Visualization using Python

An introduction to Matplotlib

Benoît Corsini

March 16th and 30th 2026

Disclaimers

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Before starting, download the file below and run it to make sure all relevant libraries are imported (the content of the file will be explained at the beginning of the presentation).

https://www.benoitcorsini.com/files/matplotlib/q0.py

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  - A “correct” answer is not a word for word file or a pixel for pixel image, but rather a method that provides a similar outcome.
  - The solution of the different questions are available online, by replacing the 0 from the above link with the corresponding question number.
  - Naturally, it is recommended to download the solution only **after** attempting the question.
- `matplotlib` is a massive package and not all methods and attributes can be explained in detail here: finding the relevant information is also part of this workshop.

Table of contents

- Extending the Figure class
- Importing images
- Creating shapes
- Creating drawings
- Conclusion

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  - `.patches`: a set of classes to create shapes on the figure.

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  - `.patches`: a set of classes to create shapes on the figure.
  - `.path`: a set of classes to handle lines and drawings.

Importing packages

```
1. import os
2. import cv2
3. import numpy as np
4. import matplotlib.pyplot as plt
5. from matplotlib.patches import *
6. from matplotlib.path import Path
7. from matplotlib.figure import Figure
8. from matplotlib.text import TextPath
```

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- It is a subclass of the `Figure` class from `matplotlib` and thus uses pre-implemented arguments and methods using `*args`, `**kwargs`, and `super()`.

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For the sake of this presentation, our class has two particularities.

- It is a subclass of the `Figure` class from `matplotlib` and thus uses pre-implemented arguments and methods using `*args`, `**kwargs`, and `super()`.
- It has a default `square` method using the `@classmethod` decorator, which creates a square figure and obtained by calling `vis = Visual.square(...)`.

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```
12. class Visual(Figure):
13.
14.     def __init__(self, *args, **kwargs):
15.         super().__init__(*args, **kwargs)
16.
17.     @classmethod
18.     def square(cls, *args, **kwargs):
19.         return cls(figsize=(1, 1), *args, **kwargs)
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- Line 12: creates a subclass of Figure
- Line 14: allows pre-existing arguments
- Line 15: applies the arguments to the superclass

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14.     def __init__(self, *args, **kwargs):  ......... allows pre-existing arguments
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17.     @classmethod  ................................ creates a default squared structure
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19.         return cls(figsize=(1, 1), *args, **kwargs)
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21.
22.
23. if __name__ == '__main__': ..................... prevents this code from running elsewhere
24.     vis = Visual.square(dpi=500)
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- In order to remove the extra space around the figure, we call `subplots_adjust(...)`.
- In order to hide the axes on the figure, we call `set_axis_off(...)`
- Finally, we put this code into a hidden *dunder* (double-under) method for clarity.

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22.     def __figure__(self):
23.         self.subplots_adjust(left=0, right=1, bottom=0, top=1)
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Auto-creating frames

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- For the video renderer, we need to have the number of frames per second (`fps`), which we add as an input of the class.
- To simplify the creation of the different frames, we implement a `new_frame` method, which automatically saves the current state of the figure and increases the frame count by 1.

Auto-creating frames

```
14.     def __init__(self, fps=30, *args, **kwargs):
15.         super().__init__(*args, **kwargs)
16.         self.__figure__()
17.         self.fps = fps
18.         self.frame_index = 0

29.     def new_frame(self):
30.         if not os.path.exists('frames'):
31.             os.mkdir('frames')
32.         self.savefig(f'frames/{self.frame_index:04d}.png')
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→ The structure of `make_video` strongly relies on the structure of the `cv2` package, in particular the existence of *silent errors*, halting the code prior to completion without raising any error.

Combining frames for the video

```
35.     def make_video(self, filename='video'):
36.         frames = sorted([
37.             os.path.join('frames', file)
38.             for file in os.listdir('frames')
39.         ])
40.         height, width, _ = cv2.imread(frames[0]).shape
41.         video = cv2.VideoWriter(
42.             filename=filename + '.mp4',
43.             fourcc=cv2.VideoWriter_fourcc(*'mp4v'),
44.             fps=self.fps,
45.             frameSize=(width, height),
46.         )
47.         for frame in frames:
48.             video.write(cv2.imread(frame))
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Line 39: lists the frame files in order of creation

Line 40: finds the size of the images (to avoid silent errors)

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- Line 43: the format of the video (mp4 here)

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- Line 39: lists the frame files in order of creation
- Line 40: finds the size of the images (to avoid silent errors)
- Line 43: the format of the video (mp4 here)
- Line 48: adds each individual frame to the video

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- Line 43: the format of the video (mp4 here)
- Line 48: adds each individual frame to the video
- Line 49: saves the video

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47.         for frame in frames:
48.             video.write(cv2.imread(frame)) .............. adds each individual frame to the video
49.         video.release() ........................................... saves the video
50.         cv2.destroyAllWindows() ................................... clears the cache
```

A first video

A first video

Q1: Create a 5 seconds video using the code described before, also available at:

https://www.benoitcorsini.com/files/matplotlib/q0.py

A first video

```
52.     def duration_to_number(self, duration):
53.         return int(duration*self.fps)
54.
55.     def wait(self, duration):
56.         for _ in range(self.duration_to_number(duration)):
57.             self.new_frame()
58.
59.
60.
61. if __name__ == '__main__':
62.     vis = Visual.square(dpi=500)
63.     vis.wait(5)
64.     vis.make_video()
```

A first video

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52.     def duration_to_number(self, duration):
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60.
61. if __name__ == '__main__':
62.     vis = Visual.square(dpi=500)
63.     vis.wait(5)
64.     vis.make_video()
```

. . . . transforms a duration (in seconds) into a number of frames

A first video

```
52.     def duration_to_number(self, duration):
53.         return int(duration*self.fps)
54.
55.     def wait(self, duration):
56.         for _ in range(self.duration_to_number(duration)):
57.             self.new_frame()
58.
59.
60.
61. if __name__ == '__main__':
62.     vis = Visual.square(dpi=500)
63.     vis.wait(5)
64.     vis.make_video()
```

- `duration_to_number`: transforms a duration (in seconds) into a number of frames
- `wait`: pauses the current state of the figure for a given duration

Table of contents

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- Importing images
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Adding an image

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Q2: Import an image into the figure.

Adding an image

```
59.     def set_boundary(self, boundary=1):
60.         self.ax.set_xlim(-boundary, boundary)
61.         self.ax.set_ylim(-boundary, boundary)
62.
63.     def add_image(self, filename, shift=0, *args, **kwargs):
64.         X = plt.imread(filename)
65.         self.image = self.ax.imshow(
66.             X=X,
67.             extent=(
68.                 shift - 1 - 2*X.shape[0]/X.shape[1],
69.                 shift + 1,
70.                 -1,
71.                 1,
72.             ),
73.             *args,
74.             **kwargs,
75.         )
```

Adding an image

```
79. if __name__ == '__main__':
80.     vis = Visual.square(dpi=500)
81.     vis.set_boundary()
82.     vis.add_image(filename='singapore.jpg', shift=0.4)
83.     vis.new_frame()
```

Making the image appear

Making the image appear

A few useful functions to import and manipulate images.

- We transform an image into a matrix by calling `X = plt.imread(filename)`.
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Q3: Make an image fade in.

Making the image appear

```
77.     def image_appear(self, duration):
78.         n_steps = self.duration_to_number(duration)
79.         for step in range(n_steps):
80.             self.image.set_alpha((1 + step)/n_steps)
81.             self.new_frame()
82.
83.
84.
85. if __name__ == '__main__':
86.     vis = Visual.square(dpi=500)
87.     vis.set_boundary()
88.     vis.add_image(filename='singapore.jpg', shift=0.4)
89.     vis.image.set_alpha(0)
90.     vis.new_frame()
91.     vis.image_appear(0.1)
```

Making the image appear

```
77.     def image_appear(self, duration):
78.         n_steps = self.duration_to_number(duration)
79.         for step in range(n_steps):
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83.
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85. if __name__ == '__main__':
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88.     vis.add_image(filename='singapore.jpg', shift=0.4)
89.     vis.image.set_alpha(0)
90.     vis.new_frame()
91.     vis.image_appear(0.1)
```

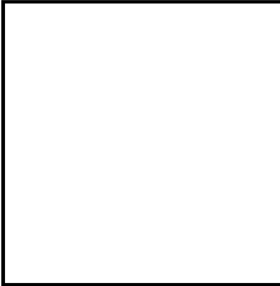

Table of contents

- Extending the Figure class
- Importing images
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- Conclusion

Shapes in matplotlib

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Shapes in `matplotlib` are handled by subclasses of `matplotlib.patches`:

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- `ax.add_patch(patch)` adds the patch to the figure.

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- `patch = Circle((0, 0), ...)` creates a circle patch centered at the origin.
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- `patch.set(...)` allows to later modify the patch.

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Q4: Create this image.

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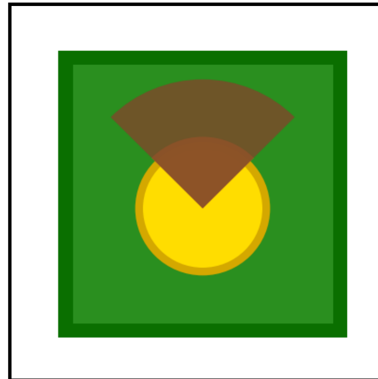

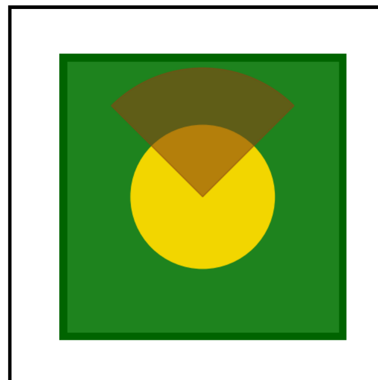

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- `patch.set(...)`

Q4: Create this image.

Shapes in matplotlib

```
85. if __name__ == '__main__':
86.     vis = Visual.square(dpi=500)
87.     vis.set_boundary(1.1)
88.     vis.ax.add_patch(Rectangle(
89.         xy=(-1, -1),
90.         width=2,
91.         height=2,
92.         edgecolor='darkgreen',
93.         facecolor='forestgreen',
94.         linewidth=4,
95.         capstyle='round',
96.         joinstyle='round',
97.     ))
```

Shapes in matplotlib

```
98.     vis.ax.add_patch(Circle(
99.         xy=(0, 0),
100.        radius=0.5,
101.        ec='darkgoldenrod',
102.        fc='gold',
103.        lw=2,
104.    ))
105.    vis.ax.add_patch(Wedge(
106.        center=(0, 0),
107.        theta1=45,
108.        theta2=135,
109.        r=1,
110.        color='crimson',
111.        lw=0,
112.        alpha=0.5,
113.    ))
114.    vis.new_frame()
```

3D effect

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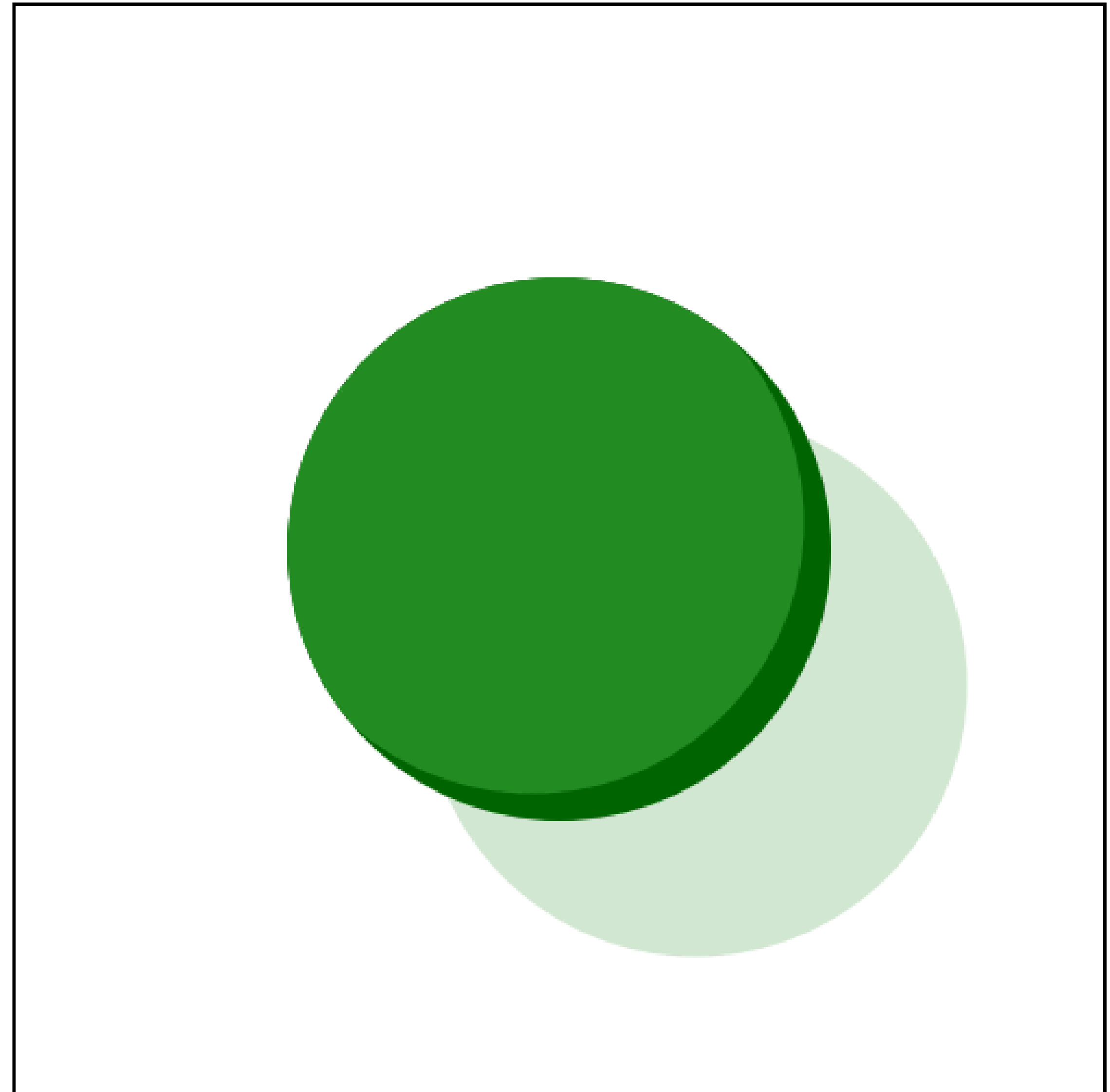

