Complex Systems & Agent-Based Modelling

Lecture 6

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08 February 2018

What is a complex system ?

http://www.youtube.com/v/3w90X92pDSs?rel=0

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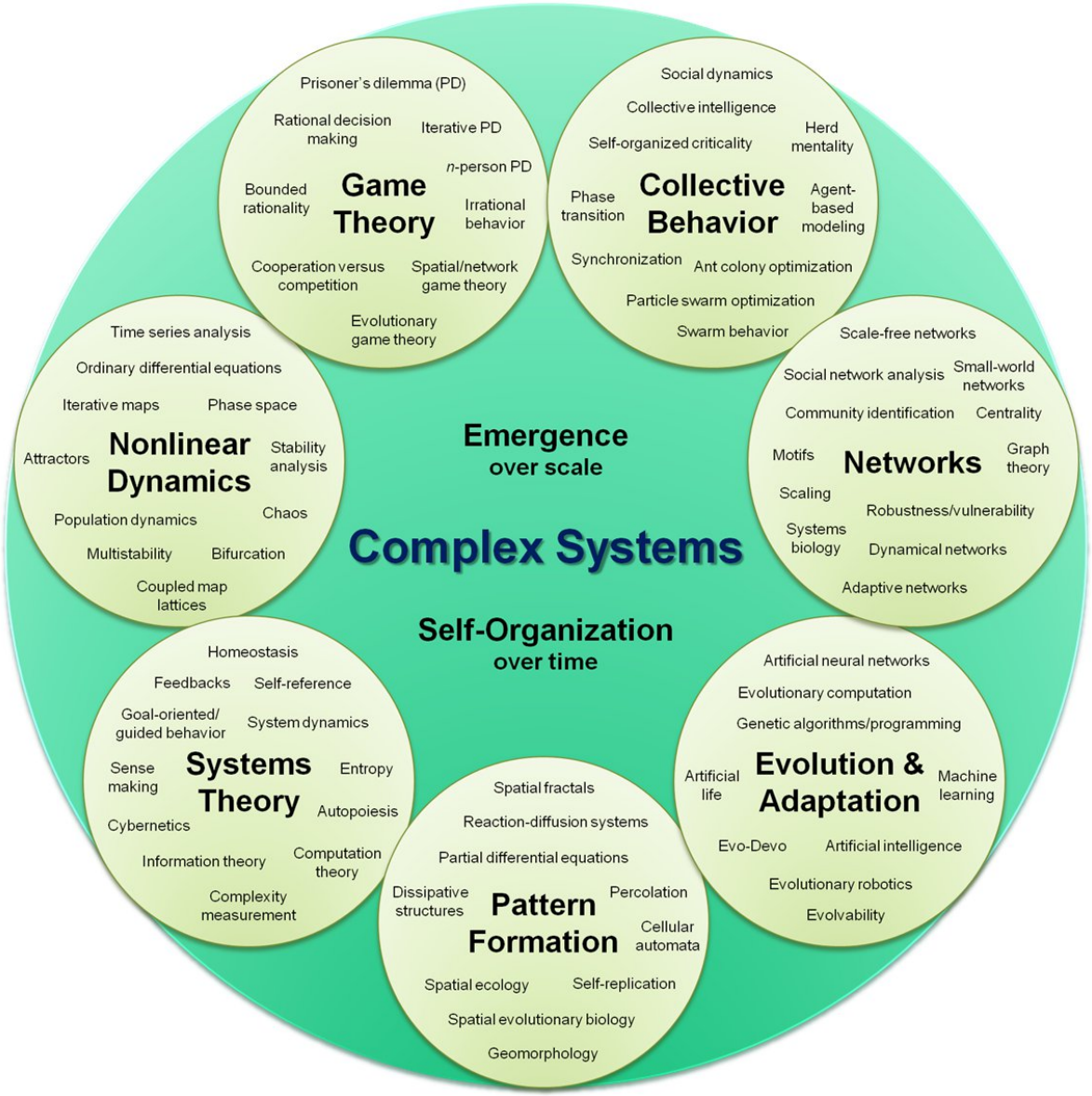
The field of complex systems cuts across all traditional disciplines of science, as well as engineering, management, and medicine.

Organizational map of Complex Systems



What are agent-based models ?

Agent-Based Models (ABMs) are arguably the most generalized tool for modelling and simulating **complex systems**, they include both Cellular Automata and Dynamical Networks models as special cases.

