Speed

CS A109

Big speed differences

- Many of the techniques we've learned take *no time at all* in other applications
- Select a figure in Word.
  - It's automatically inverted as fast as you can highlight it.
- Color changes in Photoshop happen *as you change the slider*
  - Increase or decrease red? Move it and see it happen just as fast as you can move the slider.

Where does the speed go?

- Is it that Photoshop is so fast?
- Or that Jython is so slow?
- It's some of both—it's not a simple problem with an obvious answer.
- Let's consider an issue:
  - How fast can computers get?

What a computer *really* understands

- Computers really do not understand Python, nor Java, nor any other language.
- The basic computer only understands one kind of language: *machine language.*
  - instructions to the computer expressed in terms of values in bytes
  - tell the computer to do *very* low-level activities

E.g.: Code to ADD might be 1001 . To add 1+0 and then 1+1 our program might look like this:

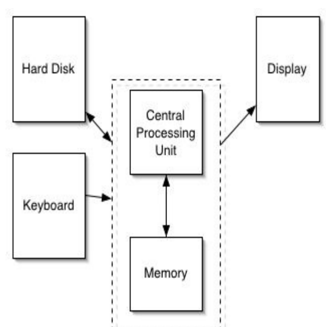
1001 0001 0000
1001 0001 0001

Assembler and machine language

- Machine language looks just like a bunch of numbers.
- *Assembler language* is a set of words that corresponds to the machine language.
  - It's a one-to-one relationship.
  - A word of assembler equals one machine language instruction, typically.
    - (Often, just a single byte.)

Each *kind* of processor has its own machine language

- Apple computers (used to) use CPU chips called G4 or G5
- Computers running Microsoft Windows may use Pentium processors.
- There are other processors called Alpha, LSI-11, and on and on.



Each processor understands only its *own* machine language

Assembler instructions

- Assembler instructions tell the computer to do things like:
  - Load numbers particular memory locations into special locations (variables) in the computer
    - These special locations are called registers
  - Store numbers into particular memory locations or into special locations (variables) in the computer.
  - Test numbers for equality, greater-than, or less-than.
  - Add numbers together, or subtract them.

An example assembly language program

```
LOAD #10,R0      ; Load special variable R0 with 10
LOAD #12,R1      ; Load special variable R1 with 12
SUM R0,R1        ; Add special variables R0 and R1
STOR R1,#45      ; Store the result into memory
                   location #45
```

Recall that we talked about memory as a long series of mailboxes in a mailroom.

Each one has a number (like #45).

The above is equivalent to Python's: `b = 10 + 12`

Assembler -> Machine

```
LOAD 10,R0        ; Load special variable R0 with 10
LOAD 12,R1        ; Load special variable R1 with 12
SUM R0,R1         ; Add special variables R0 and R1
STOR R1,#45       ; Store the result into memory location #45
```

Might appear in memory as just 12 bytes:

01 00 10
01 01 12
02 00 01
03 01 45

Another Example

- LOAD R1,#65536 ; Get a character from keyboard
- TEST R1,#13 ; Is it an ASCII 13 (Enter)?
- JUMPTRUE #32768 ; If true, go to another part of the program
- CALL #16384 ; If false, call func. to process the new line

Machine Language:
05 01 255 255
10 01 13
20 127 255
122 63 255

Devices are (often) also just memory

- A computer can interact with external devices (like displays, microphones, and speakers) in lots of ways.
- Easiest way to understand it (and is often the *actual* way it's implemented) is to think about external devices as corresponding to a memory location.
  - Store a 255 into memory location 65542, and suddenly the red component of the pixel at (101,345) on your screen is set to maximum intensity.
  - Everytime the computer reads memory location 897784, it's a new sample just read from the microphone.
- So the simple loads and stores handle multimedia, too.

Machine language is executed *very* quickly

- A mid-range laptop these days has a *clock rate* of 1.5 Gigahertz.
- What that means *exactly* is hard to explain,
  but let's interpret it as processing 1.5 *billion* bytes per second.
- Those 12 bytes would execute inside the computer, then, in 12/1,500,000,000th of a second!

Applications are typically *compiled*

- Applications like Adobe Photoshop and Microsoft Word are *compiled*.
  - This means that they execute in the computer as pure machine language.
  - They execute at *that* level speed.
- However, Python, Java, Scheme, and many other languages are (in many cases) *interpreted.*
  - They execute at a slower speed.
  - Why? It's the difference between *translating* instructions and directly *executing* instructions.

An example

- **Sample Problem:**

  Write a function **doGraphics** that will take a *list* as input. The function **doGraphics** will start by creating a canvas from the 640x480.jpg file in the mediasources folder. You will draw on the canvas according to the commands in the input list.

  Each element of the list will be a string. There will be two kinds of strings in the list:

- "b 200 120" means to draw a black dot at x position 200 y position 120. The numbers, of course, will change, but the command will always be a "b". You can assume that the input numbers will always have three digits.
- "l 000 010 100 200" means to draw a line from position (0,10) to position (100,200)

  So an input list might look like: ["b 100 200","b 101 200","b 102 200","l 102 200 102 300"] (but have any number of elements).

