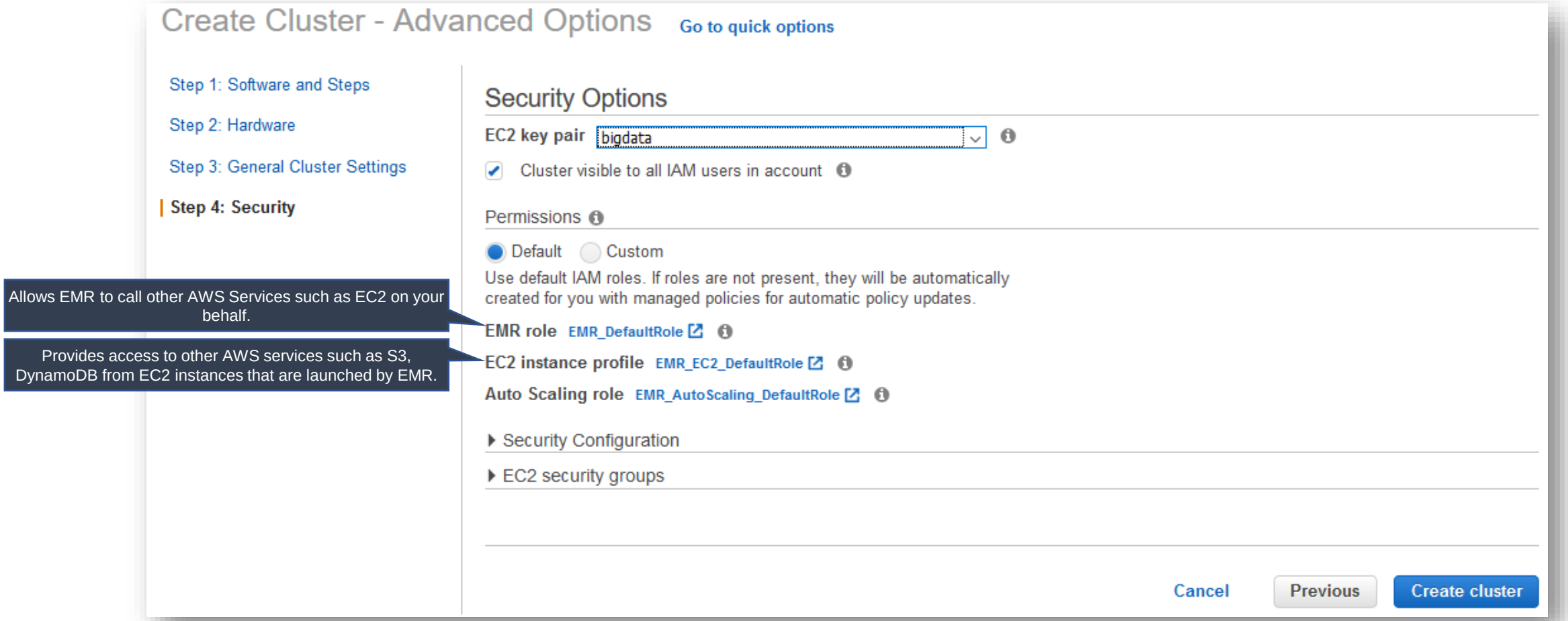
Creating the cluster



Creating the cluster



Creating the cluster



Creating the cluster

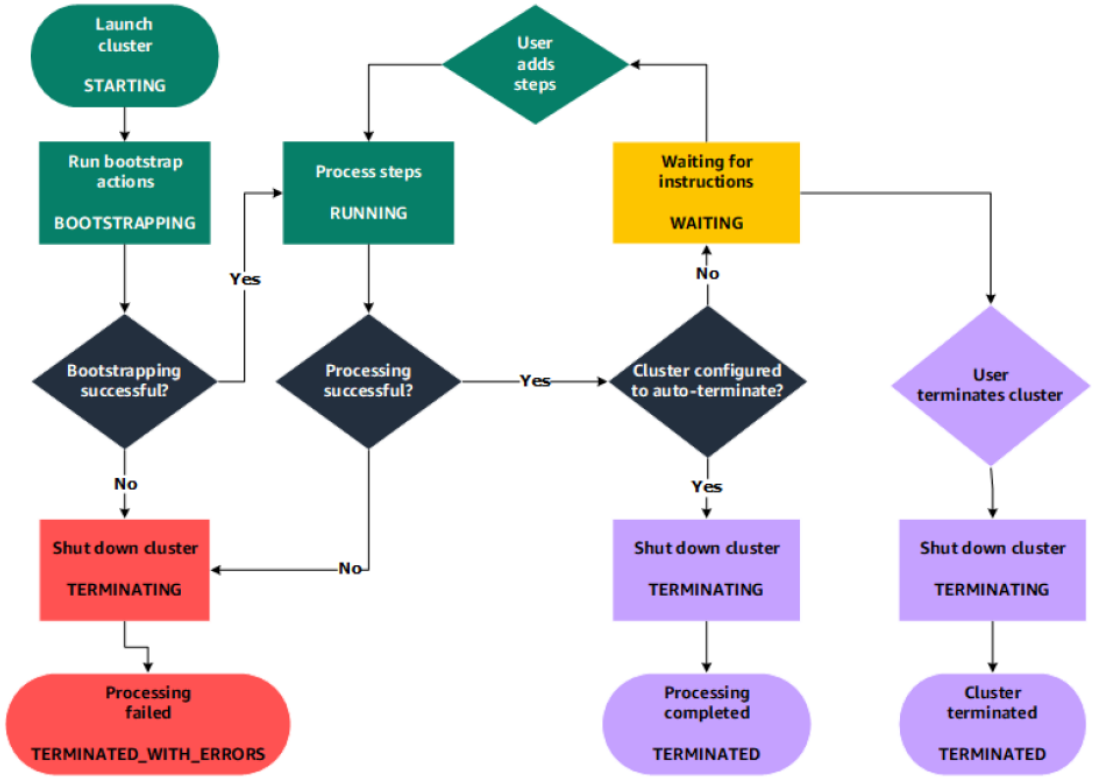
Using CLI (command line interface)

```
aws emr create-cluster --auto-scaling-role EMR_AutoScaling_DefaultRole --termination-protected --
applications Name=Hadoop Name=Hive Name=Hue Name=JupyterEnterpriseGateway Name=Spark --ebs-root-volume-
size 10 --ec2-attributes
'{"KeyName":"bigdata","InstanceProfile":"EMR_EC2_DefaultRole","SubnetId":"subnet-
5fa2f912","EmrManagedSlaveSecurityGroup":"sg-07818b5690a50b3f1","EmrManagedMasterSecurityGroup":"sg-
0e2f5550a2cb98f79"}' --service-role EMR_DefaultRole --enable-debugging --release-label emr-6.2.0 --log-
uri 's3n://aws-logs-604905954159-us-east-1/elasticmapreduce/' --name 'BigData' --instance-groups
'[{"InstanceCount":1,"BidPrice":"OnDemandPrice","EbsConfiguration":{"EbsBlockDeviceConfigs":[{"VolumeSpe
cification":{"SizeInGB":32,"VolumeType":"gp2"},"VolumesPerInstance":2}]},"InstanceGroupType":"MASTER","I
nstanceType":"m4.xlarge","Name":"Master -
1"},{"InstanceCount":1,"BidPrice":"OnDemandPrice","EbsConfiguration":{"EbsBlockDeviceConfigs":[{"VolumeS
pecification":{"SizeInGB":32,"VolumeType":"gp2"},"VolumesPerInstance":2}]},"InstanceGroupType":"CORE","I
nstanceType":"m4.xlarge","Name":"Core - 2"}]' --scale-down-behavior TERMINATE_AT_TASK_COMPLETION --
region us-east-1
```

Cluster lifecycle

Creating a cluster (it takes ~10 minutes)

