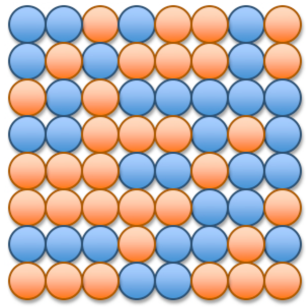


UNIT 11B
Visualizing Data: Simulations

Simulation

- The imitative representation of the functioning of one system or process by means of the functioning of another, for example a computer program. (Merriam Webster)
- Simulation involves developing a model of a system and experimental manipulation of the model to observe the results

Uses of Simulation

- Performance optimization, safety engineering, testing of new technologies
- Gaining a better understanding of natural and human systems, and making predictions
- Providing lifelike experiences in training, education, games

Models

- A *model* is an abstraction of the real system. It represents the system and the rules that govern the behavior of the system.
  - The model represents the system itself, whereas the simulation represents the operation of the system over time.
- Concerns:
  - Achieve a certain level of accuracy while keeping the complexity manageable
  - Parts of the system may be stochastic (may exhibit random behavior).

Computational Models

- Physical models: small-replicas
  - May not exist, may be unsafe to work with, expensive to build and modify.
  - Some change too slowly over time.
- Computational models deal with these issues better.
- Computational sciences use computational models as the basis of obtaining scientific knowledge.

Large Scale Simulations

- Computing power of today enables large scale simulations. For example,
  - Department of Defense: Battle simulations
  - Blue Brain Project at EPFL to reverse engineer the human brain
  - National Center for Atmospheric Research : 1,000 years of climactic changes http://www.youtube.com/watch?v=d8sHvhLvfBo

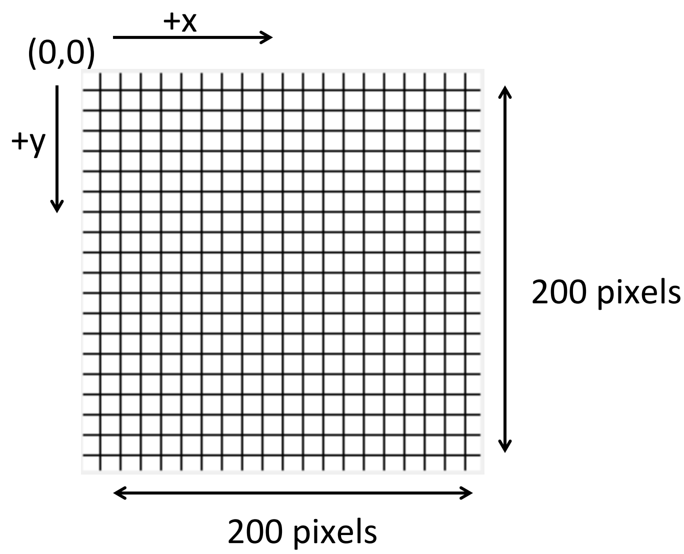
Example: Flu Virus Simulation

- Goal: Develop a simple graphical simulation that shows how disease spreads through a population.

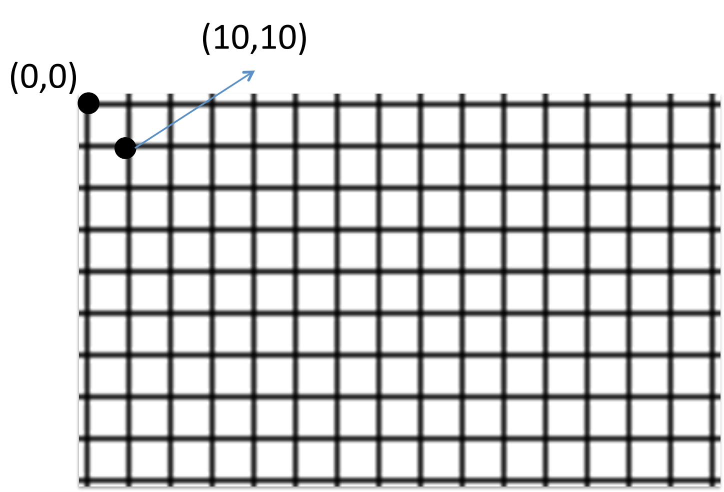
Model Assumptions

- A person starts off as healthy.
- Each day, a healthy person comes in contact with 4 random people. If any of those random people is contagious, then the healthy person becomes infected.
- It takes one day for the infected person to become contagious.
- After a person has been contagious for 4 days, then the person is non-contagious and cannot spread the virus nor can the person get the virus again due to immunity.