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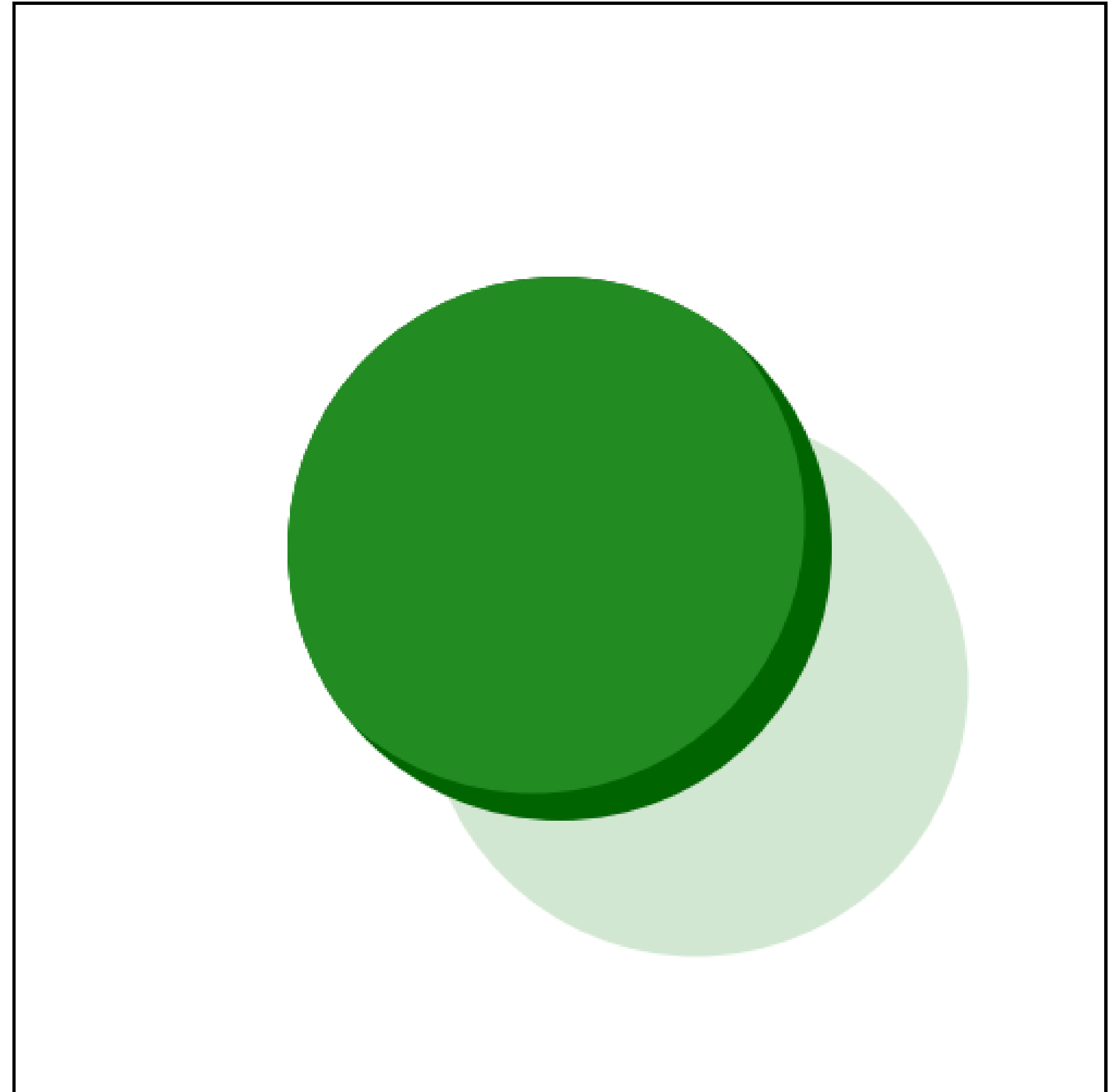

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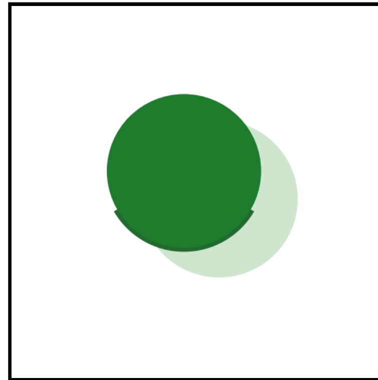

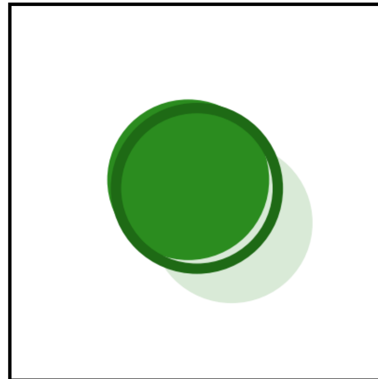

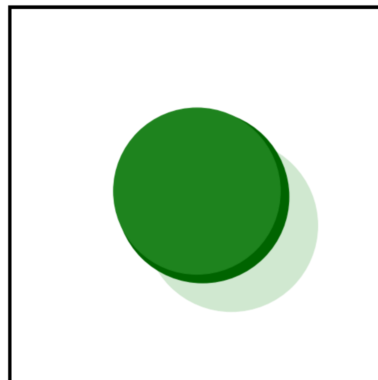

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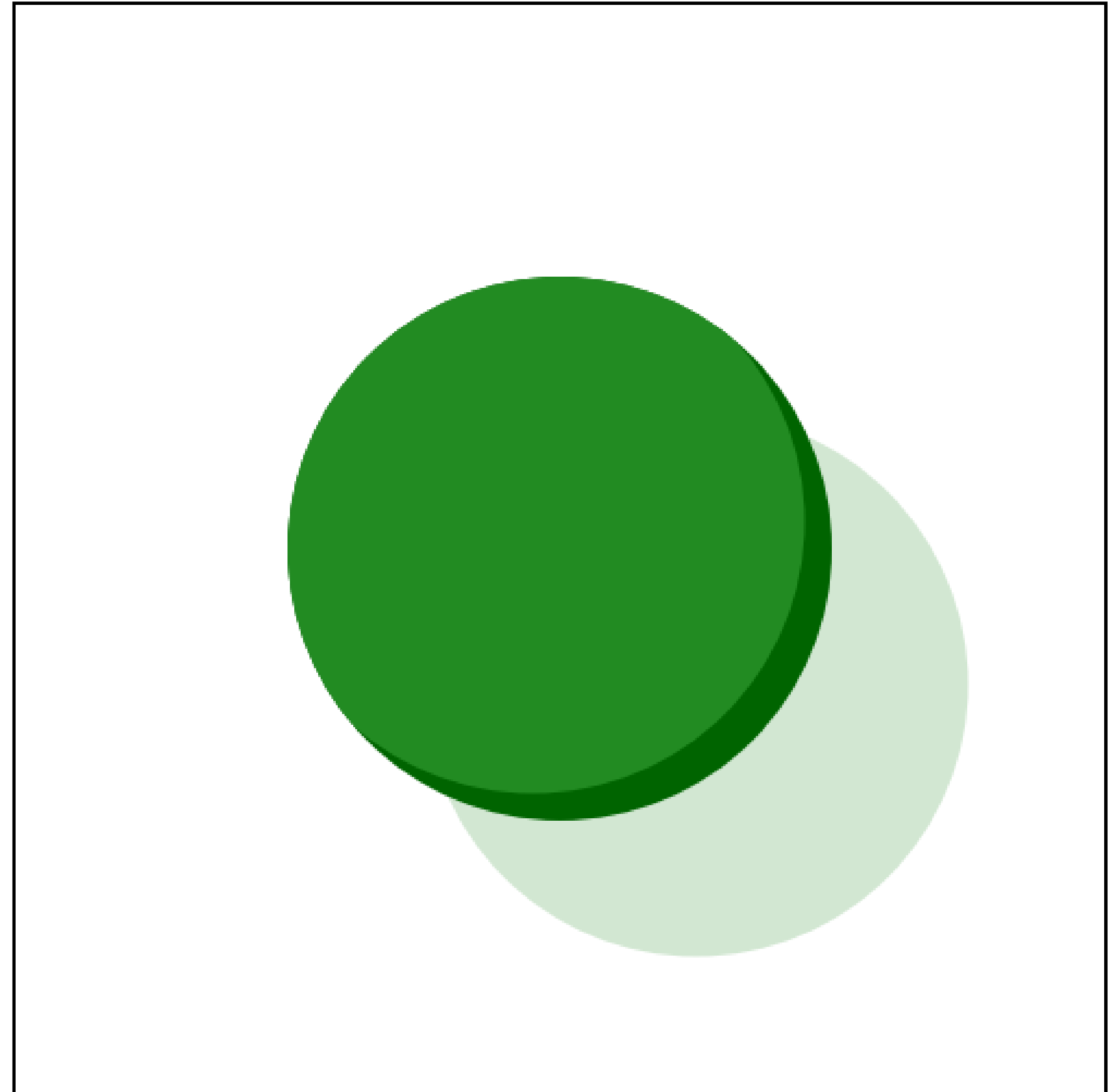
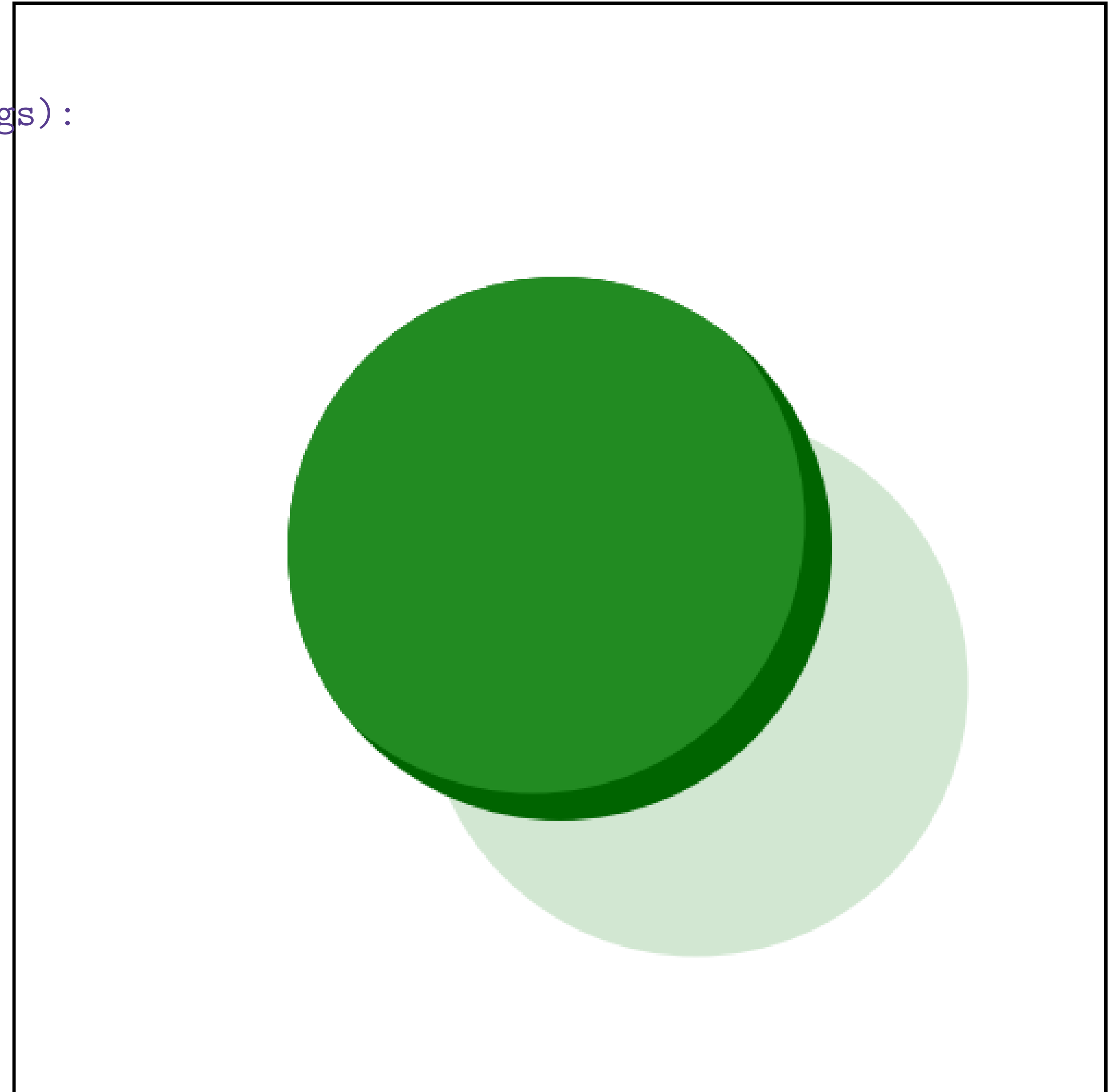


3D effect

```
83.     def add_circle(self, xy=(0, 0), radius=1, *args, **kwargs):
84.         return self.ax.add_patch(Circle(
85.             xy=xy,
86.             radius=radius,
87.             *args,
88.             **kwargs,
89.         ))
90.
91.
92.
93. if __name__ == '__main__':
94.     vis = Visual.square(dpi=500)
95.     vis.set_boundary(2)
96.     sphere = vis.add_circle(color='darkgreen')
97.     vis.new_frame()
```