- A cluster cannot be stopped
- It can only be terminated



Cluster lifecycle

`STARTING`: EMR provisions EC2 instances for each required instance

`BOOTSTRAPPING`: EMR runs actions that you specify on each instance

- E.g., install custom applications and perform customizations

Amazon EMR installs the native applications

- E.g., Hive, Hadoop, Spark, and so on

`RUNNING`: a step for the cluster is currently being run

- Cluster sequentially runs any steps that you specified when you created the cluster

`WAITING`: after steps run successfully

`TERMINATING`: after manual shut down

- Any data stored on the cluster is deleted

Cluster lifecycle

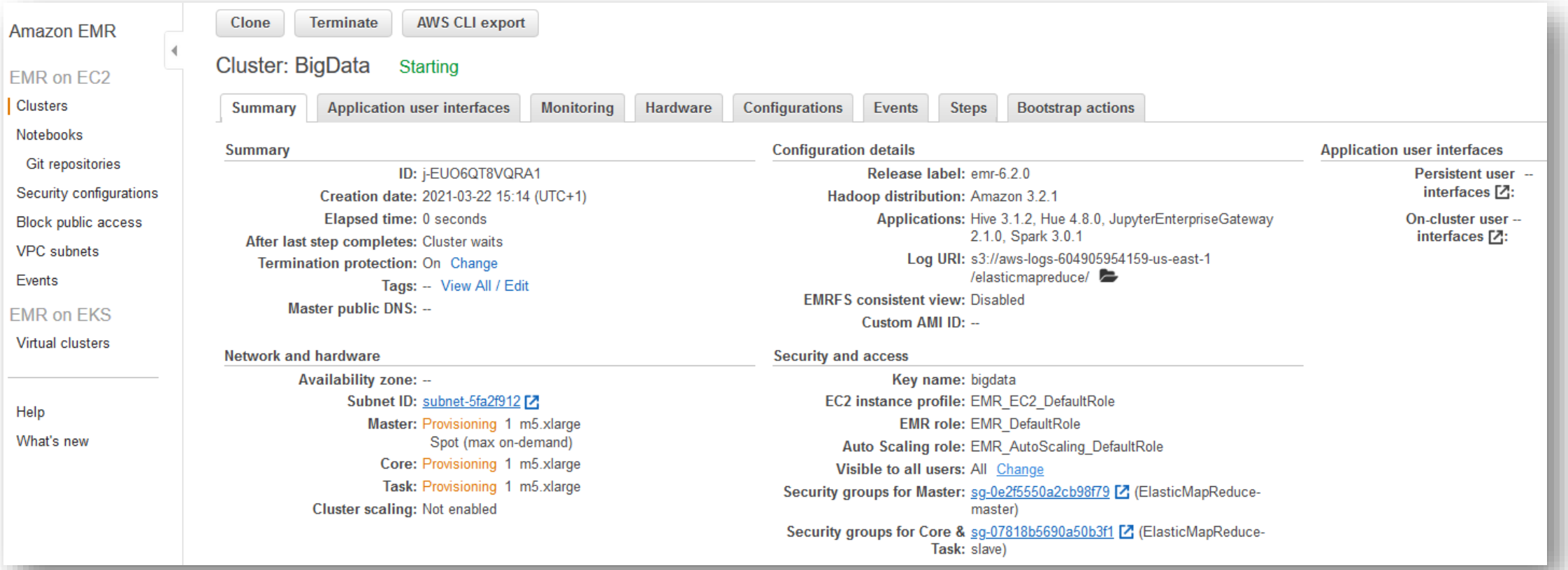
A **step** is a user-defined unit of processing

- E.g., one algorithm that manipulates the data

Step states

- `PENDING:` The step is waiting to be run
- `RUNNING:` The step is currently running
- `COMPLETED:` The step completed successfully
- `CANCELLED:` The step was cancelled before running because an earlier step failed
- `FAILED:` The step failed while running

Running the cluster



Running the cluster