COMPUTATIONAL APPLICATIONS TO POLICY AND STRATEGY (CAPS)

Session 2 – Python Primer

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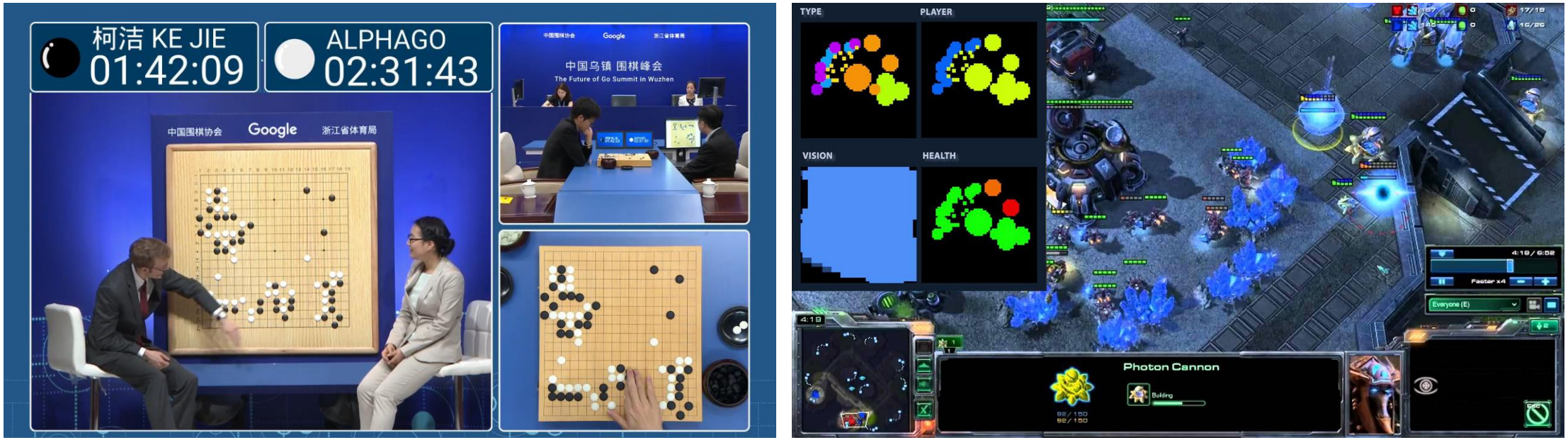
Outline

1. Workflow for Today
2. Recap Session 1
1. Python Basics
2. Object Oriented Programming
3. Asynchronous Programming
4. Required Software

Workflow for Today

> All the basics of Python code – fast-paced, please stop me if you have questions
> Breadth > depth – we will not write much code for each example
> Experiment – try to copy some of the code on the slides or just write your own as we move ahead
> Iterative – we can go back and review at any point in time

Recap – AI Agent-Environment Interaction



Screenshots from AlphaGo‘s match against world champion Ke Jie and DeepMind‘s pysc2 API for StarCraft II

Core Points

> AI as model of agent-environment interaction based on rational agency
> Different degrees of interaction (based on explicit rules or learning / adaptation)
> Each model (expert system, reinforcement learning, ...) has its own constraints
> These models provide powerful augmentations of human decision making
> Advances in AI have consequences for the global order

Combining Rule-Based and Learning Agency

- Hybrid approaches are possible and can be highly useful to focus learning
- Hybrid approach implemented in Tencent‘s StarCraft bot
- Peng Sun et al. 2018. TStarBots: Defeating the Cheating Level Builtin AI in StarCraft II in the Full Game

How?
- Rule-based aspect 1: hard-coded dependency rules of SCII (i.e. unit **z** requires building **y**, building **y** requires building **x**) are encoded in the learning algorithm
- Rule-based aspect 2: high number of decisions in SCII are trivial (i.e. which worker of workers **w** builds **x**) and unnecessarily reduce learning speed, hence hard-coded embedding

What?
- Learning-based aspects: strategic dimensions such as what to build, when to attack etc.

Understanding Computation

> To understand in detail how agents interact with an environment we need knowledge of computational decision making

> Programming is useful both to build solutions and equally as a way of thinking about problems even if your solution is qualitative

Why Python?

- Open source general-purpose language
- Supports object oriented, procedural, functional programming styles
- Interactive console
- Highly readable syntax and Zen-like best practices (`import this`)

- Additional resources:
  - https://github.com/Akuli/python-tutorial
  - https://www.edx.org/course/introduction-to-computer-science-and-programming-using-python

Python Basics

a. Strings and numbers
b. Variables
c. Conditionals
d. Iteration
e. Data structures
f. Decomposition and abstraction
g. Functions
h. Recursion
i. Modules, packages, libraries

Strings

- Strings are data types that store sequences of characters
  - “cooperate” -> “cooperate”
  - print(“cooperate”) -> cooperate
  - print(“cooperate” + “defect”) -> cooperatedefect
  - 3 * print(“defect”) -> defectdefectdefect
  - type(“defect”) -> <class 'str’>
  - len(“cooperate”) -> 9

  - # this is not a string but a comment

Numbers

- Numbers are data types that store numeric values
  - `3 + 5 -> 8`
  - `5 - 3 -> 2`
  - `5 / 3 -> 1.6666666666666667`
  - `5 // 3 -> 1`
  - `3 * 5 -> 15`
  - `3 ** 5 -> 243`
  - `type(3) -> <class 'int'>`
  - `type(1.6666666666666667) -> <class 'float'>`
  - `abs(-2) -> 2`

Working with Strings and Numbers

- Strings are mutable (we can change their individual elements)
- Numbers are immutable (we cannot change their individual elements)

- Operations on strings
  - `"cooperate"[0] -> "c"`
  - `"cooperate"[8] -> "e"`
  - `"cooperate"[-1] -> "e"`
  - `"cooperate"[0:3] -> "coo"`
  - `"cooperate"[:-1] -> "cooperat"`
  - `"cooperate"[::-1] "etarepooc"`
  - `"cooperate".index("c") -> 0`
  - `"cooperate".count("o") -> 2`

Variables

- Variables point to values, Python uses "=" to establish reference

```
> cooperate = 3
> print(cooperate) -> 3
> defect = 5
> print(defect) -> 5
> print(cooperate + defect) -> 8
> cooperate = defect
> print(cooperate) -> 5
> defect += 10
> print(defect) -> 15
```

Special Variables – Booleans and None

- There are two Booleans values, `True` and `False`. Python uses `==` to compare variables or values
  - `3 == 3 -> True`
  - `3 == 5 -> False`
  - `type(3 == 3) -> <class 'bool'>`
  - Other comparing operators are `>, <, >=, <=, !=`