3D effect

```
83.     def add_circle(self, xy=(0, 0), radius=1, *args, **kwargs):
84.         return self.ax.add_patch(Circle(
85.             xy=xy,
86.             radius=radius,
87.             *args,
88.             **kwargs,
89.         ))
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94.     vis = Visual.square(dpi=500)
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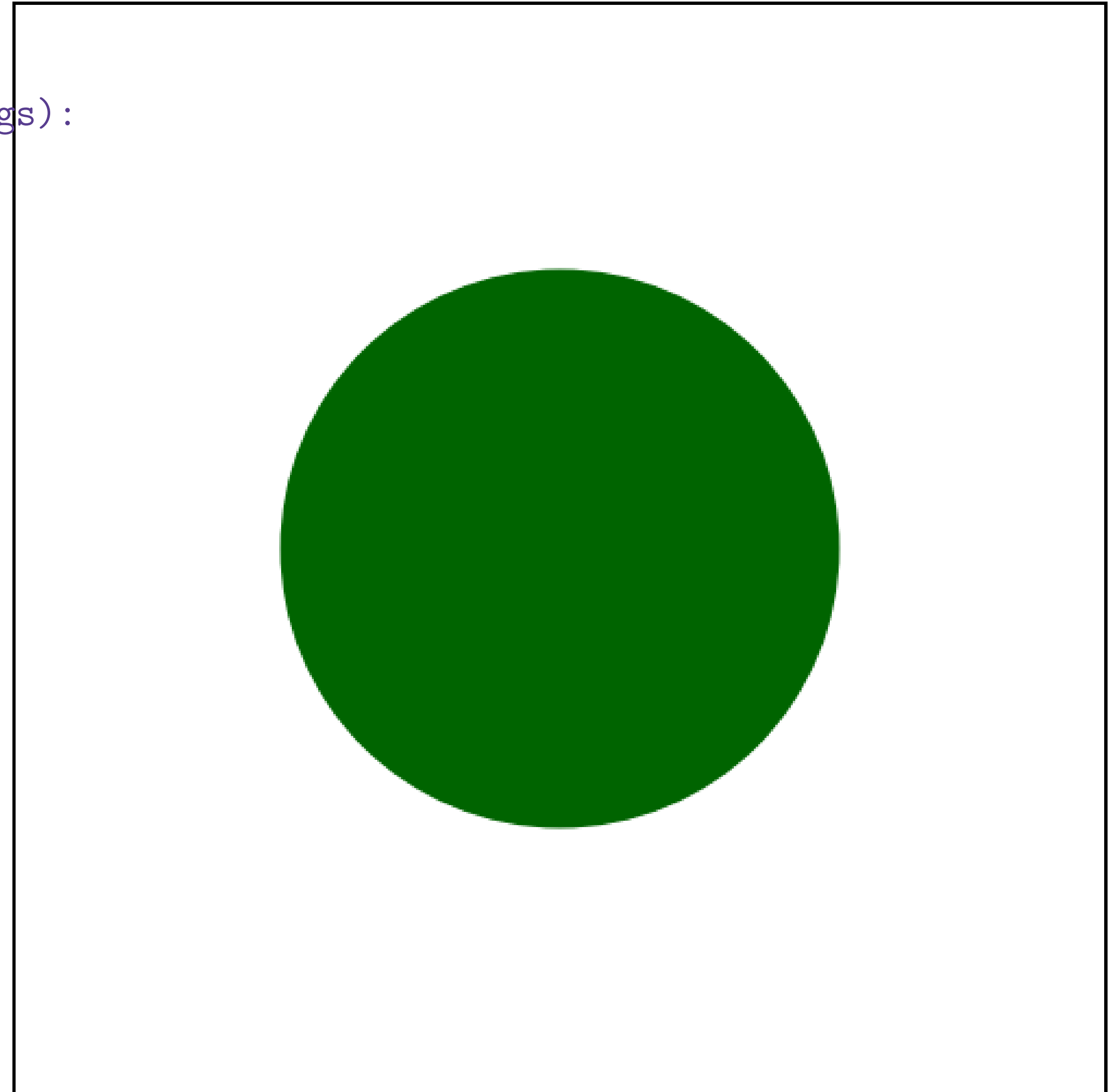
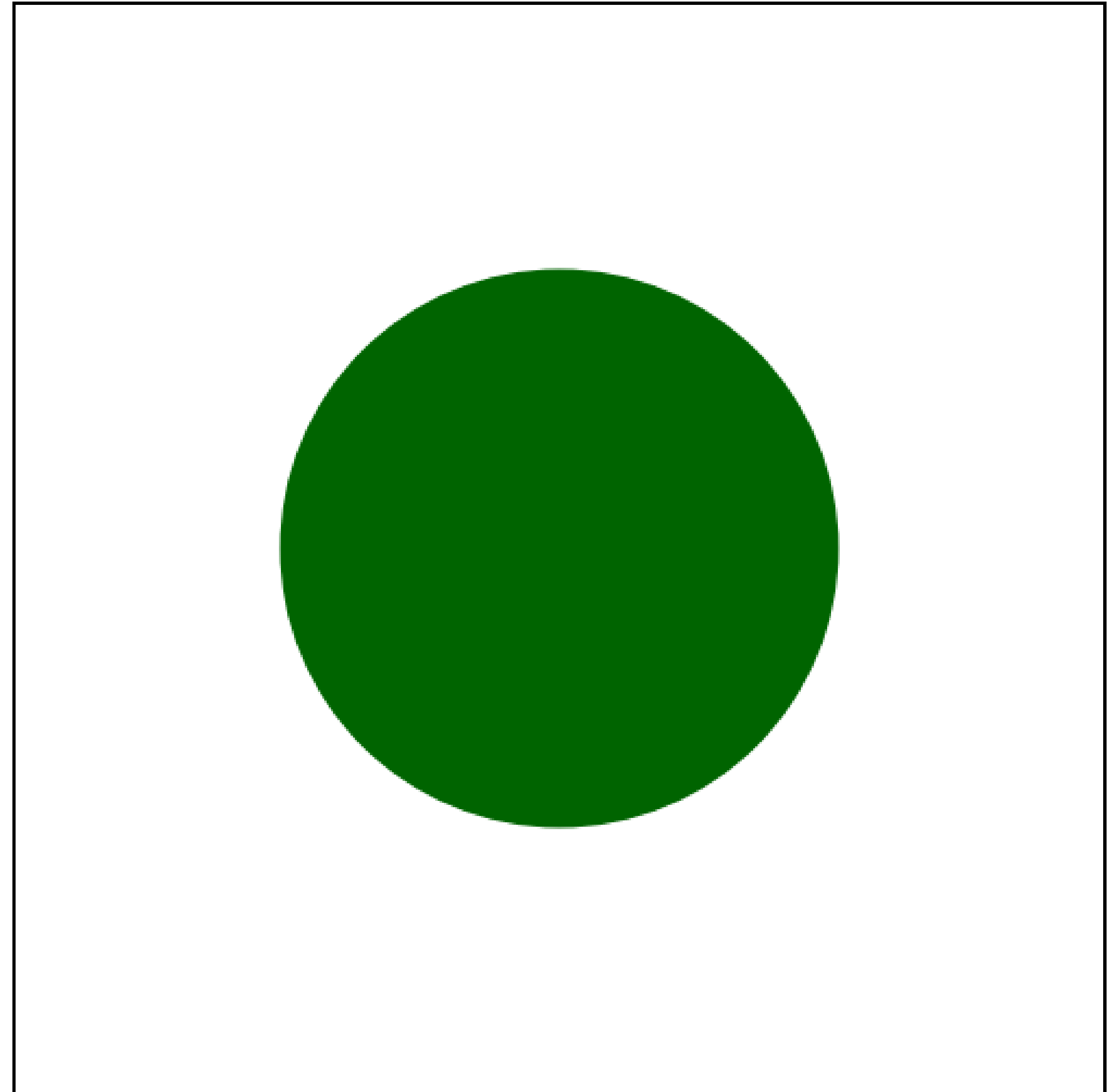


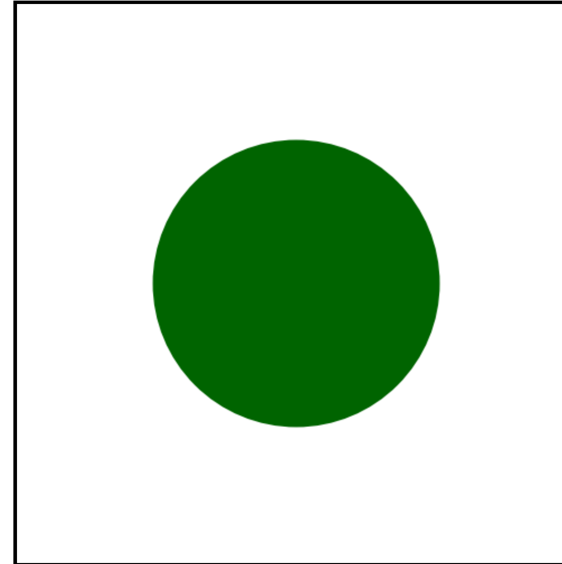
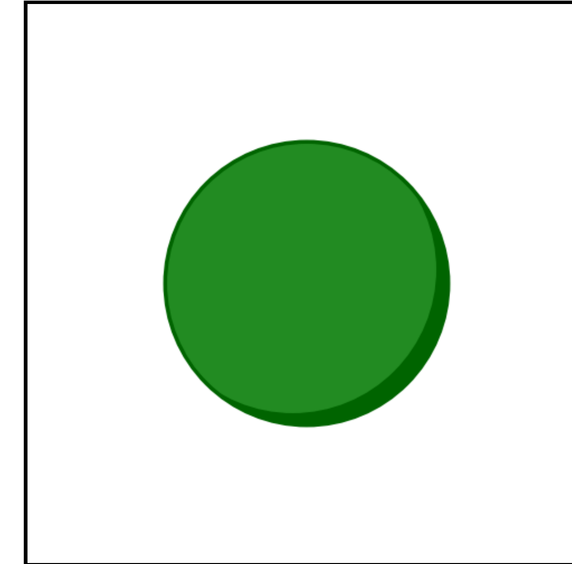
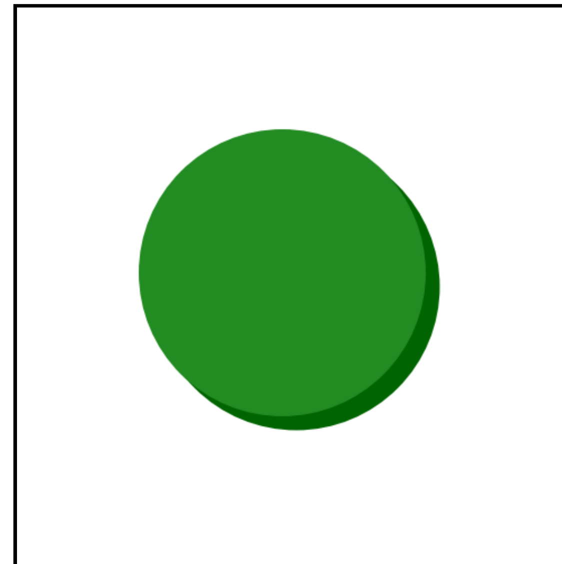
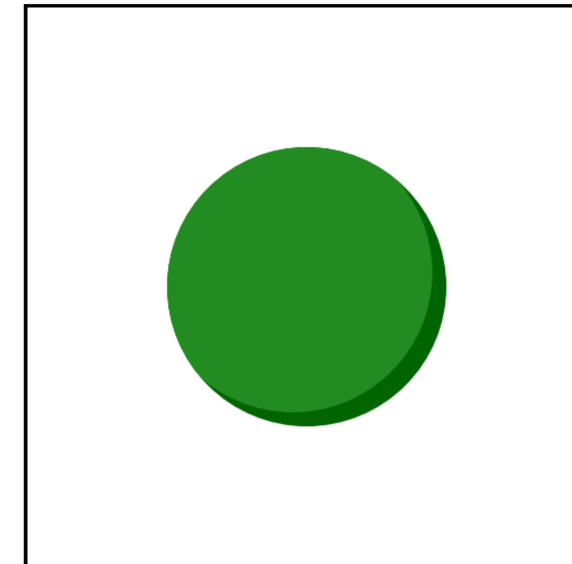
3D effect

```
98.     side_shift = 0.1
99.     light = vis.add_circle(
100.        xy=(-side_shift, side_shift),
101.        color='forestgreen',
102.    )
103.    vis.new_frame()
104.    light.set_clip_path(sphere)
105.    vis.new_frame()
106.    sphere.set_lw(0)
107.    light.set_lw(0)
108.    vis.new_frame()
```



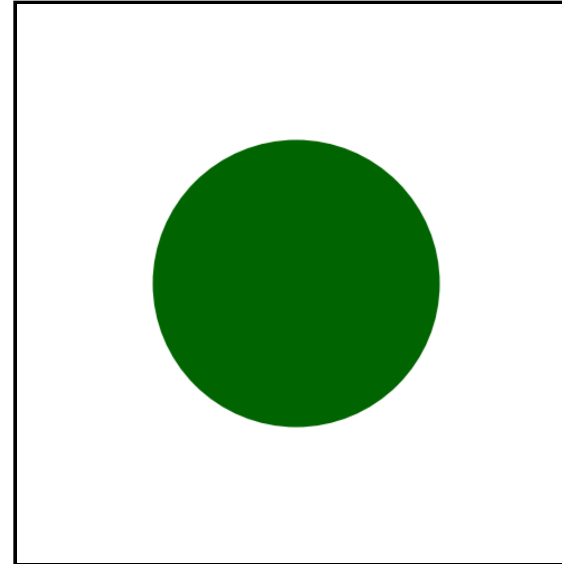
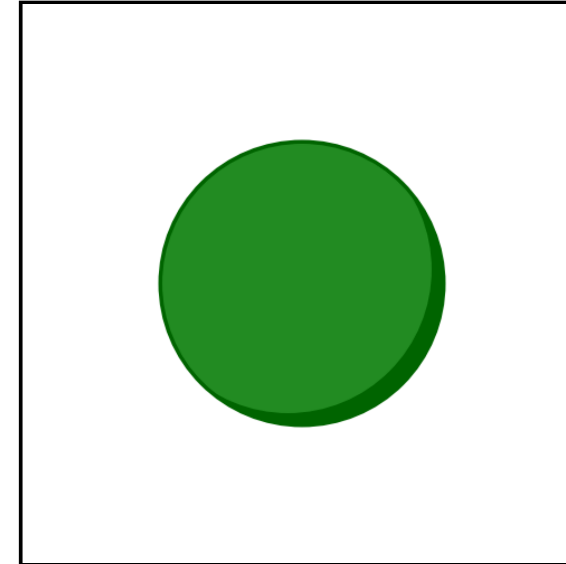
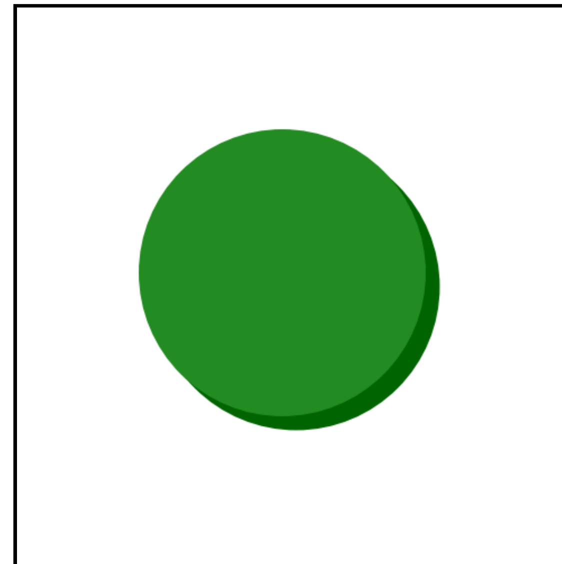
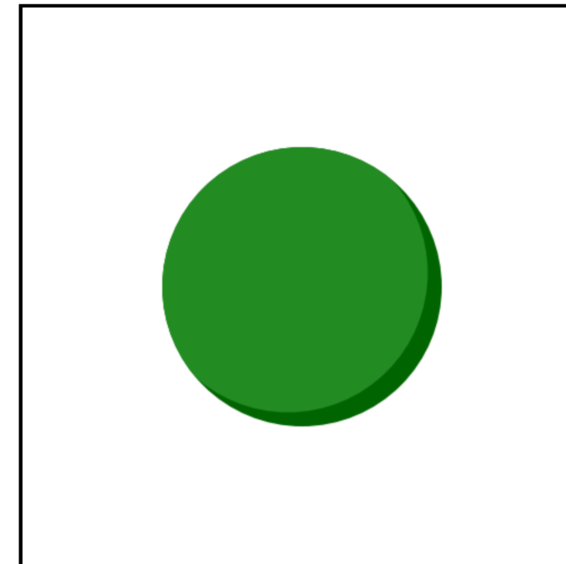
3D effect

```
 98.     side_shift = 0.1
 99.     light = vis.add_circle(
100.         xy=(-side_shift, side_shift),
101.         color='forestgreen',
102.     )
103.     vis.new_frame()
104.     light.set_clip_path(sphere)
105.     vis.new_frame()
106.     sphere.set_lw(0)
107.     light.set_lw(0)
108.     vis.new_frame()
```

3D effect

```
109.    shade = vis.add_circle(
110.        xy=(0.5, -0.5),
111.        color='forestgreen',
112.        lw=0,
113.    )
114.    vis.new_frame()
115.    shade.set_zorder(0)
116.    vis.new_frame()
117.    shade.set_alpha(0.2)
118.    vis.new_frame()
```

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109.        shade = vis.add_circle(
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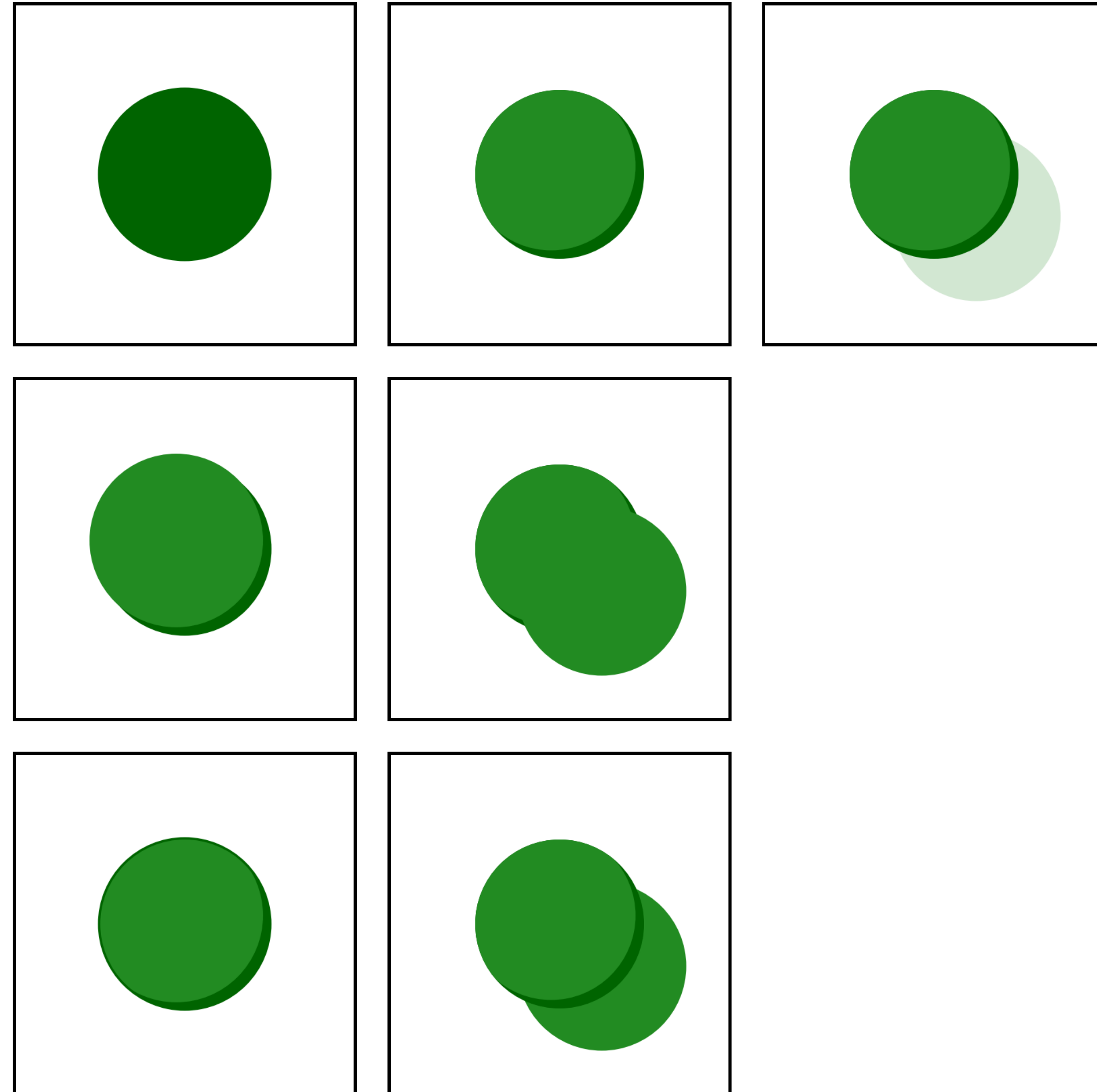

Creating a sphere

Creating a sphere

Since spheres are created using three circles, it is easier to create methods to handle them together.

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- We implement `new_sphere`, which creates and returns a dictionary named `sphere`, containing the three circles as well as other parameters (their position, radius, etc).

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- We implement `new_sphere`, which creates and returns a dictionary named `sphere`, containing the three circles as well as other parameters (their position, radius, etc).
- We implement `update_sphere`, which directly applies to the dictionary of a sphere and should thus be called using `update_sphere(**sphere)`.

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- We implement `update_sphere`, which directly applies to the dictionary of a sphere and should thus be called using `update_sphere(**sphere)`.

The `new_sphere` and `update_sphere` methods are already in the solution of **Q5**:

https://www.benoitcorsini.com/files/matplotlib/q5.py

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen',
93.             dark='darkgreen',
94.             alpha=0.2,
95.             **kwargs,
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)
99.             for key in ['main', 'light', 'shade']
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

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91.     def new_sphere(self,
92.             color='forestgreen',
93.             dark='darkgreen',
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```

(line 92: the front color of the sphere)

Creating a sphere

