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Introduction to Computer Science

Introduction to Computer Science

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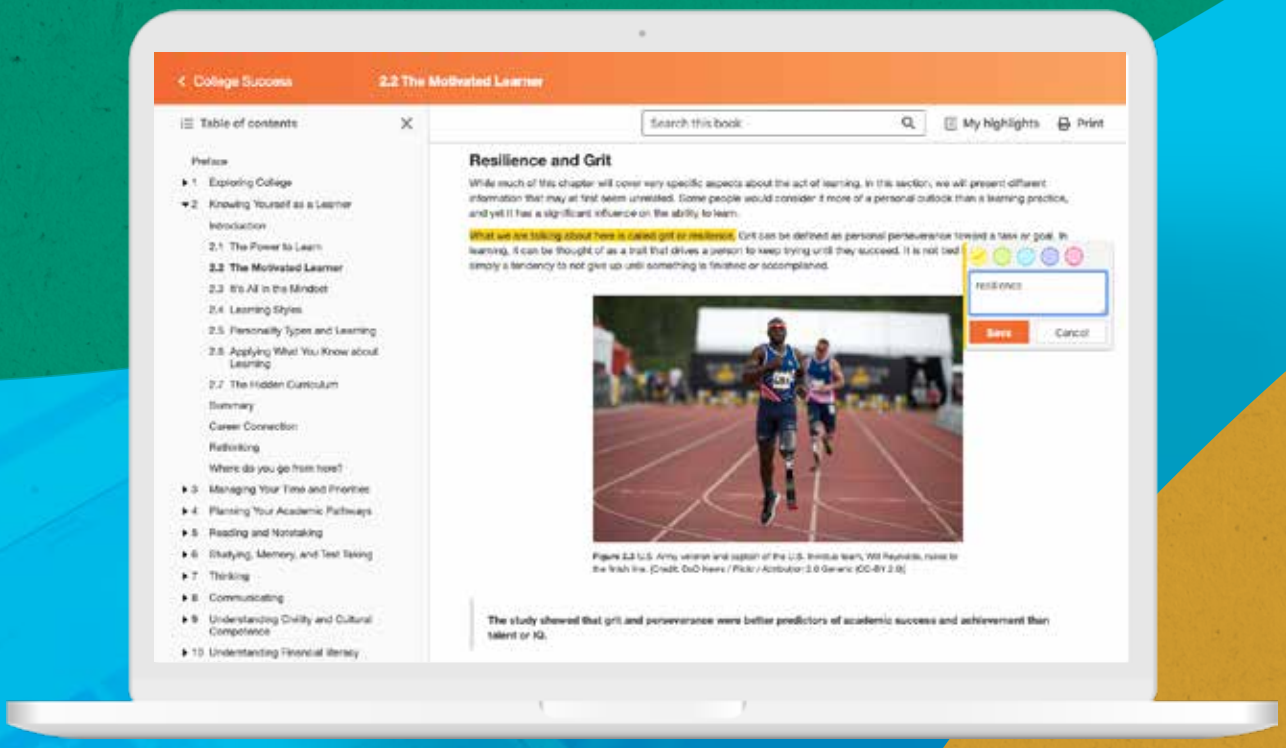

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Preface

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About *Introduction to Computer Science*

Introduction to Computer Science provides a comprehensive foundation in core computer science concepts and principles, aligning with the scope and sequence of most introductory computer science courses. The textbook serves as an engaging entry point for students pursuing diverse fields of study and employment, including computer science, business, engineering, data science, social sciences, and related disciplines. By addressing a broad learner audience—ranging from computer science majors to non-majors—the book offers a thorough introduction to computational thinking and its applications across multiple domains.

Introduction to Computer Science is designed to be both interactive and practical, focusing on real-world applications that showcase how core computer science concepts can be used to solve complex problems. Students will explore foundational topics, such as algorithms, data structures, computer systems organization, and software development, using an array of engaging, hands-on activities. The textbook integrates meaningful learning experiences through chapter-based scenarios, problem-solving exercises, and project-based assessments that encourage students to apply what they learn in authentic contexts.

Features such as embedded coding exercises, industry insights, and explorations of emerging technology trends provide a holistic approach to learning that extends beyond theory. With a forward-looking perspective, Introduction to Computer Science prepares students to engage with advanced topics in computer science, such as machine learning, cybersecurity, and cloud computing, ensuring they have a solid foundation for continued study and future professional success.

