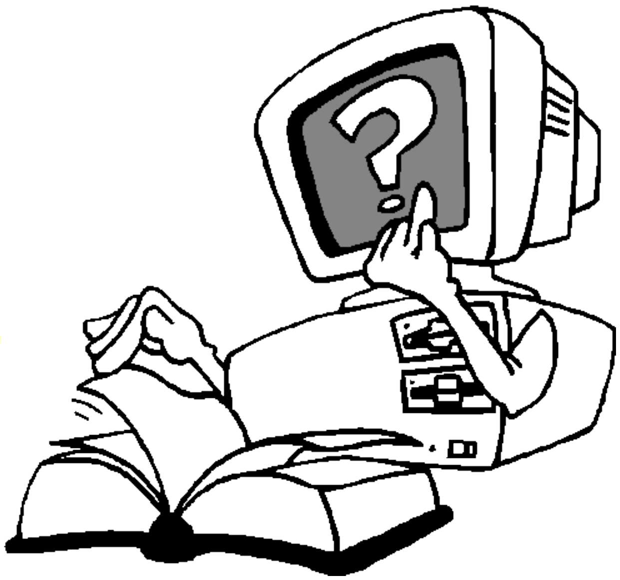
Welcome to 6.00.1x

OVERVIEW OF COURSE

- learn computational modes of thinking
- master the art of computational problem solving
- make computers do what you want them to do



https://ohthehumanityblog.files.wordpress.com/2014/09/computerthink.gif

TOPICS

- represent knowledge with **data structures**
- **iteration and recursion** as computational metaphors
- **abstraction** of procedures and data types
- **organize and modularize** systems using object classes and methods
- different classes of **algorithms**, searching and sorting
- **complexity** of algorithms

WHAT DOES A COMPUTER DO

- Fundamentally:
  - performs **calculations**
    a billion calculations per second!
        two operations in same time light travels 1 foot
  - **remembers** results
    100s of gigabytes of storage!
        typical machine could hold 1.5M books of standard size
- What kinds of calculations?
  - **built-in** to the language
  - ones that **you define** as the programmer

SIMPLE CALCULATIONS ENOUGH?

- Searching the World Wide Web
  - 45B pages; 1000 words/page; 10 operations/word to find
  - Need 5.2 days to find something using simple operations
- Playing chess
  - Average of 35 moves/setting; look ahead 6 moves; 1.8B boards to check; 100 operations/choice
  - 30 minutes to decide each move
- Good algorithm design also needed to accomplish a task!

ENOUGH STORAGE?

- What if we could just pre-compute information and then look up the answer
  - Playing chess as an example
    - Experts suggest 10^123 different possible games
    - Only 10^80 atoms in the observable universe

ARE THERE LIMITS?

- Despite its speed and size, a computer does have limitations
  - Some problems still too complex
    - Accurate weather prediction at a local scale
    - Cracking encryption schemes
  - Some problems are fundamentally impossible to compute
    - Predicting whether a piece of code will always halt with an answer for any input

turing halting problem

TYPES OF KNOWLEDGE

- computers know what you tell them
- **declarative knowledge** is **statements of fact**.
  - there is candy taped to the underside of one chair
- **imperative knowledge** is a **recipe** or "how-to" knowledge -> get the computer do something for us
  1) face the students at the front of the room
  2) count up 3 rows
  3) start from the middle section's left side
  4) count to the right 1 chair
  5) reach under chair and find it

A NUMERICAL EXAMPLE

statement of fact, but doesnt tell us how to find the square root

- square root of a number `x` is `y` such that `y*y = x`

imperative knowledge

- recipe for deducing square root of number `x` (e.g. 16)
  1) Start with a **guess**, `g`
  2) If `g*g` is **close enough** to `x`, stop and say `g` is the answer
  3) Otherwise make a **new guess** by averaging `g` and `x/g`
  4) Using the new guess, **repeat** process until close enough

-> algorithm: recipe / set of instructions for problem solving

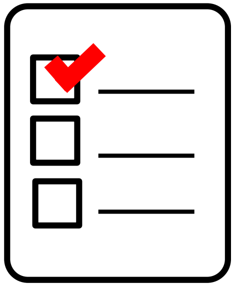
g	g*g	x/g	(g+x/g)/2
3	9	5.333	4.1667
4.1667	17.36	3.837	4.0035
4.0035	16.0277	3.997	4.000002

WHAT IS A RECIPE

1) sequence of simple **steps**

2) **flow of control** process that specifies when each step is executed

3) a means of determining **when to stop**



Steps 1+2+3 = an **algorithm**!