```
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94.             alpha=0.2,
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96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)
99.             for key in ['main', 'light', 'shade']
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

- color: the front color of the sphere
- dark: the color of the side shade of the sphere

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen', ........................ the front color of the sphere
93.             dark='darkgreen', ........................ the color of the side shade of the sphere
94.             alpha=0.2, ........................ the opacity of the floor shade of the sphere
95.             **kwargs,
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)
99.             for key in ['main', 'light', 'shade']
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen',  ............ the front color of the sphere
93.             dark='darkgreen',  ............ the color of the side shade of the sphere
94.             alpha=0.2,  ............ the opacity of the floor shade of the sphere
95.             **kwargs,  ............ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)
99.             for key in ['main', 'light', 'shade']
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen',   ........ the front color of the sphere
93.             dark='darkgreen',   ........ the color of the side shade of the sphere
94.             alpha=0.2,   ........ the opacity of the floor shade of the sphere
95.             **kwargs,   ........ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)   ........ each key leads to a circle patch
99.             for key in ['main', 'light', 'shade']
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen', ........................ the front color of the sphere
93.             dark='darkgreen', ........................ the color of the side shade of the sphere
94.             alpha=0.2, ........................ the opacity of the floor shade of the sphere
95.             **kwargs, ........................ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0) ........................ each key leads to a circle patch
99.             for key in ['main', 'light', 'shade'] .......... the sphere is composed of three circles: main, light, and shade
100.        }
101.        sphere.update(**kwargs)
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen',  ........ the front color of the sphere
93.             dark='darkgreen',  ........ the color of the side shade of the sphere
94.             alpha=0.2,  ........ the opacity of the floor shade of the sphere
95.             **kwargs,  ........ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)  ........ each key leads to a circle patch
99.             for key in ['main', 'light', 'shade']  ........ the sphere is composed of three circles: main, light, and shade
100.        }
101.        sphere.update(**kwargs)  ........ adds the input of the function as items of the dictionary sphere
102.        sphere['main'].set_color(dark)
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen',  ............ the front color of the sphere
93.             dark='darkgreen',  ............ the color of the side shade of the sphere
94.             alpha=0.2,  ............ the opacity of the floor shade of the sphere
95.             **kwargs,  ............ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0)  ............ each key leads to a circle patch
99.             for key in ['main', 'light', 'shade']  ............ the sphere is composed of three circles: main, light, and shade
100.        }
101.        sphere.update(**kwargs)  ............ adds the input of the function as items of the dictionary sphere
102.        sphere['main'].set_color(dark)  ............ the main sphere is the background and darker one
103.        sphere['shade'].set(alpha=alpha, zorder=0)
104.        return sphere
```

Creating a sphere

```
91.     def new_sphere(self,
92.             color='forestgreen', ........................ the front color of the sphere
93.             dark='darkgreen', ........................ the color of the side shade of the sphere
94.             alpha=0.2, ........................ the opacity of the floor shade of the sphere
95.             **kwargs, ........................ other possible arguments of the sphere, as found in update_sphere
96.         ):
97.         sphere = {
98.             key :  vis.add_circle(color=color, lw=0) ........................ each key leads to a circle patch
99.             for key in ['main', 'light', 'shade'] .......... the sphere is composed of three circles: main, light, and shade
100.        }
101.        sphere.update(**kwargs) ........................ adds the input of the function as items of the dictionary sphere
102.        sphere['main'].set_color(dark) ........................ the main sphere is the background and darker one
103.        sphere['shade'].set(alpha=alpha, zorder=0) ........................ the shade sphere is the one on the floor
104.        return sphere
```

Creating a sphere

```
106.     def update_sphere(self, main, light, shade,
107.             xy=(0, 0),
108.             radius=1,
109.             height=0,
110.             shift=(0.4, -0.8),
111.             side=0.15,
112.             shadow=0.5,
113.         ):
114.         xy = np.array(xy)
115.         shift = np.array(shift)
116.         for circle in [main, light, shade]:
117.             circle.set_radius(radius)
118.         main.set_center(xy + np.array([0, height]))
119.         light.set_center(xy - radius*side*shift + np.array([0, height]))
120.         shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.         shade.set_center(xy + shade_shift*shift)
122.         light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade,
107.            xy=(0, 0),
108.            radius=1,
109.            height=0,
110.            shift=(0.4, -0.8),
111.            side=0.15,
112.            shadow=0.5,
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

. . . . the three circles of the sphere

Creating a sphere

```
106.    def update_sphere(self, main, light, shade,
107.            xy=(0, 0),
108.            radius=1,
109.            height=0,
110.            shift=(0.4, -0.8),
111.            side=0.15,
112.            shadow=0.5,
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

Line 106 (main, light, shade): the three circles of the sphere

Line 107 (xy): the planar position of the sphere

Creating a sphere

```
106.    def update_sphere(self, main, light, shade,
107.            xy=(0, 0),
108.            radius=1,
109.            height=0,
110.            shift=(0.4, -0.8),
111.            side=0.15,
112.            shadow=0.5,
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

- Line 106 (`main, light, shade`): the three circles of the sphere
- Line 107 (`xy`): the planar position of the sphere
- Line 108 (`radius`): the radius of the sphere

Creating a sphere

```
106.     def update_sphere(self, main, light, shade, ..........the three circles of the sphere
107.             xy=(0, 0), ....................................the planar position of the sphere
108.             radius=1, .........................................the radius of the sphere
109.             height=0, .........................................the height of the sphere
110.             shift=(0.4, -0.8),
111.             side=0.15,
112.             shadow=0.5,
113.         ):
114.         xy = np.array(xy)
115.         shift = np.array(shift)
116.         for circle in [main, light, shade]:
117.             circle.set_radius(radius)
118.         main.set_center(xy + np.array([0, height]))
119.         light.set_center(xy - radius*side*shift + np.array([0, height]))
120.         shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.         shade.set_center(xy + shade_shift*shift)
122.         light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade, ........the three circles of the sphere
107.            xy=(0, 0), ........the planar position of the sphere
108.            radius=1, ........the radius of the sphere
109.            height=0, ........the height of the sphere
110.            shift=(0.4, -0.8), ........the directional shift of the shade of the sphere
111.            side=0.15,
112.            shadow=0.5,
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade,    .......... the three circles of the sphere
107.            xy=(0, 0),    .......... the planar position of the sphere
108.            radius=1,    .......... the radius of the sphere
109.            height=0,    .......... the height of the sphere
110.            shift=(0.4, -0.8),    .......... the directional shift of the shade of the sphere
111.            side=0.15,    .......... the amount of shift used to create the side shade
112.            shadow=0.5,
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade,   ........ the three circles of the sphere
107.            xy=(0, 0),   ........ the planar position of the sphere
108.            radius=1,   ........ the radius of the sphere
109.            height=0,   ........ the height of the sphere
110.            shift=(0.4, -0.8),   ........ the directional shift of the shade of the sphere
111.            side=0.15,   ........ the amount of shift used to create the side shade
112.            shadow=0.5,   ........ the amount of shift used to create the floor shade
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height]))
119.        light.set_center(xy - radius*side*shift + np.array([0, height]))
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

Creating a sphere

```
106.     def update_sphere(self, main, light, shade, ........ the three circles of the sphere
107.             xy=(0, 0), ........ the planar position of the sphere
108.             radius=1, ........ the radius of the sphere
109.             height=0, ........ the height of the sphere
110.             shift=(0.4, -0.8), ........ the directional shift of the shade of the sphere
111.             side=0.15, ........ the amount of shift used to create the side shade
112.             shadow=0.5, ........ the amount of shift used to create the floor shade
113.         ):
114.         xy = np.array(xy)
115.         shift = np.array(shift)
116.         for circle in [main, light, shade]:
117.             circle.set_radius(radius)
118.         main.set_center(xy + np.array([0, height])) ........ main is vertically shifted by height from xy
119.         light.set_center(xy - radius*side*shift + np.array([0, height]))
120.         shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.         shade.set_center(xy + shade_shift*shift)
122.         light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade, ........................ the three circles of the sphere
107.            xy=(0, 0), ............................................... the planar position of the sphere
108.            radius=1, ..................................................... the radius of the sphere
109.            height=0, ..................................................... the height of the sphere
110.            shift=(0.4, -0.8), ...................... the directional shift of the shade of the sphere
111.            side=0.15, ................................ the amount of shift used to create the side shade
112.            shadow=0.5, ............................... the amount of shift used to create the floor shade
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height])) ............ main is vertically shifted by height from xy
119.        light.set_center(xy - radius*side*shift + np.array([0, height])) .....light is shifted from main using shift
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift)
122.        light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade, ..........the three circles of the sphere
107.            xy=(0, 0), ...................................the planar position of the sphere
108.            radius=1, ..........................................the radius of the sphere
109.            height=0, ..........................................the height of the sphere
110.            shift=(0.4, -0.8), ...............the directional shift of the shade of the sphere
111.            side=0.15, ...................the amount of shift used to create the side shade
112.            shadow=0.5, .................the amount of shift used to create the floor shade
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height])) ..........main is vertically shifted by height from xy
119.        light.set_center(xy - radius*side*shift + np.array([0, height])) .....light is shifted from main using shift
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift) ..............shade is shifted from xy using shift
122.        light.set_clip_path(main)
```

Creating a sphere

```
106.    def update_sphere(self, main, light, shade, ..............the three circles of the sphere
107.            xy=(0, 0), ......................................the planar position of the sphere
108.            radius=1, ...........................................the radius of the sphere
109.            height=0, ...........................................the height of the sphere
110.            shift=(0.4, -0.8), .........................the directional shift of the shade of the sphere
111.            side=0.15, ..........................the amount of shift used to create the side shade
112.            shadow=0.5, .........................the amount of shift used to create the floor shade
113.        ):
114.        xy = np.array(xy)
115.        shift = np.array(shift)
116.        for circle in [main, light, shade]:
117.            circle.set_radius(radius)
118.        main.set_center(xy + np.array([0, height])) ...........main is vertically shifted by height from xy
119.        light.set_center(xy - radius*side*shift + np.array([0, height])) .....light is shifted from main using shift
120.        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
121.        shade.set_center(xy + shade_shift*shift) ..................shade is shifted from xy using shift
122.        light.set_clip_path(main) ...........................................light is clipped by main
```

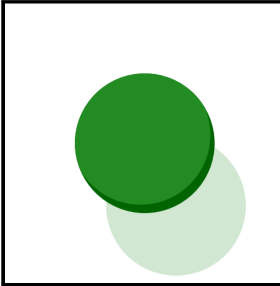
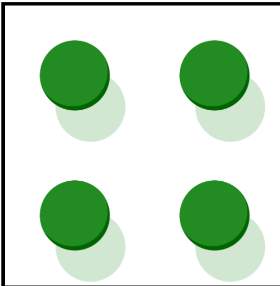
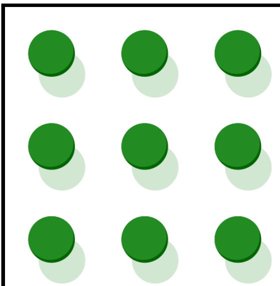
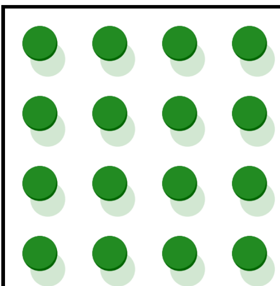
Creating spheres

Creating spheres

Q6: Create a custom number of spheres.

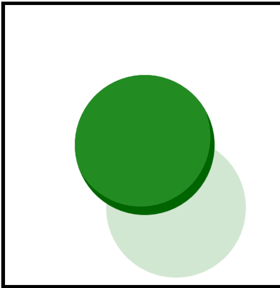
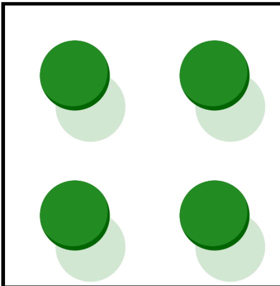
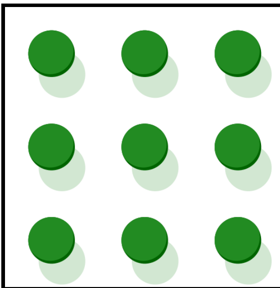
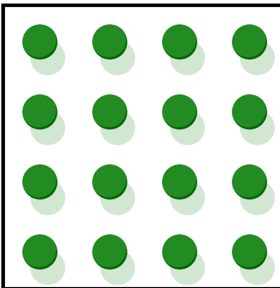
Creating spheres

Q6: Create a custom number of spheres.

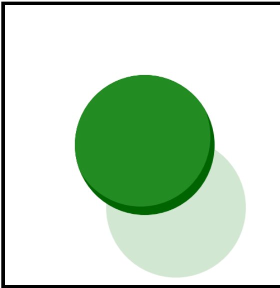
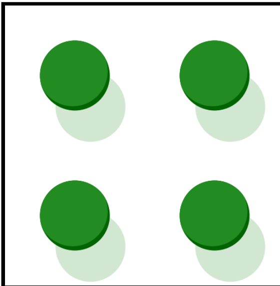
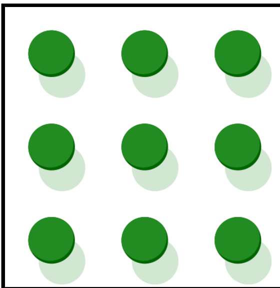
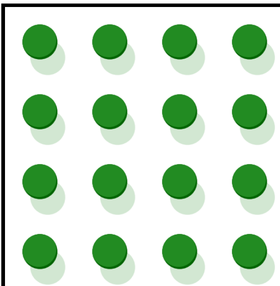
Creating spheres

```
124.    def make_spheres(self, number, ratio=0.5, *args, **kwargs):
125.        self.spheres = []
126.        for i in range(number):
127.            for j in range(number):
128.                xy = (2*i + 1)/number - 1, 1 - (2*j + 1)/number
129.                sphere = self.new_sphere(
130.                    radius=ratio/number,
131.                    xy=xy,
132.                    *args,
133.                    **kwargs,
134.                )
135.                self.update_sphere(**sphere)
136.                self.spheres.append(sphere)
```

Creating spheres

