Computer Science Principles

The Foundational Concepts of Computer Science

For AP® Computer Science

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with a foreword by Pindar Van Arman

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9 – Impact of Computing

Primary Course Goal and Learning Outcomes: Impact of Computing

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Introduction

Just a few decades ago, computers were oddities, operated by specialists and housed at universities, research facilities, and large corporations. With the introduction of the personal computer in the 1970s and 1980s, computing moved into homes, schools, and small businesses. During the 1990s the Internet became mainstream, connecting these computers—and their users—to each other. The first decade of the twenty-first century saw smartphones and other always-on devices make this digital connectivity nearly ubiquitous. While there has long been debate about computing's impact on society—note the Justice Department's 1990s investigation of Microsoft—it is only during the last decade that society as a whole has really started to grapple with computing's impact on society, both positive and negative. The mantra of Silicon Valley developers—that they're making the world a better place—began as a statement of optimistic faith in the power of technology before becoming a cliché and then a punchline. The beneficial effects of computing are impossible to deny, but it has become increasingly difficult to ignore the harms that offset the benefits of innovation. Additionally, computer networks have presented challenges to existing laws, such as those around intellectual property, privacy, and child protection. As computer users and

programmers, we have an obligation to consider the impacts of our actions. We must ask ourselves whether our actions are ethical, not just legal, and we must learn about the steps we can take to protect ourselves and others, particularly those who cannot protect themselves, such as children.

Impact: Making the World a Better Place

Computers have provided exciting new tools for expressing creativity, solving problems, and enabling communication. Two decades into the twenty-first century, there is a hardly an area of human activity that remains untouched by the power of digital computing.

In the photo editing and web design units of this books, we learned specific methods for using computers to showcase creativity. Many of today's most popular applications—from TikTok and Instagram to GarageBand and Canva—allow for the creation and sharing of images, videos, music, and more. There is little doubt that these easy-to-use and inexpensive (or free) tools have transformed popular culture.

As we saw in the compression, security, and programming units, computers can be used to find solutions to previously intractable issues. From deciding what song to listen to next to finding cures for diseases and sending humans into space, algorithms have become indispensable for solving problems both small and large.

The true power of computers only became apparent when they were networked together. One of computing's most significant impacts has been to enable communication and collaboration. Email, text messaging, and video conferencing have changed how we talk to each other. Services like Facebook and YouTube have transformed how we relate to our peers, families, celebrities, and politicians.

Digital communication enables new forms of collaboration. Git repositories like GitHub allow coders to work on programs simultaneously, while students can use tools like Google's G-Suite to coordinate class projects. Thanks to the Internet, such collaboration can take place among people who live thousands of miles from each other.

Computers also foster innovation and creativity by providing more opportunities for people to display and share their work more easily. Platforms and software like WordPress, YouTube, and Instagram allow artists and other creative workers to find audiences and engaged communities that may not have even existed before the rise of ubiquitous digital communication.

The benefits of easy communication, collaboration, and sharing can be seen clearly in free and open source software (FOSS). Open source projects can allow people to build on top of existing ideas, focusing on innovation without the constant need to reinvent the wheel. According to a 2012 estimate, if the FOSS operating system Debian—including the Linux Kernel, the GNU tools, and thousands of software

packages—were to be developed from scratch, it would cost over nineteen-billion dollars. Other flavors of Linux, like Ubuntu, benefit from not having to redevelop all this software, as does the commercial operating system MacOS, which shares much of the underlying code. Projects like the Raspberry Pi, which includes an optimized variant of Debian, and much of the Internet, which runs disproportionately on Linux servers, would not exist without this spirit of collaboration.

Obstacles: The Digital Divide

Free and open source software reflects some of the most utopian possibilities of the computer revolution, but even here obstacles remain that prevent certain groups from fully participating. Indeed, a **digital divide** characterizes the computing field, holding people back along lines of gender, race, socioeconomic status, geography, disability or accessibility needs, and more.

One aspect of the digital divide has been access to the Internet itself. Funding for schools to provide on-campus access has been growing, but having access to the Internet at home seems to be an important indicator of academic success. Having broadband at home is directly related to socioeconomic status as well as geography since rural Internet access is often nonexistent, prohibitively expensive, or unusably slow. More affordable home Internet prices could help narrow this gap, but there are deep political divides as to how to achieve this goal, with proposed solutions including both decreased and increased regulation, public investment in infrastructure, municipal broadband, and cooperatives.