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- Cell growth and morphogenesis (developmental biology):
- Collective behaviour of granular materials (physics).

Definition of agent-based models

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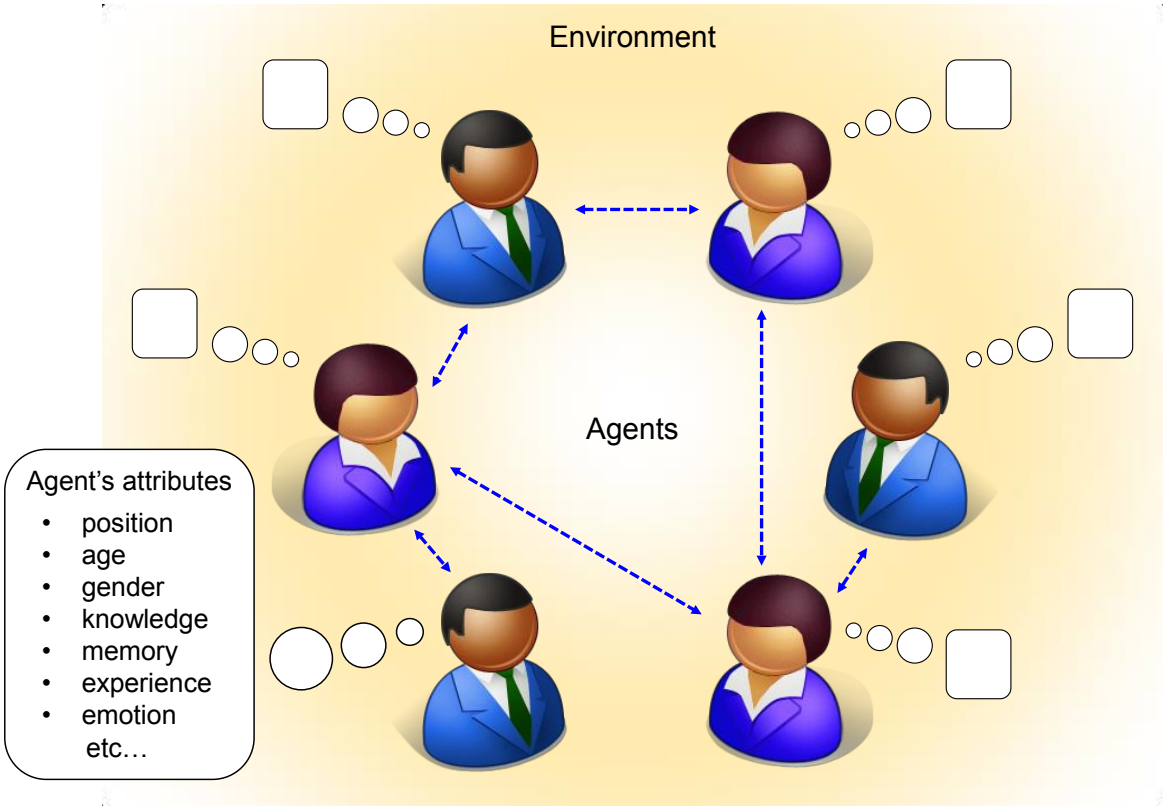
Illustration of an agent-based model



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Such representations of complex individual traits are highly valued especially in social, organizational and management sciences, where the modellers need to capture complex, realistic behaviours of human individuals. This is why ABMs are particularly popular in those research areas.

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The typical context in which an ABM is needed is when researchers want to study the *collective behaviour* of a large number of agents, otherwise it would be sufficient to use a more conventional equation-based model with a small number of variables.

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Time-continuous, differential equation models adopt continuous spatial functions as a representation of the system's state, so they are not considered ABMs.

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- ABMs often lack central supervisors / controllers.
- ABMs may produce non-trivial "collective behaviour" as a whole.

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Therefore, which model properties should be incorporated into an ABM is really up to the objective of your model.

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But beware – the increased model complexity increases the difficulty of analysing and justifying the model and its results.

If we want to derive useful, reliable conclusions from the model, we should resist the temptation to add unecessary complexity.

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Typically, IBM are built using assumptions that are derived from observations to produce previously unknown collective behaviours with the simulations.

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The first two attributes are python's default attributes that are available for any objects (you can ignore them). Aside from those, we see there are four attributes defined for the object `ag1` .