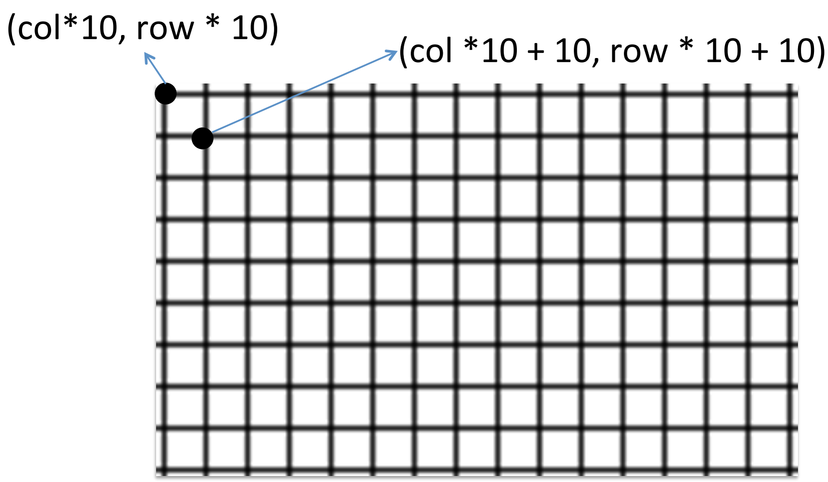
Displaying the Population



Displaying One Person



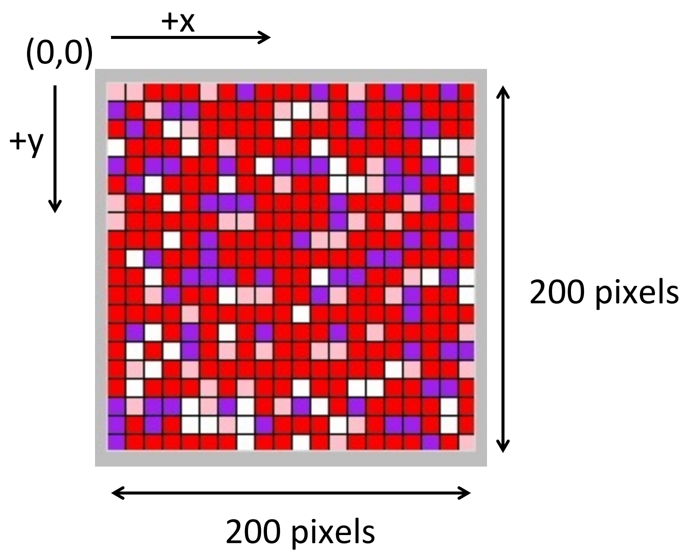
Displaying One Person



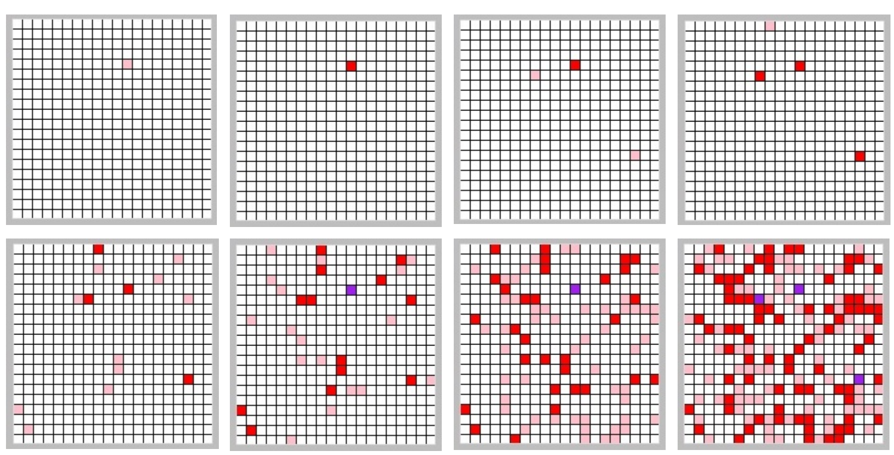
Health States

0	white	healthy	`HEALTHY = 0`
1	pink	infected	`INFECTED = 1`
2	red	contagious (day 1)	`DAY1 = 2`
3	red	contagious (day 2)	`DAY2 = 3`
4	red	contagious (day 3)	`DAY3 = 4`
5	red	contagious (day 4)	`DAY4 = 5`
6	purple	immune (non-contagious)	`IMMUNE = 6`

Display of 400 people



Example: Flu Virus Simulation



Concern: Events by chance

If a healthy person contacts a contagious person, she gets sick 40% of the time.

```
random_x = randint(0,19)
random_y = randint(0,19)
if contagious(matrix, random_x, random_y) \
        and randint(0,99) < 40:
     newmatrix[i][j] = 1
```

Concern: Finding neighbors

```
cell = matrix[i][j]

north = matrix[i-1][j]     NO!

if i == 0:                 YES!
  north = None
else:
  north = matrix[i-1][j]
```

Why Do Simulations?

