Serious Computer Programming for Youth
a Teacher's Manual for charismatic hackers

10-hour course on programming
with Python on the Linux system

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Motivation and prolegomena

The joy and beauty of serious programming

Computer programming, like music, chess and mathematics, can be tought to young children. These children can sometimes perform at the same level as adults in many areas of programming.

Many courses are taught to kids. The ones I have seen are very well developed and organized. They use a friendly programming environment in which users see a rapid visual response to their commands and snippets of code.

Unfortunately these environments do not bridge a crucial gap to programming the way it is done by professionals. The language is not one used for serious programming, the environment does not scale to more complex software development, and the graphical output, while immediate, does not then translate into production-level graphical user interfaces. When the students are confronted with real technical work, for example in a college or graduate school internship, they can feel a sense of loss that those tools did not prepare them for their "real work".

Important tools for a programmer include at least the following[1]:

- a deep understanding of how their computer and operating system work
- mastery of one or more general purpose programming languages
- a strong connection to their tools (most importantly the programming editor)
- comfort with how the command line brings together a variety of small tools.

[1] Of course this list could be arbitrarily long; I will focus on these items for now.

I have carried out various experiments in teaching this more advanced approach to students, both in the 8- to 12-year-old range and to teenagers. Some of the attempts have not worked well, but they led me to an approach which has been quite successful: the students learned the material readily, and surprised me and others with how quickly they grasped real programming tools.

An important matter comes up when teaching real-world programming, and this is not a problem unique to kids. It is the problem of understanding how computers work. When I learned to program in 1980 everyone who had a computer at home had to understand how it worked and had to put together several hardware components.

Today both children and adults can use a laptop or tablet computer to good purpose for several tasks (video conferences, reading mail, accessing web resources, ...) without understanding how the computer works or even *what the parts of the hardware and software are.*

One analogy I have come up to explain this is that of car ownership. A person can drive a car with an automatic gear shift and have no idea: *(a)* that there are gears with a different ratio between how fast the engine turns and how fast the wheels turn, *(b)* how to fix a car if it develops problems, *(c)* how to design and build a car.

Analogously to meeting kids who don't know who The Beatles are[2], today's computer users might not know the meaning of CPU, RAM, graphics cards, network controllers, hard disks. Moving up from hardware they might not know where the operating system fits into a functional diagram of computer hardware and software, or what an editor is. They might not even know what a "computer program" is.

These are all important things to understand when you write code, so we will have to start our training by understanding how hardware and software work under the fancy cover.

This is why the course requires students to find an old computer or laptop: in the first lesson the students will open up a computer to see what the parts are inside (with the instructor's guidance), and they will install a Linux distribution on their own computer so that they can do their programming on a machine they have configured, starting from bare hardware.

And now for the beauty and joy. Serious programming is not only fun: you can experience the deep joy of creating something or solving a problem. And research: research involves writing software, so the joy of unlocking

[2] A rock and roll band from the 1960s and early 1970s.

those mysteries is not available to people who don't program. We hope to do some of that in the course, so we should emphasize to the students that this activity has deep rewards.

Automation of repetitive tasks

People who have programming as a tool in their belt know that the main function of computer programming is the automation of repetitive tasks.

This is so imporant that there is a mantra which I repeat very often when I teach: "the purpose of computers is the automation of repetitive tasks". When we introduce loops, and at many other times, I have the class repeat "automation of repetitive tasks". It eventually becomes a humorous mantra, *with the joke being on the instructor* because they repeats themselves so many times, but the phrase will be remembered.

Here is how to test whether students have understood this. After they have started using the shell, have them create a bunch of files with a typo:

```
for i in `seq 0 9`
do
    fname=fille_number_$i
    echo "the number is $i" > $fname
done
```

Then tell them "now you realize that you misspelled and wrote *fille* instead of *file*. What will you do about it?"

At this point they will not have the skills to write a script to fix all the file names, but they can still give this correct answer: "the right way to fix it is to write a script of some sort."

At the end of the class you might want to give give them the script that fixes all the file names. There are many ways to do it – I might do something like this:

```
for bad_fname in fille_number_*
do
    good_fname=`echo $bad_fname | sed 's/fille_/file_/'`
    echo "renaming file from $bad_fname to $good_fname"
    mv -i $bad_fname $good_fname
done
```

Plan

This book has early sections that introduce hardware, then describe how hardware and software fit together, discuss layers of software from the operating system to application software.

After which we dive into programming in Python. In earlier programs we type many lines of code in the Python interpreter (at the `>>>` prompt), since these are demonstrating isolated bits of the python syntax.

Once we have spent some time getting familiar with python syntax we dive in to the program we are going to write: one that plays the game of tic-tac-toe against a human (or against other computer algorithms!) with a reasonable strategy.

The writing of this program takes the bulk of the time in the workshop.

We start by writing a simple representation of the board, and of how to modify the board (i.e. making moves). Then we restructure the program to use functions for all this, and give it a top-down design with a `main()` function coming first.

At this point we temporarily let the program lack in a few areas (cheating is possible, invalid input is possible, ...) so that we can jump in to "fun" stuff: introducing the first two computer algorithms ("first found" and "random").

Then we solve the problems of cheating and incorrect input.

Now, as we move toward smarter algorithms, we take a moment to introduce look-ahead mechanisms. This then lets us write our final algorithms: the "defensive" and "opportunistic" algorithm.

And here the book and the "planned" part of the course finish. If there is time left (and there usually is) I will now informally guide the students through expanding the program to play tournaments of one algorithm against the other, and write up a cross-table of how the algorithms perform.

Then I conclude with a discussion of "what comes next" – mini courses, working groups, research internships, ...

It is important to follow the plan and keep a momentum in the class: this gets the students into a state of mind where they feel the productivity, and that makes a big difference. This can be difficult in case some students need a bit more time, but we are aided by a very fortunate property of people with technical passion: they love to share their knowledge and help others. At various times during a segment the students will help each other catch up.

Since serious computing work involves solving real open-ended problems, rather than "canned" exercises, the instructor should be available during breaks and between sessions to make sure that everyone can catch up and be ready for the next class without feeling lost.

But there is a flip side: this course is aimed at students who are self-motivated and ready to step out of their comfort zones. Some students might not be ready for this. Because of this I make it clear, when I advertise the course, that students will have to work hard at learning new ways of computing. I correspond with the students (or their parents for younger kids) before the course, and try to make sure that they are not being pressed in to something they don't feel like working hard at.

Pandemic adjustments and remote teaching

During the COVID-19 pandemic I quickly shifted to teaching this workshop (and all my other materials) remotely. This was enabled by the Jitsi platform: an excellent videoconference system, based on free/open-source software. A key feature of Jitsi is that it allows several people to share their screens at once - a feature we use to debug student code.

I also learned to use the screen drawing tools in my window manager, so I could quickly annotate and draw around the text in the windows I project.

The setup I use is to have a laptop to my side, and I use the videocamera there to project myself talking. Then I use my main computer to project its screen to demonstrate the material. The main computer's screen has very high resolution, so I increase the fonts in emacs and in my terminal windows.

The other major pandemic adjustment is in setting up computers. Instead of doing it at the start of the session we have to do it remotely. I send the students instructions on how to do that, and do a lot of coaching on the telephone to help them set up.

Why use Linux and Python?

The promotional materials point out that the course involves learning to program in Python on the Linux operating system.

The motivation behind learning the Linux operating system is that:

- Linux is the basis for almost all the computers that "run the world": from the servers at Amazon and Google to the supercomputers that power science, the operating system is almost always Linux

- the Linux operating system is written by programmers for programmers: it offers a choice of several delightful programming environments and puts few barriers in the way of the programmer
- the Linux system is free (as in freedom), and software freedom is important; but it is also free as in cost: the entire system and its wealth of tools (for programming and all else) are available free of cost
- the Linux system has been packaged in many ways, some of which work quite well on very old hardware with less memory,
- Linux is a very strong element on a resume.

The motivation behind teaching Python is:

- it is a pleasant and easy language to learn
- it is also a language used for many industrial-strength applications
- it can be used for a wide variety of interesting programs.