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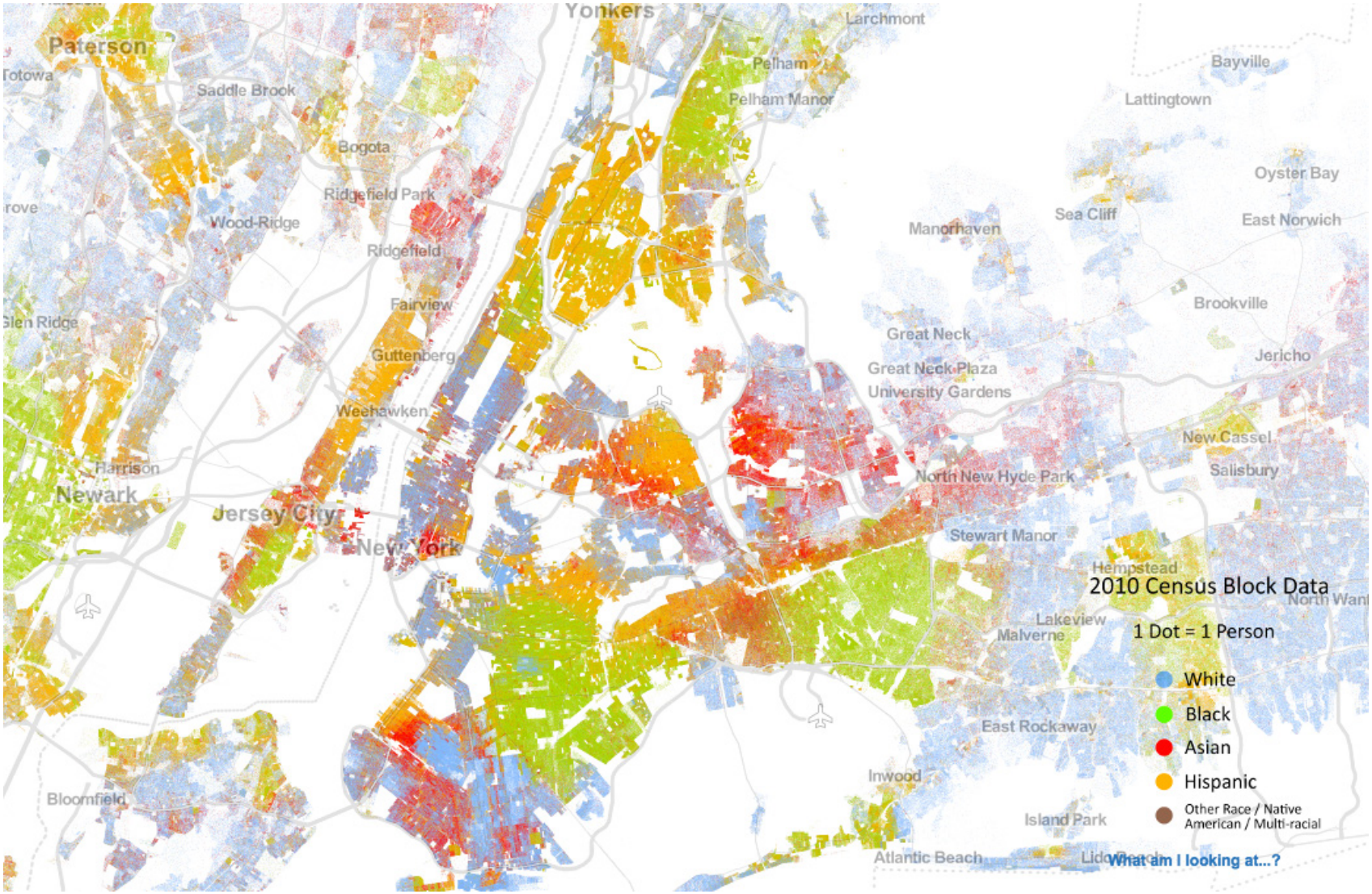

If you look at the cultural distribution of multi-ethnic cities, you will be astonished by the incredible cultural segregation. For example, the New York City map above represents data from the 2010 US Census color-coded by ethnic origin. You can clearly see the cultural segregation.

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With a very simple agent-based model, Schelling could show that what we see at the macro level may not in fact represent what is going down in the micro level.

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- In each iteration, a randomly chosen agent looks around its neighbourhood and, if the fraction of agents of the same type among its neighbours is below a *threshold*, it jumps to another location randomly chosen in the space.

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At the same time, quite against our intuition, a high level of intolerance can actually result in a well mixed society because agents keep moving without reaching a stationary state.

