INTRODUCTION TO COMPUTING & PROGRAMMING IN PYTHON®

A MULTIMEDIA APPROACH

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Georgia Institute of Technology

Fourth Edition

PEARSON

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~~Dedicated to our children,~~
~~Matthew, Katherine, and Jennifer.~~

Dedicated to our first teachers,
our parents:
Janet, Charles, Gene,
and Nancy

Contents

Preface for the Fourth Edition

We started Media Computation in the of Summer 2002, and taught it for the first time in Spring 2003. It's now over ten years later, which is a good time to summarize the changes across the second, third, and fourth editions.

Media Computation has been used successfully in an undergraduate course at Georgia Tech for the last dozen years. The course continues to have high retention rates (over 85% of students complete the class with a passing grade), and is majority female. Both students and teachers report *enjoying* the course, which is an important recommendation for it.

Researchers have been studying Media Computation in a variety of contexts. The University of Illinois-Chicago had the first Media Computation paper outside of Georgia Tech, and they showed how switching to MediaComp improved their retention rates in classes that were much more diverse than those at Georgia Tech [43]. The University of California-San Diego adopted Media Computation as part of a big change in their introductory course, where they also started using pair-programming and peer instruction. Their paper at the 2013 SIGCSE Symposium won the *Best Paper* award, and showed how these changes led to dramatic improvements in student retention, even measured a year later in the Sophomore year [42]. It's been particularly delightful to see Media Computation adopted and adapted for new settings, like Cynthia Bailey Lee's creation of a MATLAB Media Computation curriculum [41].

Mark wrote a paper in 2013, summarizing ten years of Media Computation research. It is clear from that research that Media Computation can improve retention. Our detailed interview studies with female students supports the claim that they find the approach to be creative and engaging, and that's what keeps the students in the class. That paper won the Best Paper award at the 2013 International Computing Education Research (ICER) Conference [39].

HOW TO TEACH MEDIA COMPUTATION

Over the last 10 years, we have learned some of the approaches that work best for teaching Media Computation.

- *Let the students be creative.* The most successful Media Computation classes use open-ended assignments that let the students choose what media they use. For example, a collage assignment might specify the use of particular filters and compositions, but allow for the student to choose exactly what pictures are used. These assignments often lead to the students putting in a lot more time to get *just* the look that they wanted, and that extra time can lead to improved learning.

- *Let the students share what they produce.* Students can produce some beautiful pictures, sounds, and movies using Media Computation. Those products are more motivating for the students when they get to share them with others. Some schools provide online spaces where students can post and share their products. Other schools have even printed student work and held an art gallery.
- *Code live in front of the class.* The best part of the teacher actually typing in code in front of the class is that *nobody* can code for long in front of an audience and *not* make a mistake. When the teacher makes a mistake and fixes it, the students see (a) that errors are expected and (b) there is a process for fixing them. Coding live when you are producing images and sounds is fun, and can lead to unexpected results and the opportunity to explore, "How did *that* happen?"
- *Pair programming leads to better learning and retention.* The research results on pair programming are tremendous. Classes that use pair programming have better retention results, and the students learn more.
- *Peer instruction is great.* Not only does peer instruction lead to better learning and retention outcomes, but it also gives the teacher better feedback on what the students are learning and what they are struggling with. We strongly encourage the use of peer instruction in computing classes.
- *Worked examples help with creativity learning.* Most computer science classes do not provide anywhere near enough worked-out examples for students to learn from. Students like to learn from examples. One of the benefits of Media Computation is that we provide a lot of examples (we've never tried to count the number of `for` and `if` statements in the book!), *and* it's easy to produce more of them. In class, we do an activity where we hand out example programs, then show a particular effect. We ask pairs or groups of students to figure out which program generated that effect. The students talk about code, and study a bunch of examples.

AP CS PRINCIPLES

The Advanced Placement exam in CS Principles[1] has now been defined. We have explicitly written the fourth edition with CS Principles in mind. For example, we show how to measure the speed of a program empirically in order to contrast two algorithms (Learning Objective 4.2.4), and we explore multiple ways of analyzing CSV data from the Internet (Learning Objectives 3.1.1, 3.2.1, and 3.2.2).

Overall, we address the CS Principles learning objectives explicitly in this book as shown below:

- In *Big Idea I: Creativity*:
- LO 1.1.1: . . . use computing tools and techniques to create artifacts.
- LO 1.2.1: . . . use computing tools and techniques for creative expression.

