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# Introduction to Big Data

Big data refers to the incredible amount of structured and unstructured information that humans and machines generate—petabytes every day, according to PwC. It's the social posts we mine for customer sentiment, sensor data showing the status of machinery, financial transactions that move money at hyper speed. It's also too massive, too diverse, and comes at us way too fast for old-school data processing tools and practices to stand a chance.

It's also much too valuable to leave unanalyzed. Big data infers the ability to extract insights from this broad collection of data to help an organization become more efficient, innovate faster, earn more money, and just all around win.

Luckily, advancements in analytics and machine learning technology and tools make big data analysis accessible for every company.

## What Is Big Data? Big Data Defined

Big data refers to extremely large and complex data sets that cannot be easily managed or analyzed with traditional data processing tools, particularly spreadsheets. Big data includes structured data, like an inventory database or list of financial transactions; unstructured data, such as social posts or videos; and mixed data sets, like those used to train large language models for AI. These data sets might include anything from the works of Shakespeare to a company's budget spreadsheets for the last 10 years.

Big data has only gotten bigger as recent technological breakthroughs have significantly reduced the cost of storage and compute, making it easier and less expensive to store more data than ever before. With that increased volume,

companies can make more accurate and precise business decisions with their data. But achieving full value from big data isn't only about analyzing it—which is a whole other benefit. It's an entire discovery process that requires insightful analysts, business users, and executives who ask the right questions, recognize patterns, make informed assumptions, and predict behavior.

## What are the Five "Vs" of Big Data?

Traditionally, we've recognized big data by three characteristics: variety, volume, and velocity, also known as the "three Vs." However, two additional Vs have emerged over the past few years: value and veracity.

Those additions make sense because today, data has become capital. Think of some of the world's biggest tech companies. Many of the products they offer are based on their data, which they're constantly analyzing to produce more efficiency and develop new initiatives. Success depends on all five Vs.

- **Volume.** The amount of data matters. With big data, you'll have to process high volumes of low-density, unstructured data. This can be data of unknown value, such as X (formerly Twitter) data feeds, clickstreams on a web page or a mobile app, or sensor-enabled equipment. For some organizations, this might be tens of terabytes of data. For others, it may be hundreds of petabytes.
- **Velocity.** Velocity is the fast rate at which data is received and (perhaps) acted on. Normally, the highest velocity of data streams directly into memory versus being written to disk. Some internet-enabled smart products operate in real time or near real time and will require real-time evaluation and action.
- **Variety.** Variety refers to the many types of data that are available. Traditional data types were structured and fit neatly in a relational database. With the rise of big data, data comes in new unstructured data types. Unstructured and semi structured data types, such as text, audio, and video, require additional preprocessing to derive meaning and support metadata.
- **Veracity.** How truthful is your data—and how much can you rely on it? The idea of veracity in data is tied to other functional concepts, such as data quality and data integrity. Ultimately, these all overlap and steward the organization to a data repository that delivers high-quality, accurate, and reliable data to power insights and decisions.
- **Value.** Data has intrinsic value in business. But it's of no use until that value is discovered. Because big data assembles both breadth and depth of insights, somewhere within all of that information lies insights that can benefit your organization. This value can be internal, such as operational processes that might be optimized, or external, such as customer profile suggestions that can maximize engagement.

## The Evolution of Big Data: Past, Present, and Future

Although the concept of big data is relatively new, the need to manage large data sets dates back to the 1960s and '70s, with the first data centers and the development of the relational database.

**Past.** Around 2005, people began to realize just how much data users generated through Facebook, YouTube, and other online services. Apache Hadoop, an

open source framework created specifically to store and analyze big data sets, was developed that same year. NoSQL also began to gain popularity during this time.

**Present.** The development of open source frameworks, such as Apache Hadoop and more recently, Apache Spark, was essential for the growth of big data because they make big data easier to work with and cheaper to store. In the years since then, the volume of big data has skyrocketed. Users are still generating huge amounts of data—but it's not just humans who are doing it. With the advent of the Internet of Things (IoT), more objects and devices are connected to the internet, gathering data on customer usage patterns and product performance. The emergence of machine learning has produced still more data.

**Future.** While big data has come far, its value is only growing as generative AI and cloud computing use expand in enterprises. The cloud offers truly elastic scalability, where developers can simply spin up ad hoc clusters to test a subset of data. And graph databases are becoming increasingly important as well, with their ability to display massive amounts of data in a way that makes analytics fast and comprehensive.

## Big Data Benefits

Big data services enable a more comprehensive understanding of trends and patterns, by integrating diverse data sets to form a complete picture. This fusion not only facilitates retrospective analysis but also enhances predictive capabilities, allowing for more accurate forecasts and strategic decision-making. Additionally, when combined with AI, big data transcends traditional analytics, empowering organizations to unlock innovative solutions and drive transformational outcomes.