- Python's version of nothing is `None`
  - `player_one = None`
  - `player_one -> # empty`
  - `print(player_one) -> None`

Conditionals – if

- We need conditionals to execute code depending on a Boolean condition, i.e. whether a specific relation is `True` or `False`
- Python has three conditionals `if, else, elif`
- `if`
  - `cooperate = 3`
  - `if cooperate == 3:` → condition
    `print(cooperate)` -> 3
    → consequent (note the indentation)
  - `defect = 5`

```
if defect == 3:
    print(defect) -> # as defect != 3, consequent will not be executed
```

Conditionals – else

> We need `else` to epress the alternative of the condition in our `if` statement

> `if + else`

```
> cooperate = 3
> if cooperate > 3:
      print("I'll cooperate")
  else:                                  takes no condition
      print("I'll defect") -> I'll defect
```

Conditionals – elif

- So far we have only checked for one condition. With `elif` we can check for one than one condition
- if + else + elif
  - `cooperate = 0`
  - `if cooperate > 3:` → condition A

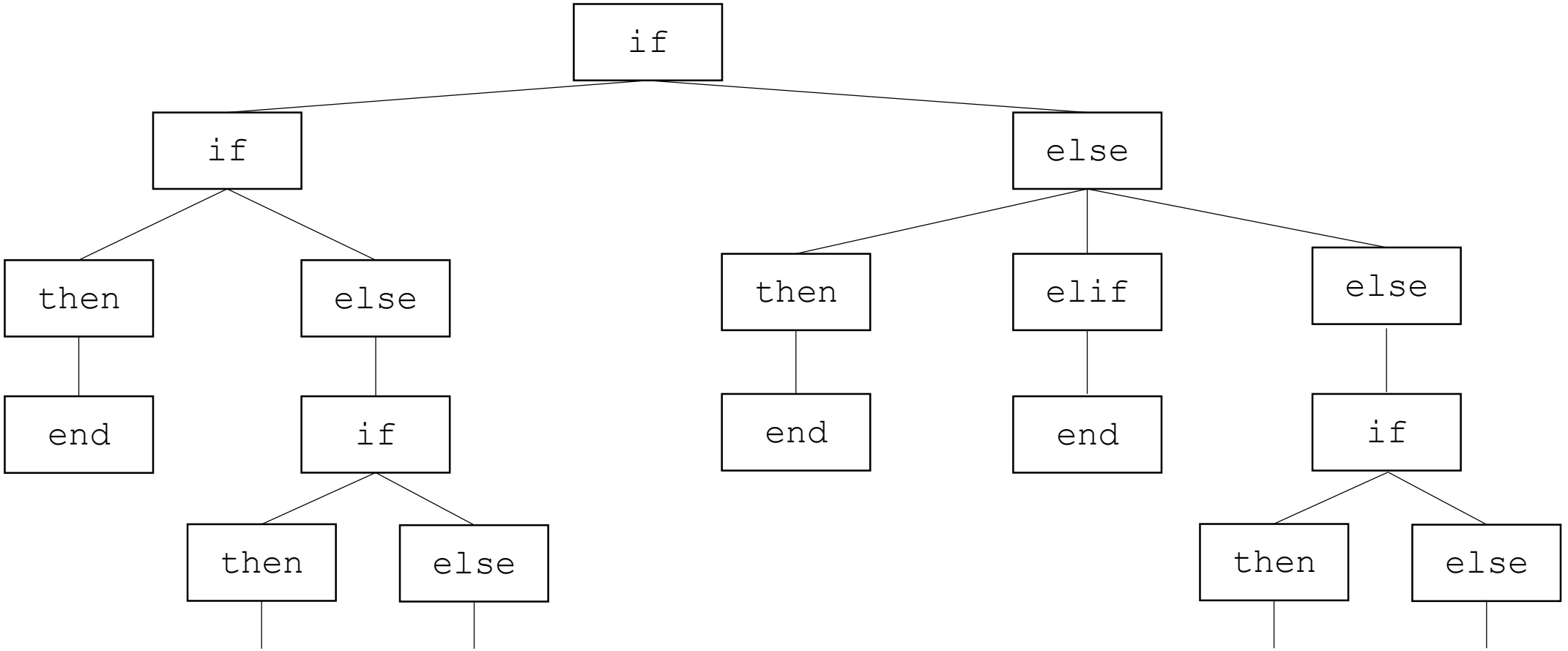
```
        print("I'll cooperate")
    elif cooperate == 0:
        print("I'll stop playing") -> I'll stop playing
else:
        print("I'll defect")
```

`elif cooperate == 0:` → condition B

`else:` → alternative of A and B

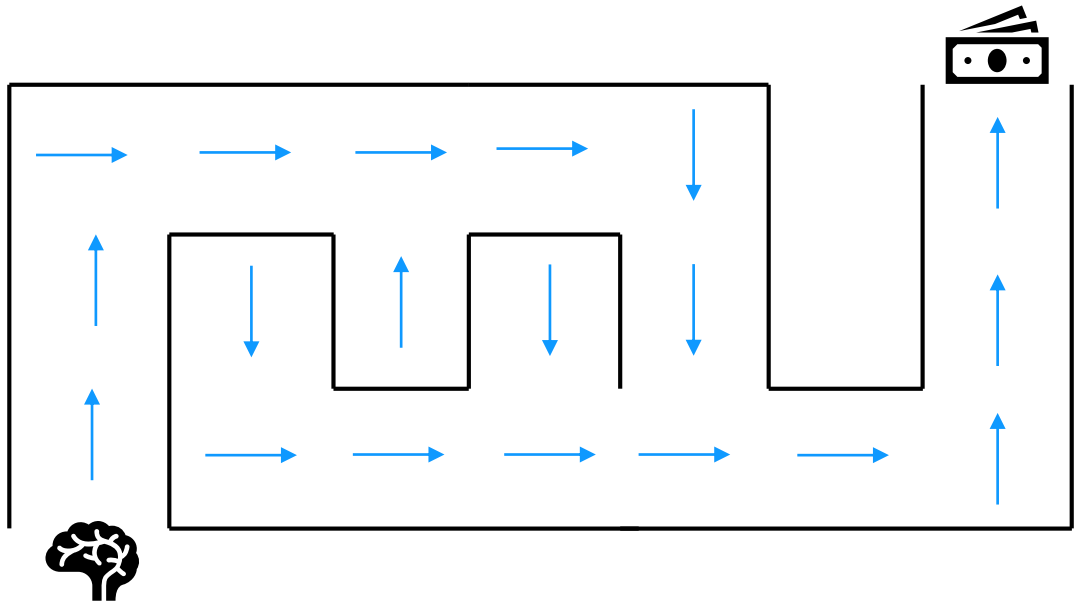
Working with Conditionals

> Conditionals can be nested and are useful tools for breaking down problems
> Conditionals are the core parts of branching algorithms