Online censorship falls along similar lines as the digital divide in internet access. Large online platforms have shown algorithmic racial bias when deciding when to leave or remove content that has been flagged as hateful. One study showed that white men receive more protection from hateful speech than women or people of color! In policing content, these platforms seem to deploy algorithms that negatively assess language more often used by minority groups.

The digital divide affects people with disabilities in terms of both access to information and greater online abuse. Laws exist that require websites and applications to provide certain accessibility options, so for example, a visually impaired person using a screen reader could still access the resource. Many disabilities, however, are not addressed by these tools, and compliance is far from universal. Online abuse can also discourage people with disabilities from using the Internet. More and better tools to prevent such abuse could improve the online experience for people with disabilities and other groups facing targeted harassment.

Computer science faces a massive and growing gender gap. Only a quarter of programming jobs are held by women. In 1984, 37 percent of computer science majors were women, but as of 2014 only 18 percent were. A 2019 study predicted that if current trends hold it would take one-hundred years for computer science researchers to achieve gender parity. This gender gap cannot be explained through any one cause. STEM-related toys have been marketed mainly to boys, and oftentimes boys have received more encouragement in developing

an interest in technology (programs like Girls Who Code seek to close this early educational gap). And many women who seek to enter the field have been discouraged by an unwelcoming or even hostile climate, including outright discrimination and harassment. Whatever the cause, the gender gap has been economically damaging as necessary and lucrative jobs have gone unfilled. Moreover, engineers, like other people, inevitably work from their own perspectives, which has overwhelmingly meant male perspectives, leaving potential products undeveloped and potential markets unserved.

Lack of home broadband along socioeconomic and geographic lines, racial disparities in online censorship and protection against hateful conduct, lack of accessibility, and the preponderance of male software engineers are only a few aspects of the digital divide both in the United States and globally. Recognizing these obstacles to everyone's full and equal participation in the digital world is a first step toward ensuring that everyone can benefit from the positive impacts of computing. As long as entire groups of people remain underrepresented as creators and users of technology, the impact of technological innovation will not be able to reach its full potential.

Effects: It's Complicated

In the sections above, we've considered some of technology's positive impacts and the obstacles many face when trying to participate in the digital realm. Technology's impacts have not, however, been entirely beneficial. Technological innovation has had many effects on society, culture, and the economy, some of which have been harmful,

intentionally or otherwise. Innovations that were created with the best intentions have had unintended consequences. Finding the balance and considering the tradeoffs between technology's beneficial and harmful effects can be tricky. Some recent or emerging technologies that present us with a mix of beneficial and harmful effects include social media, ride-sharing apps, and virtual reality.

Few technologies have impacted how we communicate in the twenty-first century more than social media, and there is little doubt that social media has brought many benefits. Sites like Facebook, Twitter, and Instagram have enabled people to make and maintain connections with many more people, even people who live thousands of miles away. These sites have also helped introverts connect with people in ways that feel more comfortable and have helped others to spread social awareness. On the other hand, research has found that heavy social media use can lead to anxiety, depression, and lower sleep quality. Social media can promote unhealthy comparisons with others, oftentimes leading to body image issues and cyberbullying. On a broader level, social media has been used to spread misinformation and outright lies, threatening democratic discourse and institutions throughout the world. Assessing whether the benefits are worth the cost is no easy task, and there is an enormous amount of evidence to stack up on either side. When making such assessments, though, it is important to remember that innovations cannot be considered in isolation. We need to weigh their impacts on society as a whole.

Just as social media has transformed how we communicate, ride-sharing apps seek to transform how we get around. These apps, however, have both positive and negative economic effects. Many drivers for companies such as Uber and Lyft like the flexibility that these apps allow. They can set their own hours and supplement income from other jobs, and more income means more spending, potentially benefitting their communities. On the other hand, if people choose to use ride-sharing apps rather than ride public transportation, we are likely to see increased automobile emissions and reduced government funding for transit, leaving those who rely on buses and trains as their sole means of transportation vulnerable. A full tally of the benefits (e.g., reduced drunk driving, less need for individual car ownership) and harms (e.g. low wages, increased congestion, lack of accessibility) of ride-sharing apps is outside the scope of this book and is the subject of a vigorous public debate. As we develop our own perspectives, though, it is important to consider both sides with a fair mind.