Coverage and Scope

The authors and contributors consulted with other educators and industry professionals from a range of institutions and organizations in order to ensure that *Introduction to Computer Science* meets the diverse needs of both computer science majors and non-majors. The book is structured into five main parts, each focusing on critical areas of the discipline:

- **Part 1: Problem Solving and Algorithms** This section introduces students to the foundations of computer science, focusing on computational thinking, problem-solving techniques, and algorithm design. Topics include data structures, formal properties of algorithms, and algorithmic paradigms. Through practical examples and exercises, students will develop the skills needed to construct and analyze algorithms and understand their applications across various domains.
- **Part 2: Realizations of Algorithms** In this part, students explore how algorithms are realized in hardware and software, starting with low-level programming languages and moving into hardware design and computer systems organization. Students will learn about models of computation, machine-level representation, processor architectures, and memory hierarchy. This foundational understanding enables students to see the connections between abstract algorithms and their physical implementations.
- **Part 3: Designing and Developing Software Solutions** This section covers the principles of software development, high-level programming languages, and data management. Students will learn the fundamentals of software engineering and gain hands-on experience with both relational and non-relational database systems. Emphasis is placed on designing robust software solutions and managing complex data structures, ensuring students are well-prepared for future roles in software development and engineering.
- **Part 4: Building Modern End-to-End Solutions to Business and Social Problems** Students apply their knowledge to design and build web and cloud-native applications. This part includes examples of modern web architectures, responsive design techniques, and cloud-based solutions using PaaS and FaaS technologies. Additionally, students will explore the development of hybrid multi-cloud digital solutions, providing them with experience in addressing complex business and social challenges using modern computing technologies.
- **Part 5: Human-Centered Responsible Computing** The final section delves into the ethical and societal implications of computing. Topics include cybersecurity, governance of cyber resources, and responsible computing practices. Students will learn to navigate the complexities of cybersecurity and governance while considering the broader impacts of technology on society.

Each core concept is designed to build on the previous one, ensuring a coherent learning experience that provides students with a clear view of the field. The book's approach enables students to not only understand the principles of computer science but also see how they can be applied to address practical, real-world problems.

Pedagogical Foundation and Features

The *Introduction to Computer Science* textbook is designed to engage students through a combination of practical, real-world applications and thought-provoking scenarios that promote critical thinking and a deeper understanding of core concepts. The pedagogical approach is centered on making computer science relevant and accessible for students from diverse backgrounds, whether they are pursuing a degree in computer science or exploring how computational thinking can be applied to their respective fields. To support this vision, the textbook incorporates several key features:

- **Concepts in Practice** features present how computer science concepts are applied in real-world contexts by both professionals and non-professionals. Each box profiles personas and practical applications that demonstrate how core topics, such as algorithms, data management, and software engineering, are utilized across various industries. The purpose is to inspire students—particularly non-majors—by showing them the value of computer science in solving everyday challenges and to foster a greater appreciation for the discipline.
- **Global Issues in Technology** features help students think globally about the societal impact of technology. These boxes highlight how technology affects communities and economies around the world and may introduce topics such as digital equity, environmental sustainability, and global data security. Students are encouraged to consider the broader implications of technological advancements and to think critically about their potential to drive positive change or create new challenges in global contexts.
- **Industry Spotlight** boxes focus on specific industry challenges and how technology progress or application can help solve them. *Industry Spotlight* features introduce students to various sectors—such as healthcare, finance, education, and law—providing a glimpse into how computer science can drive innovation and efficiency. By connecting theoretical concepts to industry-specific problems, these features encourage students to explore the wide-ranging applications of computer science and understand its value across different fields.
- **Link to Learning** features provide a very brief introduction to online resources—videos, interactives, collections, maps, and other engaging resources that are pertinent to students' exploration of the topic at hand.
- **Technology in Everyday Life** features connect computer science principles to students' personal experiences and the world around them. These boxes explore how technology intersects with daily life or current events, making computer science concepts more relatable and relevant. Some features may prompt students to think creatively and propose their own ideas for applying computer science solutions to familiar scenarios.
- **Think It Through** scenarios present students with thought-provoking dilemmas or complex problems related to the use of technology. Students are asked to reflect on ethical questions, problem-solving strategies, and real-world decision-making processes. These features emphasize that not all problems have straightforward answers and encourage students to weigh the pros and cons of different approaches. By navigating these scenarios, students learn to develop judgment skills that are crucial in business and technology environments.

Overall, these features are integrated throughout the material to foster active learning, critical thinking, and an appreciation for the practical applications of computer science. By connecting theory to practice and encouraging students to explore real-world issues, *Introduction to Computer Science* provides a meaningful and supportive learning experience that equips students with the knowledge and skills necessary for success in their academic and professional journeys.