More complete answers mean more confidence in the data—which means a completely different approach to tackling problems.

- **Better insights.** When organizations have more data, they're able to derive better insights. In some cases, the broader range confirms gut instincts against a more diverse set of circumstances. In other cases, a larger pool of data uncovers previously hidden connections and expands potentially missed perspectives. All of this allows organizations to have a more comprehensive understanding into the how and why of things, particularly when automation allows for faster, easier processing of big data.
- **Decision-making.** With better insights, organizations can make data-driven decisions with more reliable projections and predictions. When big data combines with automation and analytics that opens an entire range of possibilities, including more up-to-date market trends, social media analysis, and patterns that inform risk management.
- **Personalized customer experiences.** Big data allows organizations to build customer profiles through a combination of customer sales data, industry demographic data, and related data such as social media activity and marketing campaign engagement. Before automation and analytics, this type of personalization was impossible due to its sheer

scope; with big data, this level of granularity improves engagement and enhances the customer experience.

- **Improved operational efficiency.** Every department generates data, even when teams don't really think about it. That means that every department can benefit from data on an operational level for tasks such as detecting process anomalies, identifying patterns for maintenance and resource use, and highlighting hidden drivers of human error. Whether technical problems or staff performance issues, big data produces insights about how an organization operates—and how it can improve.

## Big Data Use Cases

Big data can help you optimize a range of business activities, including customer experience and analytics. Here are just a few.

**1. Retail and ecommerce.** Companies such as Netflix and Procter & Gamble use big data to anticipate customer demand. They build predictive models for new products and services by classifying key attributes of past and current products or services and modeling the relationship between those attributes and the commercial success of the offerings. In addition, P&G uses data and analytics from focus groups, social media, test markets, and early store rollouts to plan, produce, and launch new products.

**2. Healthcare.** The healthcare industry can combine numerous data sources internally, such as electronic health records, patient wearable devices, and staffing data, and externally, including insurance records and disease studies, to optimize both provider and patient experiences. Internally, staffing schedules, supply chains, and facility management can be optimized with insights provided by operations teams. For patients, their immediate and long-term care can change with data driving everything such as personalized recommendations and predictive scans.

**3. Financial services.** When it comes to security, it's not just a few rogue attackers—you're up against entire expert teams. Security landscapes and compliance requirements are constantly evolving. Big data helps you identify patterns in data that indicate fraud and aggregate large volumes of information to make regulatory reporting much faster.

**4. Manufacturing.** Factors that can predict mechanical failures may be deeply buried in structured data—think the year, make, and model of equipment—as well as in unstructured data that covers millions of log entries, sensor data, error messages, and engine temperature readings. By analyzing these indications of potential issues before problems happen, organizations can deploy maintenance more cost effectively and maximize parts and equipment uptime.

**5. Government and public services.** Government offices can potentially collect data from many different sources, such as DMV records, traffic data, police/firefighter data, public school records, and more. This can drive efficiencies in many different ways, such as detecting driver trends for optimized intersection management and better resource allocation in schools.

Governments can also post data publicly, allowing for improved transparency to bolster public trust.

## Big Data Challenges

While big data holds a lot of promise, it's not without challenges.

First, big data is … big. Although new technologies have been developed to facilitate data storage, data volumes are doubling in size about every two years, according to analysts. Organizations that struggle to keep pace with their data and find ways to effectively store it won't find relief via a reduction in volume.

And it's not enough to just store your data affordably and accessibly. Data must be used to be valuable, and success there depends on curation. Curated data—that is, data that's relevant to the client and organized in a way that enables meaningful analysis—doesn't just appear. Curation requires a lot of work. In many organizations, data scientists spend 50% to 80% of their time curating and preparing data so it can be used effectively.

Once all that data is stored within an organization's repository, two significant challenges still exist. First, data security and privacy needs will impact how IT teams manage that data. This includes complying with regional/industry regulations, encryption, and role-based access for sensitive data. Second, data is beneficial only if it is used. Creating a data-driven culture can be challenging, particularly if legacy policies and long-standing attitudes are embedded within the culture. New dynamic applications, such as self-service analytics, can be game changers for nearly any department, but IT teams must put the time and effort into education, familiarization, and training; this is a long-term investment that produces significant organizational changes in order to gain insights and optimizations.

Finally, big data technology is changing at a rapid pace. A few years ago, Apache Hadoop was the popular technology used to handle big data. Then Apache Spark was introduced in 2014. Today, a combination of technologies are delivering new breakthroughs in the big data market. Keeping up is an ongoing challenge.