[1] `http://apcsprinciples.org`

- LO 1.2.2: . . . create a computational artifact using computing tools and techniques to solve a problem.
- LO 1.2.3: . . . create a new computational artifact by combining or modifying existing artifacts.
- LO 1.2.5: . . . analyze the correctness, usability, functionality, and suitability of computational artifacts.
- LO 1.3.1: . . . use programming as a creative tool.
- In *Big Idea II: Abstraction*:
- LO 2.1.1: . . . describe the variety of abstractions used to represent data.
- LO 2.1.2: . . . explain how binary sequences are used to represent digital data.
- LO 2.2.2: . . . use multiple levels of abstraction in computation.
- LO 2.2.3: . . . identify multiple levels of abstractions being used when writing programs.
- In *Big Idea III: Data and information*:
- LO 3.1.1: . . . use computers to process information, find patterns, and test hypotheses about digitally processed information to gain insight and knowledge.
- LO 3.2.1: . . . extract information from data to discover and explain connections, patterns, or trends.
- LO 3.2.2: . . . use large data sets to explore and discover information and knowledge.
- LO 3.3.1: . . . analyze how data representation, storage, security, and transmission of data involve computational manipulation of information.
- In *Big Idea IV: Algorithms*:
- LO 4.1.1: . . . develop an algorithm designed to be implemented to run on a computer.
- LO 4.1.2: . . . express an algorithm in a language.
- LO 4.2.1: . . . explain the difference between algorithms that run in a reasonable time and those that do not run in a reasonable time.
- LO 4.2.2: . . . explain the difference between solvable and unsolvable problems in computer science.
- LO 4.2.4: . . . evaluate algorithms analytically and empirically for efficiency, correctness, and clarity.
- In *Big Idea V: Programming*:
- LO 5.1.1: . . . develop a program for creative expression, to satisfy personal curiosity or to create new knowledge.
- LO 5.1.2: . . . develop a correct program to solve problems.
- LO 5.2.1: . . . explain how programs implement algorithms.
- LO 5.3.1: . . . use abstraction to manage complexity in programs.

- LO 5.5.1: . . . employ appropriate mathematical and logical concepts in programming.
- In *Big Idea VI: The Internet*:
- LO 6.1.1: . . . explain the abstractions in the Internet and how the Internet functions.

CHANGES IN THE FOURTH EDITION

1. We fixed lots of bugs that our crack bug-finders identified in the third edition.
2. We changed most of the pictures in the book – they were getting stale, and our kids wanted us to not use as many pictures of them.
3. We added more end-of-chapter questions.
4. We added a whole new chapter, on text as a medium and manipulating strings (to make sentences, koans, and codes). This isn't a *necessary* chapter (e.g., we introduce `for` and `if` statements, but we didn't remove the introductions later in the book). For some of our teachers, playing with text with shorter loops (iterating over all the characters in a sentence is typically smaller than the thousands of pixels in a picture) is a more comfortable way to start.
5. We gave up fighting the battle of inventing a Web scraper that could beat out the changes that Facebook made, which kept breaking the one we put in the 3rd edition and then kept updating on the teacher's website[2]. Instead, we wrote examples in this book for processing CSV (Comma-Separated Values), a common format for sharing data on the Internet. We parse the CSV from a file using string processing, then using the CSV library in Python, and then accessing the data by URL.
6. We added some new edge detection code which is shorter and simpler to understand.
7. We added more with turtles: creating dancing turtles (using `sleep` from the `time` module to pause execution) and recursive patterns.
8. We updated the book to use the latest features in JES, which include those that reduce the need to use full pathnames (a problem identified by Stephen Edwards and his students in their SIGCSE 2014 paper [38]).

CHANGES IN THE THIRD EDITION

1. General freshening of the references, for example Netscape Navigator and 40 Gb hard disks are so 2005.
2. Introduced more computer science terms (briefly) earlier in the book, such as *algorithm, identifier*, and *local* and *global scope*.
3. A more thorough presentation of conditionals, earlier in the book, including `else` and `elif`.