Answers to Questions in the Book

The end-of-chapter Review, Conceptual Questions, Practice Exercises, Problem Sets, Thought Provokers, and Labs are intended for homework assignments or classroom discussion; thus, student-facing answers are not provided in the book. Answers and sample answers are provided in the Instructor Answer Guide, for

instructors to share with students at their discretion, as is standard for such resources.

About the Author

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Dr. Jean-Claude Franchitti is a Clinical Associate Professor of Computer Science and the Associate Director of Graduate Studies for the CS Master's program in Information Systems at NYU Courant Institute. He earned his M.S. in Electrical Engineering (1985) and his M.S. and PhD. in Computer Science from the University of Colorado at Boulder (1988, 1993). He is the founder and CEO of Archemy, Inc., and has over 40 years of experience in a myriad of industries, and over 30 years of teaching and corporate training experience. He held executive positions in large US-based corporations and leading business technology consulting firms such as Computer Sciences Corporation. He has been involved in many large business technology strategy and modernization projects and has a proven record of delivering large scale business solutions. He was the original designer and developer of jcrew.com and the suite of products now known as IBM InfoSphere DataStage. He also created the Agile Enterprise Architecture Management (AEAM) methodology and a corresponding framework that are patented components of the Archemy business evolution platform. He has developed partnerships with many companies at New York University to incubate new methodologies, transition research into business solutions, help recruit skilled graduates, and increase the companies' visibility. Dr. Franchitti has been a reviewer member on several industry standards committees including OMG, ODMG, and X3H2. Dr. Franchitti taught at CU-Boulder, Denver University, Columbia University, NYU SCPS, before joining NYU Courant Institute in 1997. He has extensive experience with corporate training and developed and delivered training and mentoring programs for the top corporate education providers. He conducted research as part of several NSF- and DARPA-funded research programs.

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We have compiled additional resources for both students and instructors, including Getting Started Guides, an instructor's answer guide, test bank, and image slides. Instructor resources require a verified instructor account, which you can apply for when you log in or create your account on OpenStax.org. Take advantage of these resources to supplement your OpenStax book.

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PowerPoint lecture slides. The PowerPoint slides provide learning objectives, images and descriptions, feature focuses, and discussion questions as a starting place for instructors to build their lectures.

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Academic integrity builds trust, understanding, equity, and genuine learning. While students may encounter significant challenges in their courses and their lives, doing their own work and maintaining a high degree of authenticity will result in meaningful outcomes that will extend far beyond their college career. Faculty, administrators, resource providers, and students should work together to maintain a fair and positive experience.

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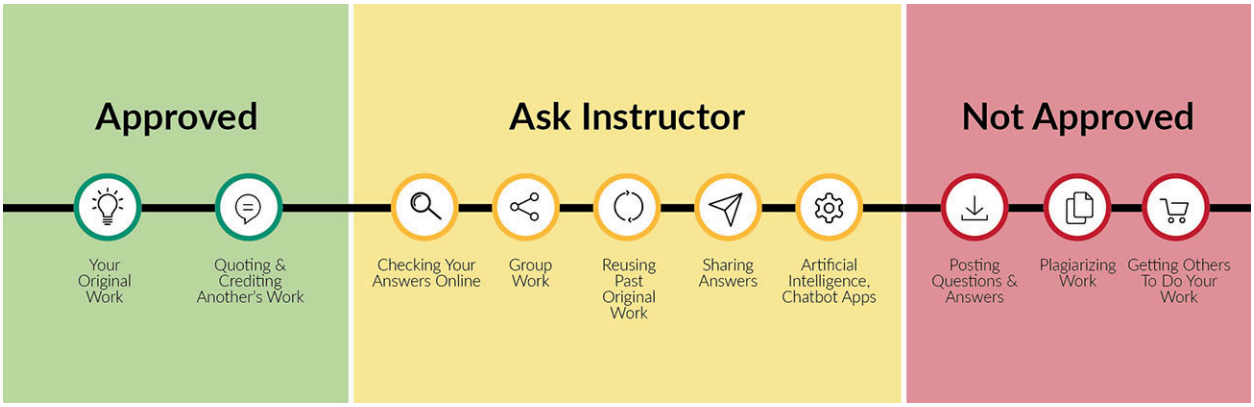

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At OpenStax we are also developing resources supporting authentic learning experiences and assessment. Please visit this book's page for updates. For an in-depth review of academic integrity strategies, we highly recommend visiting the International Center of Academic Integrity (ICAI) website at https://academicintegrity.org/ (https://academicintegrity.org/).