- An algorithm is a conceptual idea, a program is a concrete instantiation of an algorithm
(An algorithm is at a conceptual level above the program you write.)
- A computational mode of thinking means that everything can be viewed as a math problem involving numbers and formulas
- two things every computer can do: Perform calculations, Remember the results
- A recipe for deducing the square root involves guessing a starting value for y. Without another recipe to be told how to pick a starting number, the computer cannot generate one on its own.

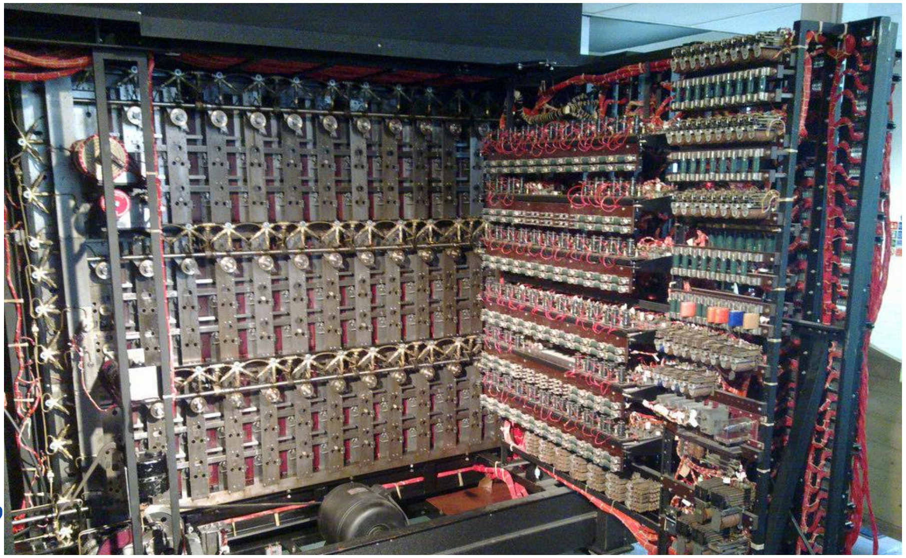
COMPUTERS ARE MACHINES

- how to capture a recipe in a mechanical process

- **fixed program** computer

  computer designed specifically to perform a particular computation

  - calculator
  - Alan Turing's Bombe



- **stored program** computer

  interpreter walks through the instructions

  - machine stores and executes instructions

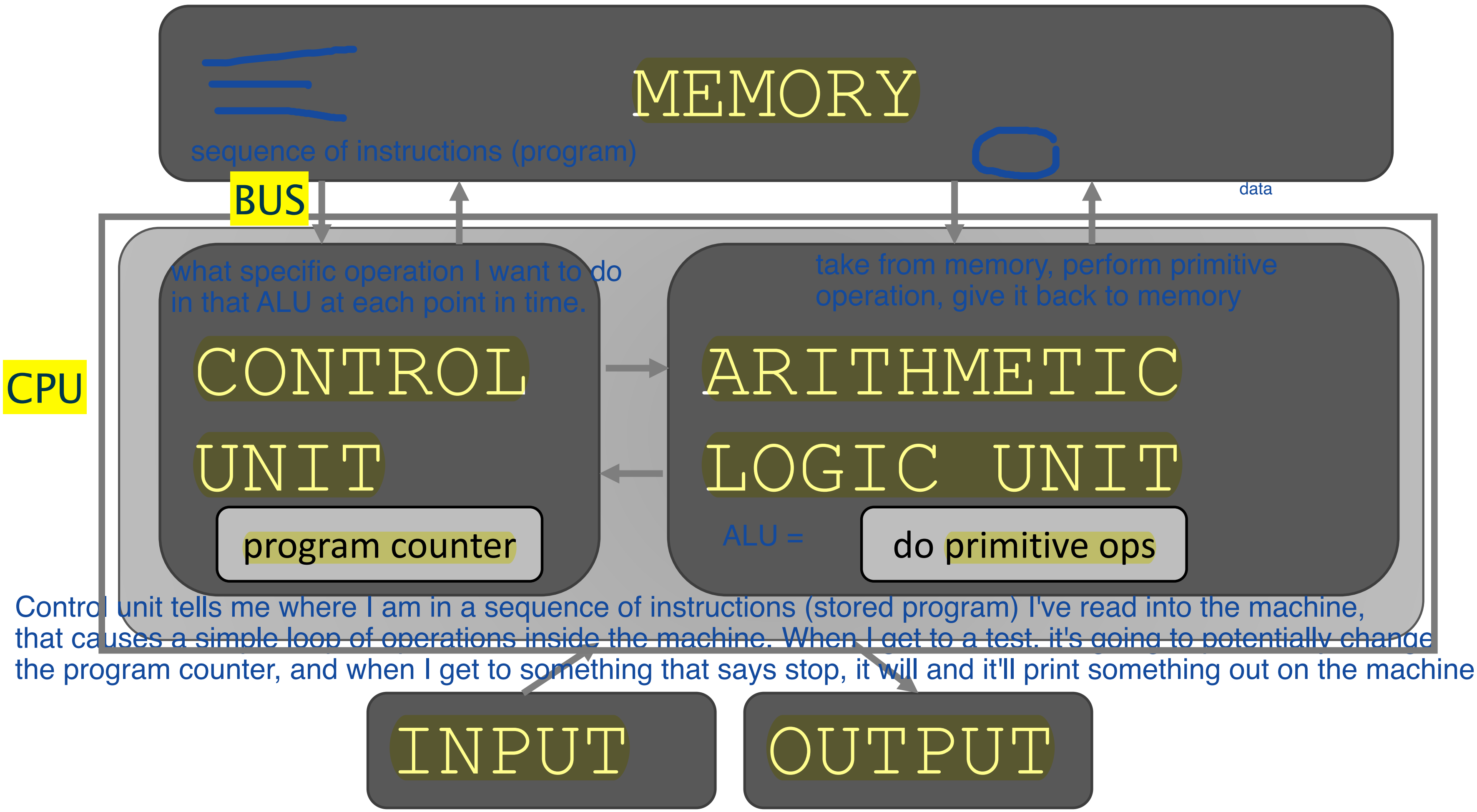
    (algorithms)

