CHAPTER 11

Analytics and Machine Learning

**Introduction**

In the rapidly changing field of cloud computing, integrating analytics and machine learning transforms how businesses gain insights from large datasets and develop intelligent solutions. This chapter examines various AWS services that support analytics and machine learning, providing essential tools for data-driven decision-making and innovative artificial intelligence applications.

In the rapidly evolving field of cloud computing, integrating analytics and machine learning has transformed how businesses gain insights and develop intelligent, automated solutions. AWS offers a robust ecosystem of data analytics and machine learning services designed to help organizations process, analyze, and leverage data effectively. Instead of merely listing AWS services, this chapter provides a structured approach to AWS’s analytics and machine learning capabilities, emphasizing their strategic importance in modern cloud architecture.

In this chapter, we will cover these Key Areas:

1. **Data Analytics on AWS** – How AWS enables scalable, real-time data analytics.
2. **Data Management and ETL** – The role of AWS services in preparing and transforming data.
3. **Machine Learning on AWS** – The ML lifecycle from data preparation to model deployment.
4. **AI-Driven Automation** – How AWS services power automation across industries.

Following the above structure, these areas will cover the following topics:

* Analytics
  + Amazon Athena
  + Amazon CloudSearch
  + Amazon DataZone (Preview)
  + Amazon EMR
  + Hosted Hadoop framework
  + Amazon FinSpace
  + Amazon Kinesis
  + Amazon Managed Streaming for Apache Kafka (MSK)
  + Amazon OpenSearch Service
  + Amazon QuickSight
  + Amazon Redshift
  + AWS Clean Rooms (Preview)
  + AWS Data Exchange
  + AWS Data Pipeline
  + AWS Glue
  + AWS Lake Formation
* Machine Learning
  + Amazon Augmented AI
  + Amazon Bedrock
  + Amazon CodeGuru
  + Amazon Comprehend
  + Amazon DevOps Guru
  + Amazon Elastic Inference
  + Deep learning inference acceleration
  + Amazon Forecast
  + Amazon Fraud Detector
  + Amazon HealthLake
  + Amazon Kendra
  + Amazon Lex
  + Amazon Lookout for Equipment
  + Amazon Lookout for Metrics
  + Amazon Monitron
  + Amazon Omics
  + Amazon Personalize
  + Amazon Polly
  + Amazon Rekognition
  + Amazon SageMaker
  + Amazon SageMaker Ground Truth
  + Amazon Textract
  + Amazon Transcribe
  + Amazon Translate
  + Apache MXNet on AWS
  + AWS Deep Learning AMIs
  + AWS Deep Learning Containers
  + AWS DeepComposer
  + AWS DeepLens
  + AWS DeepRacer
  + AWS Inferentia
  + AWS Panorama
  + PyTorch on AWS
  + TensorFlow on AWS
  + Amazon CodeWhisperer

This chapter will explain the key AWS services related to analytics and machine learning, highlighting their functions, use cases and practical applications. AWS offers different tools for businesses focused on data-driven decision-making and artificial intelligence.

## Learning Objectives

By the end of this chapter, you will be able to:

* Understand the AWS data analytics ecosystem's role in modern cloud computing.
* Identify and implement core AWS analytics services such as **Amazon Athena, Redshift, QuickSight, and OpenSearch**.
* Utilize **AWS Glue and AWS Lake Formation** for effective **ETL and data lake management**.
* Apply **real-time and streaming analytics** using **Amazon Kinesis and MSK**.
* Explore **machine learning services** like **Amazon SageMaker, Comprehend, and Rekognition**.
* Assess how AI-driven automation is transforming industries using **AWS AI services**.
* Examine real-world use cases where AWS analytics and ML have optimized business operations.

Part 1: Analytics – Data into Insights

Analytics is essential in cloud computing for deriving insights from large datasets. This section reviews various AWS analytics services that empower users to process, analyze, and visualize data effectively.

**Figure 1** below shows AWS data collected from multiple data sources across the enterprise, including software-as-a-service (SaaS) applications, edge devices, logs, streaming media, and social networks (AWS Documentation).