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    for i in xrange(n):
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        ag.x = random()
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        agents.append(ag)
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Building an Agent-Based Model

Example: Schelling's segregation model

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We assume that agents do not do anything by themselves, because their actions (movements) are triggered only by interactions with other agents. So we can ignore this design task too.

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Finally, there is something we need to implement. The model assumption says that each agent checks who are in its neighbourhood, and if the fraction of the other agents of the same type is less than a threshold, it jumps to another randomly selected location.

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We need to implement a code that allows each agent to find who is nearby.

Building an Agent-Based Model

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Building an Agent-Based Model

Example: Schelling's segregation model

There are several computationally efficient algorithms available for neighbour detection, but here we will use the simplest possible method, that is *exhaustive search*.

With this method all the agents are checked, one by one, to see if they are close enough to the focal agent. This is not computationally efficient (computation time increases quadratically as the number of agents increases), but is straightforward and easy to implement.

Building an Agent-Based Model

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```
neighbours = [nb for nb in agents
              if (ag.x - nb.x)**2 + (ag.y - nb.y)**2 < r**2 and nb != ag]
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```

Here `ag` is the focal agent whose neighbours, `nb`, are searched for.

The `if` part in the list comprehension measures the distance squared between `ag` and `nb`, and if it is less than `r` squared (`r` is the neighbourhood radius, which must be defined earlier in the code) `nb` is included in the result.

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```

Here ag is the focal agent whose neighbours, nb, are searched for.

The if part in the list comprehension measures the distance squared between ag and nb, and if it is less than r squared (r is the neighbourhood radius, which must be defined earlier in the code) nb is included in the result.

Also note that an additional condition nb != ag is given in the if part. This ensures that when nb == ag, i.e. the distance is 0, ag itself is not mistakenly included as a neighbour of ag.

Once we obtain neighbours for ag, we can calculate the fraction of the other agents whose type is the same as that of ag, and if it is less than a given threshold, the position of ag is randomly reset.

segregation.py – part 1

Complete model

```
from pylab import *

n = 1000 # number of agents
r = 0.1  # neighbourhood radius
th = 0.5 # threshold for moving to another neighbourhood

class agent:
    pass

def initialize():
    global agents
    agents = []
    for i in xrange(n):
        ag = agent()
        ag.type = randint(2) # randomly generates either a '0' or a '1'
        ag.x = random() # randomly generates a number between 0.0 and 1.0 for x position
        ag.y = random() # randomly generates a number between 0.0 and 1.0 for y position
        agents.append(ag) # append (i.e. add) the ith agent into the array 'agents'
```