Solving a Simple Pathfinding Problem 1

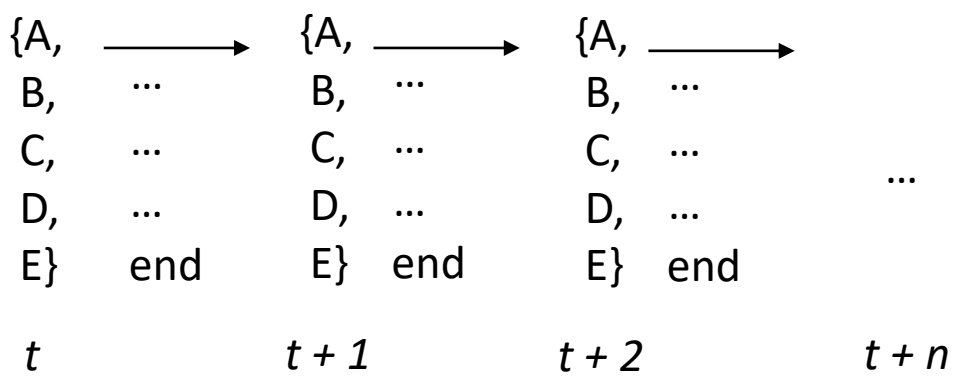
> We can use our conditional logic to solve a simple pathfinding problem



> If right clear, go right
> If right blocked, go forward
> If right and front blocked, go left
> If right, front, left blocked, go back
> If position == reward, end

Solving a Simple Pathfinding Problem 2

- Conditionals enable our agent to evaluate her position and move to the reward
- But to completely traverse the path we need to nest a lot of conditionals
  - Given a certain number of steps, we need to nest the directional options inside of each other to ensure a) all options are covered each step and b) all options can cover the next step



At each step t evaluate max. five conditions, ensure that all conditions (except E) contain all five conditions to be evaluated at t+1, etc.

  - Requires knowledge of steps **t** needed to reach reward or heuristic over-estimation of **n**
- Iteration provides an efficient way around this problem

Iteration

- Execute set of instructions n times where n > 1
- End when condition is reached
- Two ways to provide this condition, `while` and `for`

- while loop
  - `while <condition>:`

    `<expression>`

    `<expression>`

    …
  - `<condition>` evaluates to a Boolean
  - if `<condition>` is `True`, do all the steps insude the `while` code block
  - check `<condition>` again
  - end if `<condition>` is `False`

- for loop
  - `for <variable> in range(<some_num>):`

    `<expression>`

    `<expression>`

    …
  - each time through the loop, `<variable>` takes a value
  - first time, `<variable>` starts at the smallet value
  - next time, `<variable>` gets the prev value +1
  - etc.

Pseudo-Application of Iteration to Pathfinding

```
> while position != reward:
      if right == clear:
          move = right
      elif right == blocked:
          move = forward
      elif right == blocked \
      and front == blocked:
          move = left
      else:
          move = back
```

```
> for step in range(len(longest_path):
      if right == clear:
          move = right
      elif right == blocked:
          move = forward
      elif right == blocked \
      and front == blocked:
          move = left
      else:
          move = back
      if position == reward:
          break
```

if final `step` < `len(longest_path)`

Iteration – Assumptions

> Do `while` and `for` require different information about an environment?
> Are there scenarios in which you can use one but no the other?
> Which of `while` and `for` is more general than the other?
> Would you use `while` or `for` to solve the pathfinding problem?

Data Structures

- Wegner and Reily (2003)
  - “A data structure is a collection of data values, the relationships among them, and the functions or operations that can be applied to them”

- Data structures enable efficient management, access and manipulation of data
- Different data structures enable different forms of management and manipulation
- In Python, we focus on lists and dictionaries (and ignore tuples and sets)

Data Structures – Lists

- Lists are ordered sequences of elements
  - `payoffs  = [3, 0, 5, 1]`
- Lists are mutable
  - `payoffs[0] -> 3`
  - `payoffs[0] = 99`
  - `print(payoffs) -> [99, 0, 5, 1]`
  - `payoffs.append(55)`
  - `print(payoffs) -> [99, 0, 5, 1, 55]`
  - `payoffs.index(0) -> 1`
- Lists can be nested
  - `payoffs  = [[3, 0], [5, 1]]`
  - `payoffs[0] -> [3, 0]`
  - `payoffs[0][0] -> 3`

Looping Over Lists

- Constructing a for loop
  - `payoffs = [3, 0, 5, 1]`
  - `for e in payoffs:`
    `print(e*2) -> 3, 0, 5, 1`
- Using a list comprehension
  - `payoffs = [3, 0, 5, 1]`
  - `payoffs_double = [e*2 for e in payoffs]`
  - `print(payoffs_double) -> [6, 0, 10, 2]`
  - `payoffs_larger_one = [e for e in payoffs if e > 1]`
  - `print(payoffs_larger_one) -> [3, 5]`

Data Structures – Dictionaries

- Dictionaries are ordered in `key : value` pairs
  - `payoff_dict = {“cooperate” : 3, “defect” : 5}`
  - `payoff_dict[“cooperate”] -> 3`
  - `payoff_dict[“defect”] -> 5`
- More dictionary operations
  - `payoff_dict.keys() -> dict_keys(['cooperate', 'defect'])`
  - `payoff_dict.keys() -> dict_values([3, 5])`
  - `payoff_dict.items() -> dict_items([('cooperate', 3), ('defect', 3)])`
  - `payoff_dict[“nukes”] = 0`
  - `print(payoff_dict) -> {“cooperate” : 3, “defect” : 5, “nukes” : 0}`
  - `“cheat” in payoff_dict -> False`
- Note that keys must be unique and immutable

Looping Over Dictionaries

- Constructing a for loop
  - `payoff_dict = {“cooperate” : 3, “defect” : 5}`
  - `for k, v in payoff_dict.items():`
    `print(k, v) -> cooperate 3 defect 5`
- Using a dict comprehension
  - `payoff_dict = {“cooperate” : 3, “defect” : 5}`
  - `payoff_double_dict = {k : v*2 for (k, v) in payoff_dict.items()}`
  - `print(payoff_double_dict) = {“cooperate” : 6, “defect” : 10}`

Lists vs Dictionaries

- Lists
  - ordered sequence of elements
  - look up elements by an index integer
  - indicies have an order
  - index is an integer
- Dictionaries
  - matches keys to values
  - look up one item by another item
  - no order is guaranteed
  - key can be any immutable type