```
140. if __name__ == '__main__':
141.     vis = Visual.square(dpi=500)
142.     vis.set_boundary()
143.     for n in range(1, 5):
144.         vis.make_spheres(n)
145.         vis.new_frame()
146.         for sphere in vis.spheres:
147.             sphere['main'].set_visible(False)
148.             sphere['light'].set_visible(False)
149.             sphere['shade'].set_visible(False)
```

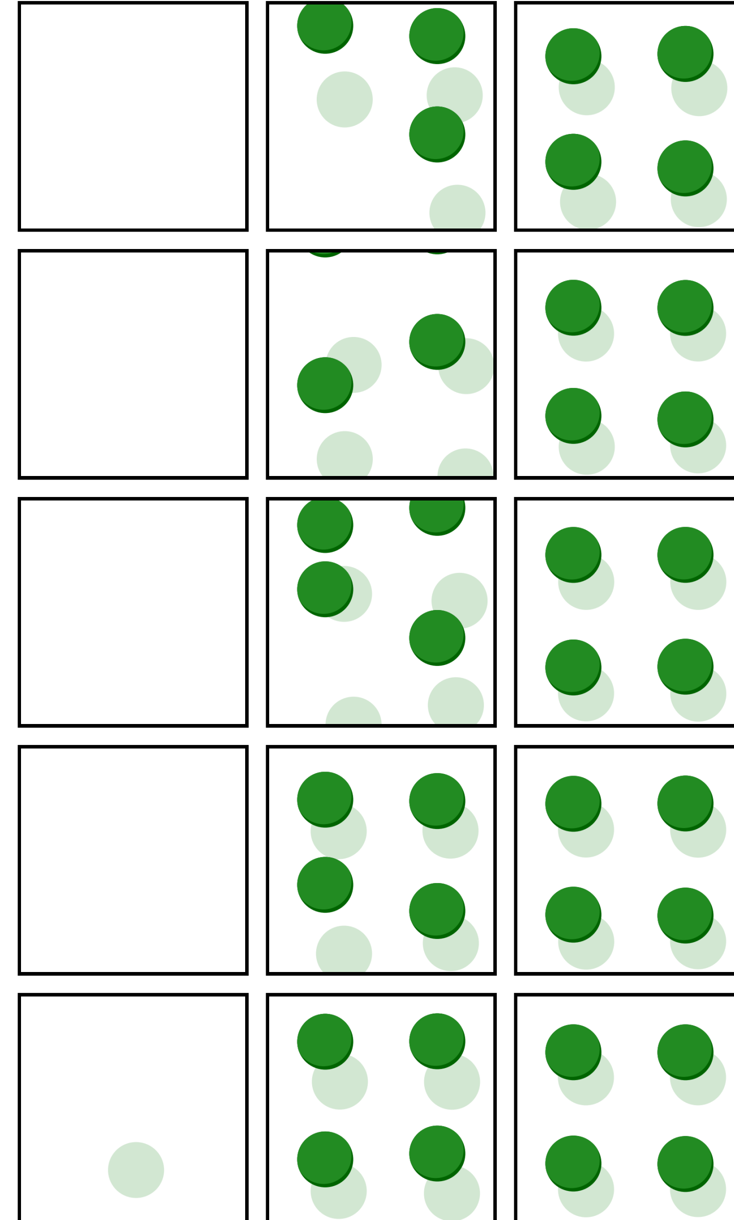
Dropping spheres

Dropping spheres

Q7: Create dropping spheres.

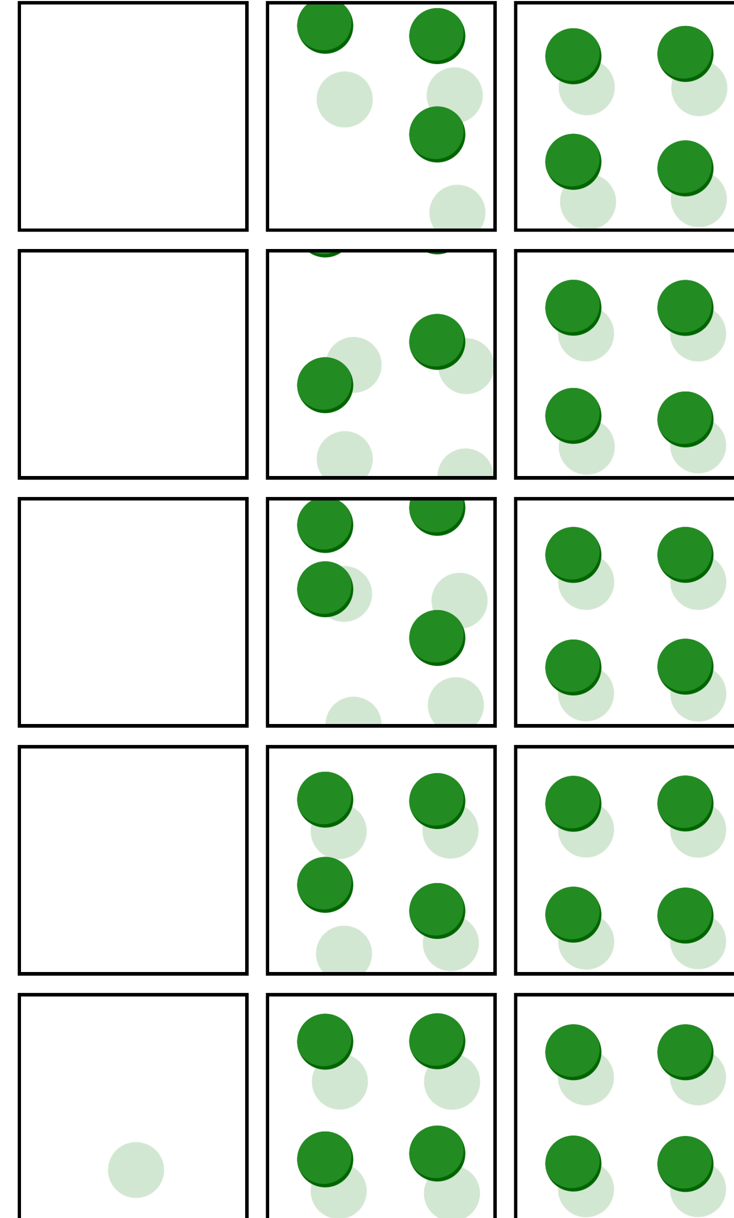
Dropping spheres

Q7: Create dropping spheres.



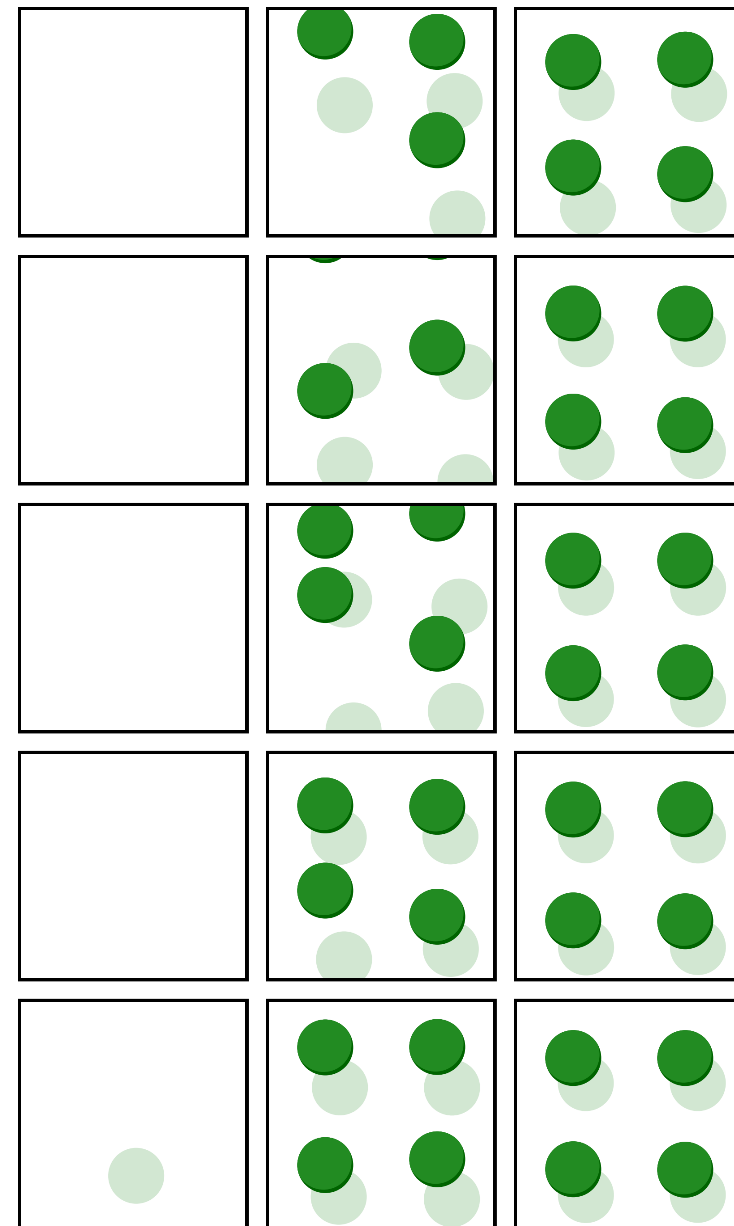
Dropping spheres

```
138.     def get_height(self,
139.             index=0,
140.             height_spread=1,
141.             height_period=0.5,
142.             height_drop=0.25,
143.             max_height=4.5,
144.         ):
145.         if not hasattr(self, 'height_shifts'):
146.             self.height_shifts = np.random.rand(len(self.spheres))
147.         shifts = index - self.fps*height_spread*self.height_shifts
148.         shifts = shifts*(shifts >= 0)
149.         flucts = np.abs(np.cos(np.pi*shifts/self.fps/height_period))
150.         heights = np.exp(-shifts/self.fps/height_drop)
151.         return max_height*flucts*heights
```



Dropping spheres

```
153.     def drop_spheres(self, duration, *args, **kwargs):
154.         for index in range(self.duration_to_number(duration)):
155.             heights = self.get_height(index, *args, **kwargs)
156.             for sphere, height in zip(self.spheres, heights):
157.                 self.update_sphere(height=height, **sphere)
158.             self.new_frame()
159.
160.
161.
162. if __name__ == '__main__':
163.     vis = Visual.square(dpi=500)
164.     vis.set_boundary()
165.     vis.make_spheres(2)
166.     vis.drop_spheres(0.5,
167.         height_spread=0.2,
168.         height_period=0.1,
169.         height_drop=0.05,
170.     )
```



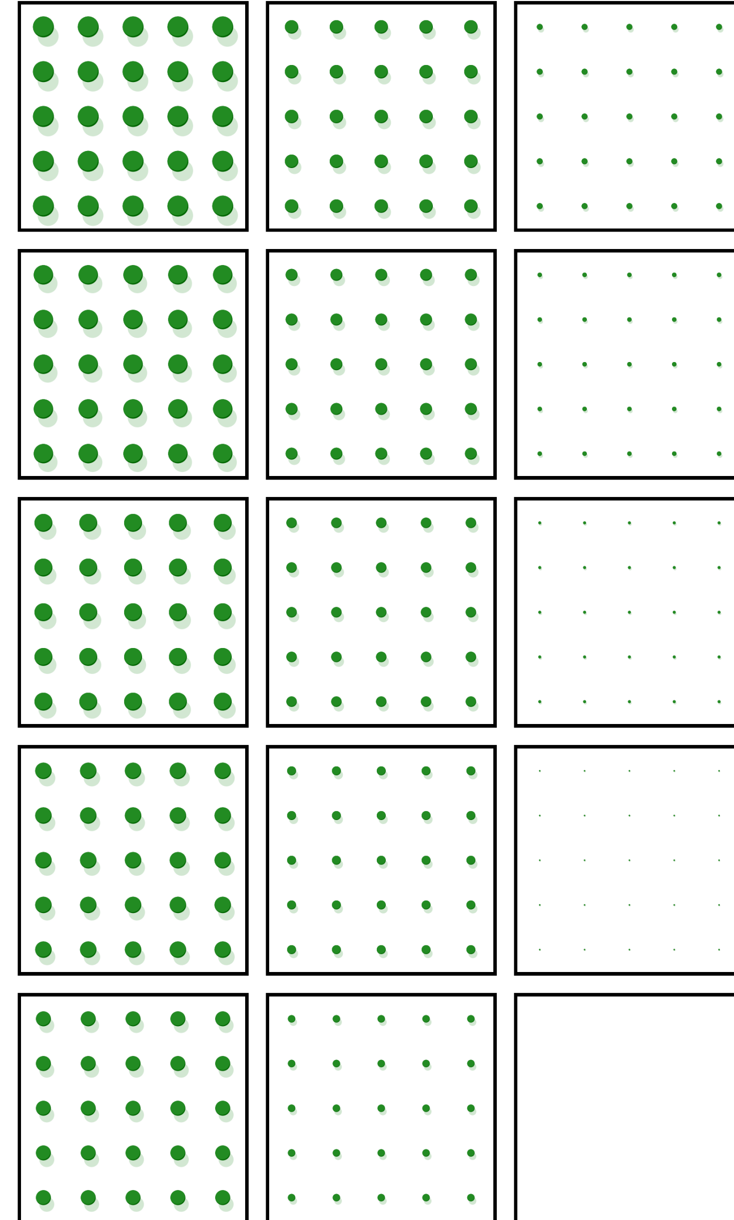
Shrinking spheres

Shrinking spheres

Q8: Create shrinking spheres.

Shrinking spheres

Q8: Create shrinking spheres.



Shrinking spheres