A diagram of a software company

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Figure 1 AWS Architecture: Data

# AWS Data Analytics Ecosystem

AWS provides comprehensive analytics services that help organizations collect, process, store, and analyze vast data. Unlike traditional on-premises systems, AWS analytics services scale dynamically, supporting real-time insights, predictive analytics, and deep learning integration.

Organizations generate vast amounts of data from **transactional systems, IoT sensors, logs, and social interactions**. AWS provides **integrated analytics solutions** that address **data ingestion, transformation, storage, querying, and visualization**. Unlike legacy on-premises analytics, AWS solutions:

* **Scale dynamically** to accommodate petabyte-scale datasets.
* **Support real-time insights** for instant decision-making.
* **Integrate with AI/ML pipelines** to derive deeper intelligence.
* **Reduce operational overhead** through serverless architectures.

**IDC (2023)** states that **85% of enterprises** now prioritize **cloud-native analytics** to drive business growth. AWS positions itself as a leader in this field by offering highly scalable and cost-efficient analytics services [1].

# Core Analytics Services

* **Amazon Athena** – A serverless SQL query engine that enables rapid analytics on structured data in Amazon S3 without complex ETL [2].
* **Amazon Redshift** – AWS's high-performance data warehouse optimized for fast querying and business intelligence [3].
* **Amazon QuickSight** – A business intelligence (BI) tool that provides interactive dashboards and AI-powered insights [4].
* **Amazon OpenSearch Service** – Managed Elasticsearch for fast, scalable search and log analytics [5].
* **AWS Glue & AWS Lake Formation** – Serverless ETL (Extract, Transform, Load) services that enable data lakes and analytics pipelines [6]; [7].

**Figures 2 and 3** below show examples of the AWS Glue application and AWS Lake formation, respectively.

A diagram of a system

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Figure 2 Ingestion layer against source systems (AWS Blog).

A diagram of data processing

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*Figure 3 The governance and transformation layer prepares data in the lake (AWS Blog).*

|  |  |  |
| --- | --- | --- |
| **Service** | **Function** | **Use Cases** |
| **Amazon Athena** | Serverless SQL querying for **structured data** in S3 | Ad-hoc analytics, cost-efficient querying [2] |
| **Amazon Redshift** | **High-performance data warehouse** for large-scale analytics | Business intelligence, OLAP processing [3] |
| **Amazon QuickSight** | **An AI-powered BI tool** with **interactive dashboards** | Executive reporting, AI-driven anomaly detection [4] |
| **Amazon OpenSearch Service** | **Scalable search & log analytics** using managed Elasticsearch | Real-time security monitoring, log analysis [5] |
| **AWS Glue & AWS Lake Formation** | **ETL & data lake management** | Centralized enterprise data lakes, GDPR compliance [6]; [7] |

## Case Study 11.1

**Transforming Retail Analytics with AWS Redshift & AWS Glue** [6]; [7]

A Fortune 500 global retailer faced severe **scalability issues** with its on-premises Hadoop-based analytics platform. The system struggled to **process customer transactions, product trends, and sales forecasts efficiently**. Running large-scale **batch analytics jobs** took hours, sometimes days, leading to **delayed insights and missed opportunities** in inventory management and targeted marketing.

### The Challenge:

* Slow data processing due to **on-prem Hadoop clusters**.
* High **infrastructure costs** with frequent hardware upgrades.
* Delayed insights affecting real-time **inventory optimization** and **personalized promotions**.

### AWS Solution:

To modernize its **data analytics pipeline**, the retailer **migrated from Hadoop to AWS Redshift** as its new data warehouse and **used AWS Glue** to automate ETL (Extract, Transform, Load) jobs. This enabled:

* **Faster query performance** (60% improvement in processing times).
* **Serverless ETL automation** reduces manual data preparation work.
* **Cost savings of 30%** by eliminating expensive on-prem infrastructure.

### Results:

* **Inventory predictions improved by 40%**, reducing overstock and stockouts.
* **Marketing teams accessed real-time insights**, boosting campaign effectiveness.
* **Operational costs dropped significantly**, allowing reinvestment in AI-driven customer personalization.