Decomposition and Abstraction

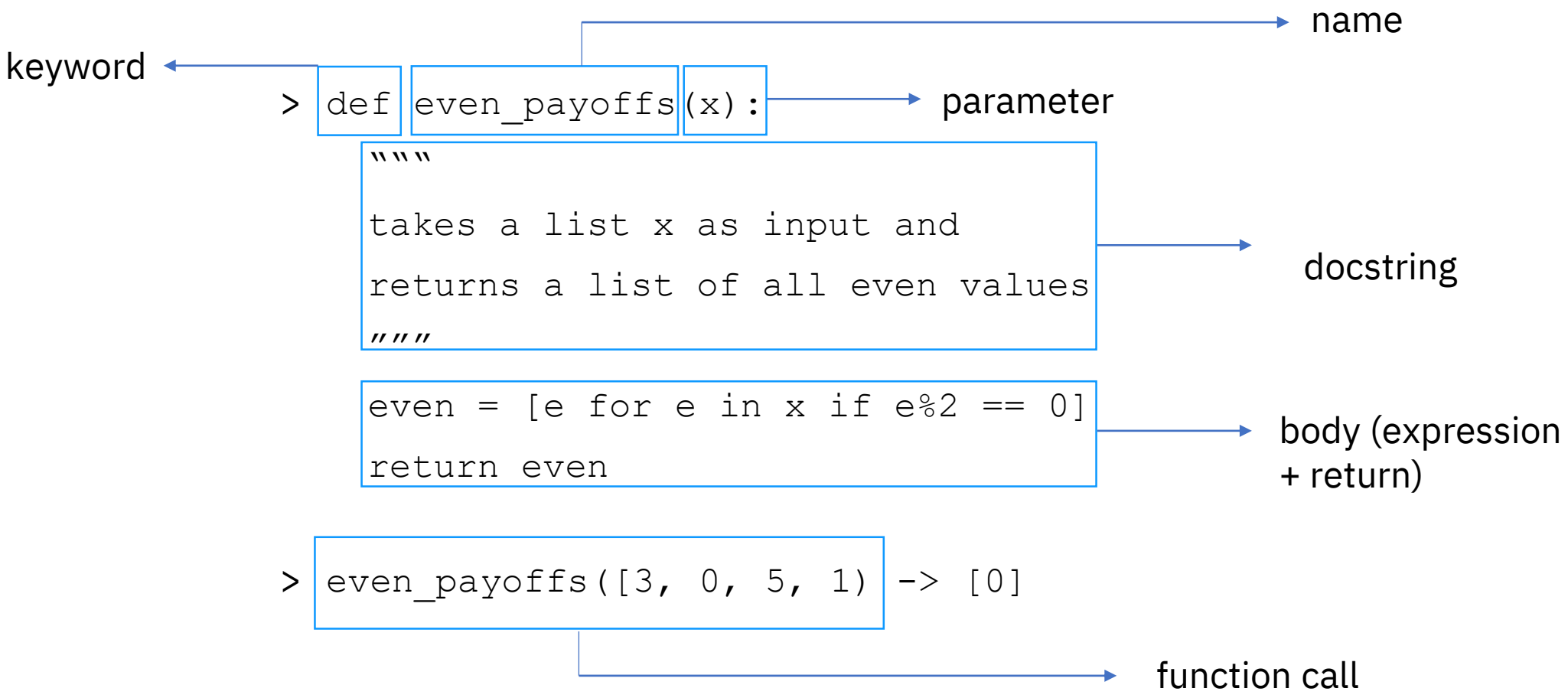
- Decomposition and abstractions are means to achieve good programming
- Decomposition
  - Concept: different devices work together to achiece an endgoal
  - Programming: break code up into self-contained modules that can be reused
  - Goal: ensure coherence, organization
  - Python: achieve decomposition through **functions** and **classes**
- Abstraction
  - Concept: do not need to know how device works to use it
  - Programming: code is black box, cannot see all details, do not want to see all details
  - Goal: provide adequate instructions for how to use code
  - Python: achieve abstraction with function **specifications** or **docstrings**

Functions

- Functions are resusable pieces of code
- Functions are not run in a program until they are “called” or “invoked”
- Characteristics of a function
  - name
  - parameters (0 or more)
  - docstring (optional but recommended)
  - body (expressions to be executed)
  - return value (the output of the function)

- Note that we have already used some of Python‘s built-in functions such as `len()`

Defining and Calling a Function



Recursion

- Recursion is the process of repeating items in a self-similar way
  - Algortithmically this means: reduce a problem to simpler versions of the same problem
  - Semantically this mens: a programming technique where a function calls itself

- Example of a recursive function:

```
def factorial(x):
    if x == 1:
        return 1
    else:
        return x*factorial(x-1)
```

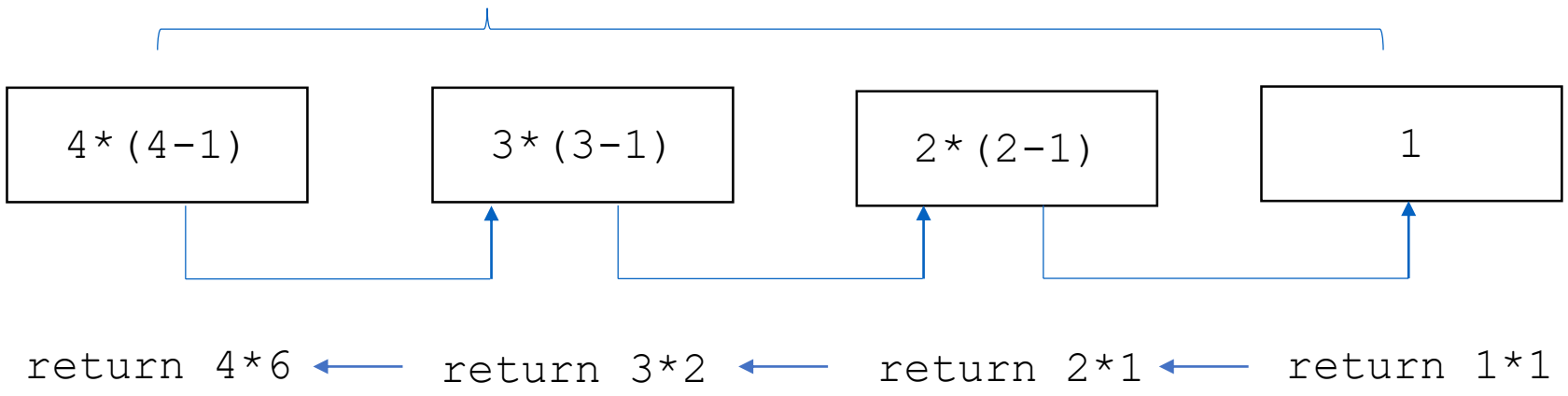
Recursion – Execution

```
> def factorial(x):
      if x == 1:
          return 1
      else:
          return x*factorial(x-1)
```

base case

recursive step

```
> factorial(4) -> 24
```



Modules, Packages, Libraries

- A module is a .py file that contains functions that you intend to reuse
- A package is a directory of modules
- A library loosely refers to published packages