Along with technology's social and economic effects, its cultural impact should not go unexamined. Virtual reality (VR) is an emerging technology that could have a tremendous cultural effect. People could have the opportunity to experience other cultures through simulations, broadening their horizons without the need to travel thousands of miles. They could learn the norms and traditions of other cultures without embarrassing mistakes and satisfy their curiosity without risk of offending real people. However, if VR becomes a replacement for rather than a supplement to real cultural exchange then people would

lose the kind of immersive experience that enables a deeper understanding of other cultures. VR tourism could enable hyper-realistic "visits" to historical landmarks without experiencing the context of the countries where these landmarks are located. Many residents of hyper-touristed cities like Barcelona or Paris might welcome the reduced traffic, but others would lose the economic benefits of tourism. Either way, VR offers both the possibility of enabling cultural experiences that would not be possible otherwise and the threat of supplanting deeper real-world culture exchange that cannot be simulated.

Beyond these three examples, there are countless ways in which new technologies bring both positive and negative social, economic, and cultural impacts. Smartphones have put powerful computers and the potential of the entire Internet into our pockets but have also left us distracted, making it difficult to focus. Self-driving trucks might reduce highway crashes and increase efficiency while also putting millions of drivers out of work. Streaming video and inexpensive audio-visual equipment allows us to enjoy movies in the comfort of our own home but without the communal experience of sitting with others in a theater. When we develop new technologies—whether hardware or software—it is critical that we take a deep look into all the different ways these innovations can affect the world around us.

Intellectual Property

Let's say you've written the next hot app, recorded a song that you're sure is going to be a smash hit, or written the great American novel? What stops someone from coming along and copying your innovation? This issue is at least as old as the printing press, but digital technology makes it even more acute since one of the features of digital artifacts is that they are endlessly reproducible without any loss of quality. Governments have legislated a variety of solutions to this problem that are broadly grouped under the umbrella of intellectual property (IP). These are rights granted to authors and inventors for exclusive control of their creations, usually for a limited period of time. IP rights seek to promote innovation through the promise of financial gain, but when applied too broadly or for too long they can have the effect of stifling innovation by preventing the next generation of creators from building on the innovations of their predecessors. There is a long-running societal debate underway on appropriate levels of IP protections. What kinds of creations should receive what kinds of protection and how long should these protections last?

IP rights apply to intangible goods, so navigating them can sometimes be tricky. Following best practices and knowing existing laws can make it easier to protect your IP while respecting others'.

A patent is one form of intellectual property. **Patents** allow inventors to exclude others from using their inventions without permission and can last up to twenty years. Although patents have historically been

applied to physical inventions, they can also be obtained for software. Legal and filing fees for a patent can run to several thousand dollars, and they can be difficult to defend in court.

Copyright is another form of intellectual property, which protects original forms of expression. In the United States, software is legally considered as a type of literary work for the purposes of copyright. In the U.S., copyright applies once a work is fixed in tangible form. It is not strictly necessary to register a work in order to receive copyright protections. However copyright registration provides for stronger protections under U.S. law and typically costs around $50. In the United States, copyright can last for the life of the author plus up to seventy years. The law does not prohibit "fair use" of a copyrighted work. Fair use allows certain exceptions to copyright for purposes such as education, news, and reviews, among others.

Trademarks protect brand names and logos in order to distinguish one company's product from other products on the market. Trademarks protect the source of a product rather than the product itself, so as nearly every soft drink manufacturer on the planet can tell you, there's no law against putting brown bubbly sugar water in a bottle or can and selling it. If you label your bottles as "Coca-Cola," however, you can expect to hear from a certain large corporation's lawyers very soon. It typically costs a few hundred dollars to register a trademark, which can last for a decade with the option to renew indefinitely.