```
160.     def shrink_spheres(self, duration):
161.         n_steps = self.duration_to_number(duration)
162.         radius = self.spheres[0]['main'].get_radius()
163.         for index in range(n_steps):
164.             ratio = 1 - (1 + index)/n_steps
165.             for sphere in self.spheres:
166.                 sphere['radius'] = ratio*radius
167.                 self.update_sphere(**sphere)
168.             self.new_frame()
169.
170.
171.
172. if __name__ == '__main__':
173.     vis = Visual.square(dpi=500)
174.     vis.set_boundary()
175.     vis.make_spheres(5)
176.     vis.shrink_spheres(0.5)
```

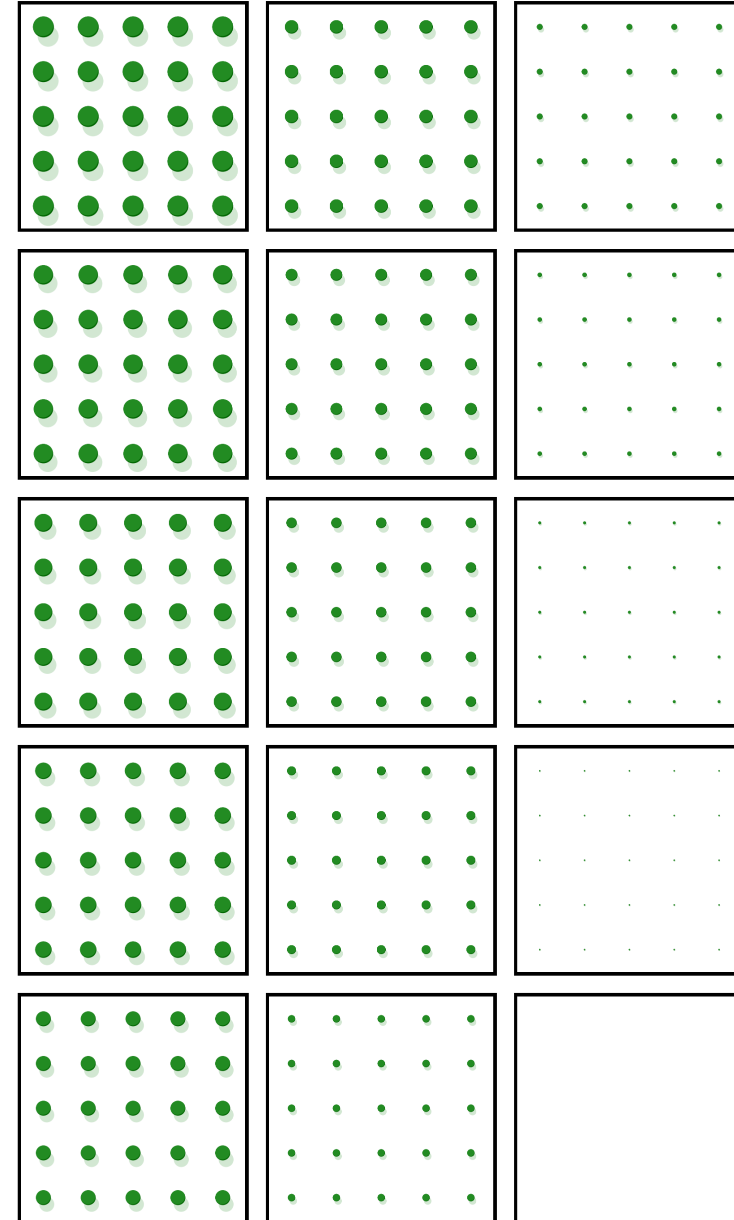


Table of contents

- Extending the Figure class
- Importing images
- Creating shapes
- Creating drawings
- Conclusion

Drawings

Drawings

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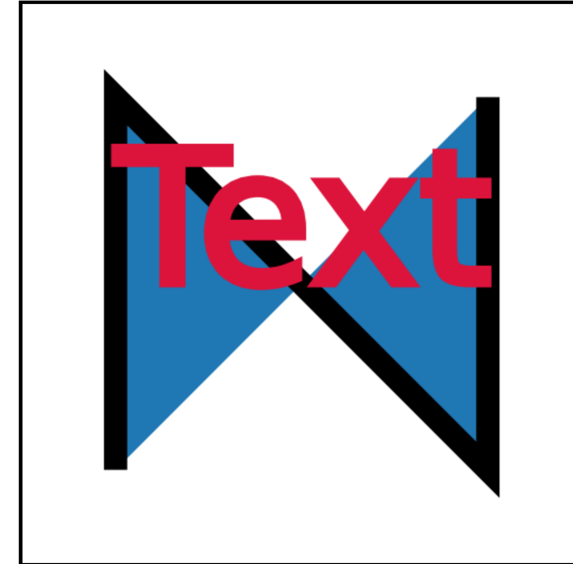

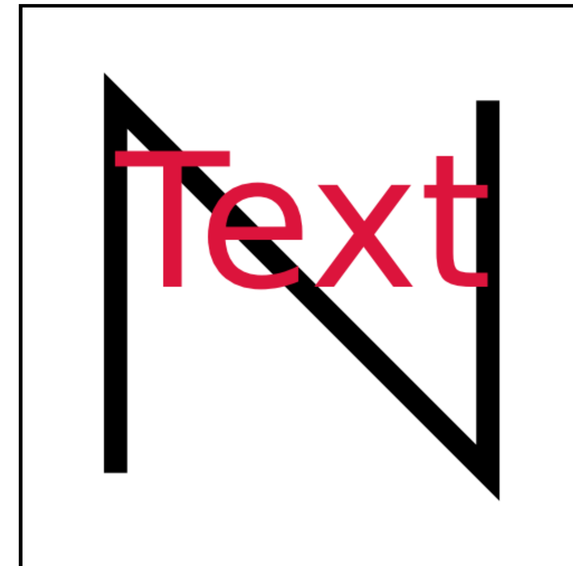

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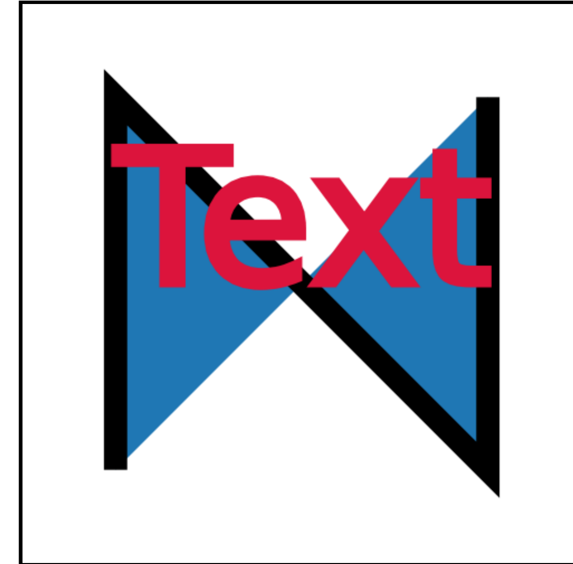

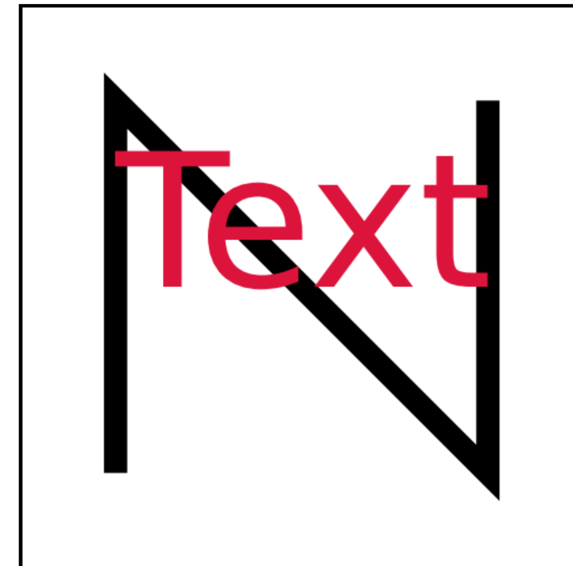

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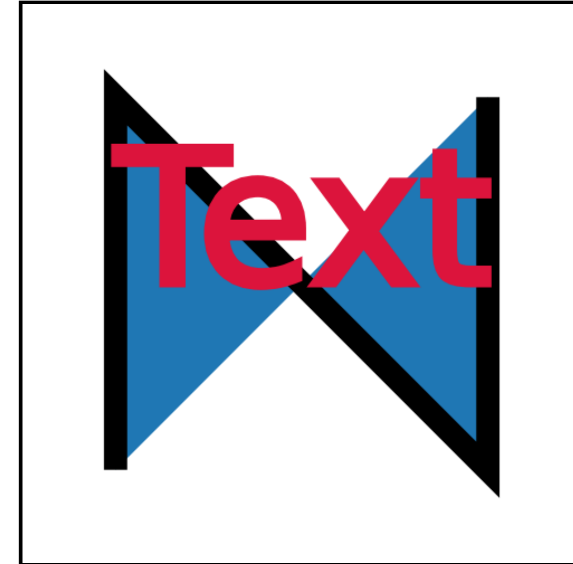

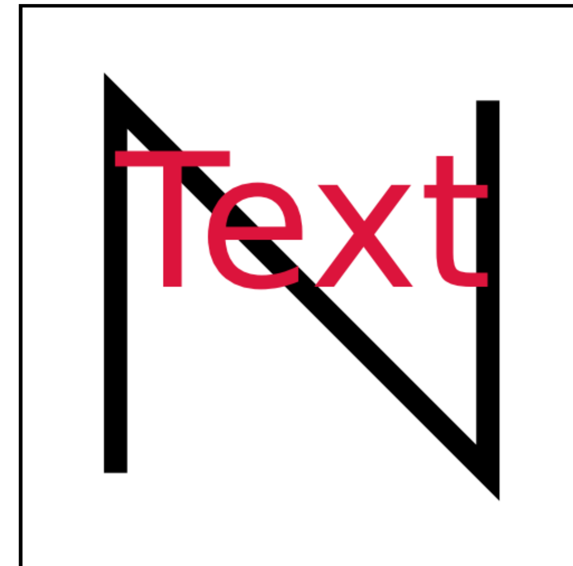

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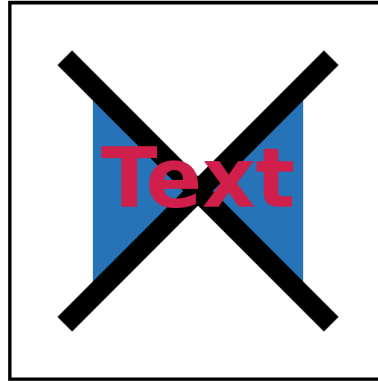

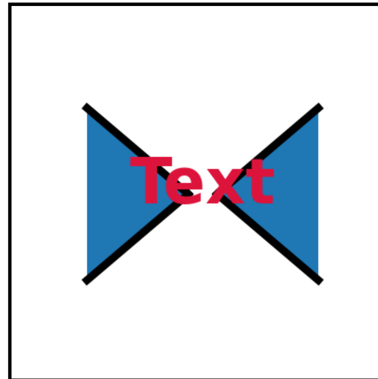

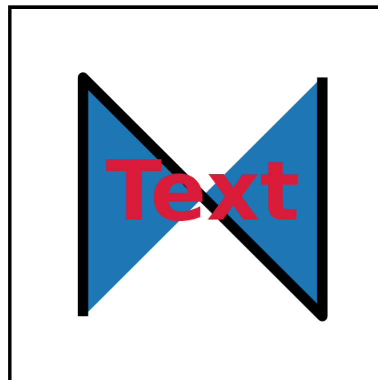

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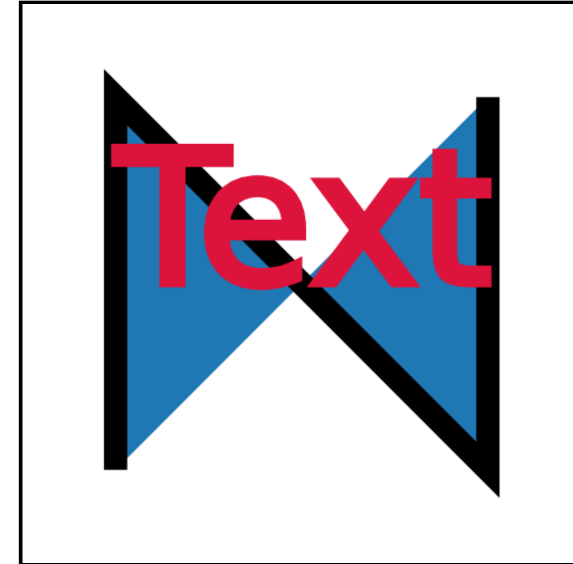
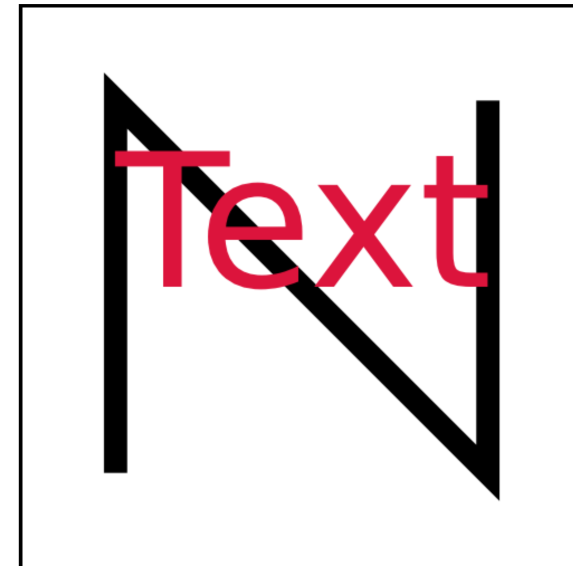
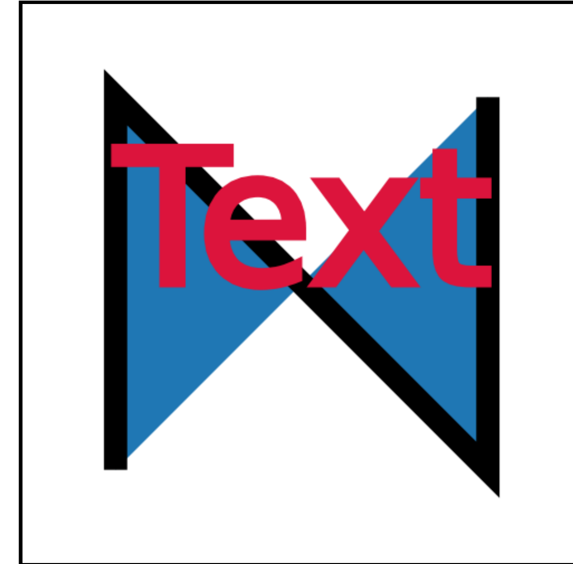
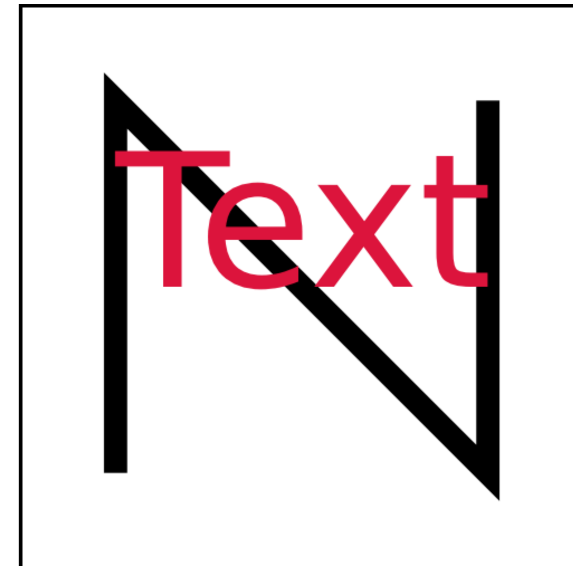




Drawings