- In Python we use `import <package_name>` to access packages and modules
  - `import random` → package
  - `random.randrange(0, 10)`

  - `from random import randrange` → module
  - `randrange(0, 10)`

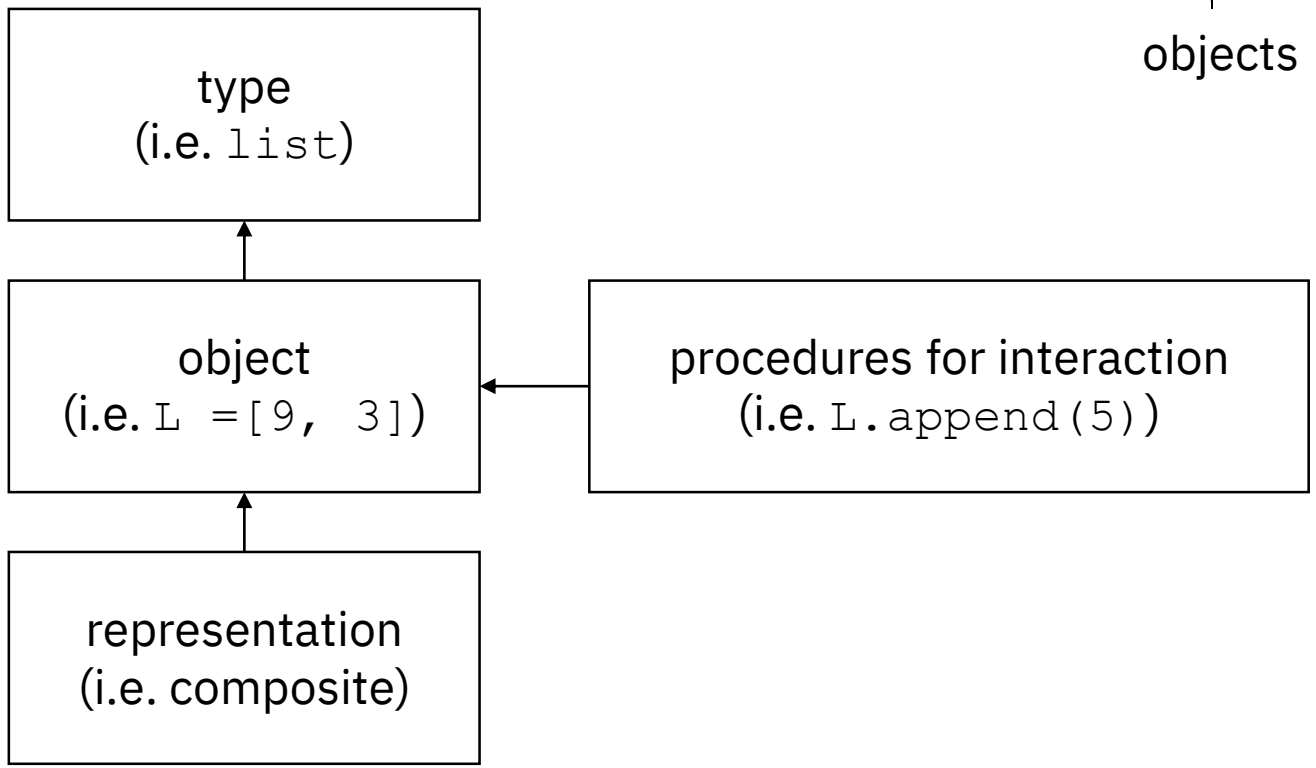
- Additional packages can be installed from the command line using `pip install <package_name>`

Understanding the Structure of a Program

> We have covered concepts and syntax that allow us to write simple programs
> A high number of rule-based StarCraft II agents are built around conditionals and iterations
> However, as these programs contain many blocks of conditionals and iterations, they are arranged according to a special paradigm that we need to understand
> This paradigm is called **Object Oriented Programming**
> In addition, the programs handel their tasks in an **asynchronous** manner
> We‘ll deal with each of these concepts in turn

Object Oriented Programming 1

> Central idea: everything in Python is an object (`2018, "Washington", [9, 3]`)



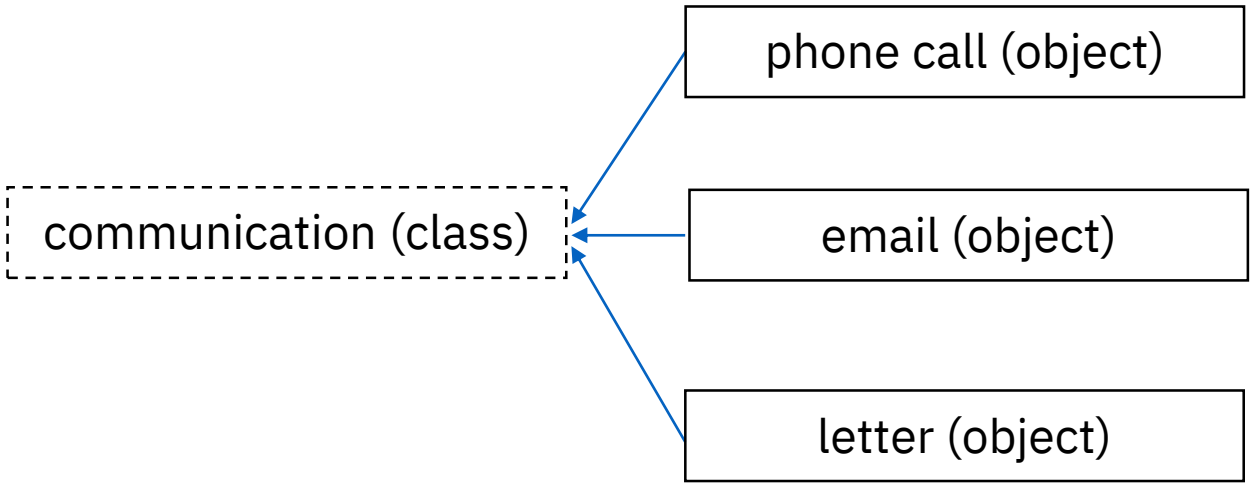
Object Oriented Programming 2

- Each object has
  - a **type**
  - an internal **data representation** (primitive or composite)
  - a set of procedures for **interaction** with the object

- An object is an instance of a type
  - `2018` is an instance of `int`
  - `L =[9, 3]` is an instance of `list`

Classes

> Every object is built from a class



> A **class** is a template or set of instructions to build a specific type of object