## How Big Data Works

Big data works by providing insights that shine a light on new opportunities and business models. Once data has been ingested, getting started involves three key actions:

### 1. Integrate

Big data brings together data from many disparate sources and applications. Traditional data integration mechanisms, such as extract, transform, and load (ETL) generally aren't up to the task. It requires new strategies and technologies to analyze big data sets at terabyte, or even petabyte, scale.

During integration, you need to bring in the data, process it, and make sure it's formatted and available in a form that your business analysts can get started with.

### 2. Manage

Big data requires storage. Your storage solution can be in the cloud, on-premises, or both. You can store your data in any form you want and bring your desired processing requirements and necessary process engines to those data sets on an on-demand basis. Many people choose their storage solution according to where their data is currently residing. Data lakes are gradually gaining popularity because it supports your current compute requirements and enables you to spin up resources as needed.

### 3. Analyze

Your investment in big data pays off when you analyze and act on your data. A visual analysis of your varied data sets gives you new clarity. Explore the data further to make new discoveries. Share your findings with others. Build data models with machine learning and artificial intelligence. Put your data to work for your organization.

## Big Data Best Practices

To help you on your big data journey, we've put together some key best practices for you to keep in mind. Here are our guidelines for building a successful big data foundation.

### 1. Align big data with specific business goals

More extensive data sets enable you to make new discoveries. To that end, it is important to base new investments in skills, organization, or infrastructure with a strong business-driven context to guarantee ongoing project investments and

funding. To determine if you are on the right track, ask how big data supports and enables your top business and IT priorities. Examples include understanding how to filter web logs to understand ecommerce behaviour, deriving sentiment from social media and customer support interactions, and understanding statistical correlation methods and their relevance for customer, product, manufacturing, and engineering data.

### 2. Ease skills shortages with standards and governance

One of the biggest obstacles to benefiting from your investment in big data is not having enough staff with the necessary skills to analyze your data. You can mitigate this risk by ensuring that big data technologies, considerations, and decisions are added to your IT governance program. Standardizing your approach will allow you to manage costs and leverage resources. Organizations implementing big data solutions and strategies should assess their skill requirements early and often and should proactively identify any potential skill gaps. These can be addressed by training/cross-training existing resources, hiring new resources, and leveraging consulting firms.

### 3. Optimize knowledge transfer with a center of excellence

Use a center of excellence approach to share knowledge, control oversight, and manage project communications. Whether big data is a new or expanding investment, the soft and hard costs can be shared across the enterprise. Leveraging this approach can help increase big data capabilities and overall information architecture maturity in a more structured and systematic way.

### 4. The top payoff is aligning unstructured with structured data

It is certainly valuable to analyze big data on its own. But you can bring even greater business insights by connecting and integrating low-density big data with the structured data you are already using today.

Whether you are capturing customer, product, equipment, or environmental big data, the goal is to add more relevant data points to your core master and analytical summaries, leading to better conclusions. For example, there is a difference in distinguishing all customer sentiment from that of only your best customers. Which is why many see big data as an integral extension of their existing business intelligence capabilities, data warehousing platform, and information architecture.

Keep in mind that the big data analytical processes and models can be both human- and machine-based. Big data analytical capabilities include statistics, spatial analysis, semantics, interactive discovery, and visualization. Using

analytical models, you can correlate different types and sources of data to make associations and meaningful discoveries.

### 5. Plan your discovery lab for performance

Discovering meaning in your data is not always straightforward. Sometimes we don't even know what we're looking for. That's expected. Management and IT needs to support this lack of direction or lack of clear requirement.

At the same time, it's important for analysts and data scientists to work closely with the business to understand key business knowledge gaps and requirements. To accommodate the interactive exploration of data and the experimentation of statistical algorithms, you need high performance work areas. Be sure that sandbox environments have the support they need—and are properly governed.

### 6. Align with the cloud operating model

Big data processes and users require access to a broad array of resources for both iterative experimentation and running production jobs. A big data solution includes all data realms including transactions, master data, reference data, and summarized data. Analytical sandboxes should be created on demand. Resource management is critical to ensure control of the entire data flow including pre- and post-processing, integration, in-database summarization, and analytical modeling. A well-planned private and public cloud provisioning and security strategy plays an integral role in supporting these changing requirements.

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## Big Data Skills and Sources

**Skills:**

- **Programming Skills**: Programming languages like **Python** and **Java** are used for custom data manipulation scripts.
- **Database Management**: Skills in **SQL** (structured data) and **NoSQL** (unstructured data) databases allow working with relational and distributed systems.
- **Distributed Computing**: Understanding frameworks like **Hadoop** (batch processing) and **Spark** (real-time processing) is crucial for handling massive datasets efficiently.
- **Machine Learning (ML)**: Skills in building predictive models and algorithms help extract actionable insights from raw data.
- **Visualization**: Proficiency in tools like **Power BI**, **Tableau**, or Python libraries (e.g., Matplotlib, Seaborn) to interpret analytics.