segregation.py – part 2

```
def observe():
    global agents
    cla() # clear axes
    white = [ag for ag in agents if ag.type == 0]
    black = [ag for ag in agents if ag.type == 1]
    plot([ag.x for ag in white], [ag.y for ag in white], 'wo')
    plot([ag.x for ag in black], [ag.y for ag in black], 'ko')
    axis('image')
    axis([0, 1, 0, 1])
    savefig(str(t) + '.png')

def update():
    global agents
    ag = agents[randint(n)]
    neighbours = [nb for nb in agents if (ag.x - nb.x)**2 + (ag.y - nb.y)**2 < r**2 and nb != ag]
    if len(neighbours) > 0:
        q = len([nb for nb in neighbours if nb.type == ag.type]) / float(len(neighbours))
        if q < th:
            ag.x, ag.y = random(), random()

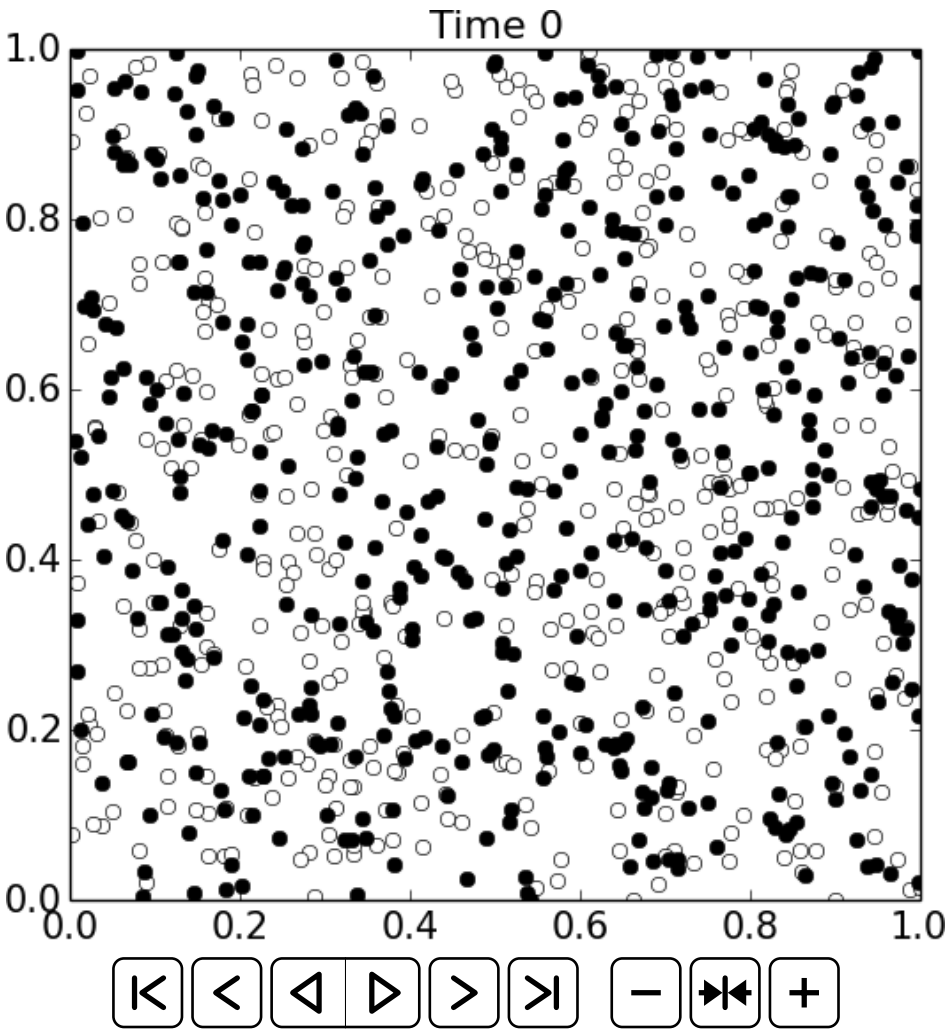
t=0
initialize()
observe()

for t in xrange(1, 100):
    update()
    observe()
```

Results of Shelling's model

This movie shows the result of Shelling's model with a neighbourhood radius of $\mathtt{r} = 0.1$ and a threshold for moving of $\mathtt{th} = 0.5$.

The agents self-organize from an initially random distribution to a patchy pattern where the two types are clearly segregated from each other.



Exercises

Exercise 1 Conduct simulations with the segregation model changing the parameteres `th` (threshold for moving) and `r` (neighbourhood radius). For each value of `r` (0.1, 0.2, 0.3, 0.4, 0.5 0.6, 0.7, and 0.8) determine the threshold at which the model shows segregation and plot these threshold values as a function of `r`.

Exercise 2 Facultative Conduct a sensitivity analysis (see Lecture 8) by developing a metric that characterizes the level of segregation (use for example the index of dissimilarity) once the model has reached a steady-state; then plot how this metric changes as parameter values (e.g. `th`) are varied.

to Further reading

Classes and Objects in Python

Understanding `classes` and `objects`

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A chair has a seat, a back, and legs. Each seat has a shape, a color, a degree of softness, and so on. These are the properties of a chair.

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What is described is *chairness* – the notion of something being a chair. In object-oriented terminology, this describes a `class` called chair.

Understanding `classes` and `objects`

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Several chairs are in the room, and each chair is an `object`. Each of these objects is an example of a chair class.

So that's how it works: the class is the description of what a chair should look like, and each individual chair is an object of that class.

Understanding `classes` and `objects`

Definition:

A `class` is simply a *description* of what things should look like, what variables will be grouped together, and what functions can be called to manipulate those variables. Using this description, python can then create many instances (`objects`) of the class, which can then be manipulated independently.

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When we talk about the class of chairs in a room, we are talking about the fact that each chair has legs, a seat, a color, and so on.

When you talk about a class of things, you are focusing on the type of properties that each of the things possesses not on their actual values.

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Table of Accounts

Account Number	Type	Balance
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1011 1234 2122 0000	Credit	-470.5
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Each object in the class `accounts` (that is, each instance of the class `accounts`) has an account number, a type, and a balance (properties of the class).

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So, the bottom row of the table is an object with account number 12-143504-00127-5. This same object has type "Savings" and a balance of 257.5.