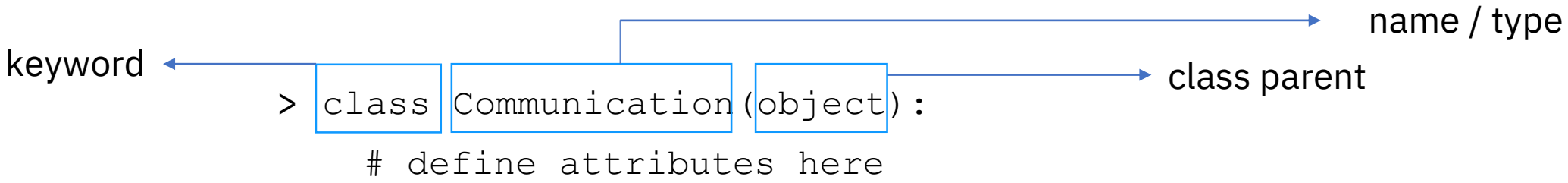
> An **instance** is an object build from a specific class

> A class can be a **subclass** of a **superclass**

Creating and Using Classes

- Distinguish between **creating a class** and **using an instance** of the class
- **Creating** the class involves
  - defining the class name
  - defining class attributes
- **Using** the class involves
  - creating new instances of objects
  - doing operations on the instances
  - i.e. `L = [9, 3]` and `L.append(5)`

Defining New Types



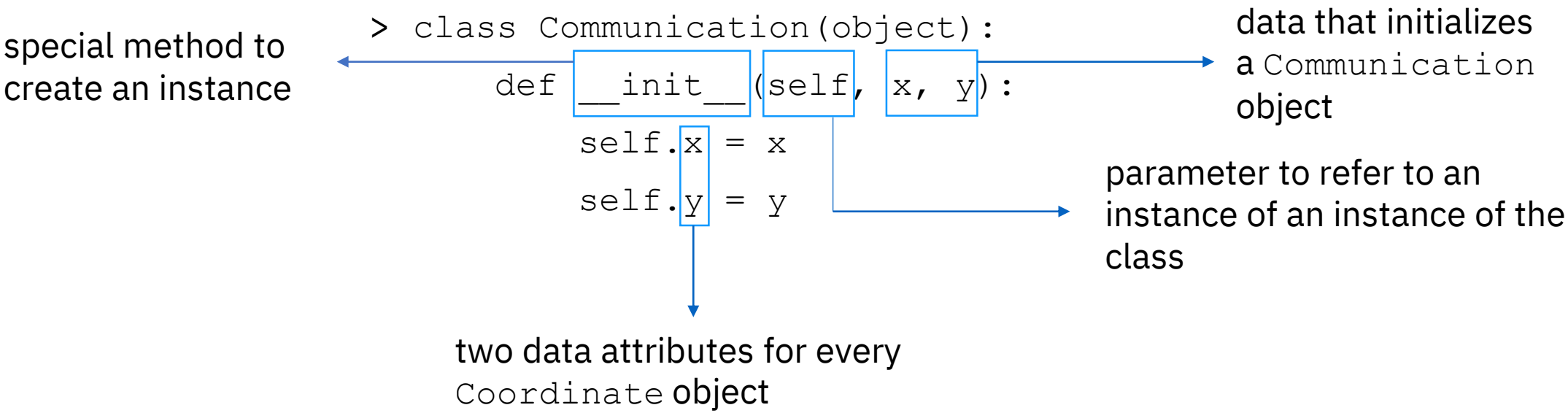
- The word `interaction` means that `Communication` is a way of interaction and **inherits** all the attributes of `interaction`
  - `Communication` is a sublass of `interaction`
  - `interaction` is a superclass of `Communication`

Attributes

- Attributes are data and procedures that **belong** to the class
- **Data attributes**
  - think of data as other objects that make up the class
  - i.e. communication is made of phone call or email or letter and two or more humans
- **Methods** (procedural attributes)
  - think of methods as functions that only work with this class
  - how to interact with the object
  - i.e. you can define a rhetorical question between two humans over a phone call but not between two clouds in the sky

Defining How to Create an Instance of a Class

> We use a special method called `__init__` to initialize data attributes



Creating an Instance of a Class

```
> c = Communication("Nitze", "Herter")
> print(c.x) -> "Nitze"
> private = Communication ("You", "Me")
> print(private.y) -> "Me"
```

create a new object of type Communication and pass in `"Nitze"` and `"Herter"` to the `__init__`

use the dot to access an attribute of instance `private`

Methods

- A method is a procedural function that only works with a specific class
- Python always passes the object as the first argument
  - Convention is to use `self` as as the name of the first argument of all methods

- The "`.`" operator is used to access any attribute (data or method)

Defining a Method for `Communication`

```
> class Communication(object):
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def allies(self, other):
        allies1 = [self.x, other.x]
        allies2 = [self.y, other.y]
        return allies1, allies2
```

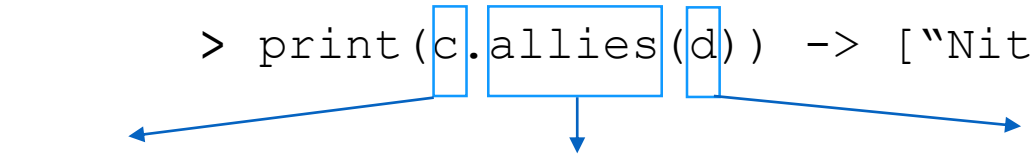
use `self` to refer to any instance

another parameter to method

dot notation to access data

Using the Method

```
> c = Communication("Nitze", "Herter")
> d = Communication("Mickey", "Donald")
> print(c.allies(d)) -> ["Nitze","Mickey"] ["Herter", "Donald"]
```