IP can be a controversial topic. Mark Twain famously believed that copyright should last forever, like other forms of property, while others argue that high drug prices enabled by pharmaceutical patents lead to countless unnecessary deaths and so should not exist at all (Drug companies would respond that without the profits enabled by patents, these lifesaving pharmaceuticals would never be developed in the first place). Many others have staked out positions between these two extremes. With debates around IP law unlikely to be resolved anytime soon, developers and artists have worked together with lawyers to create licenses that promote cooperation and sharing. Two examples of such licenses can be found in free and open source software and Creative Commons.

Free and open source software allows you to use and build upon others' work and to allow others to use and build upon your work. The original free software license, the GNU General Public License (GPL), was written by Richard Stallman in 1989. It allows anyone to use, modify, or sell the licensed software for any purpose. The GPL is a "copyleft" license, which means that any new software built by modifying the original source code must also be licensed under the same terms. In this way, it uses copyright not to restrict access to IP but to promote cooperation. Some newer FOSS licenses, such as the BSD License and the Apache License are "permissive," that is they don't impose copyleft's share-alike conditions on derivative works. Whatever license is used, having access to the source code of free and open source software has security benefits since it is easier find—and fix—backdoors and other vulnerabilities.

Creative Commons is a non-profit organization founded in 2001 by IP lawyer Lawrence Lessig and others. It offers six main licenses that promote sharing of copyrighted works. Creative Commons licenses allow creators to permit others to use their work, subject to certain conditions, without the need to seek permission. Creative Commons licenses function much like open source licenses and give creators an array of options that include allowing commercial or non-commercial use, permitting modifications of the work with or without the requirement to share-alike (imposing the same license on derivative works), and requiring or not requiring that attribution be given to the original author. In this way, Creative Commons allows creators to open up their work to be reused and remixed in a flexible and easy-to-understand manner.

Ethics

When designing software and using computers—as in other aspects of life—there are clear laws in place that prohibit certain actions. Using a computer to steal, spread malicious software, or plagiarize others' work is illegal, and breaking laws comes with consequences, including the possibility of criminal prosecution or civil penalties. However, the law provides, at best, a bare minimum standard of conduct. Just because something is legal doesn't make it right.

Ethical computing demands that as users and developers we hold ourselves to a higher standard. Ethics refers to the principles, values, standards, and practices that guide individuals and groups in doing what is right. Bullying, using data for nefarious purposes, or gaining

access to systems that you don't have authorization to access may or may not be illegal, depending on the circumstances, but these activities are probably not ethical. These examples are relatively clear but other ethical questions can be more muddled, and philosophers have argued since ancient times about which principles should guide moral values. Should we seek the greatest good for the greatest number, as utilitarians insist, or should we follow some version of the golden rule and do unto others as we would have them do unto us? These questions are not easy to resolve, but by weighing them we can develop our own personal and collective values. With this moral framework, we will have a better capacity to design innovations that take ethics into account.

Privacy and Security

The concepts of privacy and security are often confused, and they are often violated simultaneously, as during a data breach. While related, they are distinct concepts. **Privacy** deals with your personal information, how it is stored, and how it is shared. **Security**, on the other hand, refers to the steps companies take to protect your data. Protecting our privacy and security online often comes with tradeoffs, such as loss of convenience, but responsible computer users should not ignore these concerns.

How a company deals with personal data is usually spelled out in a lengthy end-user license agreement (**EULA**) that most people agree to without a second thought. Since EULAs are generally long, opaque,

and purposely confusing, insisting on reading each of these legally binding agreements would make participating in online life virtually impossible. When you click "agree," however, you may be giving permission for a company to sell your data or to use it for its own profitable activities, such as targeted advertising, which may feel like a violation of your privacy. In other cases, your data might be sold without even this nominal form of consent, or it might be stolen in a data breach.

Even though many of these privacy violations are at least technically legal, there are several steps you can take to help safeguard your privacy online. These safeguards include taking action to limit sites from tracking you. One way to limit such tracking is by using a private browser that does not store cookies across sites. Another is by using a **virtual private network** (VPN) or related service to hide your IP address. On mobile devices, you can check your privacy settings to ensure that you have not given apps permission to collect unnecessary data, including location, contact information, or microphone and camera access. Both iOS and Android let you specify these permissions at the app level and ask that you accept them when the app is installed or first opened.