-> imitating a fixed program computer for each program that I load in

http://www.upgradenrepair.com/computerparts/computerparts.htm

program counter: points to location of the first instruction - when I ask the machine to execute, program counter reads that first instruction. It's going to cause an operation (arithmetic operation) in ALU to take place, move things back into memory, and is then going to add one to the program counter, which is going to take it to the next instruction in the sequence.
Eventually, we're going to get to a test, and that test is going to say whether somethingis true or false.
And based on that, we're going to change the program counterto go back up, for example, to the beginning of the code

BASIC MACHINE ARCHITECTURE

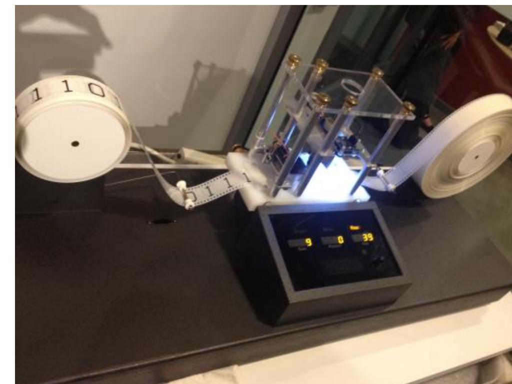


STORED PROGRAM COMPUTER

- sequence of **instructions stored** inside computer
  - built from predefined set of primitive instructions
    1) arithmetic and logic
    2) simple tests
    3) moving data
- special program (interpreter) **executes each instruction in order**
  - use tests to change flow of control through sequence
  - stop when done

BASIC PRIMITIVES

- Turing showed you can **compute anything** using 6 primitives
  move left, move right, scan, read, write, do nothing



Turing machine

By GabrielF (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

- modern programming languages have more convenient set of primitives
- can abstract methods to **create new primitives**
- anything computable in one language is computable in any other programming language
  In some languages, it's going to be easier to do some kinds of things than others.

- program counter points the computer to the next instruction to execute in the program.
- the computer walks through the sequence executing some computation: computer executes the instructions mostly in a linear sequence, except sometimes it jumps to a different place in the sequence