```
172. if __name__ == '__main__':
173.     vis = Visual.square(dpi=500)
174.     vis.set_boundary(1.5)
175.     N = vis.ax.add_patch(PathPatch(
176.         path=Path([(-1, -1), (-1, 1), (1, -1), (1, 1)]),
177.         lw=3,
178.     ))
179.     T = vis.ax.add_patch(PathPatch(
180.         path=TextPath(xy=(-1, 0), s='Text', size=1),
181.         color='crimson',
182.     ))
183.     vis.new_frame()
184.     N.set_fill(False)
185.     T.set_lw(0)
186.     vis.new_frame()
```





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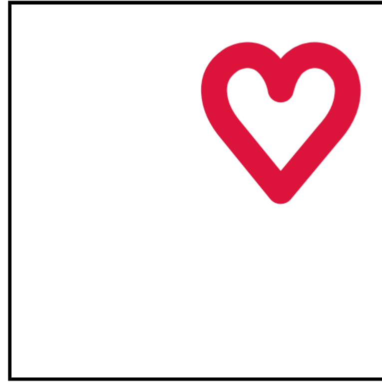

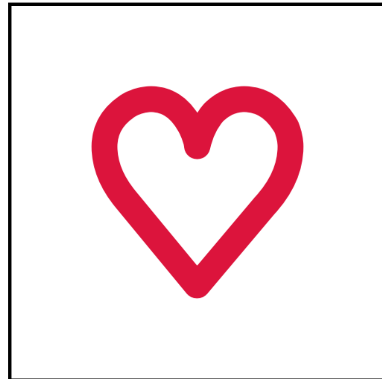

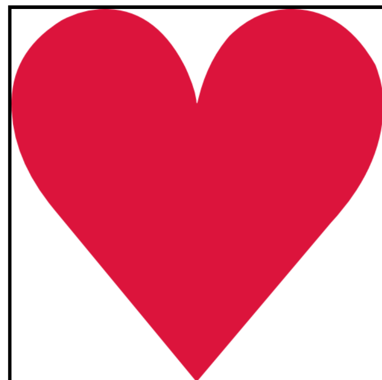

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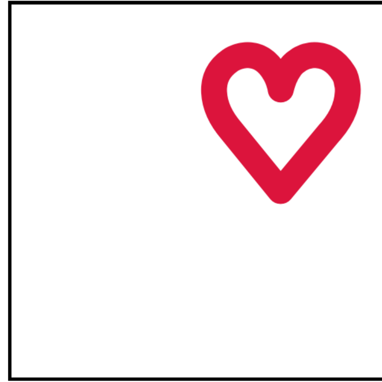
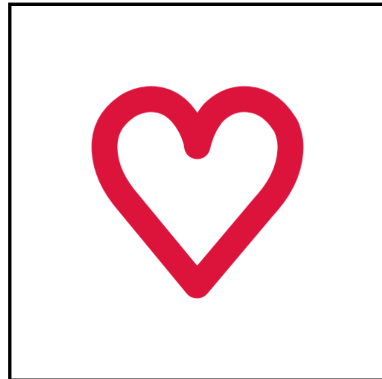
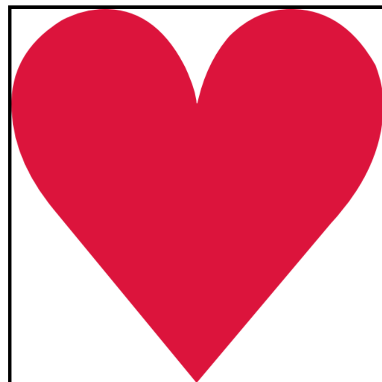
Q10: Create these three images.







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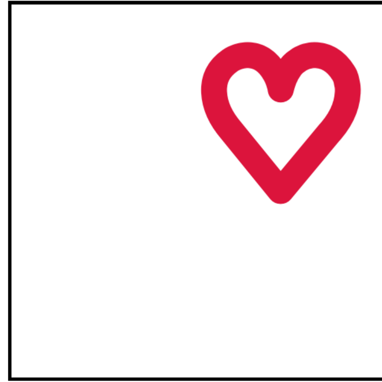

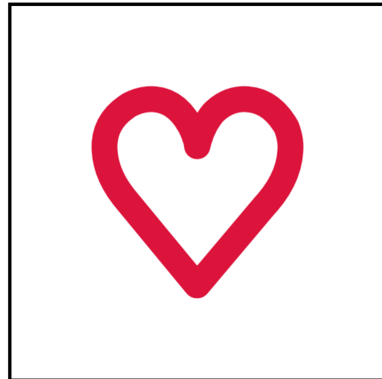

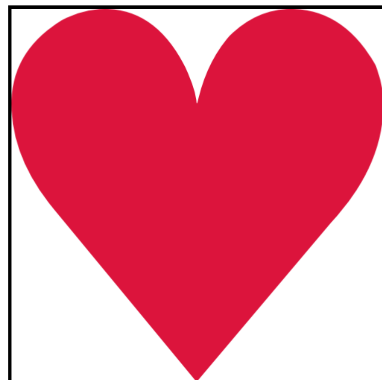

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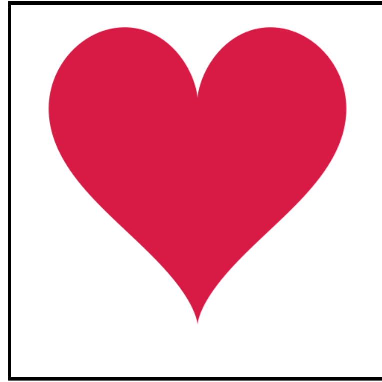

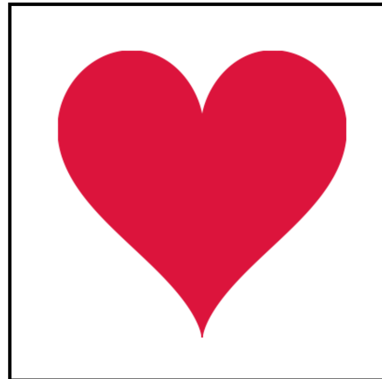

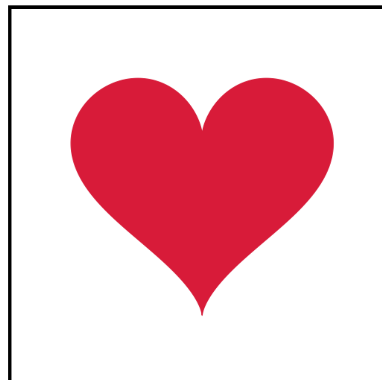

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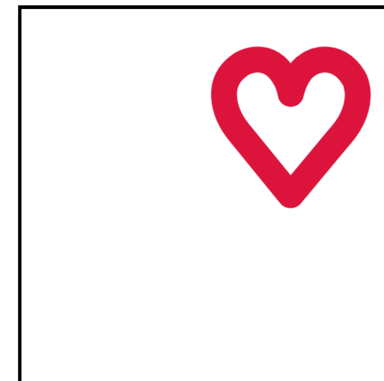

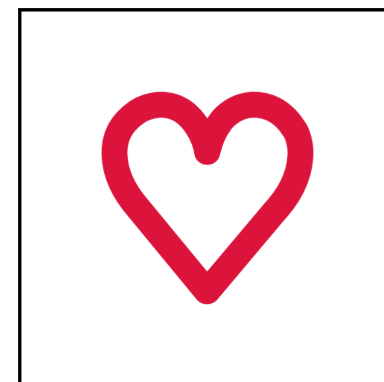

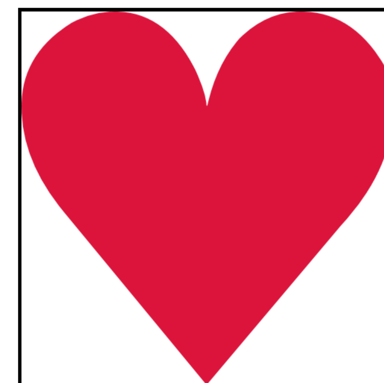

Drawings

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173.     vis = Visual.square(dpi=500)
174.     vis.set_boundary()
175.     path = TextPath(xy=(0, 0), s='\u2665', size=1)
176.     patch = vis.ax.add_patch(PathPatch(path=path))
177.     patch.set(lw=5, color='crimson', fill=False, joinstyle='round')
178.     vis.new_frame()
179.     bbox = path.get_extents()
180.     vertices = (path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size
181.     path = Path(vertices=vertices, codes=path.codes)
182.     patch.set(path=path)
183.     vis.new_frame()
184.     vis.set_boundary(0.5)
185.     patch.set(lw=0, fill=True)
186.     vis.new_frame()
```

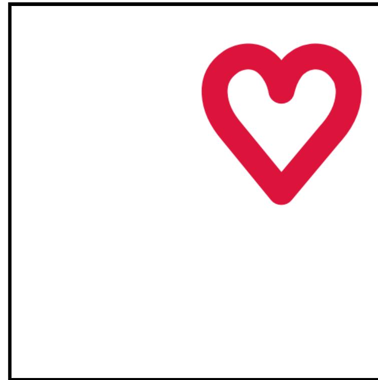

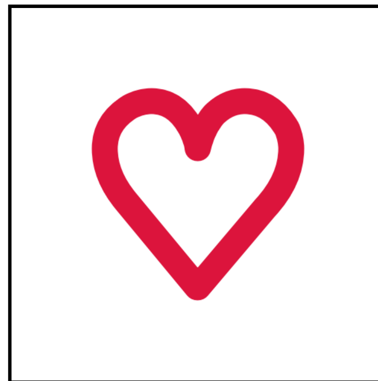

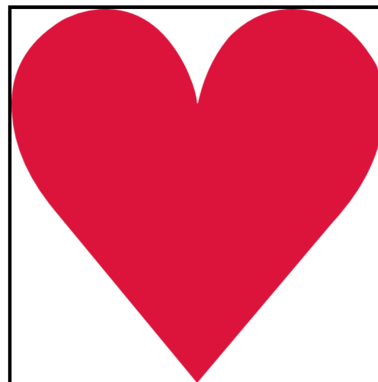

Drawing a heart

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The solution of **Q10** includes the following code which automatically adds a `patch` accessed using the `heart` attribute of the class.

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```
170.     def add_heart(self, size=1, *args, **kwargs):
171.         path = TextPath(xy=(0, 0), s='\u2665', size=1)
172.         bbox = path.get_extents()
173.         vertices = size*(path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size
174.         path = Path(vertices=vertices, codes=path.codes)
175.         self.heart = vis.ax.add_patch(PathPatch(path=path, *args, **kwargs))
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170.     def add_heart(self, size=1, *args, **kwargs):
171.         path = TextPath(xy=(0, 0), s='\u2665', size=1)
172.         bbox = path.get_extents()
173.         vertices = size*(path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size ........ resizes the vertices around the origin
174.         path = Path(vertices=vertices, codes=path.codes)
175.         self.heart = vis.ax.add_patch(PathPatch(path=path, *args, **kwargs))
```

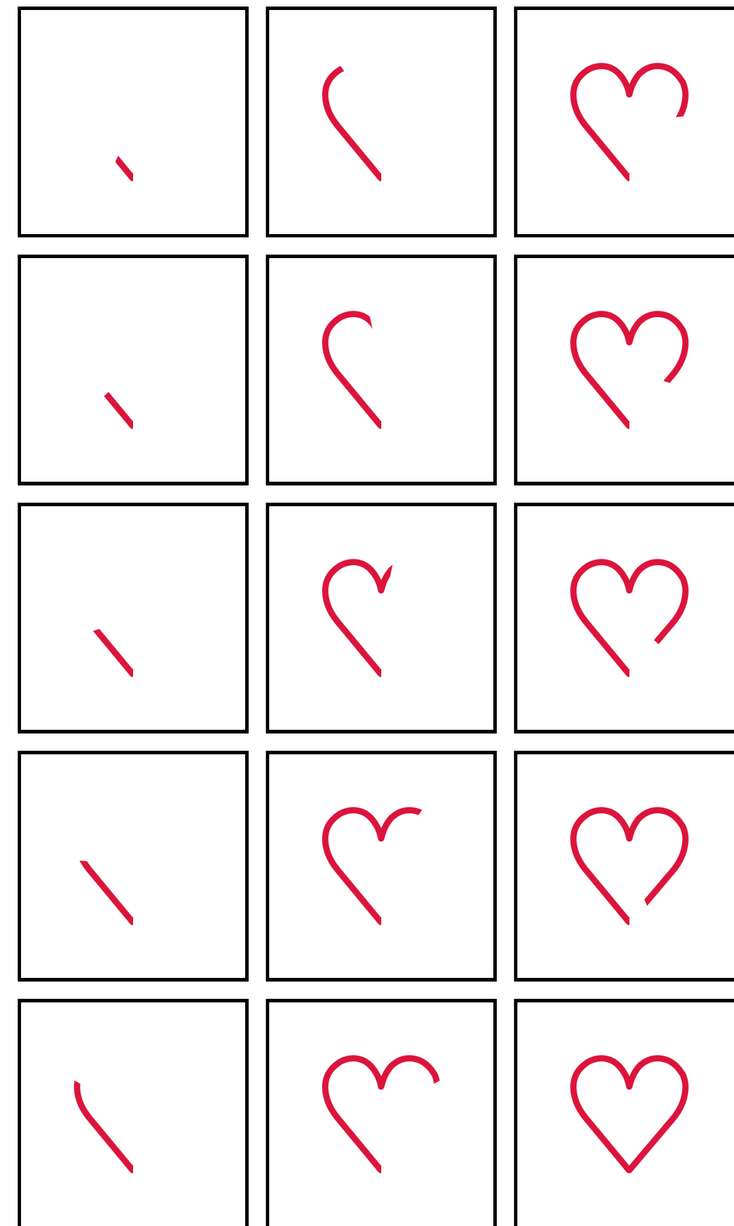
Drawing a heart

Drawing a heart

Q11: Create the drawn heart effect.

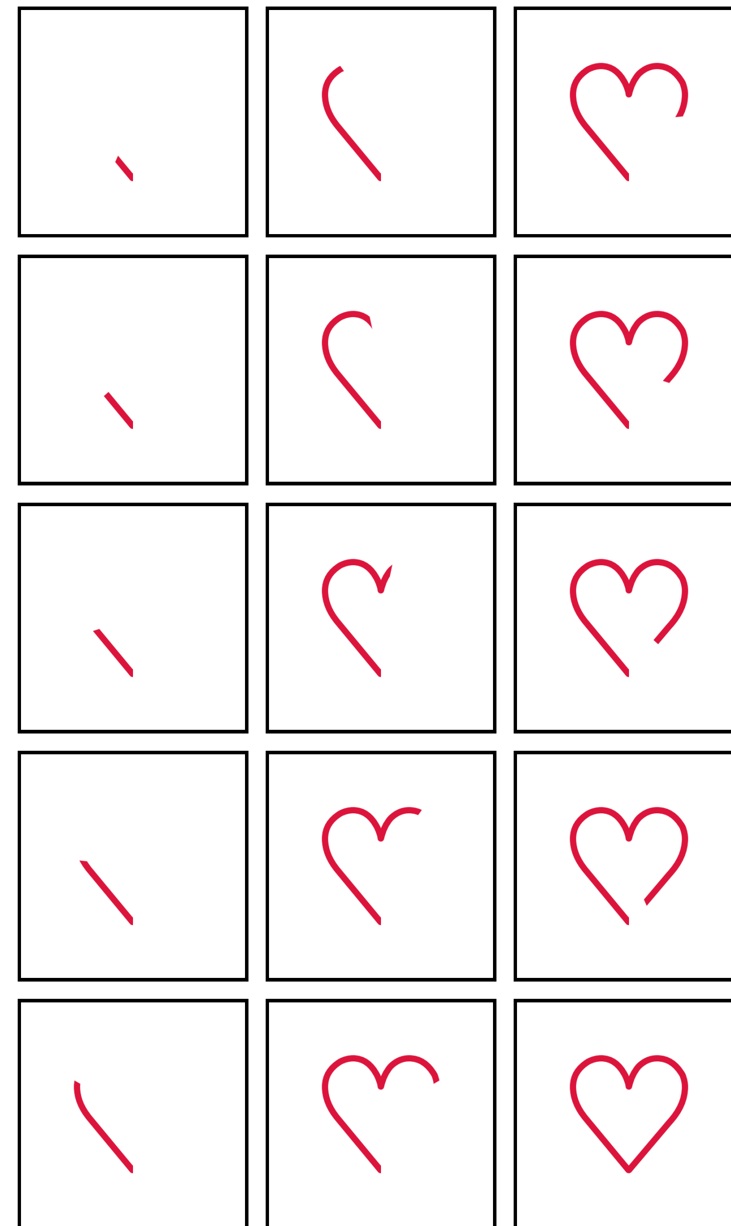
Drawing a heart

Q11: Create the drawn heart effect.



Drawing a heart