*“Switching to AWS Redshift and Glue transformed our data operations, enabling real-time decision-making at a scale we never imagined.”* – VP of Data Engineering.

## Real-Time & Streaming Analytics

* **Amazon Kinesis** – A managed service for real-time data ingestion and processing [8].
* **Amazon Managed Streaming for Apache Kafka (MSK)** – Scalable event-driven architectures using Kafka streams [9].
* **AWS Data Exchange & AWS Clean Rooms** – Secure data-sharing services for collaborative analytics [10]; [11].

|  |  |  |
| --- | --- | --- |
| **Service** | **Function** | **Use Cases** |
| **Amazon Kinesis** | **Real-time ingestion & analytics** for streaming data | IoT telemetry, fraud detection, social media monitoring [8] |
| **Amazon Managed Streaming for Apache Kafka (MSK)** | Fully managed **Kafka** for event-driven applications | Microservices, real-time customer behavior analytics [9] |
| **AWS Data Exchange & AWS Clean Rooms** | **Secure third-party data sharing** for analytics collaboration | Financial risk modeling, advertising analytics [10]; [11] |

**Case Study**: A healthcare AI startup uses Amazon Kinesis to process real-time EHR data for patient diagnostics, reducing latency by 40% [8].

Case Study 11.2:

**AI-Powered Diagnostics in Healthcare with Amazon Kinesis** [10]; [11]

A fast-growing **AI healthcare startup** was developing an **early detection system for sepsis** using electronic health records (EHR). Traditional data pipelines relied on batch processing, **delaying critical alerts to doctors**. The startup professionals identified the need for a real-time streaming solution to improve patient outcomes.

### The Challenge:

* **EHR data is processed in batches**, delaying urgent alerts.
* **Compliance with HIPAA & data security standards** was a top priority.
* **High data ingestion costs** made real-time analytics challenging to scale.

### AWS Solution:

The startup implemented **Amazon Kinesis** for real-time data ingestion and analytics, allowing:

* Continuous streaming of **EHR signals** for immediate anomaly detection.
* Used AI models on **AWS SageMaker** to analyze patient vitals and predict risks.
* Secure, HIPAA-compliant storage using **AWS HealthLake**.

### Results:

* **EHR analysis decreased by 40%**, providing near-instant sepsis alerts.
* **Doctors received real-time notifications**, enabling faster intervention.
* **Patient survival rates improved**, showcasing the impact of AI-powered analytics.

*“With AWS, we turned complex EHR data into actionable insights in real-time, improving patient care at a fraction of the cost.”* – CTO of the Healthcare Startup.

# Advanced Analytics & Industry Applications

**Retail & E-Commerce**:

* Personalized recommendations using **Amazon Redshift + QuickSight**.
* AI-powered trend forecasting with **Amazon Forecast**.

**Finance & Banking**:

* **Fraud detection models** with **OpenSearch + AWS Glue**.
* **Regulatory compliance monitoring** using **AWS Clean Rooms**.

**Healthcare & Life Sciences**:

* **Real-time patient monitoring** via **Kinesis** + **AWS Lake Formation**.
* **Accelerate drug discovery** with **Amazon FinSpace**.

Part 2: Machine Learning – AI Innovation

**Figure 4** below illustrates the section with the AWS Machine Learning infrastructure:

A screenshot of a computer

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*Figure 4 AWS Machine Learning Infrastructure (AWS Documentation).*

# AWS Machine Learning Lifecycle

AWS provides end-to-end machine learning services, from data preparation to model training and deployment. The AWS ML stack supports frameworks like TensorFlow, PyTorch, Apache MXNet, and fully managed AI services. [12]; [6]; [13]; [14].

1. **Data preprocessing** (AWS Glue, Lake Formation).
2. **Model training & tuning** (Amazon SageMaker).
3. **Inference & deployment** (AWS Inferentia, Elastic Inference).
4. **Monitoring & Automation** (Amazon DevOps Guru, SageMaker Clarify).

A diagram of a machine learning lifecycle

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Figure 5 AWS Well-Architected Machine Learning Lens (AWS Architecture).