[2] `http://home.cc.gatech.edu/mediaComp` and `http://www.mediacomputation.org`

4. A section on functions and parameters, with a discussion of when to use return and when it isn't necessary.
5. More explanation of how variables work, especially with respect to objects.
6. More on mirroring pictures, with a more generalized example.
7. Updated the Web examples with references to accessing common, modern sites.
8. More on the differences between image formats.
9. Removed some of the more trivial Turtle examples in Chapter 16, and adding a couple of sophisticated examples with turtles.
10. Updated the section on hardware and networks to reference newer hardware, including multi core processors and cell phones.
11. Made clearer what can be done in Jython and CPython, in comparison with JES.
12. Added another steganography-related example.
13. Added figures and additional explanation for the areas that reviewers saw as confusing for students.

Changes in the Second Edition

1. We increased our coverage of the Python language, including more of the standard libraries, global scope, and additional control structures.
2. There is an increased emphasis on abstraction and on creating reusable code.
3. The movie chapter includes instructions on how to create standard AVI and QuickTime movies for sharing with others.
4. We increased the number of exercises at the end of each chapter significantly.
5. All indices start with zero instead of one. By starting with zero as the first index instead of one, we are more compatible with standard Python.
6. We removed the chapter on creating a user interface in Swing and the one on JavaScript.
7. We rewrote the chapter on design and debugging to include design and testing examples, with an emphasis on maintenance.
8. We split the chapter on creating and modifying text into two chapters. We added an example of steganography.
9. We split the language paradigms chapter (styles of programming) into two chapters to provide more content on functional (such as non mutable functions) and object-oriented programming (e.g., introducing objects through use of Logo-like turtles).
10. We have added in coverage of concepts that many teachers want to touch on in their introductory course, such as binary representations of negative numbers.
11. Overall, we have made the English clearer and removed some unnecessary detail. (We hope.)
12. There is no longer a CD in the back of the book. The latest versions of all software and materials can be found at `http://mediacomputation.org`.

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- At the top of the list is Susan Schwarz of the US Military Academy at West Point. Susan runs a large course with many instructors, and pays careful attention to what's going in all of the sections of the course. She turned that attention on the third edition of this book. She caught many bugs, and gave us lots of useful feedback. Thanks, Susan!
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Preface to the First Edition

Research in computing education makes it clear that one doesn't just "learn to program." One learns to program *something* [5, 22], and the motivation to do that something can make the difference between learning and not learning to program [8]. The challenge for any teacher is to pick a *something* that is a powerful enough motivator.

People want to communicate. We are social creatures and the desire to communicate is one of our primal motivations. Increasingly, the computer is used as a tool for communication even more than a tool for calculation. Virtually all published text, images, sounds, music, and movies today are prepared using computing technology.

This book is about teaching people to program in order to communicate with digital media. The book focuses on how to manipulate images, sounds, text, and movies as professionals might, but with programs written by students. We know that most people will use professional-grade applications to perform these type of manipulations. But, knowing *how* to write your own programs means that you *can* do more than what your current application allows you to do. Your power of expression is not limited by your application software.

It may also be true that knowing how the algorithms in a media applications work allows you to use them better or to move from one application to the next more easily. If your focus in an application is on what menu item does what, every application is different. But if your focus is on moving or coloring the pixels in the way you want, then maybe it's easier to get past the menu items and focus on what you want to say.

This book is not just about programming in media. Media-manipulation programs can be hard to write or may behave in unexpected ways. Natural questions arise, like "Why is the same image filter faster in Photoshop?" and "That was hard to debug—Are there ways of writing programs that are *easier* to debug?" Answering questions like these is what computer scientists do. There are several chapters at the end of the book that are about *computing*, not just programming. The final chapters go beyond media manipulation to more general topics.

The computer is the most amazingly creative device that humans have ever conceived. It is completely made up of mind-stuff. The notion "Don't just dream it, be it" is really possible on a computer. If you can imagine it, you can make it "real" on the computer. Playing with programming can be and *should* be enormous fun.

OBJECTIVES, APPROACH AND ORGANIZATION

The curricular content of this book meets the requirements of the "imperative-first" approach described in the ACM/IEEE *Computing Curriculum 2001* standards document [4]. The book starts with a focus on fundamental programming constructs: assignments, sequential operations, iteration, conditionals, and defining functions. Abstractions (e.g., algorithmic complexity, program efficiency, computer organization, hierarchical decomposition, recursion, and object-oriented programming) are emphasized later, after the students have a context for understanding them.