We will be using version 3 of Python (`python3`) which is now quite widespread. As I revise this book in 2022 Python2 has finally mostly disappeared, so there is no need to discuss how to update programs from python2 to python3.

Preparation for class: venue and materials

If you get a group of kids signed up for the course you need to be ready to make the class time move at a good pace. If time is lost getting equipment to work or figuring out the network then you will lose the kids' attention.

I do a careful preparation of the site: I verify that we have electrical outlets, that we have hard ethernet as well as wi-fi, that there is a blackboard or whiteboard, tables, chairs, ...

I also correspond extensively with the kids (or their parents for the younger kids), making sure that they have obtained a piece of hardware and finding out what kind of computer it is.

Then I have a couple of boxes of equipment I bring to the classes with (at least) the following items:

- an ethernet hub with ports for any students who will not have wi-fi
- USB wi-fi adaptors

- dry erase markers
- several USB mice
- loaner laptops: a combination of cheap ones I purchased with a grant for the course, and of old computers the center had sitting around
- CDs and DVDs with several Linux distributions (labeled) (I have stopped doing that recently: few laptops have CD drives anymore)
- USB flash drives (memory sticks) with several Linux distributions (labeled).

I also do a test install of the operating system on at least one of each model of loaner laptop, and I write down the procedure. The most important part is probably to figure out how to make that laptop boot from a removable USB flash drive.

Using, adapting and improving this book

I have written this teacher's manual in case you want to use it as a starting point to develop our own course for children. You may obtain a copy of the source document for this manual[3] and modifiy it to fit your needs, and even redistribute your modifications (see Appendix C for the license on this document).

I have not written this book to be a tutorial for students. You, the reader, are going to be tutoring the children, so this book is written to give you an outline and many possible details on what to do.

The target audience (that's still you) is someone who has at least some small experience programming. In that case the examples in this book will make sense to you and you will be able to explain them to the kids, even as you are learning yourself!

There are some areas you will most likely need to adapt, such as Appendix B which I tailored to the specific hardware we had available in the classes I taught. You might want to adapt other areas to fit your style or your audience.

And naturally if you have ideas for improving the course or developing follow-on courses, please be in touch with me!

[3] https://bitbucket.org/markgalassi/seriousprogramming-teacher-manual

Lesson 1

The hardware and the operating system

1.1 Having students bring hardware

An essential part of this course is that the students should install an operating system themselves onto bare metal. This will give them a much better overall view of what the hardware + software combination that is a computer is made of.

There are several side benefits: *(a)* the students are exposed to a free software environment, *(b)* people who teach Python classes always grapple with installing and using Python on widely different systems — we will not have this problem, *(c)* the students become versed in the UNIX and Linux way of computing and learn some system administration skills.

In announcing the course I urge students to bring in an old computer, such as "grandparent's old laptop". The idea is to encourage them to ask around: many families will have old computers sitting around, and if not their neighbors probably do. But even if they do not it is still worth having students take such initiative. Teachers can also raise grant money to find laptops for students, and I have found several very usable computers with the *freecycle* mailing list.

1.2 Start the installation

Installation instructions for the computers I have used in my course are in Appendix B. I have also had very good luck getting members of the local Linux user group in Santa Fe to come help with the installation. Former

students are also often willing and helpful. These volunteers are only needed at the very start of the course.

It is important to get to this point rather early in the first 2-hour lesson, since this is rich ground for unpredicted problems. The students might bring hardware that does not work, or that is so strange that it is hard to install Linux on it (although that is rare these days). Or they might have brought something that is more than 10 years old, for which you would need a truly tiny Linux distribution.

To limit the delays that can come from this I recommend having some "loaner" laptops available for students to use in class if it turns out that their computer is just not working. If the installation appears to not be working then make sure you shift to using your loaner laptops.

As for a choice of distributions: I show up with several CDs/DVDs and USB memory sticks so that I am ready to install many different styles of Linux. To help with hardware detection I now mostly use the Ubuntu (long term support version) and Mint distributions, but this can change as the Linux distributions evolve.

I also have a couple of USB wi-fi adaptors that are known to work without special drivers, since certain laptops have built-in wi-fi that requires special drivers.

In 2022 I stopped putting the time in to working with laptops that have less than 4 gigabytes of RAM. At this time a web browser uses more than 3 gigabytes even before doing much work, so having less than 4 gigabytes (even with a low-resource distribution) does not work well.

In class we will mostly use a programming editor and the Python interpreter, so the style of desktop doesn't really matter that much.

The installation can take from a few minutes to half an hour, and we will use this time to go to the front of the class and discuss computer hardware. **Remote teaching note:** when teaching remotely the students do the installation themselves. I then do a "tech check" with each student where we spend a few minutes in videoconference to make sure that they can share their screen, and that they have installed a programming editor (I have them install emacs).

1.3 Opening up a computer to demonstrate its parts

This "show and tell" should be done with a desktop computer, preferably a pretty old one, since the parts are more spread out and easier to identify.

The computer should be opened on a desk near the blackboard so that you can draw a hardware block diagram (see Section 1.4.1) at the same time.

You will want to practice opening it up, and learn to identify the components.

(a) The computer before we open it up.

(b) The back - note opening screws and connectors.

You should identify the CPU, RAM and peripherals, discussing how they are connected to the CPU. Sometimes a peripheral is on the same board, and hence is connected via short solder connections. Other times it's on a separate card, plugged in to the "bus" (in most modern PCs it's a PCI bus).

Here is a basic list of some of the components you might identify:

power supply plugs in to the wall, often has fan, has many colored wires coming out

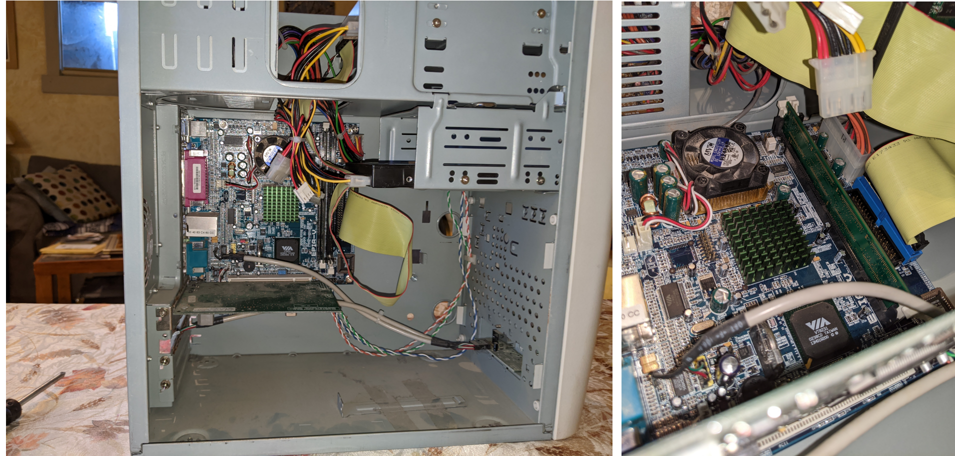
backplane/bus where the cards are seated

motherboard the board with the CPU, much of the RAM, . . .

CPU the biggest item on the motherboard

RAM the computer's fastest memory, sits on the motherboard in DIMMs — mini-cards, short and wide which plug in to the motherboard

graphics find the graphics chipset, either on the motherboard or in a separate card (it might be useful to bring two different computers)



(a) The computer's innards from the side.

(b) Details of motherboard and memory module daughterboard.

hard disk is usually somewhat separate from the motherboard, with a wide ribbon cable connecting them in older computers (IDE) or a narrower cable in newer computers (SATA); has its own power connector as well

optical drive CD/DVD drive, often connected the same way as the hard disk

network port looks like a telephone jack but wider

serial port trapezoidal connector with 15 or 9 pin sockets

video connector there are so many different types, but for a long time the standard was called VGA, and the connector is trapezoidal, often blue, with 9 pin sockets

1.4 Lecture on the blackboard

1.4.1 Hardware block diagram

While you have the "show and tell" computer open (Section 1.3) you should draw a block diagram of how the hardware fits together. Many examples of block diagrams can be found on the web, but they often go into too much detail. I use a simple block diagram, a bit like the one in Figure 1.3.