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1 Introduction to Computer Science

Figure 1.1 Computing is everywhere, affecting everyone, for better and for worse. (credit: modification of "Whereas design is expansive, engineering is narrowing" by Jessie Huynh/Critically Conscious Computing, CC0)

Chapter Outline

1.1 Computer Science
1.2 Computer Science across the Disciplines
1.3 Computer Science and the Future of Society

Introduction

This textbook will introduce you to the exciting and complex world of computer science. In this chapter, you'll review the history of computer science, learn about its use in different fields, and explore how computer science will impact the future of society. Computer science is a powerful tool, and computer scientists have used their vast knowledge of technology to create and implement technology that has transformed societies around the world.

This book will also introduce the computational thinking aspects of problem-solving and analytical thinking that enable the study of algorithms, which are step-by-step instructions for solving specific problems or carrying out computations. Therefore, this book also covers algorithms and their realization via programming languages, computer systems architectures, networks, and operating systems. The book subsequently delves into computer science areas that enable the design and development of software solutions using high-level programming languages (i.e., coding languages designed to be more intuitive for humans), architectural styles and related models, data management systems, and software engineering. Finally, the book demonstrates how to leverage computer science realizations and areas to build modern end-to-end solutions to business and social problems. In particular, the book focuses on modern web applications development, cloud-native applications development, and hybrid Cloud/on-premise digital solutions. The various chapters emphasize how to achieve software solution qualities such as performance and scalability. The last chapter explains how to secure software applications and their applications in the context of various cyber threats. It also explains how to make the right decisions about using computers and information in society to navigate social, ethical, economic, and political issues that could result from the misuse of technology. To conclude this textbook, we'll introduce you to cybersecurity and help you understand why responsible computing is essential to promote

ethical behavior in computer science. The book is designed to help students grasp the full meaning of computer science as a tool that can help them think, build meaningful solutions to complex problems, and motivate their careers in information technology (IT).

You're already familiar with computer science. Whenever you use a laptop, tablet, cell phone, credit card reader, and other technology, you interact with items made possible by computer science. Computer science is a challenging field, and the outputs of computer science offer many benefits for society. At the same time, we have to be cautious about how we use computer science to ensure it impacts society in ethical ways. To help you understand this, the next section will explain how computer science came to be and discuss the field's potential.

1.1 Computer Science

Learning Objectives

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

- Discuss the history that led to the creation of computer science as a field
- Define computer science
- Assess what computer science can do, as well as what it should not do

The field of **computer science (CS)** is the study of **computing**, which includes all phenomena related to computers, such as the Internet. With foundations in engineering and mathematics, computer science focuses on studying algorithms. An **algorithm** is a sequence of precise instructions that enables computing. This includes components computers use to process information. By studying and applying algorithms, computer science creates applications and solutions that impact all areas of society. For example, computer science developed the programs that enable online shopping, texting with friends, streaming music, and other technological processes.

While computers are common today, they weren't always this pervasive. For those whose lives have been shaped by computer technology, it can sometimes seem like computer technology is ahistorical: computing often focuses on rapid innovation and improvement, wasting no time looking back and reflecting on the past. Yet the foundations of computer science defined over 50, and as much as 100, years ago very much shape what is possible with computing today.

The Early History of Computing

The first computing devices were not at all like the computers we know today. They were physical calculation devices such as the abacus, which first appeared in many societies across the world thousands of years ago. They allowed people to tally, count, or add numbers (Figure 1.2). Today, abaci are still used in some situations, such as helping small children learn basic arithmetic, keeping score in games, and as a calculating tool for people with visual impairments. However, abaci are not common today because of the invention of number systems such as the Arabic number system (0, 1, 2, 3, . . .), which included zero and place values that cannot be computed with abaci. The concept of an algorithm was also invented around this time. Algorithms use inputs and a finite number of steps to carry out arithmetic operations like addition, subtraction, multiplication, and division, and produce outputs used in computing. Today's computers still rely on the same foundations of numbers, calculations, and algorithms, except at the scale of billions of numbers and billions of calculations per second.

To introduce a concrete example of an algorithm, let us consider binary search algorithm, which is used to locate a number in a sorted array of integers efficiently. The algorithm operates by repeatedly dividing the search interval in half to perform the search. If the number being searched is less than the integer in the middle of the interval, the interval is narrowed to the lower half. In the alternative, the interval is narrowed to the upper half. The algorithm repeatedly checks until the number is found or the interval is empty.