This unusual ordering is based on the findings of research in the learning sciences. Memory is associative. We remember new things based on what we associate them with. People can learn concepts and skills on the premise that they will be useful some day but the concepts and skills will be related only to the premises. The result has been described as "brittle knowledge" [9]—the kind of knowledge that gets you through the exam but is promptly forgotten because it doesn't relate to anything but being in that class.

Concepts and skills are best remembered if they can be related to many different ideas or to ideas that come up in one's everyday life. If we want students to gain *transferable* knowledge (knowledge that can be applied in new situations), we have to help them to relate new knowledge to more general problems, so that the memories get indexed in ways that associate with those kinds of problems [26]. In this book, we teach with concrete experiences that students can explore and relate to (e.g., conditionals for removing red-eye in pictures) and later lay abstractions on top of them (e.g., achieving the same goal using recursion or functional filters and maps).

We know that starting from the abstractions doesn't really work for computing students. Ann Fleury has shown that students in introductory computing courses just don't buy what we tell them about encapsulation and reuse (e.g., [13]). Students prefer simpler code that they can trace easily and they actually think that such code is *better*. It takes time and experience for students to realize that there is value in well-designed systems. Without experience, it's very difficult for students to learn the abstractions.

The **media computation** approach used in this book starts from what many people use computers for: image manipulation, exploring digital music, viewing and creating Web pages, and making videos. We then explain programming and computing in terms of these activities. We want students to visit Amazon (for example) and think, "Here's a catalog Web site—and I know that these are implemented with a database and a set of programs that format the database entries as Web pages." We want students to use Adobe Photoshop and GIMP and think about how their image filters are actually manipulating red, green, and blue components of pixels. Starting from a relevant context makes transfer of knowledge and skills more likely. It also makes the examples more interesting and motivating, which helps with keeping students in the class.

The media computation approach spends about two-thirds of the time on giving students experiences with a variety of media in contexts that they find motivating. After that two-thirds, though, they naturally start to ask questions about *computing*. "Why is it that Photoshop is faster than my program?" and "Movie code is slow—How slow do programs get?" are typical. At that point, we introduce the abstractions and the valuable insights from computer science that answer *their* questions. That's what the last part of this book is about.

A different body of research in computing education explores why withdrawal or failure rates in introductory computing are so high. One common theme is that computing courses seem "irrelevant" and unnecessarily focus on "tedious details" such as efficiency [31, 1]. A communications context is perceived as relevant by students (as they tell us in surveys and interviews [15, 27]). The relevant context is part of the explanation for the success we have had with retention in the Georgia Tech course for which this book was written.

The late entrance of abstraction isn't the only unusual ordering in this approach. We start using arrays and matrices in Chapter 3, in our first significant programs. Typically, introductory computing courses push arrays off until later, because they are obviously more complicated than variables with simple values. A relevant and concrete context is very powerful [22]. We find that students have no problem manipulating matrices of pixels in a picture.

The rate of students withdrawing from introductory computing courses or receiving a D or F grade (commonly called the *WDF rate*) is reported in the 30–50% range or even higher. A recent international survey of failure rates in introductory computing courses reported that the average failure rate among 54 U.S. institutions was 33% and among 17 international institutions was 17% [6]. At Georgia Tech, from 2000 to 2002, we had an average WDF rate of 28% in the introductory course required for all majors. We used the first edition of this text in our course *Introduction to Media Computation*. Our first pilot offering of the course had 121 students, no computing or engineering majors, and two-thirds of the students were female. Our WDF rate was 11.5%.

Over the next two years (Spring 2003 to Fall 2005), the average WDF rate at Georgia Tech (across multiple instructors, and literally thousands of students) was 15% [21]. Actually, the 28% prior WDF rate and 15% current WDF rate are incomparable, since all majors took the first course and only liberal arts, architecture, and management majors took the new course. Individual majors have much more dramatic changes. Management majors, for example, had a 51.5% WDF rate from 1999 to 2003 with the earlier course, and had a 11.2% failure rate in the first two years of the new course [21]. Since the first edition of this book was published, several other schools have adopted and adapted this approach and evaluated their result. All of them have reported similar, dramatic improvements in success rates [37, 36].

Ways to Use This Book

This book represents what we teach at Georgia Tech in pretty much the same order. Individual teachers may skip some sections (e.g., the section on additive synthesis, MIDI, and MP3), but all of the content here has been tested with our students.

However, this material has been used in many other ways.