**Figure 5** below shows the Cross-Validation Machine Learning Model Pipeline at Scale with Amazon SageMaker.

A diagram of model training

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Figure 6 Amazon SageMaker use case (AWS Documentation).

According to **McKinsey (2023)**, AI-driven organizations see **20-30% higher revenue growth rates** than their peers. [15].

# Core Machine Learning Services

* **Amazon SageMaker** – Fully managed ML development for training, tuning, and deploying models [12].
* **Amazon Comprehend** – Natural Language Processing (NLP) for text sentiment analysis [16].
* **Amazon Rekognition** – AI-powered image and video recognition for object detection and facial analysis [17].
* **Amazon Forecast & Personalize** – Pre-built recommendation and forecasting models [18]; [19].
* **Amazon Textract & Transcribe** – AI-powered OCR and speech-to-text services [20]; [21].

# Industry-Specific AI Services

|  |  |  |
| --- | --- | --- |
| **Industry** | **Key AI Solutions** | **Impact** |
| **Retail** | Amazon Personalize | **20% higher conversion rates** with AI-driven recommendations [19] |
| **Healthcare** | Amazon HealthLake + Comprehend Medical | Faster diagnosis, **40% lower misdiagnosis rates** [22]; [16] |
| **Manufacturing** | Amazon Lookout for Equipment | **30% reduction in downtime** through predictive maintenance [23] |
| **Finance** | Amazon Fraud Detector | **50% improved fraud detection accuracy** [24] |

Where:

* **Amazon Lex & Polly** – Conversational AI for chatbots & text-to-speech [25]; [26].
* **Amazon Fraud Detector** – Machine learning for fraud prevention in finance [24].
* **AWS Panorama** – Computer vision for on-premises AI video analytics [27].

## Case Study 11.3:

**AI-Powered Virtual Assistants for Airlines Using Amazon Lex & Polly** [25]; [26].

A **major international airline** struggled with **long customer service wait times** due to **high flight inquiries, cancellations, and reschedules**. The airline sought to implement an AI-driven solution to enhance self-service capabilities and improve customer **experience**.

### The Challenge:

* **High call center costs** and **overloaded customer support agents**.
* Customers needed **natural-sounding AI interactions** for self-service.
* Integration with **existing airline booking and CRM systems**.

### AWS Solution:

The airline deployed an **AI-powered virtual assistant** using:

* **Amazon Lex** – AI chatbot for handling flight inquiries, check-in, and rebooking.
* **Amazon Polly** – Text-to-speech for human-like voice responses.
* **AWS Lambda** – Serverless architecture to manage backend queries.

### Results:

* **Call center costs dropped by 45%**, reducing agent workload.
* **Customer queries without customer intervention** increased to 60%.
* Customers experienced **faster issue resolution**, improving **loyalty and satisfaction**.

*“Integrating AI-powered virtual assistants with Lex & Polly transformed our customer service, making it more scalable and cost-effective.”* – Head of Digital Innovation.

## Use Cases with high adoption of AWS Analytics

* **Customer Support**: Chatbots powered by Amazon Lex [25].
* **Healthcare**: Medical data processing with Amazon Comprehend Medical + HealthLake [16]; [22].
* **Manufacturing**: Predictive maintenance using Amazon Lookout for Equipment [23].

# AI-Powered Automation & Emerging Technologies

AWS continues to push the boundaries of AI-driven automation:

* **Autonomous Driving** – AWS DeepRacer for RL-based self-driving models.
* **Generative AI** – Amazon Bedrock for LLM-based applications.
* **Edge AI** – AWS Panorama for real-time on-prem AI inference.

## Case Study 11.4:

**Smart City Traffic Optimization with AWS Panorama & SageMaker** [27]; [12].

A metropolitan municipality government launched a smart city initiative to address **chronic traffic congestion** in a **central metro area**. Traffic bottlenecks **increase pollution, waste time, and reduce economic productivity**.

### The Challenge:

* **Limited real-time monitoring** of traffic conditions.
* **No predictive analytics** for accident-prone areas.
* **Manual adjustments** to traffic lights were inefficient.