Sample Solution

```
def doGraphics(mylist):
  canvas =
    makePicture(getMediaPath("640x480.jpg"))
  for i in mylist:
    if i[0] == "b":
      x = int(i[2:5])
      y = int(i[6:9])
      print "Drawing pixel at ",x,":",y
      setColor(getPixel(canvas, x,y),black)
    if i[0] =="l":
      x1 = int(i[2:5])
      y1 = int(i[6:9])
      x2 = int(i[10:13])
      y2 = int(i[14:17])
      print "Drawing line at",x1,y1,x2,y2
      addLine(canvas, x1, y1, x2, y2)
  return canvas
```

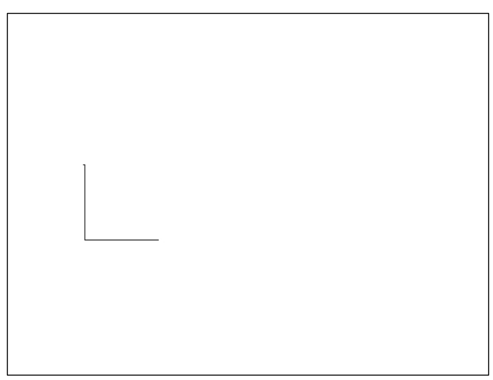
This program processes each string in the command list.

If the first character is “b”, then the x and y are pulled out, and a pixel is set to black.

If the first character is “l”, then the two coordinates are pulled out, and the line is drawn.

Running *doGraphics()*

```
>>> canvas=doGraphics(["b 100 200","b 101 200","b 102 200","l 102 200 102 300","l 102 300 200 300"])
Drawing pixel at  100 : 200
Drawing pixel at  101 : 200
Drawing pixel at  102 : 200
Drawing line at 102 200 102 300
Drawing line at 102 300 200 300
>>> show(canvas)
```



We've invented a new language

- ["b 100 200","b 101 200","b 102 200","l 102 200 102 300","l 102 300 200 300"] is a program in a new graphics programming language.
- Postscript, PDF, Flash, and AutoCAD are not too dissimilar from this.
  - There's a language that, when interpreted, "draws" the page, or the Flash animation, or the CAD drawing.
- But it's a *slow* language!

Would this run faster? Does the exact same thing

```
def doGraphics():
  canvas =
    makePicture(getMediaPath("640x480.j
    pg"))
  setColor(getPixel(canvas,
    100,200),black)
  setColor(getPixel(canvas,
    101,200),black)
  setColor(getPixel(canvas,
    102,200),black)
  addLine(canvas, 102,200,102,300)
  addLine(canvas, 102,300,200,300)
  show(canvas)
  return canvas
```

Which do you think will run faster?

```
def doGraphics(mylist):
  canvas =
    makePicture(getMediaPath("640x480.j
    pg"))
  for i in mylist:
    if i[0] == "b":
      x = int(i[2:5])
      y = int(i[6:9])
      print "Drawing pixel at ",x,":",y
      setColor(getPixel(canvas, x,y),black)
    if i[0] =="l":
      x1 = int(i[2:5])
      y1 = int(i[6:9])
      x2 = int(i[10:13])
      y2 = int(i[14:17])
      print "Drawing line at",x1,y1,x2,y2
      addLine(canvas, x1, y1, x2, y2)
  return canvas
```

```
def doGraphics():
  canvas =
    makePicture(getMediaPath("640x480.j
    pg"))
  setColor(getPixel(canvas,
    100,200),black)
  setColor(getPixel(canvas,
    101,200),black)
  setColor(getPixel(canvas,
    102,200),black)
  addLine(canvas, 102,200,102,300)
  addLine(canvas, 102,300,200,300)
  show(canvas)
  return canvas
```

Above just *draws* the picture.

The left one *figures out* (interprets) the picture, then draws it.

Could we *generate* that second program?

- What if we could write a function that:
  - Takes ["b 100 200","b 101 200","b 102 200","l 102 200 102 300","l 102 300 200 300"]
  - Writes a file that is the Python version of that program.

```
def doGraphics():
  canvas = makePicture(getMediaPath("640x480.jpg"))
  setColor(getPixel(canvas, 100,200),black)
  setColor(getPixel(canvas, 101,200),black)
  setColor(getPixel(canvas, 102,200),black)
  addLine(canvas, 102,200,102,300)
  addLine(canvas, 102,300,200,300)
  show(canvas)
  return canvas
```