- A short introduction to computing could be taught with just Chapters 2 (introduction to programming) and 3 (introduction to image processing), perhaps with some material from Chapters 4 and 5. We have taught even single-day workshops on media computation using just this material.
- Chapters 6 through 8 basically replicate the computer science concepts from Chapters 3 through 5 but in the context of sounds rather than images. We find the replication useful—some students seem to relate better to the concepts of iteration and conditionals when working with one medium than with the other.

Further, it gives us the opportunity to point out that the same **algorithm** can have similar effects in different media (e.g., scaling a picture up or down and shifting a sound higher or lower in pitch are the same algorithm). But it could certainly be skipped to save time.

- Chapter 12 (on movies) introduces no new programming or computing concepts. While motivational, movie processing could be skipped to save time.
- We recommend getting to at least some of the chapters in the last unit, in order to lead students into thinking about computing and programming in a more abstract manner, but clearly not *all* of the chapters have to be covered.

Python and Jython

The programming language used in this book is Python. Python has been described as "executable pseudo-code." We have found that both computer science majors and non majors can learn Python. Since Python is actually used for communications tasks (e.g., Web site development), it's a relevant language for an introductory computing course. For example, job advertisements posted to the Python Web site (`http://www.python.org`) show that companies like Google and Industrial Light & Magic hire Python programmers.

The specific dialect of Python used in this book is *Jython* (`http://www.jython.org`). Jython *is* Python. The differences between Python (normally implemented in C) and Jython (which is implemented in Java) are akin to the differences between any two language implementations (e.g., Microsoft vs. GNU C++ implementations)—the basic language is *exactly* the same, with some library and details differences that most students will never notice.

TYPOGRAPHICAL NOTATIONS

Examples of Python code look like this: `x = x + 1`. Longer examples look like this:

```
def helloWorld():
  print "Hello, world!"
```

When showing something that the user types in with Python's response, it will have a similar font and style, but the user's typing will appear after a Python prompt (»>):

```
>>> print 3 + 4
7
```

User interface components of JES (Jython Environment for Students) will be specified using a small caps font, like SAVE menu item and the LOAD button.

There are several special kinds of sidebars that you'll find in the book.

Computer Science Idea: An Example Idea

Key computer science concepts appear like this.

Common Bug: An Example Common Bug

Common things that can cause your program to fail appear like this.

Debugging Tip: An Example Debugging Tip

If there's a good way to keep a bug from creeping into your programs in the first place, it's highlighted here.

Making It Work Tip: An Example How to Make It Work

Best practices or techniques that really help are highlighted like this.

INSTRUCTOR RESOURCES

The instructor resources are available on the author's website `http://mediacomputation.org` or the Pearson Education's Instructor Resource Center at `www.pearsonhighered.com/guzdial`:

- PowerPoint® Presentation slides

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About the Authors

Mark Guzdial is a professor in the School of Interactive Computing in the College of Computing at Georgia Institute of Technology. He is one of the founders of the ACM's International Computing Education Research workshop series. Dr. Guzdial's research focuses on learning sciences and technology, specifically, computing education research. His first books were on the programming language Squeak and its use in education. He was the original developer of "Swiki" (Squeak Wiki), the first wiki developed explicitly for use in schools. Mark has published several books on the use of media as a context for learning computing, which have influenced undergraduate computing curricula around the world. He is on the editorial boards of the *Journal of the Learning Sciences* and *Communications of the ACM*. He was a recipient of the 2012 IEEE Computer Society Undergraduate Teaching Award. He is a Senior Member of the ACM.

Barbara Ericson is a research scientist and the director of Computing Outreach for the College of Computing at Georgia Tech. She has been working on improving introductory computing education since 2004.

She has served as the teacher education representative on the Computer Science Teachers Association board, the co-chair of the K-12 Alliance for the National Center for Women in Information Technology, and as a reader for the Advanced Placement Computer Science exams. She enjoys the diversity of the types of problems she has worked on over the years in computing including computer graphics, artificial intelligence, medicine, and object-oriented programming.

Mark and Barbara received the 2010 ACM Karl V. Karlstrom Award for Outstanding Computer Educator for their work on Media Computation including this book. They led a project called "*Georgia Computes!*" for six years, which had a significant impact in improving computing education in the US state of Georgia [40]. Together, they Mark and Barbara are leaders in the *Expanding Computing Education Pathways* (ECEP) alliance[3]

[3] `http://www.ecepalliance.org`