

Artificial Intelligence Basics

A Comprehensive Guide to Understanding AI Fundamentals

Introduction

Artificial Intelligence has become one of the most transformative technologies of the twenty-first century, reshaping industries, economies, and societies across the globe. From healthcare diagnostics to autonomous vehicles, from virtual assistants to financial forecasting, AI systems are increasingly integrated into nearly every aspect of modern life. Despite its widespread presence and profound impact, many people lack a clear understanding of what artificial intelligence truly is, how it functions, and what implications it holds for the future.

This document provides a comprehensive exploration of artificial intelligence basics, designed for readers seeking to understand the fundamental concepts, methodologies, and applications of AI technology. Whether you are a student, professional, or simply a curious individual interested in learning about AI, this guide will equip you with the knowledge needed to comprehend the technology shaping our world.

The foundation of understanding AI lies in recognizing that it is not a single monolithic technology but rather a collection of related approaches and methodologies united by a common goal: creating machines that can perform tasks typically requiring human intelligence. This requires not only sophisticated algorithms and computational power but also vast amounts of data and carefully designed learning mechanisms.

Part One: Foundations and Core Concepts

Chapter 1: What Is Artificial Intelligence?

Defining Artificial Intelligence

Artificial Intelligence refers to the development of computer systems capable of performing tasks that historically required human intelligence. These tasks encompass a wide range of cognitive functions including learning from experience, recognizing patterns, understanding language, making decisions, solving problems, and perceiving the environment through various sensory mechanisms.

The term artificial intelligence was first coined in the 1950s at the Dartmouth Conference, marking the formal beginning of AI as an academic discipline. At its essence, AI seeks to create systems that can replicate or simulate human-like intelligence through computational means. However, it is important to note that AI does not necessarily mimic human intelligence in appearance or method; rather, it achieves similar outcomes through different mechanisms and approaches.

One of the most critical aspects of understanding AI is recognizing that it operates through algorithms and mathematical models rather than biological processes. While human intelligence emerges from complex neural interactions, AI intelligence emerges from mathematical operations performed on digital computers. This fundamental difference means that AI systems excel in tasks that can be mathematized and systematized, while they may struggle with tasks that require subjective judgment, emotional understanding, or common sense reasoning.

The Evolution of AI: From Theory to Reality

The history of artificial intelligence spans several decades and multiple waves of development, each bringing new insights, technologies, and applications. The early years of AI research, from the 1950s through the 1970s, were characterized by optimism and ambitious goals. Researchers believed that creating intelligent machines would be straightforward, requiring primarily powerful computers and clever algorithms.

However, this early optimism gave way to the "AI winter" period of the 1980s and 1990s, during which funding dried up and progress slowed considerably. The challenges proved more formidable than anticipated, and the limitations of existing technologies became apparent. Computers lacked sufficient processing power, datasets were limited, and the algorithms available were insufficient for solving complex real-world problems.

The landscape changed dramatically in the 2010s with advances in several key areas. The availability of massive datasets through the internet and digital systems, coupled with exponential increases in computational power through modern processors and distributed computing architectures, created conditions favorable for AI advancement. Additionally, breakthroughs in deep learning and neural network research demonstrated that computers could learn complex patterns in data with remarkable accuracy.

Today, AI systems are achieving superhuman performance in numerous domains, from playing complex strategic games to diagnosing medical conditions to generating natural language. This resurgence has fundamentally transformed both academic research and practical applications of AI technology.

Core Objectives of AI

The overarching objectives of AI research and development can be categorized into several complementary goals. First, AI aims to automate tasks that are repetitive, time-consuming, or dangerous for humans to perform. Second, AI seeks to augment human capabilities by providing tools that enhance decision-making and productivity. Third, AI endeavors to solve complex problems that have resisted human efforts due to their scale, complexity, or the vast amount of data they involve.

Beyond these practical objectives, there is also a more philosophical aim: to understand intelligence itself. Through the process of creating intelligent machines, researchers gain insights into how intelligence functions, what its essential components are, and how information processing systems can achieve sophisticated reasoning and behavior.