CREATING RECIPES

- a programming language provides a set of primitive **operations**

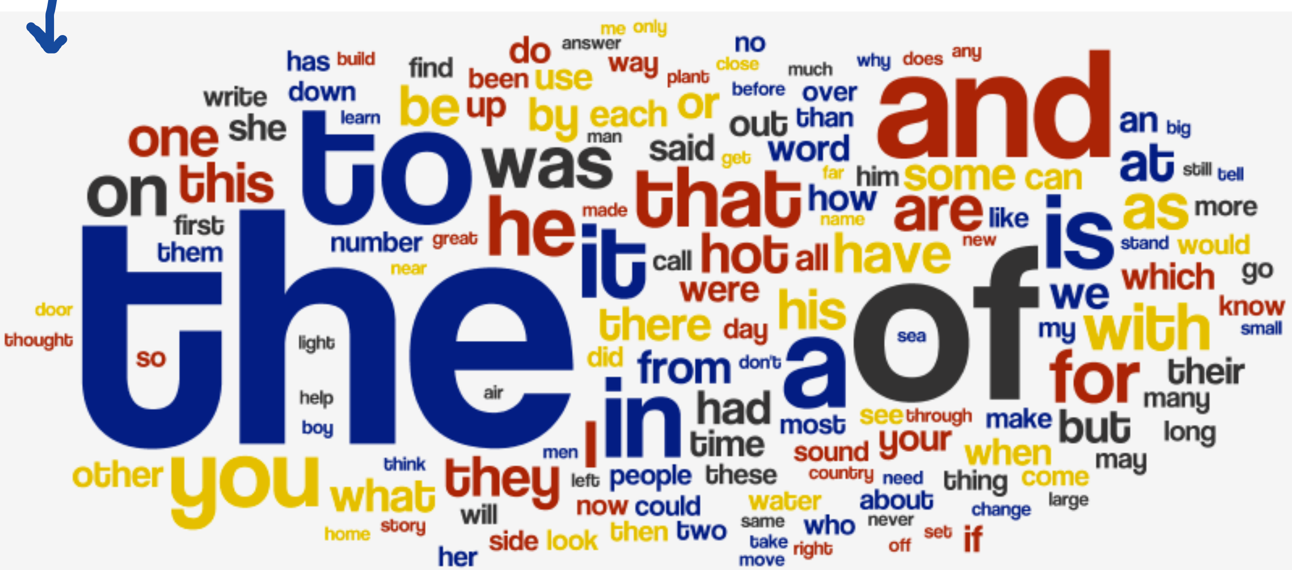
We want to now go from a description of a process to a specific set of statements so that the interpreter can then run those operations to use the primitives inside the machine to do the work for us

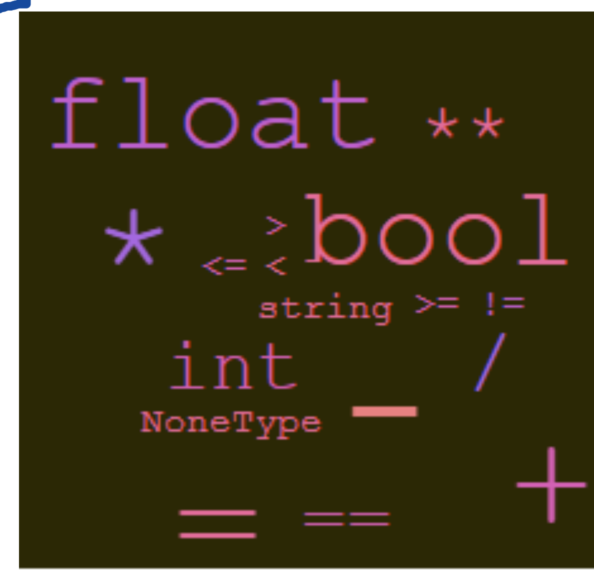
- **expressions** are complex but legal combinations of primitives in a programming language
- expressions and computations have **values** and meanings in a programming language

ASPECTS OF LANGUAGES

- **primitive constructs**
  - English: words
  - programming language: numbers, strings, simple operators

+ combination (putting those primitives together to create new expressions)
+ abstraction, (a way of taking some complex expression and treating it as it's a primitive)





ASPECTS OF LANGUAGE

- **syntax**
  - English: `"cat dog boy"` → not syntactically valid
    `"cat hugs boy"` → syntactically valid
  - programming language: `"hi"5` → not syntactically valid
    `3.2*5` → syntactically valid

ASPECTS OF LANGUAGES

- **static semantics** is which syntactically valid strings have meaning
  - English: `"I are hungry"` → syntactically valid
    but static semantic error
  - programming language: `3.2*5` → syntactically valid
    `3+"hi"` → static semantic error
    syntactically valid

ASPECTS OF LANGUAGES

- **semantics** is the meaning associated with a syntactically correct string of symbols with no static semantic errors
  - English: can have many meanings –
    - “Flying planes can be dangerous”
    - “This reading lamp hasn’t uttered a word since I bought it?”
  - programming languages: have only one meaning but may not be what programmer intended