- To predict the behavior of a system.
  - Will this building survive an earthquake?
- To test a theory against data.
  - Do the predictions generated by these equations match what we observe in the real world?
- To explore consequences of assumptions.
  - How quickly does the flu virus spread?

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Continuous-Time Simulations

- Often used to model physical phenomena involving forces acting on objects.
- Is "time" really continuous?
  - Philosophical question. No one knows.
  - Just pretend it is.
- Is simulated time continuous?
  - No. It's divided into discrete time steps.
  - But they can be as small as we like.

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N-Body Simulations

- Newton's theory: Planets and other bodies move according to the gravitational effects of the objects around them
- With just two bodies, we can write a simple formula to calculate their positions at any future time, given their starting positions.
- *But with 3 or more bodies, no formula exists for this, because the system is highly nonlinear, and potentially chaotic.*
- Our only recourse is simulation.

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Simulating Gravitational Attraction

Newton's law of universal gravitation:

$$F = G \cdot m_1 \cdot m_2 / d^2$$

where G = gravitational constant,
m_1 and m_2 are the masses, and
d is the distance between them.

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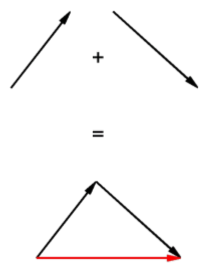
Force Vectors in PythonLabs

- SphereLab bodies use vectors to keep track of positions, velocities, and accelerations: (x, y, z) coordinates
- Forces are additive and vector addition performs ordinary addition on each component:
  (x1, y1, z1) + (x2, y2, z2) = (x1+x2, y1+y2, z1+z2)



This vectors in this
example has 0 for the z coordinate.

The north and south vectors cancel out each other

The east vectors add up

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Force Action on a Single Body

- Calculate all the force vectors influencing the body
- Add the vectors together to determine the cumulative force

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Falling Body Experiment

```
>>> from PythonLabs.SphereLab import *
>>> b = make_system(':fdemo.txt')
```

The first body is supposed to fall toward the other 5 bodies that are stationary.

```
>>> view_system(b)
>>> step_one(b[0], b[1:5], 1.0)
```

Simulates the motion of one body for a time step of 1.0.

What happens when we repeat the experiments 10's of times?

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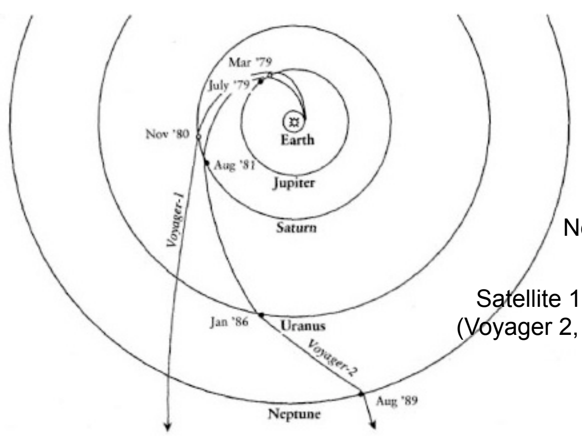
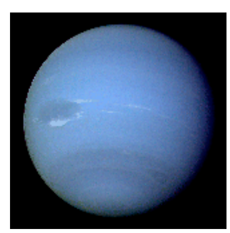
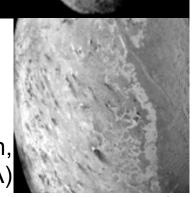
Paths of Voyager 1 and 2





Neptune (Voyager 2, NASA)

Satellite 1989N1, (Voyager 2, NASA)



Triton, (Voyager 2, NASA)

frankie0701.wordpress.com

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Moving Multiple Bodies

- At each time step move each body by calculating the force vectors in each direction
- Suppose we are given a method interaction(a,b) that calculates the gravitational force between the bodies a and b
- We need to compute all pairwise interactions.
- How many force calculations are there?

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Simulating The Solar System

```
>>> from PythonLabs.SphereLab import
  make_system, view_system
>>> import time
>>> b = make_system(':solarsystem.txt')
>>> view_system(b[0:4], dash = True)
>>> for i in range(365):
        step_system(b, 86459)
        time.sleep(0.1)
```

number of seconds in a day

Notice that the orbits are elliptical (Kepler).

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Simulation At Extreme Scales

- Cosmologists use simulations to study the formation of galaxies (clusters of stars), and even clusters of galaxies.

- At the other extreme, physicists simulate individual atoms and molecules, e.g., to model chemical reactions.

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