Understanding these objectives is crucial because they shape how AI systems are designed, what metrics are used to evaluate success, and what kinds of problems are targeted for AI solutions.

Chapter 2: Core Components and Building Blocks

Algorithms: The Foundation of AI

At the heart of every artificial intelligence system lies an algorithm, which is a set of mathematical instructions and logical steps designed to process information, identify patterns, and make decisions.

Algorithms are the fundamental computational units that drive AI systems. Without algorithms, there would be no way to translate the goal of intelligent behavior into executable computer code.

AI algorithms vary enormously in their complexity, scope, and application. Simple algorithms might involve straightforward rules and logic, such as if-then statements that guide decision-making. More complex algorithms, particularly those used in modern AI, involve sophisticated mathematical operations including matrix operations, probability calculations, optimization procedures, and iterative learning mechanisms.

The quality and efficiency of an AI system depend heavily on the algorithms employed. A poorly designed algorithm might produce inaccurate results or require excessive computational resources to operate. Conversely, a well-designed algorithm can solve complex problems efficiently and produce reliable outputs. This is why algorithm research remains a central focus of AI development.

Data: The Fuel of Modern AI

If algorithms are the engine of AI, then data is its fuel. Modern artificial intelligence systems, particularly those based on machine learning, are fundamentally data-driven. They learn patterns, relationships, and regularities from data, rather than having these patterns explicitly programmed by humans.

The importance of data in AI cannot be overstated. The quantity of data available for training affects how well AI systems learn. The quality of data—its accuracy, completeness, and relevance—

determines whether the patterns learned are meaningful and applicable to real-world situations. The diversity of data ensures that AI systems can generalize their learning to situations they have not directly encountered.

Data collection and preparation represent significant portions of any real-world AI project. This process involves identifying relevant data sources, extracting and organizing data, cleaning data to remove errors and inconsistencies, and structuring data in formats suitable for algorithm processing. In many cases, data preparation consumes more time and effort than algorithm development or model training.

Computational Power: Enabling AI at Scale

The computational resources required to train and operate modern AI systems are substantial. Deep learning models, in particular, involve millions or billions of parameters and require immense amounts of calculation. The ability to perform these calculations quickly and efficiently is essential for practical AI applications.

The explosive growth in AI capabilities over the past decade has been enabled partly by dramatic increases in computational power. Modern graphics processing units, specialized AI accelerators, and distributed computing systems allow researchers and practitioners to tackle previously intractable problems. As computational resources continue to expand, new possibilities for AI applications emerge.

However, it is important to recognize that computational power is not unlimited. There are real costs associated with training large AI models, both in monetary terms and in environmental impact. The energy consumption required to train state-of-the-art models can be substantial, raising important questions about the sustainability and environmental responsibility of AI development.

Part Two: Machine Learning and Learning Paradigms

Chapter 3: Machine Learning Fundamentals

What Is Machine Learning?

Machine learning is a subset of artificial intelligence that focuses on creating systems capable of learning from data without being explicitly programmed for every possible scenario. Rather than having their behavior hardcoded by programmers, machine learning systems adjust their behavior based on patterns observed in data.

The fundamental premise of machine learning is that many tasks can be learned by analyzing examples. A machine learning system examines a collection of examples—called training data—and identifies underlying patterns and relationships. Once these patterns are learned, the system can apply this learned knowledge to new, unseen examples, making predictions or decisions about situations it has not directly encountered.

This learning-from-examples approach fundamentally differs from traditional programming, where a programmer explicitly specifies every rule and condition the program should follow. Machine learning trades explicit programming for automatic pattern discovery, allowing systems to adapt to changing conditions and handle complexity that would be impractical to program manually.

Supervised Learning: Learning from Labeled Examples

Supervised learning is the most commonly used machine learning paradigm. In supervised learning, the training data consists of input-output pairs. Each example includes both the input data and the correct answer, called the label or target. The machine learning algorithm learns to map inputs to outputs by analyzing these labeled examples.