Once you have the hardware block diagram on the blackboard you can animatedly talk about how each of those components is related to what the children have seen in their daily life.

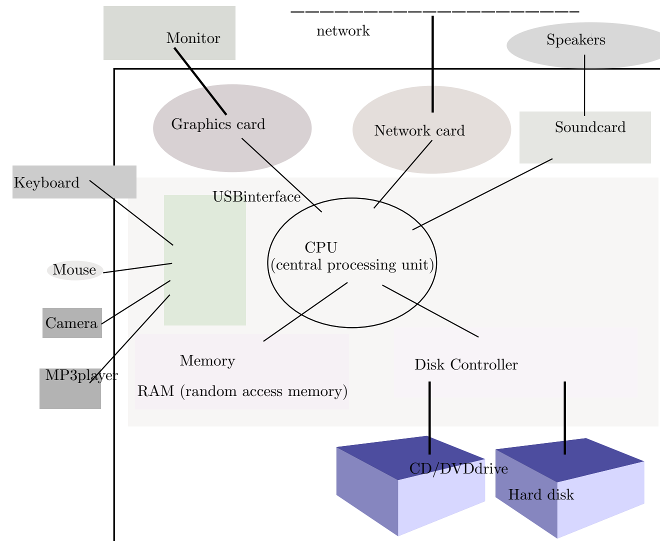


Figure 1.3: A diagram of the hardware parts of a typical personal computer.

For example: "has anyone here ever seen a movie streaming on the network, like with Netflix?" and when someone says "yes" you can point to the portions of the diagram which shows the ethernet port and the graphics card and the cable that connects to the monitor.

Or: "has anyone here ever looked at a weather forecast?", at which point you can point to the CPU and RAM and talk about how those forecasts come from a lot of very intense calculations inside the CPU.

The goal of this kind of interactive dialogue is to get the students to feel that they part of the class, and also to make their subconscious sense a connection between this understanding of the hardware and their every day experience.

1.4.2 Software functional diagram

Draw a diagram similar to that in Figure 1.4.

In explaining this to young people, draw the layers from the inside and work out. The operating system sits between the hardware and the application programs and provides two things:

- An abstraction layer on top of the hardware.
- Protection of memory and other resources from incorrect access by programs that run simultaneously.

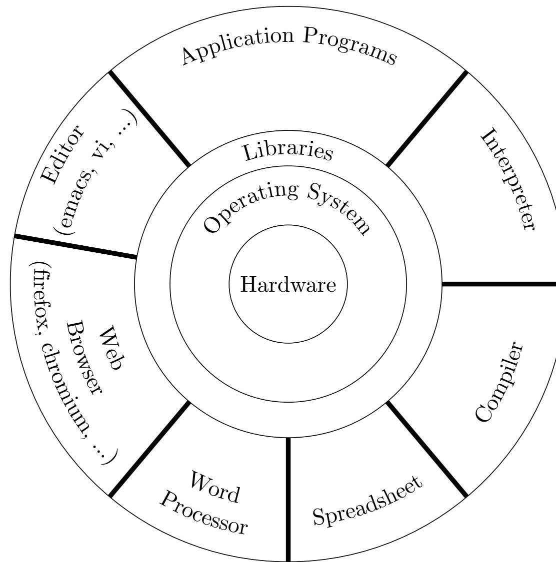


Figure 1.4: A diagram of the layers of software above the hardware.

To make this part interactive you can ask "who can tell me what an example of an operating system is?" Kids will answer "Windows" or "Macintosh". I find it useful to point out the importance of free software operating systems by saying something like "very good", and then writing down the list on the blackboard starting with the Linux operating system, and putting their responses below with the company that sells those operating systems. For example:

- Linux — used by programmers and on all supercomputers and servers.
- Microsoft Windows — used in many office and gaming computers.
- Apple OS X — used in many Macintosh computers.

and then I give a brief discussion (more will come throughout the course) of how the Linux system is designed and developed by volunteers with the goal of offering users a free[1] operating system that is not steered by a company's marketing agenda.

But then I go on to explain that there are many *embedded* operating systems: I have the students call out what operating system runs in their phone - when they say Android I point out that the kernel is a Linux kernel,

[1] "free" as in "freedom"; see Appendix C.

but it is different from our Linux systems because it has a touch-screen interface on top of it. I will also ask them to look around and see if there is a thermostat in the room. If it is programmable then it will have a computer and operating system in it. Other examples are cars, satellites, airplanes, ...

Libraries allow higher level ideas to be expressed using basic building blocks. You can give the example of a task in daily life that involves numerous tiny steps, such as getting milk from the refrigerator. You could ask someone to get you milk from the refrigerator by saying: "please step forward 2 paces, then turn left 40 degrees, then step forward two more paces, then put your arm out, then close your fingers around the handle, then pull, ..."

Or you could simply ask someone "please get me milk from the refrigerator". A library gives you higher level ways of expressing the task, delegating the small details to the library.

When you get to the "Application Software" layer remember that many of them don't know what a "program" is. Or better: they probably know what a program is, but they don't know it's called a program. You can give them examples of programs they have seen in school or they might have used at home.

1.5 After the installation

Having finished our lecture on hardware and software architecture, we start telling the students to bring up a terminal.

Typing at the terminal and at a programming editor will be what we do all the time, so they need to start getting used to typing commands at the shell prompt in the terminal. Eventually they will develop a feeling for what the terminal and the shell are.

The first thing we can do is have them type:

```
$ tuxtype
```

The computer will tell them to install it with:

```
$ sudo apt-get install tuxtype
```

and they should do that. This is an entertaining "typing tutor" which will get them in the habit of touch-typing.

I let the students stay in `tuxtype` until about 5 minutes before the end of this first 2-hour lesson.

At this point we can finally start programming. Use just a few minutes before we take our first break to:

- Have them bring up a terminal.
- Have them run "`sudo apt-get update`" and "`sudo apt-get install python3`"
- Have them bring up the Python interpreter by typing "`python3`" on the command line
- Have them type their first line of code: `print('hello world')`

This way the kids finish the first lesson having run a brief program.

And then:

```
>>> for i in range(10):
...     print(i, i*i, i*i*i)
```

Then we can take a break.

Lesson 2

Start programming in Python

2.1 Concepts before we start

There are (at least) two ways of having a computer run your Python program: you can type instructions in the Python interpreter, which only works for a few lines of code, or you can use a text editor (preferably a programming editor) to write the program, save it to a file on disk, and then run the Python interpreter on that file.

When I teach this I alternate between the two approaches: I might give a quickie to explore a feature of the language, in which case I will have students type it into the interpreter. But as the program grows I have them type it in an editor and execute it from the command line.

This means that the students need to get familiar with a few ideas and techniques. I start by explaining the following concepts at the blackboard:

- file
- shell
- how you can (and should) use the shell to do things instead of a graphical file manager
- editor

in addition to other ideas:

- programming language
- the literal-mindedness of computers

2.2 Learning to type and learning the editor

Students might not know how to type yet. I have them install the typing tutor tuxtype with "`sudo apt-get install tuxtype`", after which they can run tuxtype on the command line to practice typing. I don't have them spend more than a couple of minutes on it at this time in class, but I tell slow typists that they need to practice.

I then have students install the programming editor emacs with "`sudo apt-get install emacs`" and spend a longer amount of time learning emacs. This can be done with the emacs tutorial. Initially students will try to rely on the mouse and the arrow keys, and a proficiency test would be if by the end of the week they are using native emacs navigation and other approaches from the tutorial.

Once they are comfortable creating a new file in emacs (`C-x C-f`) and saving it to disk (`C-x C-s`) we are ready to move on to writing code.

2.3 Reiterating "hello world" and starting loops

I write all the codes here on the blackboard during the lecture. I have the students input them, either at the Python interpreter or in an editor, to then be run from the command line.

When teaching remotely I have a terminal or emacs window with hugely magnified fonts and I type the code in directly. In this introductory workshop I *never* show already-written code – this is important so that the students write together with me.