WHERE THINGS GO WRONG

- **syntactic errors**
  - common and easily caught
- **static semantic errors**
  static semantic errors are caught before runtime in languages which are compiled
  - some languages check for these before running program
  - can cause unpredictable behavior python
- no semantic errors but **different meaning than what programmer intended**
  - program crashes, stops running
  - program runs forever
  - program gives an answer but different than expected

OUR GOAL

- Learn the syntax and semantics of a programming language
- Learn how to use those elements to translate "recipes" for solving a problem into a form that the computer can use to do the work for us
- Learn computational modes of thought to enable us to leverage a suite of methods to solve complex problems

SYNTAX: Determines whether a string is legal
STATIC SEMANTICS: Determines whether a string has meaning
SEMANTICS: Assigns a meaning to a legal sentence

shell = window into which I can type expressions. They get passed into the Python interpreter, it follows the set of instructions to figure out what's the semantics - what's the meaning associated with that expression?
And then it prints out the result.

PYTHON PROGRAMS

- a **program** is a sequence of definitions and commands
  - definitions **evaluated** — assigning names to values and more importantly, creating procedures that we're going to treat as if they're primitives
  - commands **executed** by Python interpreter in a shell
- **commands** (statements) instruct interpreter to do something
- can be typed directly in a **shell** or stored in a **file** that is read into the shell and evaluated

OBJECTS

- programs manipulate **data objects**
- objects have a **type** that defines the kinds of things programs can do to them
- objects are
  - scalar (cannot be subdivided)
  - non-scalar (have internal structure that can be accessed)

in Python words are case-sensitive. The word True is a Python keyword (it is the value of the Boolean type) and is not the same as the word true

SCALAR OBJECTS

- `int` – represent **integers**, ex. `5`
- `float` – represent **real numbers**, ex. `3.27` decimal point
- `bool` – represent **Boolean** values `True` and `False`
- `NoneType` – **special** and has one value, `None`
  represent the absence of a value. None is the only value in Python of type NoneType
- can use `type()` to see the type of an object

```
In [1]: type(5)
Out[1]: int

In [2]: type(3.0)
Out[2]: float
```

what you write into the Python shell

what shows after hitting enter

TYPE CONVERSIONS (CAST)

- can **convert object of one type to another**
- `float(3)` converts integer `3` to float `3.0`
- `int(3.9)` truncates float `3.9` to integer `3`

PRINTING TO CONSOLE

- To show output from code to a user, use `print` command

```
In [11]: 3+2
Out[11]: 5

In [12]: print(3+2)
5
```

side effect is to print out 5, but there is no value to be returned

no 'Out' because no value returned, just something printed

EXPRESSIONS

- **combine objects and operators** to form expressions
- an expression has a **value**, which has a type
- syntax for a simple expression

```
<object> <operator> <object>
```

OPERATORS ON ints and floats

- `i+j` → the **sum**
- `i-j` → the **difference**
- `i*j` → the **product**

- if both are ints, result is int
- if either or both are floats, result is float

- `i/j` → **division**

- result is float

- `i//j` → **int division**

- result is int, quotient without remainder

- `i%j` → the **remainder** when `i` is divided by `j`
- `i**j` → `i` to the **power** of `j`

expression:
3+2

value associated with that expression:
5

SIMPLE OPERATIONS

- parentheses used to tell Python to do these operations first
  - 3*5+1 evaluates to 16
  - 3*(5+1) evaluates to 18
- **operator precedence** without parentheses
  - **
  - *
  - /
  - + and – executed left to right, as appear in expression

BINDING VARIABLES AND VALUES

- equal sign is an **assignment** of a value to a variable name

store this value (float 3.14159) into the variable (called pi)

variable

value

```
pi = 3.14159
pi_approx = 22/7
```

If use 22//7, value of expression is 3

- value stored in computer memory
- an assignment binds name to value
- retrieve value associated with name or variable by invoking the name, by typing `pi`

ABSTRACTING EXPRESSIONS

- why **give names** to values of expressions?
- **reuse names** instead of values
- easier to change code later

```
pi = 3.14159
radius = 2.2
area = pi*(radius**2)
```

PROGRAMMING vs MATH

- in programming, you do not "solve for x"

= is an ASSIGNMENT!
(its NOT the mathematical equal sign!!)

```
pi = 3.14159
radius = 2.2
# area of circle
area = pi*(radius**2)
radius = radius+1
```

comment in python

an assignment
- value on the right
- name on the left
- equivalent is `radius += 1`