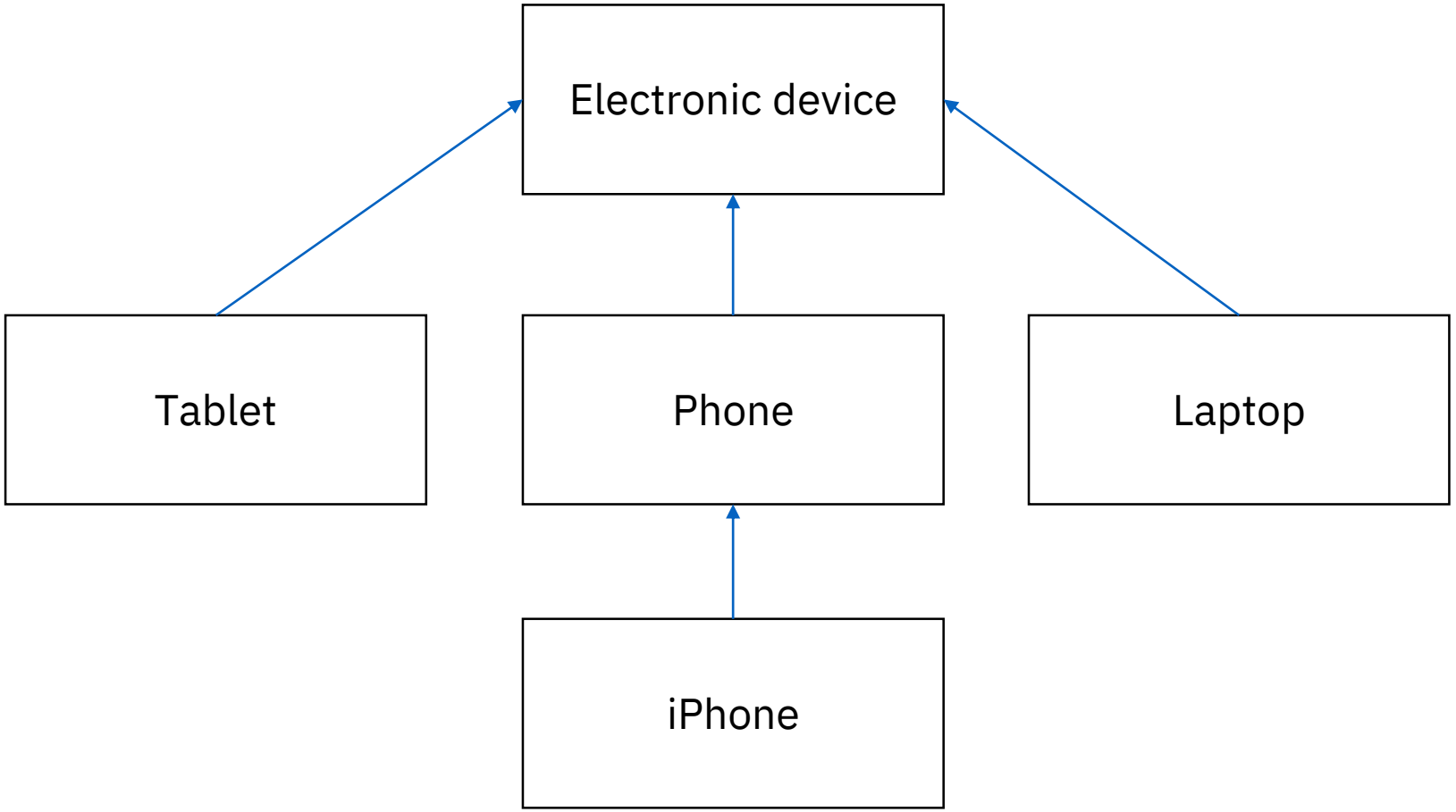
object to call method on

name of method

parameters (not including `self`)

Hierarchies and Inheritance

- **Parent class** (superclass)
- **Child class** (subclass)
  - Inherits all data and behavior from parent class
  - Add more info
  - Add more behvaior
  - Override behavior



Object Oriented Programming Recap

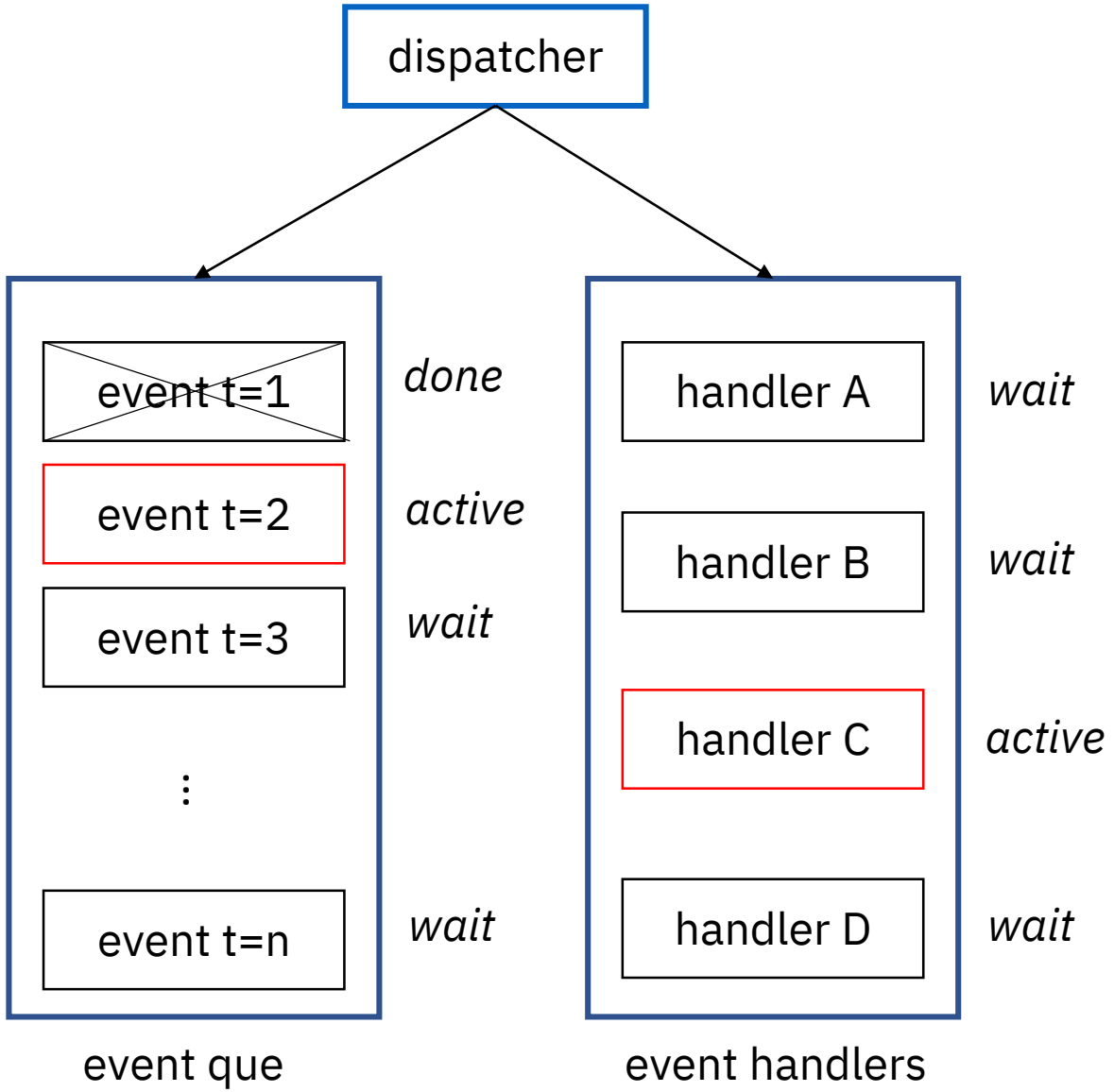
> Create your own **collections of data**
> **Organize** information
> **Division** of work
> Access information in a **consistent** manner
> Add **layers** of complexity
> Like functions, classes are a mechanism for **decomposition** and **abstraction**