A practical example of supervised learning is email spam classification. The training data consists of emails along with labels indicating whether each email is spam or legitimate. The algorithm learns patterns that distinguish spam from legitimate emails by

analyzing the training examples. Once trained, the system can classify new emails it has never seen before, predicting whether they are likely to be spam based on the patterns it learned.

Supervised learning is particularly effective for problems where the correct answers are known and can be provided as training data. Common applications include image classification, language translation, medical diagnosis, fraud detection, and sales prediction. The main limitation of supervised learning is that it requires labeled data, which can be expensive and time-consuming to produce.

Unsupervised Learning: Finding Hidden Patterns

Unsupervised learning addresses a different set of problems. In unsupervised learning, the training data consists only of inputs without corresponding output labels. The algorithm's task is to discover hidden structure, patterns, or organization within the data.

A common application of unsupervised learning is customer segmentation. A company might have data about customer purchase history, browsing behavior, and demographics, but no pre-defined categories. Unsupervised learning algorithms can discover natural groupings within this data, identifying customer segments with similar characteristics. These discovered segments might then be used for targeted marketing or personalized service delivery.

Unsupervised learning is valuable for exploratory data analysis, discovering unexpected patterns in data, and handling situations where labeled data is unavailable. However, evaluating the quality of unsupervised learning results is more challenging than evaluating supervised learning, since there is no ground truth to compare against.

Reinforcement Learning: Learning Through Interaction

Reinforcement learning represents a third major machine learning paradigm. In reinforcement learning, an agent learns by interacting with an environment, receiving rewards or penalties for its actions. The agent's goal is to learn a strategy that maximizes long-term cumulative reward.

Reinforcement learning is inspired by how biological organisms learn: through trial and error, with positive reinforcement strengthening successful behaviors and negative reinforcement discouraging unsuccessful ones. This learning mechanism is particularly appropriate for sequential decision-making problems where an agent must choose actions in a dynamic environment.

Applications of reinforcement learning include autonomous vehicles, game playing, robot control, and resource optimization. One notable achievement of reinforcement learning was the development of AlphaGo, a system that defeated world champions in the game of Go, a challenge that many believed would require decades for AI to overcome.

Chapter 4: Deep Learning and Neural Networks

Neural Networks: Inspired by Biology

Deep learning is a specialized subset of machine learning based on artificial neural networks, which are computational systems inspired by the structure and function of biological neural networks found in animal brains. While artificial neural networks are dramatically simplified compared to biological brains, they capture some essential principles of how biological brains process information.

An artificial neural network consists of interconnected nodes, often called neurons, organized into layers. The input layer receives data, hidden layers perform intermediate processing and feature extraction, and the output layer produces the final predictions or classifications. Each connection between neurons has an associated weight that determines the strength of the connection.

The power of neural networks lies in their ability to learn complex, non-linear relationships between inputs and outputs. By adjusting the weights of connections through the learning process, neural networks can represent sophisticated functions and patterns that simpler models cannot capture.

The Architecture of Deep Neural Networks

Deep neural networks are characterized by having multiple hidden layers between the input and output layers. The term deep refers to this multiplicity of layers, which can range from three or four layers in simpler networks to hundreds or thousands of layers in state-of-the-art models.

Each layer in a deep network performs a transformation on the data it receives from the previous layer. Early layers tend to learn simple features, while subsequent layers combine these simple features to recognize increasingly complex patterns. This hierarchical feature extraction is a key advantage of deep learning for tasks like image recognition and natural language processing.

The depth of networks comes with both advantages and challenges. Deeper networks can represent more complex functions and patterns in data. However, training deep networks presents technical challenges related to gradient flow and optimization. Innovations in architecture design, regularization techniques, and training procedures have addressed many of these challenges, enabling the successful training of very deep networks.

Training Neural Networks: Forward and Backward Propagation

Training a neural network involves finding the values of all the weights in the network that minimize the difference between the network's predictions and the actual correct answers. This is an optimization problem that involves calculating how each weight contributes to the overall error and then adjusting weights in directions that reduce error.

The primary algorithm used to train neural networks is called backpropagation, which efficiently calculates how each weight should be adjusted. During forward propagation, data passes through the network, and predictions are generated. During backward propagation, the error signal is propagated back through the network, and gradients are calculated for each weight.