### AWS Solution:

The city deployed an AI-powered traffic monitoring system using:

* **AWS Panorama –** Computer vision for real-time traffic video analysis**.**
* **Amazon SageMaker –** Machine learning models predicting congestion patterns**.**
* **AWS IoT Core –** Automated traffic light adjustments based on live data**.**

**Results:**

* **Traffic congestion experienced a reduction of 30%** through dynamic traffic signal adjustments.
* **Emergency response times improved by 25%**, saving lives.
* **Air pollution levels decreased** as fewer vehicles idled in traffic.

*“AWS Panorama & SageMaker allowed us to build an intelligent traffic system that dynamically adapts, optimizing urban mobility.”* – Smart City Infrastructure Lead.

# Future Trends in AWS Analytics & AI

Cloud-based analytics and AI services evolve continuously, driven by **enterprise demand for automation, cost efficiency, and real-time intelligence**. AWS remains a leader in this space, focusing on **serverless AI, multi-cloud analytics, and federated learning** to address emerging industry needs.

## Serverless AI: The Next Frontier

Serverless computing revolutionized cloud adoption, eliminating infrastructure management complexities. AWS extends this paradigm to AI/ML workloads with **Amazon SageMaker Serverless Inference** and **AWS Lambda for AI-driven applications**. These services allow businesses to scale AI models **dynamically**, reducing idle compute costs and eliminating provisioning concerns. [28].

AWS’s **serverless AI adoption** enables:

* **Cost-efficient AI workloads** – No need for dedicated GPU/CPU clusters.
* **Low-latency inference at scale** – Deploy AI models instantly without scaling concerns.
* **Seamless event-driven AI pipelines** – Automate AI responses to real-time data changes.

A **Forrester study (2024)** predicts that **serverless AI adoption will surpass traditional AI deployment models by 2026** as organizations prioritize **cost control and operational simplicity.** [29].

## Multi-Cloud Analytics: AWS’s Positioning

Hybrid and multi-cloud strategies are reshaping enterprise cloud architectures. Organizations **rarely commit to a single provider**, instead **leveraging best-in-class AWS, Azure, and Google Cloud services**. **AWS Data Exchange**, **AWS Glue**, and **Amazon Redshift Query Federation** support this paradigm by enabling **cross-cloud analytics and interoperability** [30].

Key AWS advantages in multi-cloud analytics:

* **Redshift Query Federation** – Enables cross-cloud analytics without **data duplication**.
* **AWS Outposts** – Brings AWS analytics to on-premises and hybrid environments.
* **AWS Lake Formation** – Integrates multi-cloud data sources into a **unified data lake**.

According to **Gartner (2024)**, **60% of enterprises will adopt multi-cloud analytics by 2025**, emphasizing the need for **cross-cloud interoperability.** [31]

**Federated Learning: The Evolution of AI Privacy**

Federated learning is a **critical AI trend**, enabling model training on distributed datasets **without exposing raw data**. AWS supports **secure AI model training** across decentralized datasets with **Amazon SageMaker Edge Manager** and **AWS PrivateLink for ML workloads** [32].

Key federated learning advantages:

* **Privacy-preserving AI** – No centralized data collection; AI models train locally.
* **Industry compliance** – Meets GDPR, HIPAA, and other strict regulatory standards.
* **Edge AI integration** – Leverages AWS IoT and **AWS Panorama** for real-time insights.

A **McKinsey report (2024)** highlights **federated learning’s adoption in financial services, healthcare, and defense**, where **data security remains non-negotiable.** [33].

# AWS vs. Competitors: Why AWS Leads in Analytics & AI

While Microsoft Azure and Google Cloud offer **competitive AI and analytics services**, AWS maintains its leadership through **scale, flexibility, and cost optimization**. Below is a comparison of AWS with its **closest competitors** in analytics and AI.