An Assumption About Program Execution

- Program is executed line by line, one line at a time
- Each time a function is called, program execution waits until that function returns before continuing to the next line of code
- Refered to as **synchronous** programming
- Trade-offs
  - if a function is called and starts a time consuming process, the program has to wait until the process is complete
  - “wait at every step” even if steps are independent can diminish the program’s responsiveness and performance

Synchronous Flow

- Events (data) are qued up according to time *t* of their occurance
- Events are processed by event handlers (blocks of code)
- **Dispatcher** assigns control of program to either que or handlers
  - record event (**que**)
  - process event (**handler**)
- At time *t* all handlers (except one) and all events from *t=t + 1...n* are waiting for event *t* to finish processing

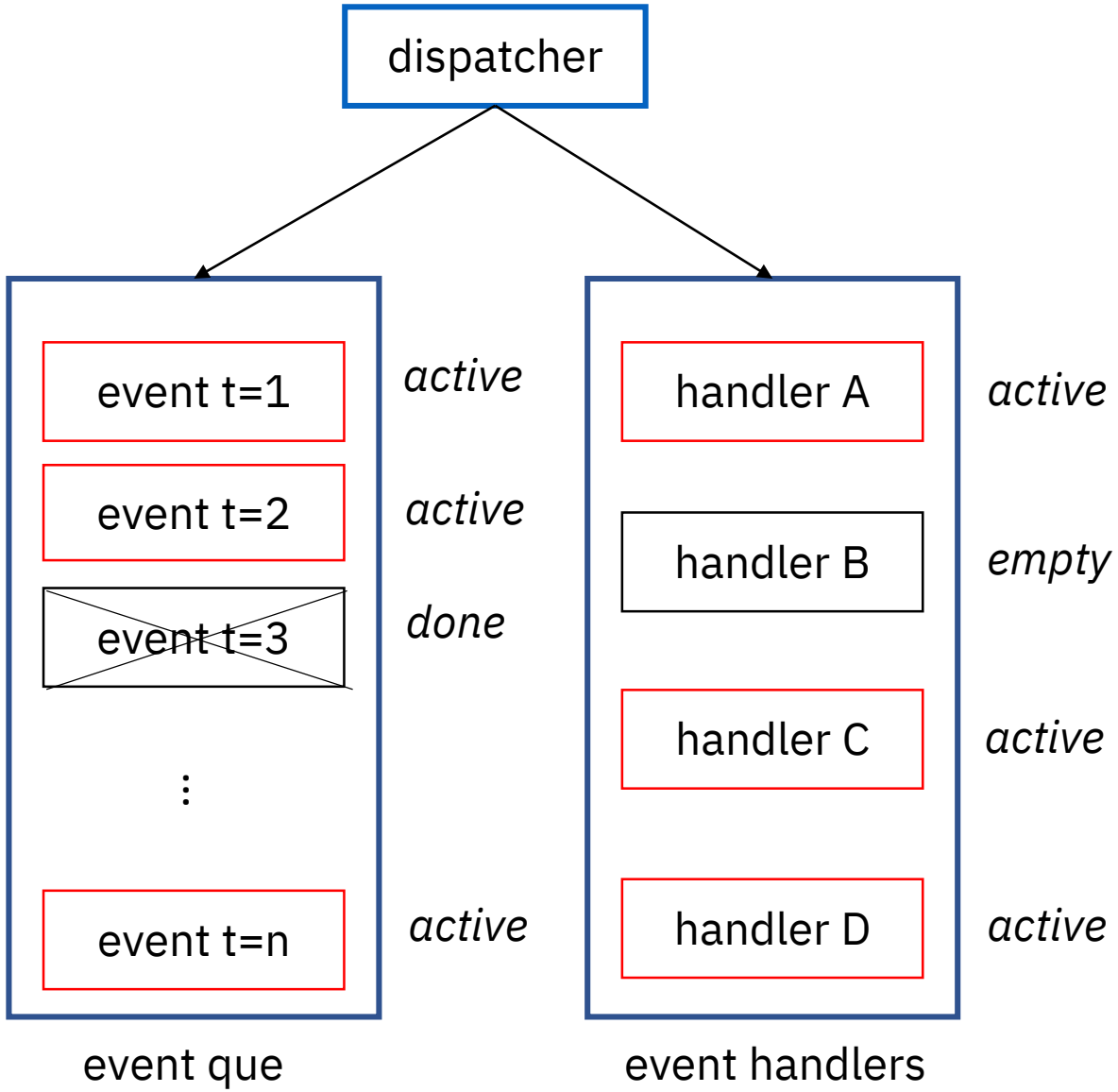


Asynchronous Programming

- In **asynchronous** programming we switch from “waiting at every step” to “waiting at the end for all steps to complete”
  - If a function is called and starts a time consuming process, we “spend our waiting time” by moving to the next step and again repeat this behaviour until the last step is reached
- We wait at the last step until all preceding steps have been executed

Asynchronous Flow

- At time *t=n* all events that have occured up to *n* are being processed (exception: waiting for identical handler)
- This is not done in parallel but in **rapid alternation between functions**
- The order of execution is **no longer predictable** (event *t=3* executed before event *t=1*)
- Instead, the order of execution depends on the events generated



Asynchronous Python

> We define an asynchronous function through `async def my_func():`
> We invoke an asynchronous function through `await my_func()`

Summary

- Python allows us to perform operations on **primitive data types** such as strings and numbers (integers, floats)
- Primitive types can be aggregated into **composite data types** (lists, dictionaries) that differently access, management and manipulate data **Conditionals** (if, elif, else) allows us to structure our program around conditions that need to be satisfied for code to be executed
- **Iteration** (for, while) and **recursion** provide further mechanisms for structuring our program depending on the task we need to achieve
- **Functions** and **classes** allow the abstraction and decomposition of our code
- **OOP** allows division of work and layered complexity in our program
- **Asnychronous programming** allows dealing with a high number of events

Required Software

- For next week you need StarCraft II and python-sc2
- Python-sc2
  - via command line: pip install sc2
- StarCraft II (free to play)
  - https://us.battle.net/account/download/
  - This will take some time so best to do it at home
- StarCraft II maps
  - https://github.com/Blizzard/s2client-proto#map-packs
  - Once installed, extract the maps as subdirectories into StarCraft II's map directory
  - Do this after you have installed StarCraft II