Introducing a *compiler*

```
def makeGraphics(mylist):
  file = open("graphics.py","wt")
  file.write('def doGraphics():\n')
  file.write('  canvas = makePicture(getMediaPath("640x480.jpg"))\n');
  for i in mylist:
    if i[0] == "b":
      x = int(i[2:5])
      y = int(i[6:9])
      print "Drawing pixel at ",x,":",y
      file.write('  setColor(getPixel(canvas, '+str(x)+','+str(y)+'),black)\n')
    if i[0] =="l":
      x1 = int(i[2:5])
      y1 = int(i[6:9])
      x2 = int(i[10:13])
      y2 = int(i[14:17])
      print "Drawing line at",x1,y1,x2,y2
      file.write('  addLine(canvas, '+str(x1)+','+str(y1)+','+
     str(x2)+','+str(y2)+')\n')
  file.write('  show(canvas)\n')
  file.write('  return canvas\n')
  file.close()
```

Compilers are amazing

- Think about what that last program does:
  - It inputs a program in one language (our mini l/b graphics language)
  - And *generates* another program in another language (Python) that does the same thing.
- It's a program that writes programs!
  - Given a specification of a process.
  - Create a specification of the same process, but in another notation.

Why do we write programs?

- One reason we write programs is to be able to do the same thing over-and-over again, without having to rehash the same steps in Photoshop each time.
- A compiler makes that re-running the program a thousand times faster.

Which one leads to shorter time overall?

- Interpreted version:
  - 100 times
    - doGraphics(["b 100 200","b 101 200","b 102 200","l 102 200 102 300","l 102 300 200 300"]) involving interpretation and drawing each time.
- Compiled version
  - 1 time makeGraphics(["b 100 200","b 101 200","b 102 200","l 102 200 102 300","l 102 300 200 300"])
    - Takes as much time (or more) as interpreting.
    - But only *once*
  - 100 times running the very small graphics program.

Applications are *compiled*

- Applications like Photoshop and Word are written in languages like C or C++
  - These languages are then *compiled* down to machine language.
  - That stuff that executes at a rate of 1.5 billion bytes per second.
- Jython programs are interpreted.
  - Actually, they're interpreted *twice!*

Java programs typically don't compile to machine language.

- Recall that every processor has its *own* machine language.
  - How, then, can you create a program that runs on *any* computer?
- The people who invented Java also invented a *make-believe processor*—a *virtual machine*.
  - It doesn't exist anywhere.
  - Java compiles to run on the virtual machine
    - The Java Virtual Machine (JVM)

What good is it to run only on a computer that doesn't exist?!?

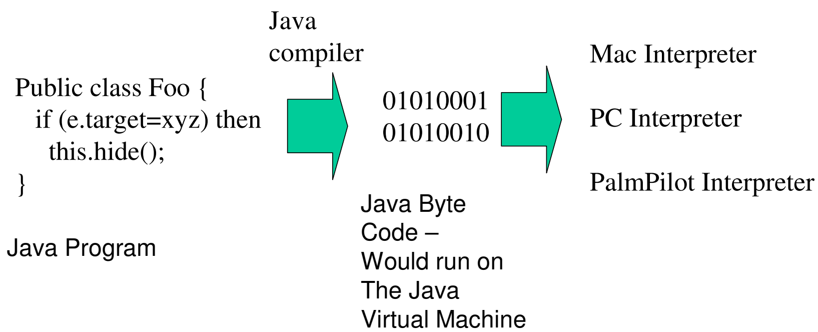
- Machine language is a *very* simple language.
- A program that *interprets* the machine language of some computer is not hard to write.

```
def VMinterpret(program):
  for instruction in program:
    if instruction == 1:  #It's a load
     ...
    if instruction == 2:  #It's an add
      ...
```

Java runs on everything…

- Everything that has a JVM on it!
- Each computer that can execute Java has an *interpreter* for the Java machine language.
  - That interpreter is usually compiled to machine language, so it's very fast.
- Interpreting Java machine is pretty easy
  - Takes only a small program
- Devices as small as wristwatches can run Java VM interpreters.

Running a Java Program



What happens when you execute a Python statement in JES

- Your statement (like “show(canvas)”) is *first* compiled to Java!
  - Really! You’re actually running Java, even though you wrote Python!
- Then, the Java is compiled into Java virtual machine language.
  - Sometimes appears as a .class or .jar file.
- *Then*, the virtual machine language is interpreted by the JVM program.
  - Which executes as a machine language program (a .exe)

Is it any wonder that Python programs in JES are slower?

- Photoshop and Word simply execute.
  - At 1.5 Ghz and faster!
- Python programs in JES are compiled, then compiled, then interpreted.
  - Three layers of software before you get down to the real speed of the computer!
- It only works at all because 1.5 *billion* is a *REALLY* big number!

Why interpret?

- For us, to have a command area.
  - Compiled languages don't typically have a command area where you can print things and try out functions.
  - Interpreted languages help the learner figure out what's going on.
- For others, to maintain portability.
  - Java *can* be compiled to machine language.
    - In fact, some VMs will actually compile the virtual machine language for you while running—no special compilation needed.
  - But once you do that, the result can only run on one kind of computer.
  - Programs for Java (.jar files typically) can be moved from any kind of computer to any other kind of computer and just *work*.
  - Also good for many web apps, since speed often not a key requirement