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Each object in the class `accounts` (that is, each instance of the class `accounts`) has an account number, a type, and a balance (properties of the class).

So, the bottom row of the table is an object with account number 12-143504-00127-5. This same object has type "Savings" and a balance of 257.5.

If you opened a new account, you would have another object, and the table would grow an additional row. The new object would be an instance of the same class account.

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A `class` is a *blueprint*. It is not something in itself, it simply describes how to *make* something. as mentioned such objects are known technically as *instances* of the class.

So how do you create these classes ?

Very easily, with the `class` operator.

Creating a `class` in python

Example: defining a class

We can use a class to create a simple data structure that groups several variables together, e.g.:

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>>> individual1.name = 'Sherlock Holmes'
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>>> individual1.name = 'Sherlock Holmes'
>>> individual1.address = '221B Baker Street'
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>>> individual1.phone = '+40 20 7452 339'
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```
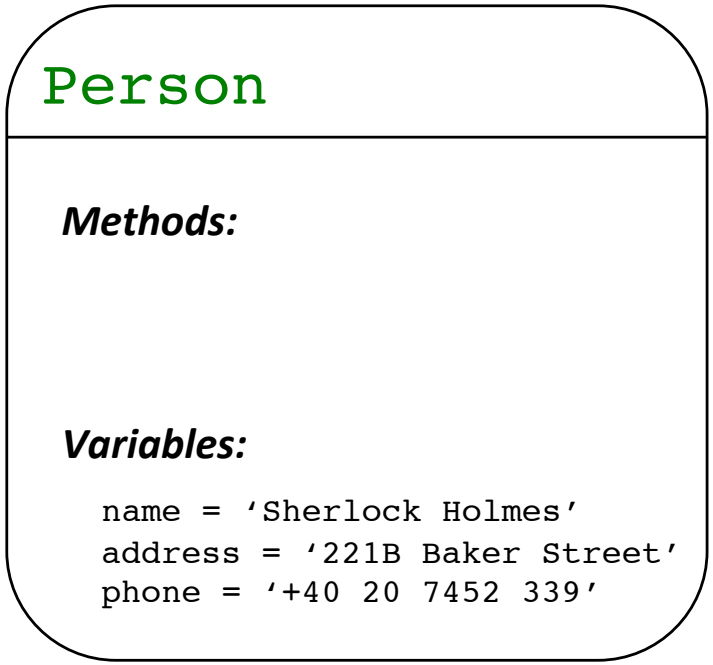

So, we created an empty class definition, then took advantage of the fact that python will automatically create member variables when they are first assigned.

Creating a `class` in python

Example: defining a class

The object `individual1` can be represented with the following diagram:



back to agents

List Comprehension in Python

List comprehension in python

Python supports a concept called "list comprehension". It can be used to construct lists in a very natural and easy way, like a mathematician is used to do.

The following are common ways to describe lists (or sets, or tuples, or arrays) in mathematics:

$$\mathtt{S} = \{\mathtt{x}^2 \ \forall \ \mathtt{x} \ \in \ \{0, \ldots, 9\}\}$$
$$\mathtt{V} = \{1, 2, 3, 4, 8, \ldots, 2^{12}\}$$
$$\mathtt{M} = \{\mathtt{x} \ \forall \ \mathtt{x} \ \in \ \mathtt{S} \ \mathtt{and} \ \mathtt{x} \ \mathtt{even}\}$$

List comprehension in python

Translated in "normal" language, this means:

Consider a list S with x^2 for all x in $\{0, \ldots, 9\}$

Consider a list V with 1, 2, 4, 8, . . ., 2^{12}

Consider a list M with x for all even x in S

This is how you do the above in python:

```
>>> S = [x**2  for x in range(10)]
>>> V = [2**i  for i in range(13)]
>>> M = [x  for x in S  if x%2 == 0]
>>>
>>> print S; print V; print M
[0, 1, 4, 9, 16, 25, 36, 49, 64, 81]
[1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096]
[0, 4, 16, 36, 64]
```

List comprehension in python

The list comprehension starts with `[` and ends with `]`, to help you remember that the result is going to be a list.

The basic syntax is:

```
result = [ transform      iteration          filter ]
```

For example:

```
result = [   x**2     for x in range(5)     if x%2 == 0   ]
```

Which is equivalent to:

```
result = []
for x in range(5):
     if x%2 == 0:
          result.append(x**2)
```

back to model

Further reading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