At the command line type "`$ python3`" and at the python prompt type:

```
>>> print('hello world')
```

and then a few more instructions to see how to use Python as a simple calculator:

```
>>> 7*4
>>> print(7*4)
>>> 125/13.5
>>> import math
>>> math.sqrt(1.7 + 32/17.1)
```

Then introduce variables with:

```
>>> x = 7
>>> y = 4
>>> x*y
>>> print(x*y)
```

Then move on to something more interesting with:

```
>>> for i in range(10):
...     print(i, i*i, i*i*i)
```

where I also ask the students to tell me what has just happened.

This example allows the telling of humorous anecdotes about sadistic teachers. I mention that in the old days (including my own childhood) students were often given punishment for being unruly in class. Sometimes they were unruly because they were too smart for the course material, other times becuase they were just ill-behaved. A common form of punishment was to have the child write something repeatedly on the blackboard. My teacher would make me write 50 times:

```
I will not disturb in class
```

Here I might have them write an inline program which prints that out 10 times (so you can still see the for loop in the terminal), and then run it 50 times and then 1000 times. I might also have them update it for modern times with:

```
I will not look at my cell phone in class
```

This brings us to the anecdote of Carl Friedrich Gauss (here I'll ask the kids "do you have a favorite mathematician superhero?" and run with that idea for a while...). The legend (possibly apocryphal – who knows what apocryphal means? what's a famous apocryphal story?) tells that his math teacher asked him (and maybe the whole class) to add all the numbers from 1 to 100 so that the teacher could take a break.

The teacher's break was brief: Gauss answered right away. What is the answer? If the class does not see it we can demonstrate it: write out 1+100 + 2+99 + 3+98 and so forth to 49+52 and 50+51. That makes for 50*100, which is 5050. More generally, Gauss got:

$$\sum_{i=1}^{n} i = \frac{n(n+1)}{2}$$

So if you are given a repetitive task by a sadistic teacher, how do you handle it? Two solutions: either you come up with a cool math formula that lets you calculate it immediately, or you write a computer program to do it. That's what we did with our loop.

Now take that looping program and put it in a file called `loop.py`. The code in the file will look like:

```
for i in range(10):
    print(i, i*i, i*i*i)
```

Listing 2.1: loop.py - first program

and you can run it with

```
$ python3 loop.py
```

Then expand on the program (and use `i**3` for 3rd power):

```
import math
for i in range(10):
    print(i, i*i, i**3, math.sqrt(i))
```

Listing 2.2: loop.py - adding code

Students might enjoy changing the 10 to be 100 or even 1000 to see what happens; some will plug in ridiculous numbers, which gives the teacher the opportunity to have the students run their CPU hard on a tight loop, put their ear close to the computer, and listen closely to the whining of the fan. Then hit `control-C` and hear the whine stop.

Now show the formula for Fahrenheit and Celcius conversion:

$$T_{\text{degC}} = (T_{\text{degF}} - 32) * \frac{5.0}{9.0} \tag{2.1}$$

and write the following program and save it to a file called `fahr.py`:

```
for degF in range(100):
    degC = (degF -32) * 5.0 / 9.0
    print(degF, degC)
```

Listing 2.3: fahr.py

And of course here I point out that "sure, you could take a calculator and write down all the possible fahrenheit–celcius conversions, but . . . [drum roll] *the purpose of computers is to automate repetitive tasks!*"

Now let us actually do Gauss's task the hard way and the easy way. Put the following into `gauss_sum.py`:

```
sum = 0
for i in range(1,101):
    sum = sum + i
print('hard way: the sum from 1 to 100 was: ', sum)

sum_gauss = (100 * (100 + 1)) / 2
print('easy way: the sum from 1 to 100 was: ', sum_gauss)
```

```
if sum == sum_gauss:
    print('yay! Gauss was right!')
else:
    print('hmmmf! Gauss was wrong!')
```

Listing 2.4: gauss_sum.py

2.4 Introducing strings and lists

2.4.1 Strings

I write on the board (and have the students type at the Python interpreter) several tutorial snippets to get students comfortable with strings.

```
>>> s = 'hello'
>>> t = 'world'
>>> print(s, t)
>>> s + t
## Oh cool: I can stop typing print() every time when I'm
## typing at the interpreter; from now on we will use print()
## in programs, but seldom in examples at the >>> interpreter
## prompt
>>> s + ' ' + t
```

2.4.2 Lists

First I do a “show and tell” with a shopping bag with three different types of things in it. They could be a pencil, a box of crackers, and a notepad. I then introduce the list as analogous to the shopping bag: it contains several elements of different types. (For now I gloss over the fact that a list is ordered while the shopping bag is typically not ordered.)

I then write on the board (and have the students type at the Python interpreter) several tutorial snippets to get students comfortable with lists.

```
>>> mylist = [2.5, 17, 'dude']
>>> print(mylist)
>>> mylist
>>> mylist[0]
>>> mylist[1]
>>> mylist[2]
```

AAAARGHH: repetitive task alert!!

```
>>> for i in range(3):
...     print(i, mylist[i])
```

Now there is a problem with using `range(3)`: what if the list grows? For example, if you add to the list and then *reuse* that same loop, you'll end up in trouble:

```
>>> mylist.append(42)
>>> mylist.append('the universe')
>>> print(mylist)
>>> for i in range(3):
...     print(i, mylist[i])
```

```
>>> for item in mylist:
...     print('item is:', item)
>>> print(len(mylist))
>>> for i in range(len(mylist)):
...     print(i, mylist[i])
```

2.4.3 All sorts of types

We have seen a few data types already: integer, floating point number, string, list. Let's type some commands at the Python interpreter to get a better feel for these.

Now I write the following on the blackboard and the students type them into their python3 interpreter:

```
>>> type(4)
>>> n = 42
>>> type(n)
>>> type(4.4)
>>> x = 3.141592654
>>> type(x)
>>> type(2.0), type(2)
>>> type('hello world')
>>> s = 'hello world'
>>> type(s)
>>> mylist = [2.5, 17, 'dude']
>>> mylist
>>> type(mylist)
>>> mylist[0]
>>> type(mylist[0])
>>> len(mylist)
>>> type(len(mylist))
>>> mylist
>>> for i in range(len(mylist)):
```

```
...     print('index:', i, 'list-entry:', mylist[i], 'type:', \
    type(mylist[i]))
```

I then go to another portion of the board and ask "so what different types of data do we have in Python?" The audience might answer something like "numbers, strings, lists". I would then say that it's a good start, but to note that there are two different types of numbers: floating point and integer. This comes up in particular when we print the type of 2 and of 2.0.

For younger kids I would digress briefly to mention that floating point numbers are the ones with a decimal point, while integers are "whole numbers". It is always an interesting challenge to match terminology between programming languages and the particular terms a young student's math curriculum uses.

Then we can also discuss how to turn strings into integers. We will first introduce *conditionals* (`if`-statements), logic, and booleans (we don't need to call them booleans for younger kids).

```
>>> if 2 > 3:
...     print('the impossible just happened')
... else:
...     print('phew: 2 is not greater than 3')
>>> x = 7
>>> y = 8
>>> if x*y < (x+1)*(y+1):
...     print('that made sense')
>>> x, y
>>> x == y
>>> x, y
>>> x = y
>>> x, y
>>> x == y
```

This gives us a chance to talk about the meaning of `=` (assignment) and `==` (test for equality).

Now we can explore type conversions:

```
>>> ns = '42'
>>> n = 42
>>> print(n)
>>> print(ns)
>>> n == ns
>>> n, str(n)
>>> str(n) == ns
>>> ns, int(ns)
>>> n == int(ns)
```

These last sequences (and in fact all "type at the interpreter" sequences) should be accompanied by a lot of discussion:

1. You write one or more expressions on the board.
2. You wait until they have all typed it in the interpreter.
3. You work slowly and carefully with a student who has not spoken up much recently to discuss what it means.

2.5 Start talking about tic-tac-toe

Our goal is to write a non-trivial program. We will write a program to play tic-tac-toe. Lessons 3, 4 and 7 will develop the program in detail.

But at the end of this lesson we should start whetting the student's appetite by showing how we can use lists and strings to represent a tic-tac-toe board.

First ask "if you need to represent a row on a tic-tac-toe board, what would you use?" Then mention that it's a sequence of three characters: either an `'x'` or an `'o'` or a `' '` (space), and finally get to the choice of a list. Then we need three rows, so we will use a list of lists.