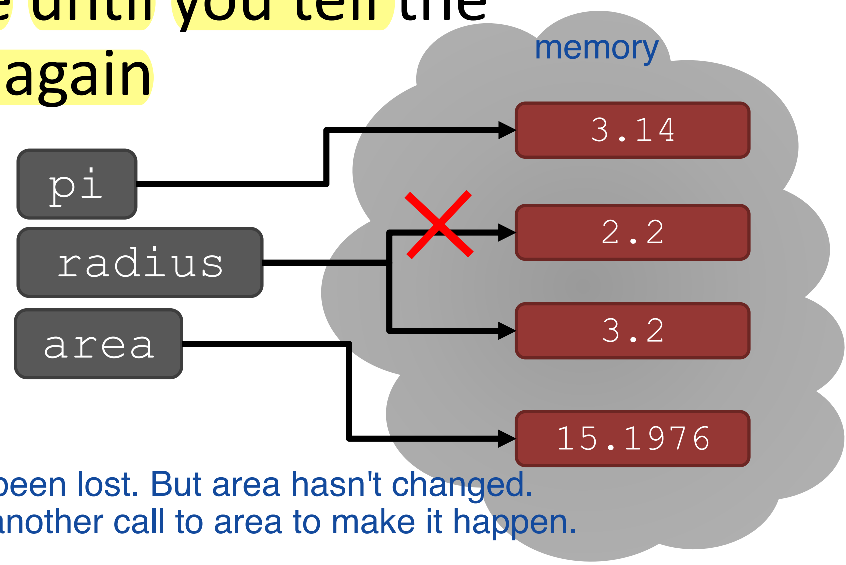
shorthand for incrementing

An assignment statement says,
find the value on the right hand side of the expression
Take the name on the left and assign that name to that value.

CHANGING BINDINGS

- can **re-bind** variable names using new assignment statements
- previous value may still stored in memory but lost the handle for it
- value for area does not change until you tell the computer to do the calculation again

```
pi = 3.14
radius = 2.2
area = pi*(radius**2)
radius = radius+1
```



we just changed the assignment of radius, the first association has been lost. But area hasn't changed.
If I wanted to recompute the area for this circle, I would need to do another call to area to make it happen.

COMPARISON OPERATORS ON `int` and `float`

- `i` and `j` are any variable names

`i>j` -> test, returns True if True and False if False

`i>=j`

`i<j`

`i<=j`

`i==j` → **equality** test, `True` if `i` equals `j` (= is ASSIGNMENT)

`i!=j` → **inequality** test, `True` if `i` not equal to `j`

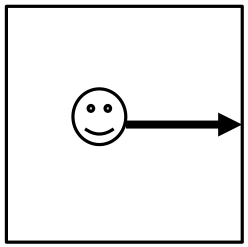
LOGIC OPERATORS ON bools

- `a` and `b` are any variable names

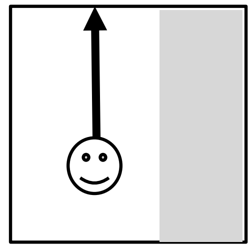
`not a` → `True` if `a` is `False`
`False` if `a` is `True`

`a and b` → `True` if both are `True`

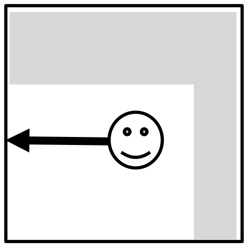
`a or b` → `True` if either or both are `True`