Deliberately long and confusing EULAs have done little to help consumers make informed choices about their personal data online. For many companies, protecting users' privacy is not a priority. Indeed, surveillance of user behavior has in many cases become central to their business models. As public opinion has begun to grapple with this

reality, some laws have been passed to help protect personal data. The Children's Online Privacy Protection Act (COPPA), a U.S. federal law, protects children under the age of 13. The California Consumer Privacy Act (CCPA) applies to the largest state in the United States, where many tech companies are based, and the European Union's General Data Protection Regulation (GDPR) protects personal data both in and outside the world's largest single market. Each of these laws are unique, but they all aim to protect users and to provide more transparency into online companies' data collecting practices.

Corporate respect for user privacy is a necessary but not sufficient element of protecting personal data. If bad actors steal your private data then a company's best intentions are irrelevant. That's why security is also important. As discussed in Unit Five, hackers have many ways to access your data ranging from your mistakes (such as using weak passwords or falling for phishing schemes) to companies' failures to provide proper safeguards (such as storing sensitive data in plaintext). There are obvious things you can do to improve your security, including not reusing passwords, using multi-factor authentication where available, and learning to recognize phishing attempts. Unfortunately, you don't have much control over companies' practices. You can try to do business only with companies that have a solid track record of effective security, and you can hope companies follow existing laws and regulations intended to ensure that they safeguard personal data. As the number of high-profile data breaches increases, more companies are hiring Chief Information Security

Officers (CISOs) in order to avoid these embarrassing and sometimes costly mistakes.

Storing data in "the cloud," that is on distributed servers, raises its own questions in terms of privacy and security. Cloud computing is definitely convenient. It is easy to use, reliable, globally available, and cheaper to scale, but it is important to consider potential risks to privacy and security. There are trade-offs between cloud storage and keeping data on machines that you control. A few questions to think about when deciding whether to use cloud-based storage are who owns the data, can the service provider access the data, how often do they back up the data, what privacy and security measures do they have in place, can they use the data to advertise, and are you giving up privacy protections by putting your data into the cloud.

Whenever we make such decisions we face tradeoffs between privacy, security, convenience, and cost. Each person or group will feel comfortable with a different balance—and this balance will change depending on what kind of data we're dealing with. Many people will feel much more strongly about the privacy of their medical data or the security of their bank accounts than they will about a birthday message to their grandmother. Still, it is impossible to find the balance that is right for you if you're not informed about the available options and their tradeoffs.

Summary

Computers have become—for better or worse—an inescapable part of modern life. The benefits of the computing revolution are impossible to deny. Communication, sharing, and collaboration have been made easier and richer by the presence of computers in our life. Still, in many areas of life, the effects of computing have been murkier. The social, economic, and cultural effects of networked computers have been both positive and negative, and we would do well to keep these mixed effects in mind when evaluating new technologies. IP law both protects and sometimes stifles innovation, which has led to efforts to reform or add flexibility to copyright and other forms of intellectual property. Ethical computing demands that we, as users and developers, hold ourselves to a higher standard than what is simply legal, and as users and developers, we have an obligation to protect our own and others' security and privacy. In these areas, as in others, there are not always easy answers. Our decisions involve tradeoffs, but if we're informed and thoughtful about the impact of our actions, we can work to find a balance that we're comfortable with.

In the preceding nine units, we've had the opportunity to become acquainted with the foundations of computing and to learn a set of practical skills that will enable you to used computers more creatively and effectively. If you've made it this far, you have become a better informed and more skilled computer user, but you have also gained skills and knowledge that could make you a better artist, a more productive worker, and a more informed citizen. Computers have

become central to modern society in a way that few imagined even a few decades ago. By mastering the principals of computer science, you are now better equipped to navigate the society we all share.

Important Vocabulary

- **Copyright** – a form of intellectual property, which protects original forms of expression
- **Digital Divide** – the gap between those who have access to technology and those who do not
- **Ethical computing** – demands that users and developers hold themselves to a higher standard. Refers to the principles, values, standards, and practices that guide individuals and groups in doing what is right
- **EULA** – end-user license agreement
- **Patents** – allow inventors to exclude others from using their inventions without permission, can last up to twenty years
- **Privacy** – deals with your personal information, how it is stored, and how it is shared
- **Security** – refers to the steps companies take to protect your data
- **Trademarks** – protect brand names and logos in order to distinguish one company's product from other products on the market
- **VPN** – virtual private network