Let us turn that into code. Type these lines into the interpreter:

```
>>> row0 = [' ', 'x', 'o']
>>> row1 = [' ', 'o', ' ']
>>> row2 = ['x', ' ', 'x']
>>> board = [row0, row1, row2]
>>> print(board)
>>> for row in board:
...     print(row)
```

Then open a file called `board.py` in emacs and type in this program:

```
row0 = [' ', 'x', 'o']
row1 = [' ', 'o', ' ']
row2 = ['x', ' ', 'x']
board = [row0, row1, row2]

for row in board:
    for cell in row:
        print(cell + ' ', end="")
    print
```

Listing 2.5: board.py - first stab

Students can save the program with `C-x C-s` and run it by going to their terminal, the one with the `$` prompt, and typing:

```
$ python3 board.py
```

This will be slightly better than what we got with the trivial loop and `print()` statement above, but we can do even better by adding these lines to the end of the file `board.py`:

```
print('-------')
for row in board:
    for cell in row:
        print('|', end="")
        print(cell, end="")
    print('|')
    print('-------')
```

Listing 2.6: board.py - first stab

then save the file. In the terminal window run the command:

```
$ python3 board.py
```

which should give the following ascii output:

```
-------
| |x|o|
-------
| |o| |
-------
|x| |x|
-------
```

With this we stop for the day.

Lesson 3

Functions to do tasks, more tic-tac-toe

We have written some Python instructions to print out a tic-tac-toe board. There were about seven lines of code.

Suppose we want to print the board out often. Should we put in those seven lines of code each time?

The answer is "certainly not" (repeat the mantra on repetitive tasks). The programming language feature that helps us avoid this duplication is called a "function" (also called "procedure", "subroutine" or "method").

Let us start with simple mathematical functions:

```
>>> def f(x):
...     result = x*x
...     return result
```

the function takes a variable x, does things to it (in this case squaring it), and returns another value (the square of x).

Functions don't always have to be mathematical, nor do they have to return a value: they could make things happen on your screen. Here is how we can print a tic-tac-toe board. We will modify `board.py`:

```
def print_board(board):
    print('-------')
    for row in board:
        for cell in row:
            print('|', sep="", end="")
            print(cell, sep="", end="")
        print('|')
        print('-------')
```

```
row0 = [' ', 'x', 'o']
row1 = [' ', 'o', ' ']
row2 = ['x', ' ', 'x']
board = [row0, row1, row2]
print_board(board)
```

Listing 3.1: board.py - with print_board()

We can now look at how to modify the tic-tac-toe board, and then see how functions help us with that.

Let us say that now it is o's turn to play and she places an 'o' on the middle square of row two. That would be row 2, column 1. The way we would do that in Python is by adding this at the end of the previous code snippet:

```
# ...
board[2][1] = 'o'
print_board(board)
```

Listing 3.2: board.py - setting a cell

and the "`print_board(board)`" will show us the new state of the board, which should now look like:

```
-------
| |x|o|
-------
| |o| |
-------
|x|o|x|
-------
```

We now write a function to set a position on the board. The entire program now looks like:

```
#! /usr/bin/env python3
def print_board(board):
    print('-------')
    for row in board:
        for cell in row:
            print('|', sep="", end="")
            print(cell, sep="", end="")
        print('|')
        print('-------')

def set_cell(board, row, col, val):
    board[row][col] = val
```

```
row0 = [' ', 'x', 'o']
row1 = [' ', 'o', ' ']
row2 = ['x', ' ', 'x']
board = [row0, row1, row2]
print(before:')
print_board(board)
set_cell(board, 2, 1, 'o')
print('after:')
print_board(board)
```

Listing 3.3: board.py - with print_board and set_cell

The main difference here is that instead of setting the cell with

```
board[2][1] = 'o'
```

we use

```
set_cell(board, 2, 1, 'o')
```

This does not look like a big savings, but this way of expressing things will have advantages later.

We are now ready to start playing out moves.

3.1 Structuring the program

With the code we have written in this lesson, starting from Listing 3.3, we can write a program which plays a sequence of moves and shows the board after each one.

First a discussion on the overall structure of a program. It's a good idea to define a "main function" in which you put the main flow of the program. This main flow should consist of a sequence of Python instructions, most of which should be function calls.

The following code shows a small example of this structure:

```
#! /usr/bin/env python3
def main():
    print('f(2.2) is ', f(2.2))
    print('f(2.7) is ', f(2.7))
    for x in range(5):
        print('f(', x, ') is ', f(x))

def f(x):
    return x*x

main()
```

It's a good time to discuss the invocation of `main()` at the end. Point out that the first two functions were *defined* but never *called*. At the end, after we define all our functions, we call `main()` to start the program.

Now let's move on to a structured program that uses `set_cell()` and `print_board()` to play out a sequence of moves.

At this point I usually tell the students that I will come by each of their computers and help them restructure the program while they work with me. I talk through the process of moving chunks of text around in the editor, and end up with the program in Listing 3.4. This also gives the instructor a chance to talk through how I use the editor, and to inspire the students to use the editor effectively.

```
#! /usr/bin/env python3
def main():
    board = new_board()
    print_board(board)
    # make a move as 'x'
    set_cell(board, 1, 1, 'x')
    print_board(board)
    # make a move as 'o'
    set_cell(board, 0, 1, 'o')
    print_board(board)
    # make a move as 'x'
    set_cell(board, 2, 2, 'x')
    print_board(board)
    # make a move as 'o'
    set_cell(board, 0, 0, 'o')
    print_board(board)

def new_board():
    """Makes a board where all markers are spaces"""
    row0 = [' ', ' ', ' ']
    row1 = [' ', ' ', ' ']
    row2 = [' ', ' ', ' ']
    board = [row0, row1, row2]
    return board

def print_board(board):
    """prints the current state of the board"""
    print('-------')
    for row in board:
        for cell in row:
            print('|', sep="", end="")
            print(cell, sep="", end="")
        print('|')
        print('-------')
```

```
def set_cell(board, row, col, val):
    board[row][col] = val

main()
```

Listing 3.4: board.py - play a sequence of moves

Now is a good time to talk about the idea of "top down programming". The program now appears as an English language narrative: the `main()` function has a top level description of what the program does, and it almost reads like an *English language narrative* of what hte program is doing. Note that we did not *write* the program in a top-down manner - I don't do so in this course - but it is possible to write the `main()` function first, leaving empty stubs for all the functions, and then flesh out the details later. This allows a programmer to think of the high level narrative first.

One interesting thing to point out about the program in Listing 3.4 is that the main function can be read (almost) as if it were English, and this is one of the fantastic things about computer programming: if we structure our program well, then the program flow is expressed with great clarity.

This ends our lesson, which is one of the easier ones. Things will get more intense in the final lessons.

Lesson 4

Tic-tac-toe: playing moves

4.1 Taking input moves from the players

Now that we have seen how to program in moves I will tell the students: “you should be saying ‘but *Maaaark*, this is just a sequence of pre-programmed moves; nobody is playing!’ ” I then urge them to have patience because we will now start taking input from players.

First an example of taking input. This can be typed at the interpreter:

```
>>> row_str = input('row? ')
## [it will ask you for input; you should type a number 0, 1 or 2
## students might be confused and hit <enter> again without typing
## a number, so it bears some explanation and some retries]
>>> print('the row was:', row_str)
```

Remember that in Section 2.4.3 we discussed that strings (with digits in them) are different types from numbers. You can see that `row_str` is a string and not a number.