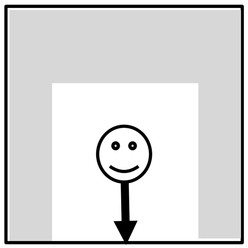
If right clear,
go right



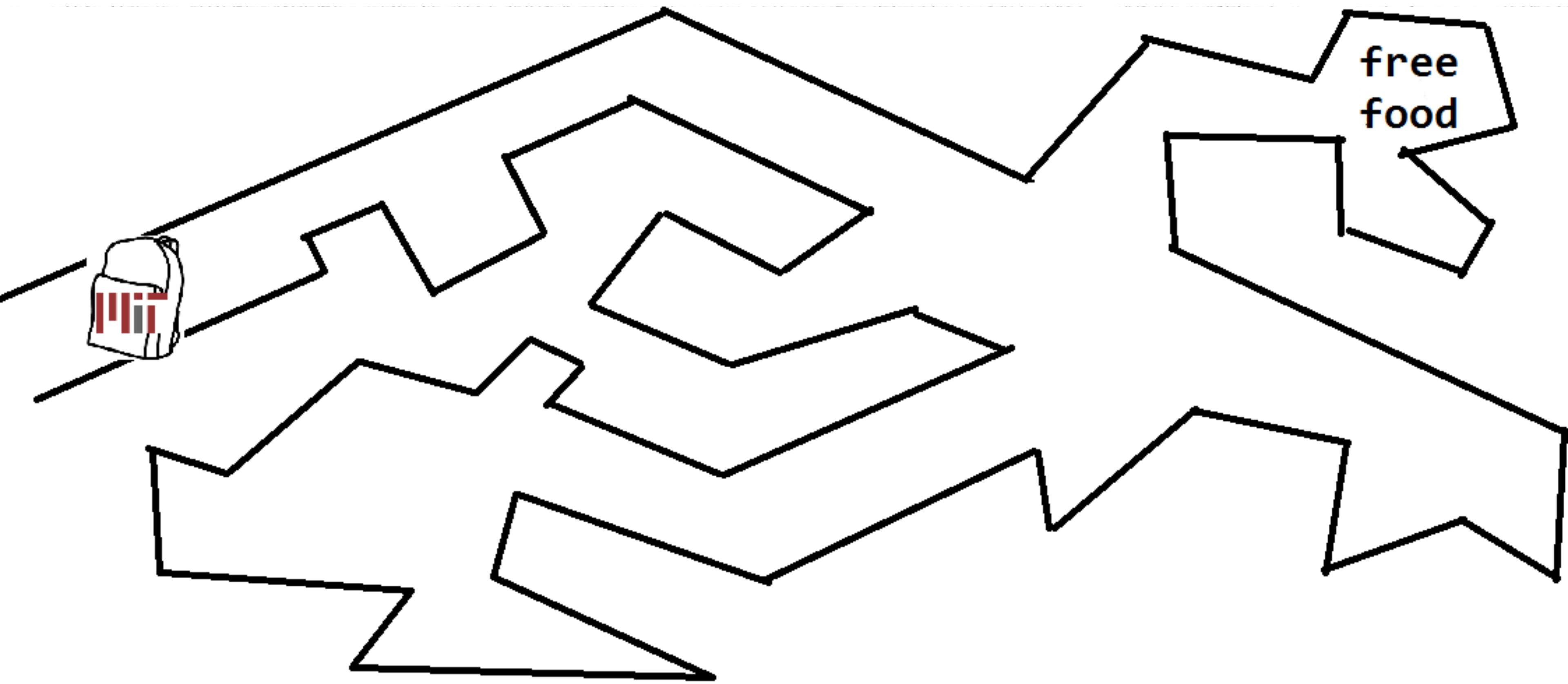
If right blocked,
go forward



If right and
front blocked,
go left

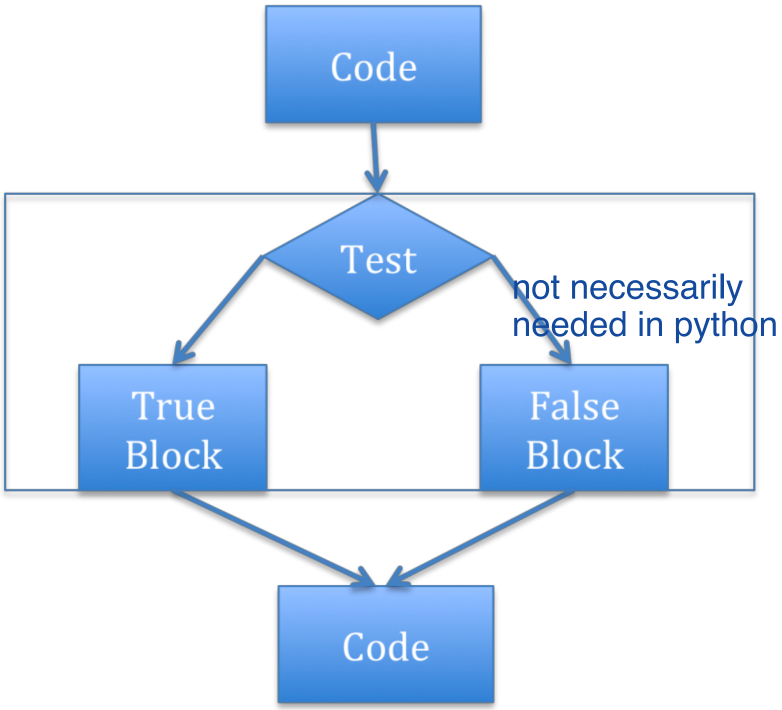


If right , front,
left blocked,
go back



BRANCHING PROGRAMS

- The simplest branching statement is a **conditional**
  - A test (expression that evaluates to `True` or `False`)
  - A block of code to execute if the test is `True`
  - An optional block of code to execute if the test is `False`