**Sources of Big Data:**

- **Public Sources**: Open data repositories (e.g., Kaggle, World Bank).
- **Private Sources**: Enterprise systems (e.g., CRM or ERP tools).
- **IoT Devices**: Generate real-time sensor data from smart devices.

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## Big Data Adoption

**Why Adopt Big Data?** Organizations must deal with a rapidly growing influx of data from internal and external sources. Adopting Big Data ensures businesses can:

- Predict market trends.
- Optimize internal processes.
- Enhance customer experience through personalized services.

**Stages of Adoption**:

1. **Planning**: Identify specific business needs for Big Data solutions.
2. **Implementation**: Set up the necessary infrastructure (e.g., cloud-based or hybrid systems).
3. **Integration**: Align Big Data tools with existing workflows.
4. **Optimization**: Regularly refine data models and update strategies.

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## Characteristics of Big Data

Each characteristic plays a unique role in defining Big Data's complexity:

- **Volume**: Refers to the unprecedented size of datasets, ranging from terabytes to petabytes.
- **Velocity**: Indicates the speed at which data is generated and processed. For example:
  - Social media generates millions of posts per second.
  - Stock markets produce real-time data that requires instant analysis.
- **Variety**: Diverse data types like videos, emails, spreadsheets, or sensor logs complicate processing.
- **Veracity**: Ensures data integrity and reliability, crucial for making sound decisions.
- **Value**: Refers to the actionable insights derived from analyzing data.

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## Key Aspects of a Big Data Platform

- **Data Management**: Platforms like HDFS offer robust data storage solutions for handling distributed datasets.
- **Data Processing**: Tools like Spark provide in-memory processing for faster computation of large datasets.
- **Real-Time Capabilities**: Apache Kafka allows streaming data ingestion for instant insights.
- **Automation**: Automating repetitive tasks, such as ETL (Extract, Transform, Load), boosts efficiency.
- **Interoperability**: Integration with ML tools and existing IT systems ensures seamless operation.

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## Challenges of Conventional Systems

Conventional systems struggle to keep pace with modern data requirements due to:

- **Fixed Storage Capacity**: Relational databases have limits in handling unstructured data types.
- **Slow Data Processing**: Batch processing models cannot meet real-time analytical needs.
- **Inflexibility**: Legacy systems lack support for integrating with advanced tools.
- **Lack of Scalability**: Vertical scaling (adding resources to a single machine) is expensive and inefficient compared to horizontal scaling.

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## Nature of Data

Understanding the nature of data is vital for choosing the right processing techniques:

- **Structured Data**: Example: Sales records in a tabular format.
  - Managed using relational databases like MySQL or Oracle.
- **Unstructured Data**: Example: Images, audio, and video files from social media.
  - Requires advanced tools like Elasticsearch for indexing.
- **Semi-Structured Data**: Example: XML and JSON data formats used in APIs.
  - Best processed with document-oriented databases like MongoDB.

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**Evolution of Analytic Scalability**

- **Past**: Systems relied on centralized databases with limited computational resources.
- **Present**: Introduction of distributed systems (e.g., Spark, Hadoop) has enabled faster analytics at scale.
- **Future Trends**:
    - **Edge Computing**: Data processing occurs closer to the data source, reducing latency.
    - **Quantum Computing**: Promises unprecedented speeds for solving large-scale analytical problems.

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**Governance for Big Data**

**Definition**: Governance ensures data is used responsibly while adhering to regulatory compliance.

- **Core Principles**:
    1. **Data Quality**: Ensuring accuracy and consistency.
    2. **Access Management**: Role-based controls to protect sensitive information.
    3. **Compliance**: Adherence to legal frameworks like GDPR, HIPAA, etc.
    4. **Monitoring**: Continuous auditing for data usage.

**Taxonomy**:

- **Operational Governance**: Focuses on short-term objectives like daily access control.
- **Strategic Governance**: Focuses on long-term objectives, such as aligning data practices with business goals.

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**Big Data Value for the Enterprise**

- **Operational Efficiency**:
    - Example: Predictive maintenance in manufacturing reduces downtime.
- **Customer Insights**:

    - Example: Analyzing shopping patterns to improve recommendations.
- **Cost Reduction**:
    - Example: Using cloud-based solutions minimizes hardware expenses.
- **Revenue Growth**:
    - Example: Targeted marketing campaigns generate higher conversion rates.
- **Innovation**:
    - Example: AI-driven product design to match emerging trends.

- **Operational Efficiency**: Automating and optimizing processes.
- **Market Insights**: Understanding customer behavior and preferences.
- **Innovation**: Identifying trends for new products or services.
- **Competitive Advantage**: Leveraging data-driven decisions for faster market responses.
- **Revenue Growth**: Enhancing personalization, reducing churn, and improving upselling.