You can convert a string to a number with “`int(row_str)`”:

```
>>> row_str = input('row? ')
## [it will ask you for input; you should type a number 0, 1 or 2]
>>> row = int(row_str)
>>> print('the row was:', row)
>>> print('types:', type(row_str), type(row))
```

Let us now write a function which accepts a player’s move. We should create a new program file called `ttt.py`, starting from `board.py`. We can do this at the shell with:

```
$ cp board.py ttt.py
```

In emacs we can edit `ttt.py` instead of `board.py` in two ways: with `C-x C-f` to load the new file, or we can exit emacs (`C-x C-c`) and then (from the shell) re-run emacs on the new file:

```
$ emacs ttt.py
```

Now we add, between the functions `print_board()` and `set_cell()`, the following:

```
# [...]
def get_move(board, marker):
    """asks the player for a move and sets the appropriate cell"""
    row = int(input('row? '))
    col = int(input('col? '))
    set_cell(board, row, col, marker)
# [...]
```

This works and we can now rewrite the main program like this:

```
# [...]
def main():
    board = new_board()
    print_board(board)
    # player 1 move
    get_move(board, 'x')
    print_board(board)
    # player 2 move
    get_move(board, 'o')
    print_board(board)
    # player 1 move
    get_move(board, 'x')
    print_board(board)
    # player 2 move
    get_move(board, 'o')
    print_board(board)
# [...]
```

Listing 4.1: ttt.py with player input

The game now could go as shown in Figure 4.1.

4.2 Improving flow and robustness

The function we have written works well and our program now is equivalent to a piece of paper and a pen: it allows two players to input their tic-tac-toe moves.

This is a good time to ask the students to make a list of complaints about the program as it is. The list usually ends up looking like this:

```
$ python3 ttt.py
-------
| | | |
-------
| | | |
-------
| | | |
-------
please enter row: 1
please enter col: 1
-------
| | | |
-------
| |x| |
-------
| | | |
-------
please enter row: 2
please enter col: 0
-------
| | | |
-------
| |x| |
-------
|o| | |
-------
please enter row: 0
please enter col: 0
-------
|x| | |
-------
| |x| |
-------
|o| | |
-------
please enter row: 2
please enter col: 2
-------
|x| | |
-------
| |x| |
-------
|o| |o|
-------
```

Figure 4.1: A run of the tic-tac-toe program with two players alternating moves.

- It does not check that the row and column are correct (i.e. equal to 0, 1 or 2).
- It does not check if the cell was already occupied! This allows cheating.
- The computer does not play its own moves, so we have not really improved upon ancient Egyptian technology.
- There is no way of determining if the game has finished.

I usually take a poll of which issues the students want to address first. We usually end up choosing to make the computer play, so we implement the first two algorithms in Lesson 5, after which we return here.

A version of this function which checks on the row and column is:

```
# [...]
```

```
def get_move(board, marker):
    """asks the player for a move and sets the appropriate cell"""
    row, col = -1, -1
    while not row in (0,1,2):
        row = int(input('please enter row: '))
    while not col in (0,1,2):
        col = int(input('please enter col: '))
    set_cell(board, row, col, marker)
# [...]
```

Listing 4.2: version of get_move() which ensures that row and col are valid.

In my experience students can have trouble understanding that they have an editor can can change the existing function (thus typing very little), while I have to write a lot more on the board. I have seen the students type the whole thing again, ending up with two copies of the the function, so it is worth shepherding them through this first significant edit.

We are left with one final problem: the current program allows you to stomp on an existing cell, so we need to modify `get_move()` to check for that:

```
# [...]
def get_move(board, marker):
    """asks the player for a move; player types numbers 0, 1 or 2 for row
    and col"""
    valid = False
    while not valid:
        row, col = -1, -1
        while not row in [0, 1, 2]:
            row = int(input('row? '))
        while not col in [0, 1, 2]:
            col = int(input('col? '))
        if board [row][col] == ' ':
            valid = True
    set_cell(board, row, col, marker)
# [...]
```

Listing 4.3: version of get_move() which checks if the cell is free

When I write this last function on the board I start paying attention to indentation and really pointing out what the levels of loops/logic are. I will usually take a different color chalk or marker and draw arrows with a head for each level of indentation, writing 4, 8, 12, . . . This is important because students will often make mistakes in the indentation of their code.

Try it out! See if you can set row or column to be less than 0 or greater than 2. See if you can stomp on existing cells.

Before moving on to detecting a winner, let us clean up the flow of the main program. Our students should have commented on how the main function has a lot of repetition in taking moves from the players, which is quite unnecessary. We will use a *while loop* to clean that up, and our while loop will for now just run forever:

```
# [...]
def main():
    board = new_board()
    print_board(board)
    ## start a loop that takes moves from the players
    ## NOTE: you need to type control-C to exit the program
    while True:
        get_move(board, 'x')
        print_board(board)
        # move to next player
        get_move(board, 'o')
        print_board(board)
# [...]
```

Listing 4.4: ttt.py - main function cleaned up with a while loop

This is a good time to point out how short and sweet this main function is: it *tells the story*. We can also explain how the terminal interrupt character (control-C) can help them exit this program when it seems to go on forever.

But while pointing out that this is sweet, we can also point out that we have done no more than re-invent the paper and pen: we have created ancient Egyptian technology, and we should feel a burning desire to move beyond.

Lesson 5

Tic-tac-toe: simplest computer play

At this point I ask the class what the program most needs. The kids might suggest the two most important things:

* Determine if there is a winner.

* Have the computer play some moves.

I encourage the kids to start with the second one: programming the simplest computer algorithms. This is a good idea beacause checking for a winner is a bit tedious, so it's a morale booster to see the computer playing against us.

Still, if the class is really determined, you could first jump to Chapter 6 and then come back here.

5.1 First found

First we write a very simple algorithm that puts a marker in the first empty cell it can find.

Here I sometimes will draw the board and tell the class something like "when I come up with an algorithm I like to play a movie in my mind of what it's going to look like" and then I demonstrate visually how the first found algorithm will walk through the various rows and the cells in each row.

Then we start typing!

We write a function `play_computer_first_found()`:

```
def play_computer_first_found(board, marker):
    """simplest computer algorithm: put your marker on the first empty
```

```
    cell you find"""
    for row in range(3):
        for col in range(3):
            if board[row][col]==' ':
                set_cell(board, row, col, marker)
                return
```

Listing 5.1: play_computer_first_found()

We also modify the main loop to play the computer's move instead of getting a human move:

```
# [...]
def main():
    board = new_board()
    print_board(board)
    while True:
        ## ask the player for a move
        get_move(board, 'x')
        print_board(board)
        ## now play the computer move
        play_computer_first_found(board, 'o')
        print_board(board)
# [...]
```

Listing 5.2: ttt.py - with computer playing moves

This will allow students to play a game against the computer. They will enjoy it enormously until they realize that the computer is making very uninteresting moves. This will be fixed in further sections.

The students should be able to quickly devise a strategy to beat the computer every time. What can make for a good humorous moment is to ask the students if they can *lose* to this algorithm.

5.2 Random play

Next we will write an algorithm to play a random move for the computer. We start by showing how Python can generate random numbers:

```
>>> import random
>>> random.random()
>>> random.random()
>>> random.random()
>>> random.randint(-3, 10)
>>> random.randint(-3, 10)
>>> random.randint(-3, 10)
>>> random.randint(0, 2)
```

```
>>> random.randint(0, 2)
>>> random.randint(0, 2)
>>> random.randint(0, 2)
>>> random.randint(0, 2)
```

The students can keep repeating these calls with the arrow keys until they are convinced that they have a random sequence. This is also a good time to discuss what random means. As usual, these more "background" and "philosophical" discussions should eventually be truncated so that we can continue the hands-on work.

Next we have a discussion with the students, asking each student to volunteer ideas on how to have the program place a marker at random.

Since we will be using the random number library, as well as the system exit function, at the top of our program we put the lines:

```
#! /usr/bin/env python3

import random
# [...]
```

Listing 5.3: import statements at top of file

Then we we write our `play_computer_random()` routine:

```
def play_computer_random(board, marker):
    """another simple computer algorithm: place your marker in a random
    empty location"""
    done = False
    while not done:
        row=random.randint(0, 2)
        col=random.randint(0, 2)
        if board[row][col]==' ':
            set_cell(board, row, col, marker)
            done = True
```

Listing 5.4: play_computer_random()

```
# [...]
        ## now play the computer move
        ## uncomment the line for the algorithm you want to use
        #play_computer_first_found(board, 'o')
        play_computer_random(board, 'o')
        print_board(board)
# [...]
```

Listing 5.5: main() - adapted to allow choice of computer algorithm

The students can now to play more games against the computer. They might find it slightly more challenging than playing against the first_found algorithm.

And if there is a bit of time and you are feeling impish, you can suggest that they have the computer play itself: first-found algorithm against random algorithm!