Training a neural network is an iterative process. In each iteration, called an epoch, the network processes the training data, calculates gradients, and updates weights. Typically, many epochs are required

for a network to learn effectively. The process continues until the network's performance on validation data plateaus or begins to decline, at which point training is stopped to prevent overfitting.

Part Three: AI Applications and Techniques

Chapter 5: Natural Language Processing

Understanding Language Through AI

Natural Language Processing is a branch of artificial intelligence focused on enabling computers to understand, interpret, and generate human language in meaningful and contextually appropriate ways. Language is one of the most complex and nuanced forms of human communication, making NLP one of the most challenging areas of AI research.

The complexity of language derives from several factors. Language is ambiguous—the same words or phrases can have different meanings depending on context. Language involves subtle nuances and cultural references that are difficult to formalize. Language evolves continuously, with new words, expressions, and meanings emerging regularly. Additionally, different languages have fundamentally different structures and rules.

Despite these challenges, NLP has achieved significant progress. Modern NLP systems can perform tasks including translation between languages, sentiment analysis determining whether text expresses positive or negative sentiment, named entity recognition identifying people and places mentioned in text, and question answering systems that can respond to user queries.

Applications of Natural Language Processing

The practical applications of NLP are increasingly visible in daily life. Virtual assistants like Siri, Alexa, and Google Assistant rely on NLP to understand spoken commands and generate appropriate responses. Email systems use NLP-based spam filters to distinguish legitimate messages from spam. Machine translation systems like Google Translate apply NLP to translate text between languages, though human translation remains superior for nuanced content.

Search engines use NLP to better understand what users are searching for, not just matching keywords but understanding the intent behind queries. Sentiment analysis, powered by NLP, allows companies to monitor brand perception by analyzing social media posts and customer reviews. Automated text summarization can condense large documents into brief summaries, helping people quickly grasp key information.

These applications demonstrate that NLP is not merely an academic curiosity but a practical technology with real-world value and impact.

Chapter 6: Computer Vision and Perception

How AI Sees: Image Processing and Understanding

Computer Vision is the field of AI dedicated to enabling machines to interpret and understand visual information from images and videos. This field addresses the question of how computers can extract meaningful information from digital images, much as humans extract meaning from visual perception.

The challenges in computer vision are profound. While human vision seems effortless, it is actually the result of billions of years of biological evolution and development. A human infant takes years to develop full visual understanding. Creating computational systems that can understand images with human-like accuracy requires sophisticated algorithms and substantial learning.

Early approaches to computer vision relied on manually designed features and classical image processing techniques. Modern computer vision is dominated by deep learning approaches, particularly convolutional neural networks, which are specifically designed to process image data. These networks can learn to recognize objects, faces, text, and other visual elements with remarkable accuracy.

Real-World Applications of Computer Vision

Computer vision has enabled numerous practical applications that were previously impossible. Autonomous vehicles rely on computer vision systems to perceive their surroundings, identify pedestrians

and other vehicles, read traffic signs, and navigate safely. Medical imaging systems use computer vision to detect tumors, analyze X-rays, and assist radiologists in diagnosis.

Retail businesses use computer vision for checkout-free stores where customers can pick items and leave without interacting with cashiers, with the system tracking purchases through computer vision.

Security systems use computer vision for surveillance, facial recognition, and anomaly detection. Manufacturing plants use computer vision for quality control, identifying defects in products during production.

The widespread deployment of camera-equipped devices and improvements in computer vision algorithms have created unprecedented opportunities for visual intelligence applications.

Chapter 7: AI Applications Across Industries

Healthcare and Medical Diagnosis

Artificial intelligence is revolutionizing healthcare by enabling more accurate diagnosis, personalized treatment recommendations, and drug discovery. AI systems trained on medical imaging data can detect diseases like cancer, diabetic retinopathy, and cardiac conditions with accuracy comparable to or exceeding specialized physicians. Beyond diagnosis, AI helps predict patient outcomes, identify patients at high risk of complications, and recommend optimized treatment plans.