```
177.     def draw_heart(self, duration, *args, **kwargs):
178.         n_steps = self.duration_to_number(duration)
179.         wedge = self.ax.add_patch(
180.             Wedge((0, 0), 1, 270, 270, visible=False)
181.         )
182.         self.heart.set_clip_path(wedge)
183.         for index in range(n_steps):
184.             wedge.set_theta1(270 - 360*(1 + index)/n_steps)
185.             self.new_frame()
186.
187.
188.
189. if __name__ == '__main__':
190.     vis = Visual.square(dpi=500)
191.     vis.set_boundary()
192.     vis.add_heart(ec='crimson', lw=2, fill=False, joinstyle='round')
193.     vis.draw_heart(0.5)
```



Zooming effect

Zooming effect

Q12: Create a zooming and fading effect.

Zooming effect

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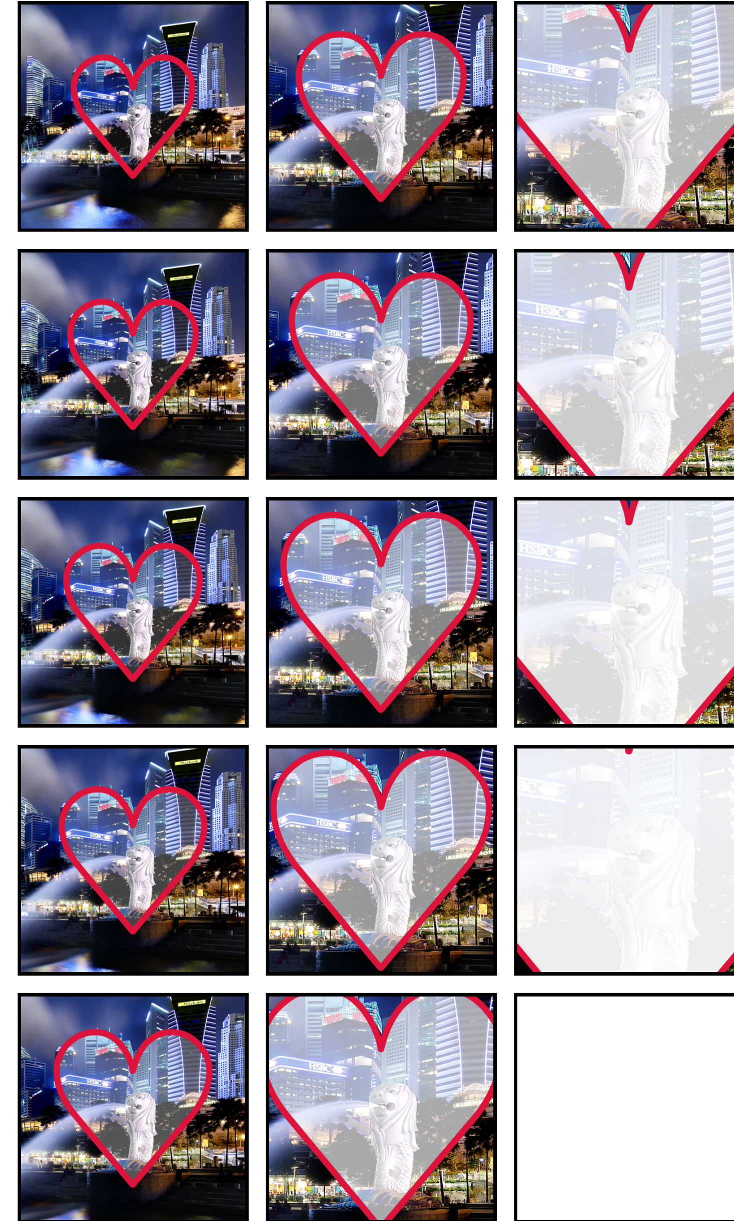
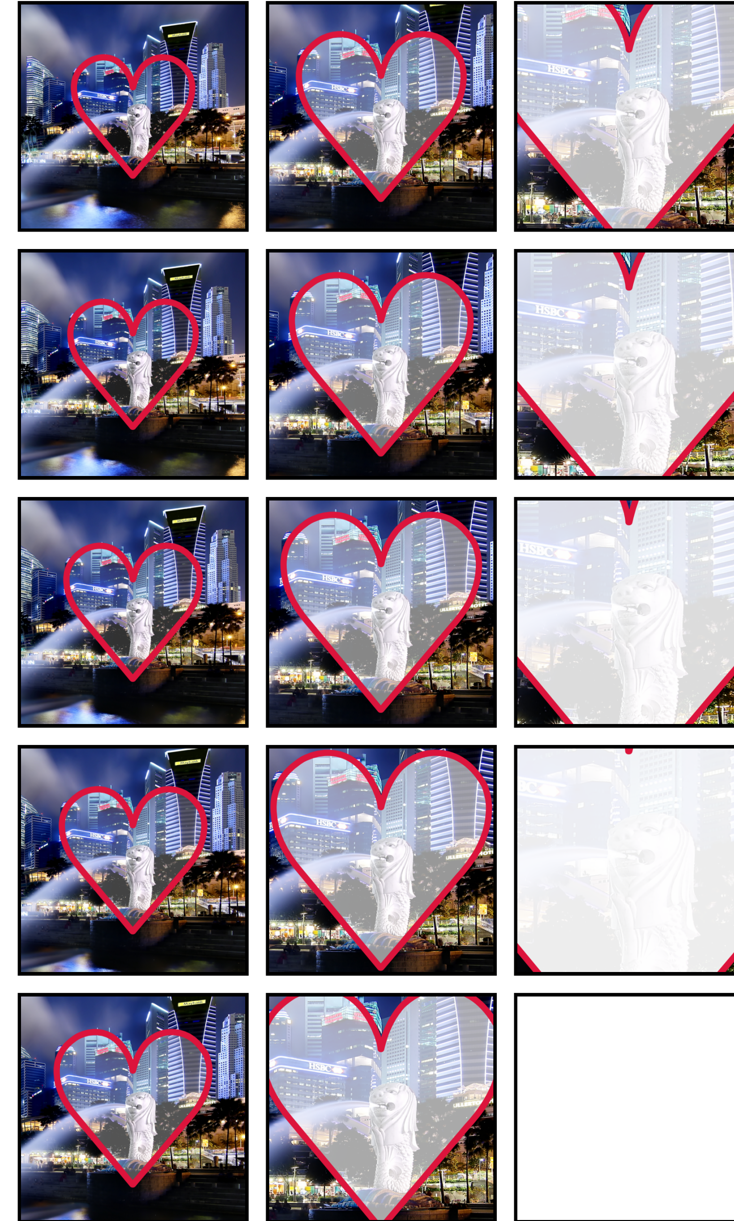


Zooming effect

```
187.     def zoom_in(self, duration, zoom=0.5):
188.         n_steps = self.duration_to_number(duration)
189.         for index in range(n_steps):
190.             ratio = (1 + index)/n_steps
191.             self.heart.set_fc((1, 1, 1, ratio))
192.             self.set_boundary(1 - ratio*(1 - zoom))
193.             self.new_frame()
194.
195.
196.
197. if __name__ == '__main__':
198.     vis = Visual.square(dpi=500)
199.     vis.set_boundary()
200.     vis.add_image(filename='singapore.jpg', shift=0.4)
201.     vis.add_heart(ec='crimson', lw=2, joinstyle='round')
202.     vis.zoom_in(0.5, zoom=0.2)
```



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Final video

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Q13: Combine all functions to create the original video.

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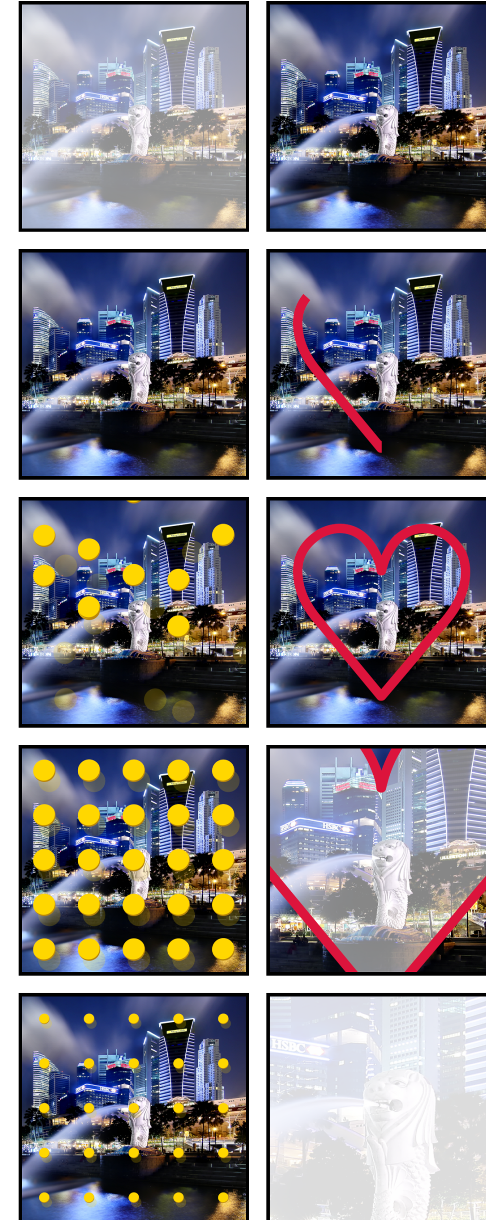
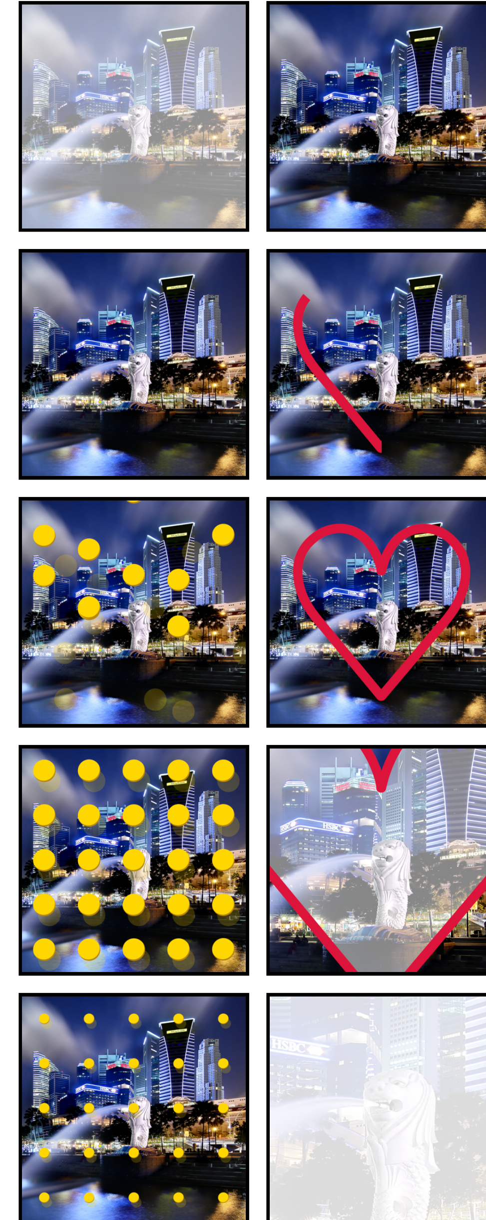


Final video

```
197. if __name__ == '__main__':
198.     vis = Visual.square(dpi=1000)
199.     vis.set_boundary()
200.     vis.wait(duration=0.5)
201.     vis.add_image(filename='singapore.jpg', shift=0.4)
202.     vis.image_appear(duration=1)
203.     vis.wait(duration=0.5)
204.     vis.make_spheres(number=5, color='gold', dark='darkgoldenrod')
205.     vis.drop_spheres(duration=3)
206.     vis.shrink_spheres(duration=1)
207.     vis.wait(duration=0.5)
208.     vis.add_heart(size=1.5)
209.     vis.heart.set(ec='crimson', fc=4*[0], lw=3, joinstyle='round')
210.     vis.draw_heart(duration=1)
211.     vis.wait(duration=0.5)
212.     vis.zoom_in(duration=1, zoom=0.2)
213.     vis.make_video()
```



Final comments

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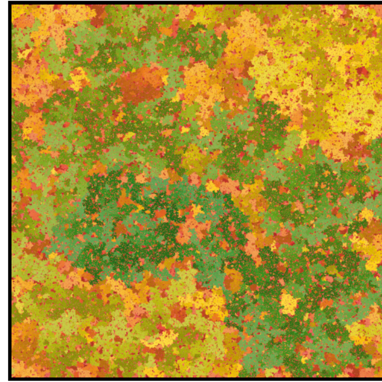

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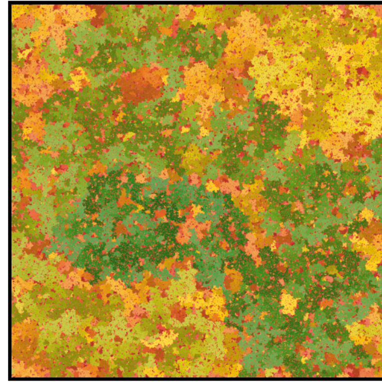

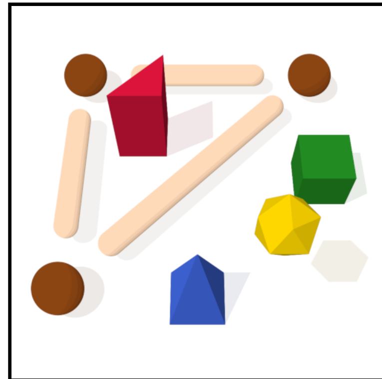

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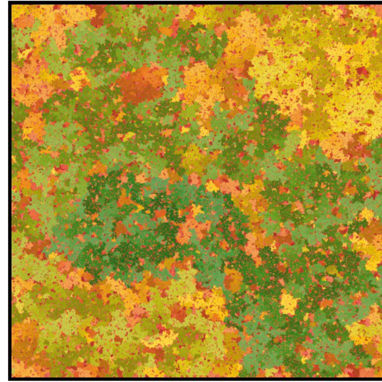

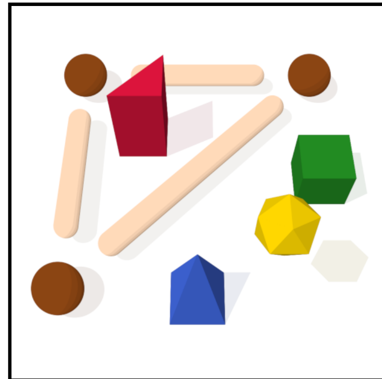

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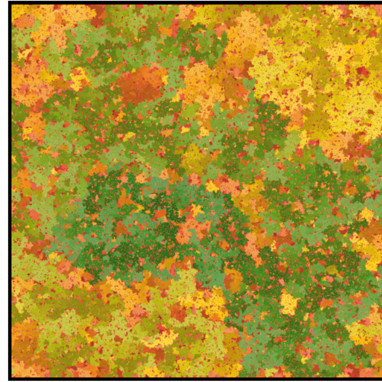

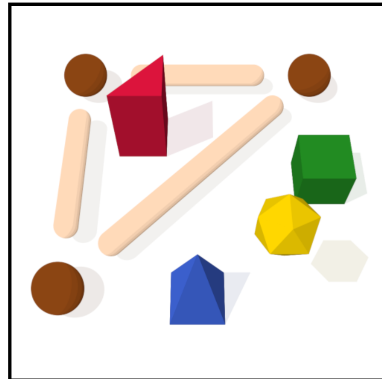

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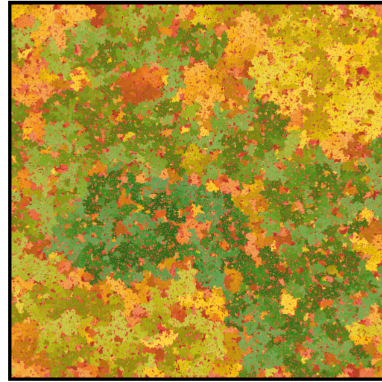

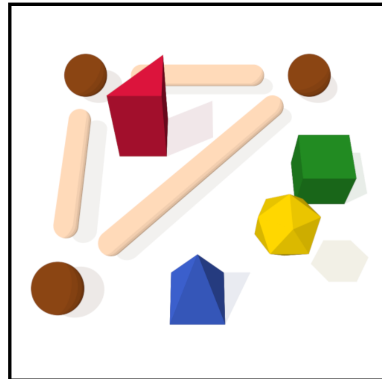

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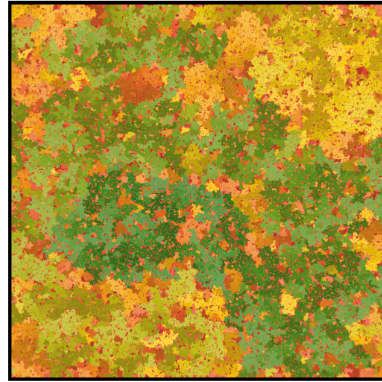

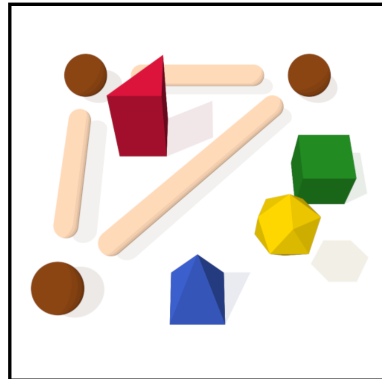

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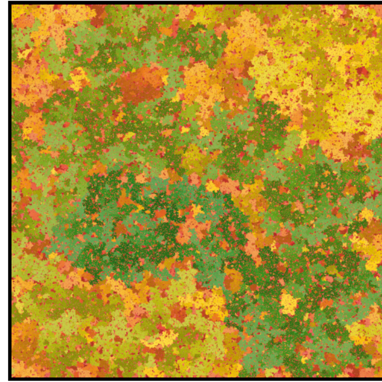
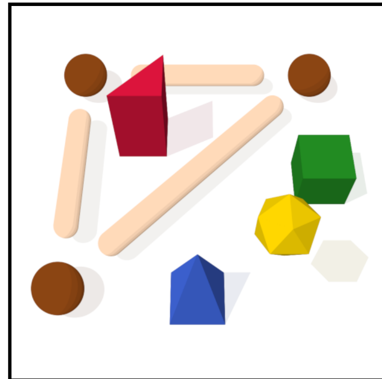
And so much more still remains to be discovered and applied!





Thank you!
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Thank you!
Thank you!
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