Lesson 6

Checking if someone has won

There are many areas of improvement for the entire program. In Chapter 7 we will add the very important functionality of having the computer play a more interesting game. But before we get to that we must add some important smarts: having the computer check if there is a winner, and hence quit at the right time.

The condition for winning tic-tac-toe is “three in a row”: you need three of the same symbols in a column or a row or one of the two diagonals.

We will write functions that return `True` or `False` if a row has three ‘x’ or three ‘o’ cells. Rows are the easiest since we represent our board as a list of rows, but we will be able to use this function for columns and diagonals as well, though we will need to *extract* them from the board.

```
def find_winner(board):
    """return winner 'x' or 'o', or ' ' if there is no winner yet"""
    for row in board:
        winner = find3(row)
        if winner != ' ':
            return winner
    for col_no in range(3):
        col = extract_col(board, col_no)
        winner = find3(col)
        if winner != ' ':
            return winner
    winner = find3(extract_slash(board))
    if winner != ' ':
        return winner
    winner = find3(extract_bslash(board))
    if winner != ' ':
        return winner
    return ' '
```

Listing 6.1: function that tests if there is a winner

As often happens, this function requires four other functions to be written: `find3()`, `extract_col()`, `extract_slash()` and `extract_bslash()`.

Here they come. This is a marathon portion of the course (writing a ton of new code in a hurry), but quite worth it.

```
def find3(row):
    """sees if the given list has a solid win. note that the list is just
    alist of 3 cells, so if you pack a column or diagonal into this
    list it will also work to find column and diagonal winners
    """
    if row[0] == row[1] and row[1] == row[2]:
        return row[0]
    else:
        return ' '

def extract_col(board, col_no):
    """packages the entries for the given column into a list"""
    col = [board[0][col_no], board[1][col_no], board[2][col_no]]
    return col

def extract_slash(board):
    """packages the entries for the "slash" diagonal into a list"""
    slash = [board[0][2], board[1][1], board[2][0]]
    return slash

def extract_bslash(board):
    """packages the entries for the "backslash" diagonal into a list"""
    bslash=[board[0][0], board[1][1], board[2][2]]
    return bslash
```

Listing 6.2: functions needed fof find_winner())

And finally, to resolve the issue of ending a game, we also need a function to see if the board is full:

```
def board_is_full(board):
    """returns True if the board is full, False otherwise"""
    for row in board:
        for cell in row:
            if cell==' ':
                return False
    return True
```

Listing 6.3: ttt.py see if we have a winner in main()

Now we can modify `main()` to use this new code and see if there is a winner.

```
# [...]
def main():
    board = new_board()
    print_board(board)
    while True:
        ## ask the player for a move; note that this line could be
        ## replaced by one of the "play_computer..." functions below
        get_move(board, 'x')
        print_board(board)
        winner = find_winner(board)
        if winner != ' ' or board_is_full(board):
            break
        get_move(board, 'o')
        print_board(board)
        winner = play_computer_random(board)
        if winner != ' ' or board_is_full(board):
            break
    if winner == ' ':
        print('Tie!')
    else:
        print('winner is', winner)
# [...]
```

Listing 6.4: ttt.py see if we have a winner in main()

And we see a big leap forward in our program: it actually has an algorithm that makes a decision! If you play against the computer it should report victories and ties, and exit.

We can now point out that our program has finally gone even further beyond acting like paper and pencil: we now have a smart piece of paper which announces the winner.

At this point I will slow down and ask the students what they think are the "great adventures of the human mind". After pointing out quantum mechanics, and the eradication of smallpox, I will mention that an algorithm that does something interesting out of lots of little decisions is one of our great advances.

Lesson 7

Tic-tac-toe: more intelligent-play

Final stretch: making our computer with some intelligence.

7.1 Defensive play

Now let us add another computer-playing algorithm called `play_computer_defensive()`. This will check to see if the opponent is about to win.

If the opponent is about to win, the computer needs to block it by placing its own marker on the last available slot on the opponent's winning slot.

We start with a description of the algorithm (procedure):

1. Iterate through the three rows one by one.
2. For that row we go through each cell.
3. If that cell is blank then we play a *hypothetical* opponent move in that cell.
4. See if that hypothetical move lets our opponent win.
5. Restore the board by returning that cell to a blank (space).
6. If the opponent could win on that square, we put *our own* marker on that square to block them.
7. If we have no defensive moves to play, we default to playing the random algorithm.

We will need some “helper functions” to reflect the steps of the algorithm:

```
def find_win_candidate(board, marker):
    """scan each cell on the board to see if the given marker could
    win on that cell. returns a triplet (row, col, marker) if that
    marker could win; returns (None, None, None) if there is no
    victory chance"""
    for row in range(3):
        for col in range(3):
            if board[row][col] == ' ':
                is_win = check_if_winning_move(board, row, col, marker)
                if is_win == marker:
                    return [row, col, is_win]
    return [None, None, None]

def check_if_winning_move(board, row, col, marker):
    """See if the given cell allows a win by the given marker. Returns
    that winning marker if so, otherwise returns a space ' ' """
    assert(board[row][col] == ' ') # only call this on blank cells
    ## temporarily set the cell to this marker
    set_cell(board, row, col, marker)
    winner = find_winner(board)
    ## restore the cell to a space
    set_cell(board, row, col, ' ')
    ## see if there is a winner
    if winner == marker:
        return winner
    return ' '
```

Listing 7.1: find_win_candidate() - functions to see if someone is about to win

Then we write `play_computer_defensive()` to use those helper functions:

```
def play_computer_defensive(board, my_marker):
    """plays a defensive strategy: if there is a threat by the opponent,
    we plug it up; otherwise we play the random algorithm"""
    opp_marker = 'x' if my_marker == 'o' else 'o'
    [row, col, win_candidate] = find_win_candidate(board, opp_marker)
    if win_candidate == opp_marker:
        set_cell(board, row, col, my_marker)
    else:
        play_computer_random(board, my_marker)
```

Listing 7.2: play_computer_defensive()

Finally we set call our new function in `main()`:

```
# [...]
        ## uncomment the line for the algorithm you want to use
```

```
        #play_computer_first_found(board, marker)
        #play_computer_random(board, marker)
        play_computer_defensive(board, marker)
# [...]
```

This is a good place to comment on *(a)* how short and easy it was to write this function once we had already written all the other helper functions, and *(b)* how easy it is to read this function.

7.2 Opportunistic play

Now let us add a computer-playing algorithm called `play_computer_opportunistic()`. This will check to see if there is a cell where putting our marker would win!

We can use these helper functions from before, using the our own marker instead of the opponent's to see if *we* are about to win. Note that if we don't have the opportunity to win we back up to playing the defensive algorithm.

```
def play_computer_opportunistic(board, marker):
    """plays opportunistically: if we can win we put our marker in that
    slot; otherwise we play the defensive algorithm"""
    [row, col, win_candidate] = find_win_candidate(board, marker)
    if win_candidate == marker:
        set_cell(board, row, col, marker)
    else:
        play_computer_defensive(board, marker)
```

Listing 7.3: play_computer_opportunistic()

Finally we set call our new function in `main()`:

```
# [...]
        ## uncomment the line for the algorithm you want to use
        #play_computer_first_found(board, marker)
        #play_computer_random(board, marker)
        #play_computer_defensive(board, marker)
        play_computer_opportunistic(board, marker)
# [...]
```

7.3 Concluding words

The best computer-playing algorithm is much more complex and it involves some restructuring of the program. At this point I leave it as an exercise for the students to do with a mentor.

The problem is this: to have the computer play an optimal move by looking ahead at what the opponent might do.

Based on this write a function called `play_computer_lookahead(board, marker)` which plays the optimal game of tic-tac-toe.

And with that encouragement to move forward, we can conclude class by having the students play the various algorithms (first_found, random, opportunistic, defensive) *against each other!*

And they should try to predict which algorithm will win.

And as their parents come pick them up, they should try having `play_-computer_opportunistic()` play against their parents.

Appendix A

Life after the course

It is important to let the children and parents know that they can corresponde with you after the course. That way they can continue working on the program and ask questions of they get stuck.