Pharmaceutical research, historically a slow and expensive process, is being accelerated by AI systems that can predict how molecular compounds will behave and identify promising drug candidates. AI is also improving healthcare administration by optimizing hospital operations, managing resources, and predicting patient admissions.

Finance and Business

In the financial sector, AI powers fraud detection systems that identify suspicious transactions in real time. Risk assessment models use AI to evaluate creditworthiness and determine appropriate lending decisions. Algorithmic trading systems use AI to analyze

market data and execute trades at speeds and scales impossible for human traders.

Beyond finance, AI optimizes business operations across industries. Supply chain management systems use AI to predict demand, optimize inventory, and coordinate logistics. Customer relationship management systems use AI to personalize interactions and predict customer churn. Pricing optimization systems use AI to determine optimal prices based on demand, competition, and other factors.

Transportation and Autonomous Systems

Autonomous vehicles represent one of the most ambitious applications of AI, requiring integration of computer vision, sensor fusion, decision-making systems, and real-time control. While fully autonomous vehicles remain limited in deployment, they promise to transform transportation, improve safety, and reduce congestion.

Beyond autonomous vehicles, AI powers optimization systems that plan efficient routes for delivery services, optimize traffic signal timing, and predict maintenance needs for transportation infrastructure.

Manufacturing and Robotics

Manufacturing has been transformed by AI-powered robotics and automation. Modern manufacturing facilities use robots guided by AI for precision assembly, quality control, and hazardous material handling. Predictive maintenance systems use AI to predict equipment failures before they occur, minimizing downtime and maintenance costs.

Part Four: Challenges, Ethics, and the Future

Chapter 8: Limitations and Challenges of AI

Technical Limitations

Despite remarkable achievements, artificial intelligence systems face significant limitations. AI systems require large amounts of training data, and their performance often depends heavily on data quality. Most AI systems excel in narrow, specific domains but lack the generalization ability humans possess, where knowledge and skills transfer easily across domains.

Interpretability remains a major challenge. Many sophisticated AI systems, particularly deep neural networks, function as "black boxes" where it is difficult to understand why the system made a particular decision. This lack of transparency is problematic in high-stakes applications like healthcare and criminal justice where decisions must be explained and justified.

AI systems can be fooled by adversarial inputs—carefully crafted variations of normal inputs that cause misclassification. These adversarial examples reveal fundamental vulnerabilities in AI systems that remain poorly understood and difficult to address. Additionally, AI systems often struggle with common sense reasoning and contextual understanding that humans find trivial.

Data-Related Challenges

The quality and appropriateness of training data fundamentally limits AI system performance. Data that is incomplete, biased, or unrepresentative leads to AI systems that make biased or poor decisions. Data privacy concerns arise from the need to collect and store large amounts of data, often including sensitive personal information. Data security challenges emerge from the need to protect collected data from theft and misuse.

Many AI applications suffer from data scarcity. While large companies can accumulate massive datasets, many domains and applications lack sufficient data for training AI systems effectively. Additionally, labeled data, which is necessary for supervised learning, is expensive and time-consuming to produce.

Chapter 9: Ethics and Responsible AI Development

Bias and Fairness

One of the most pressing ethical concerns in AI is the problem of bias. AI systems learn patterns from historical data, and if that historical data reflects human biases and discrimination, the AI system will inherit and potentially amplify these biases. An AI hiring system trained on data reflecting historical discrimination against certain groups will perpetuate that discrimination.

Addressing bias requires attention at multiple stages: during data collection to ensure representative data; during algorithm design to incorporate fairness constraints; during training to monitor for discriminatory outcomes; and during deployment to continuously assess and mitigate real-world harms.

Privacy and Data Security

AI systems require access to vast amounts of data, often including sensitive personal information about individuals. This creates significant privacy risks. Data breaches can expose private information to unauthorized parties. Even without breaches, the collection and analysis of data raises questions about what information is collected, how it is used, who has access to it, and whether individuals have consented to its use.