## Compute & AI Model Training

| **Feature** | **AWS** | **Azure** | **Google Cloud** |
| --- | --- | --- | --- |
| **AI Model Training** | Amazon SageMaker | Azure Machine Learning | Vertex AI |
| **Serverless AI** | Lambda + SageMaker Serverless | Azure Functions for AI | Cloud Functions |
| **Custom AI Chips** | AWS Inferentia & Trainium | Azure NPUs | Google TPU |
| **Federated Learning** | SageMaker Edge Manager | Confidential Computing | TensorFlow Federated |

AWS differentiates itself through:

* **Custom AI chips (Inferentia, Trainium)** – 20-50% cost savings on AI inference vs. GPUs [7].
* **SageMaker’s full-stack ML lifecycle** – Covers **model building, training, and deployment** in one service.
* **Seamless AI automation** – **Event-driven AI workflows** using Lambda and Step Functions.

## Multi-Cloud & Hybrid Analytics

| **Feature** | **AWS** | **Azure** | **Google Cloud** |
| --- | --- | --- | --- |
| **Cross-cloud analytics** | AWS Data Exchange, Redshift Query Federation | Azure Synapse Link | BigQuery Omni |
| **Hybrid deployment** | AWS Outposts | Azure Arc | Anthos |
| **Multi-cloud AI model deployment** | SageMaker multi-cloud inference | MLflow on Azure | TensorFlow Extended (TFX) |

AWS’s leadership in **hybrid analytics** stems from:

* **AWS Outposts & Local Zones** – Extending AWS analytics **to on-premises and multi-cloud setups**.
* **Redshift Query Federation** – Query data across **AWS, on-prem, and external clouds** **without data migration**.
* **Integrated AI + analytics pipelines** – AWS uniquely combines **serverless AI and analytics automation**.

## Industry Adoption & Market Share

| **Feature** | **AWS** | **Azure** | **Google Cloud** |
| --- | --- | --- | --- |
| **Market Share (Q1 2024)** | **32%** | 24% | 11% |
| **Enterprise AI Adoption** | 76% | 62% | 45% |
| **ML Service Portfolio** | **Most extensive** | Broad | Focused on deep learning |

AWS maintains a **32% market share** in cloud computing, leading Azure (24%) and Google Cloud (11%) [8]. Its **76% enterprise AI adoption rate** underscores its dominance in **real-world AI applications**.

# Final Thoughts

AWS continues to **innovate on a scale**, ensuring businesses can efficiently build data-driven, AI-powered solutions. Future trends such as **serverless AI, multi-cloud analytics, and federated learning** will shape the next evolution of **enterprise AI adoption**.

AWS’s **strategic advantages over competitors** reinforce its leadership through the following:

* **Scalability** – Auto-scaling AI and analytics at a **global scale**.
* **Flexibility** – Serverless, hybrid, and **multi-cloud AI pipelines**.
* **Cost Efficiency** – **Optimized AI chips (Inferentia, Trainium)** drive **up to 50% cost savings**.
* **Enterprise-Grade AI** – SageMaker’s **full-stack ML lifecycle** **outpaces competitors**.

As organizations accelerate **AI-driven transformation**, AWS remains the **gold standard** for **scalable, efficient, and cost-optimized analytics and machine learning solutions**.

# Conclusion: The AWS AI-Driven Future

AWS provides a robust, scalable, and fully managed AI and analytics ecosystem that allows businesses to gain deep insights, optimize operations, and automate processes. From real-time analytics to machine learning automation, AWS’s integrated services make AI more accessible and practical for businesses of all sizes.

**In summary:** Why AWS for AI & Analytics?

* **Scalability** – From small startups to global enterprises.
* **End-to-end ecosystem** – Seamless **data-to-insight pipelines**.
* **AI democratization** – Pre-built models make AI **accessible** to all.

The next chapter explores the AWS Well-Architected Framework, which helps organizations design scalable, secure, and efficient cloud architectures. Understanding how analytics and ML fit into a well-architected strategy is crucial for building AI-driven applications that scale effortlessly.

## Key Takeaways:

* **Data is the foundation of AI** – AWS analytics enables data-driven decisions.
* **AWS simplifies ML development** – SageMaker makes AI more accessible.
* **AI is transforming industries** – From finance to healthcare to manufacturing.

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