I have taken the approach of also offering in-person help after the course by pointing families to the New Mexico Linux user group meeting. I go to many of those meetings, as do other hackers, and we are always willing to help.

I have also developed a “scientific computing for kids” course which requires nothing but this course’s material. I have written a teacher’s manual for it (Galassi 2016), analogous to this one.

Another continuation would be some lessons on GUI programming, in particular developing a GUI for this tic-tac-toe game.

Appendix B

Notes on installing Linux in class

B.1 Issues with old/cheap hardware

An old computer can still be quite useful: the Linux operating system is often much more efficient with hardware resources, so it can give new life to an old hunk of metal, as long as it is less than about 10 years old. (Computers more than 10 years old will usually need a more specialized operating system distribution.)

Still, older computers can have some problems. Mostly these will come down to:

limited memory This is the biggest problem. Today's (early 2015) desktops require more than 2GB of RAM or they will not operate very well. You can install a low memory use distribution, such as LUbuntu, but the problem really comes down to the web browser: a contemporary version of full featured browsers like Firefox and Chromium will rapidly climb up to using several gigabytes of RAM, slowing down your computer dramatically. On Linux systems it is easy to install the Midori web browser which works on many "fancy" web pages but does not use too much memory.

limited disk space An old computer might come with a small hard drive. It turns out that this is seldom a problem: computers less than 10 years old usually have hard disks with more than 5GB of storage, and that is good enough for our purposes.

slower CPU This is actually not really a problem: the limited memory will slow you down much more than an older CPU.

older graphics card Older graphics cards don't offer some of the fancy visual effects that are used in contemporary desktops, such as "heads up display" features. This is not really a limitation: there are dozens of choices of window manager on a Linux system, and many hackers prefer the non-compositing window managers which run well on older graphics cards.

A note on very low RAM: the world of low-memory Linux distributions is a messy one, with many of them being poorly maintained or fiddly to use. In spring 2016 I evaluated various alternatives and found Bodhi to be more usable than the others, but apparently Simplicity Linux is also currently maintained.

B.2 The Asus X551MA laptop

This is a very inexpensive laptop which offers rather light weight, big screen, big hard drive (half a terabyte) and plenty of RAM (4GB). The low price is probably due to the lack of certain features like bluetooth and a DVD drive, which does not affect software development at all.

B.2.1 Preparing a USB memory stick

This laptop has 4GB of RAM so we can comfortably run a full contemporary version of a Linux distribution. In my course I just point people to the Ubuntu Linux distribution.

Download the Ubuntu 14.04 image from `http://www.ubuntu.com/download/desktop`

Then take a 2GB (or bigger) memory stick and prepare it on an existing computer following the instructions at the following URLs, depending on whether you are coming from:

Linux `http://www.ubuntu.com/download/desktop/create-a-usb-stick-on-ubuntu`

MS Windows `http://www.ubuntu.com/download/desktop/create-a-usb-stick-on-windows`

MacOS `http://www.ubuntu.com/download/desktop/create-a-usb-stick-on-mac-osx`

B.2.2 Saving off laptop info and restore drive

It might be a good idea to save *another* USB memory stick with the computer's Windows installation. This is called a "recovery drive". This is not because we might want to use Windows (we don't), but rather in case we should need to return the computer and thus need it to have its original operating system.

1. Write down the PC product key. In Windows do `Settings -> PC And Devices -> PC Info` and you will see the product key.

2. Make a recovery drive on a 16GB USB memory stick. Note that the memory stick will be erased. Plug it in and go to `Settings -> Control Panel -> Action Center -> Recovery -> Create recovery drive`

B.2.3 Booting from a USB stick

Recent vintage computers have a "secure boot" feature which is aimed at making it harder to replace Microsoft Windows on that computer. I have found that these Asus computers allow you to boot from a memory stick without problems.

Follow this procedure:

1. Insert the USB drive with Ubuntu Linux 14.04

2. Power on the laptop while holding the `ESC` key

3. You will get a "boot menu" which allows you to either

    - boot Windows
    - boot the Ubuntu Linux installation USB memory stick
    - enter a setup menu

    Choose to boot from the USB memory stick.

B.2.4 Installing Linux

You can select "run Ubuntu without installing" and it will put you into a working desktop environment.

Here you will have an install icon. You should double-click that icon and it will start the installation procedure.

You can answer most of the questions in the obvious default manner and it will go well for you.

One place where you might want to change from the default is when it asks if you want to "install 3rd party software". Turning this on can install useful software to play mp3 files and view movies.

One question will be if you want to "download updates while installing". In a classroom setting I would *not* set that option because it can take much more time to install. It is quite easy to run:

```
sudo apt-get update
sudo apt-get dist-upgrade
```

later on.

The trickiest question is about partitioning the hard drive. For our purposes you should erase all existing partitions and install Linux on the entire drive.

At this point your computer will reboot into the Linux operating system and you are ready to go.

B.3 The old Mac G4 PowerPC laptop

These are older, somewhat chunky Apple laptops with a PowerPC processor instead of an Intel Pentium. Many of these are still around. They are pretty much unusable with the Mac operating system, which has not been supported on the PowerPC since 2007, but can still be used with various Linux distributions.

I experimented with some old G4 laptops and various distributions and came up with the following recipe. In your searches you will find the Mint PPC distribution, which I found to take many many hours to install, and the Ubuntu 12.04 PPC, which I found installed in a reasonable amount of time. There will certainly be many others as well, but here I will show how to install the lightweight Ubuntu 12.04 PPC distribution.

B.3.1 Preparing an installation CD

You can download an LUbuntu 12.04 PowerPC image from `https://wiki.ubuntu.com/PowerPCDownloads` which will take you to `http://cdimage.ubuntu.com/lubuntu/releases/precise/release`

Pick the image with a name like `lubuntu-12.04-alternate-powerpc.iso` and download it. Once you have that ISO file you burn it onto a blank CD.

B.3.2 Booting from CD and installing

To boot a G4 laptop from the CD you need to:

1. insert the CD
2. power on the computer while holding down the ‘c’ key

(note that you might need to power the computer on enough to get it to swallow the CD, and then power it off and turn it on again so you can hold the ‘c’ key and boot from CD.)

You are now given the “yaboot prompt” that says `boot:` and you can just hit the `enter` key to start booting.

The installation procedure asks you many questions. You can give the default answer for most of them, but a few will require a specific response from you:

keyboard You could look for the Mac keyboard variant, but it will work fine with the default American keyboard.

network It might not find wi-fi immediately and we might need to install special wi-fi drivers once the whole system is up. It is OK to install without a network, or even better to plug it in to a wired ethernet network.

time zone You should put in your time zone. Here in Santa Fe it will be US Mountain time.

disk partitioning Choose `Guided, use entire disk`.

user account Create yourself a login name. I recommend that you pick something that is all lower case. You can use letters, digits, underscore and hyphen, but absolutely never use a space in your login name. Mine, for example, is `markgalassi`

Of course for your full name you should include a space!

B.3.3 Post installation

You are almost ready to go with a wired ethernet network, but we will take one last step to get the wi-fi working. We will install the package `firmware-b43-installer` with the following instructions:

```
sudo apt-get update
sudo apt-get firmware-b43-installer
```

At this point, possibly with a final reboot, you should be ready to go with wi-fi and all.

But these are truly old computers with little memory, so you might install the Midori browser with:

```
sudo apt-get install midori
```

and to use that instead of Firefox if you are always low on RAM.

Appendix C

Software Freedom

A big part of what has made my scientific career pleasant and effective has been the free software movement. Using software for scientific research, without the burden of being hostage to a corporation's marketing plan, is very liberating.

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The operating system and each individual program is offered to users with full freedom to use, modify and customize (through access to source code) and redistribute (including redistributing modified copies).

Many thousands of volunteers and paid professionals have contributed to the free software movement to the point where the machines running the Linux operating system are now the most important part of the infrastructure of the computer world.

It is in that spirit that I teach these classes: I want students to learn very serious programming, but I also want them to know that we can develop software not just to make a widget for a company to sell, but also because it can be part of a large effort to improve the high tech world.

In particular, this book is a free (as in freedom, but also free in cost) manual for anyone who might want to teach similar courses.

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