A SIMPLE EXAMPLE

```
x = int(input('Enter an integer: '))
if x%2 == 0:
    print('')
    print('Even')
else:
    print('')
    print('Odd')
print('Done with conditional')
```

test

True Block will be executed if test evaluates to True

indentation tells us whats a block of code

test evaluates to False

False Block will be executed if test evaluates to False

SOME OBSERVATIONS

- The expression `x%2 == 0` evaluates to `True` when the remainder of `x` divided by `2` is `0`
- Note that `==` is used for comparison, since `=` is reserved for assignment
- The indentation is important – each indented set of expressions denotes a block of instructions
  - For example, if the last statement were indented, it would be executed as part of the `else` block of code
- Note how this indentation provides a visual structure that reflects the semantic structure of the program

NESTED CONDITIONALS

```
if x%2 == 0:
    if x%3 == 0:
        print('Divisible by 2 and 3')
    else:
        print('Divisible by 2 and not by 3')
elif x%3 == 0:
    print('Divisible by 3 and not by 2')
```

COMPOUND BOOLEANS

```
if x < y and x < z:
    print('x is least')
elif y < z:
    print('y is least')
else:
    print('z is least')
```

I could have multiple elif statements. It's a way of giving me a sequence of tests in order.

CONTROL FLOW - BRANCHING

```
if <condition>:
    <expression>
    <expression>
    ...
```

```
if <condition>:
    <expression>
    <expression>
    ...
else:
    <expression>
    <expression>
    ...
```

```
if <condition>:
    <expression>
    <expression>
    ...
elif <condition>:
    <expression>
    <expression>
    ...
else:
    <expression>
    <expression>
    ...
```

- `<condition>` has a value `True` or `False`
- evaluate expressions in that block if `<condition>` is `True`

INDENTATION

- matters in Python
- how you denote blocks of code

```
x = float(input("Enter a number for x: "))
y = float(input("Enter a number for y: "))
if x == y:
    print("x and y are equal")
    if y != 0:
        print("therefore, x / y is", x/y)
elif x < y:
    print("x is smaller")
else:
    print("y is smaller")
print("thanks!")
```

binding a value to a variable

compare for equality

= VS ==

```
x = float(input("Enter a number for x: "))
y = float(input("Enter a number for y: "))
if x == y:
    print("x and y are equal")
    if y != 0:
        print("therefore, x / y is", x/y)
elif x < y:
    print("x is smaller")
else:
    print("y is smaller")
print("thanks!")
```

What if x = y here?

get a SyntaxError

WHAT HAVE WE ADDED?

- Branching programs allow us to make choices and do different things
- But still the case that at most, each statement gets executed once.
- So maximum time to run the program depends only on the length of the program (number of instructions)
- These programs run in **constant time**

linear programs :run in constant time because I execute each instruction at most once, however I might skip a set of statements if I skip over that branch

Hint: Python boolean types

Remember that in Python words are case-sensitive. The word `True` is a Python keyword (it is the value of the Boolean type) and is not the same as the word `true`. Refer to the Python documentation on Boolean values.

Hint: Priority order of Boolean operations

For these problems, it's important to understand the priority of Boolean operations. The order of operations is as follows:

1. Parentheses. Before operating on anything else, Python must evaluate all parentheticals starting at the innermost level.
2. `not` statements.
3. `and` statements.
4. `or` statements.

What this means is that an expression like

```
not True and False
```

evaluates to `False`, because the `not` is evaluated first (`not True` is `False`), then the `and` is evaluated, yielding `False and False` which is `False`.

However the expression

```
not (True and False)
```

evaluates to `True`, because the expression inside the parentheses must be evaluated first - `True and False` is `False`. Next the `not` can be evaluated, yielding `not False` which is `True`.

Overall, you should always use parenthesis when writing expressions to make it clear what order you wish to have Python evaluate your expression. As we've seen here, `not (True and False)` is different from `(not True) and False` - but it's easy to see how Python will evaluate it when you use parentheses. A statement like `not True and False` can bring confusion!