Privacy-preserving approaches to AI development aim to develop AI systems that derive insights from data while minimizing privacy risks. Techniques include data anonymization, differential privacy, federated learning, and encryption methods that allow computation on encrypted data.

Transparency and Accountability

When AI systems make decisions affecting individuals, those decisions should ideally be explainable. Particularly in domains like criminal justice, healthcare, and lending, people have a right to understand why a decision was made and to challenge or appeal that decision. However, many sophisticated AI systems cannot easily explain their decisions.

Accountability frameworks must establish who is responsible when AI systems cause harm. Is responsibility with the developers who created the system, the organizations deploying it, the data collectors who provided training data, or others? Clear lines of accountability must be established to encourage responsible development and deployment of AI systems.

AI Safety and Alignment

As AI systems become more autonomous and consequential, ensuring they remain aligned with human values becomes increasingly important. An AI system that optimizes for a specified objective might pursue that objective in harmful or unintended ways if not carefully designed. For example, an autonomous system optimizing for industrial productivity might cause environmental damage or harm workers if not constrained by appropriate safety measures.

Alignment research focuses on ensuring that as AI systems become more powerful and autonomous, they remain beneficial and do not pursue objectives that conflict with human wellbeing. This involves technical research into safe AI design and governance questions about how society should regulate and oversee AI development.

Chapter 10: The Future of Artificial Intelligence

Emerging Trends and Developments

The field of artificial intelligence continues to evolve rapidly, with new capabilities and applications emerging continuously. Transformer-based language models have demonstrated remarkable capabilities in understanding and generating human language, leading to powerful systems like those behind modern chatbots and virtual assistants.

Multimodal AI systems, which can process and integrate information from multiple types of data including text, images, and audio, are becoming increasingly sophisticated. These systems can understand relationships between different types of information, enabling new applications.

Few-shot and zero-shot learning approaches that allow AI systems to learn from very small amounts of data represent an important direction, potentially reducing data requirements for AI applications. Continual learning systems that can adapt and learn throughout their deployment, rather than being static once trained, promise to make AI systems more flexible and practical.

The Path Toward More General Intelligence

Current AI systems excel at narrow tasks but lack the general intelligence that humans possess. An AI system that can diagnose medical images cannot translate languages or play chess at expert level; a different specialized system is required for each task. Creating artificial general intelligence—systems with broad cognitive abilities comparable to human intelligence across diverse domains—remains an important long-term research goal.

The path to artificial general intelligence involves numerous unsolved problems. How can systems acquire common sense reasoning? How can knowledge transfer across domains? How can systems learn from fewer examples? These questions remain active areas of research.

Societal Implications and Governance

As AI becomes increasingly integrated into society, governance questions become more pressing. How should AI development be regulated? What rights do individuals have regarding AI decisions affecting them? How should society ensure that AI benefits are distributed broadly rather than concentrated among a few powerful entities?

International bodies, governments, and organizations are developing frameworks to guide responsible AI development and deployment. These include ethical guidelines, regulation proposals, and governance structures aimed at ensuring AI development benefits society broadly while minimizing harms.

Conclusion

Artificial intelligence has evolved from a speculative concept into a transformative technology reshaping nearly every domain of human activity. Understanding the fundamentals of AI—its core concepts, learning paradigms, applications, and limitations—is increasingly essential for making informed decisions about society's relationship with this powerful technology.

This document has traced the foundations of AI from its basic definitions through its evolution, covered core machine learning and deep learning concepts, explored diverse applications across industries, and examined critical challenges including technical limitations, ethical concerns, and governance questions.

The future of AI remains uncertain but undoubtedly consequential. The decisions made by researchers, developers, policymakers, and society regarding AI development will shape the technology's trajectory and its impact on humanity. By developing a solid understanding of AI fundamentals, individuals can participate more effectively in these crucial decisions and navigate a world increasingly influenced by artificial intelligence.

As this technology continues to advance, maintaining both the optimism about its potential benefits and the caution about its risks remains essential. Through responsible development, thoughtful governance, and broad engagement with AI technology and its implications, society can work toward ensuring that artificial intelligence benefits humanity broadly while minimizing potential harms.

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