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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  - 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
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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

```
import os
import cv2
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.patches import *
from matplotlib.path import Path
from matplotlib.figure import Figure
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(...)`.

Initializing the file

```
class Visual(Figure):

    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)

    @classmethod
    def square(cls, *args, **kwargs):
        return cls(figsize=(1, 1), *args, **kwargs)



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
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class Visual(Figure):  ..... creates a subclass of Figure

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class Visual(Figure):                                   creates a subclass of Figure

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    def square(cls, *args, **kwargs):
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if __name__ == '__main__': ..... prevents this code from running elsewhere
    vis = Visual.square(dpi=500)
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- Finally, we put this code into a hidden *dunder* (double-under) method for clarity.

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    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)
        self.__figure__()

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    def square(cls, *args, **kwargs):
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        self.subplots_adjust(left=0, right=1, bottom=0, top=1)
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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 organizes 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'):
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→ The structure `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

```
    def make_video(self, filename='video'):
        frames = sorted([
            os.path.join('frames', file)
            for file in os.listdir('frames')
        ])
        height, width, _ = cv2.imread(frames[0]).shape
        video = cv2.VideoWriter(
            filename=filename + '.mp4',
            fourcc=cv2.VideoWriter_fourcc(*'mp4v'),
            fps=self.fps,
            frameSize=(width, height),
        )
        for frame in frames:
            video.write(cv2.imread(frame))
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        video.release() ..... saves the video
        cv2.destroyAllWindows() ..... clears the cache
```

A first video

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

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

A first video

```
    def duration_to_number(self, duration):
        return int(duration*self.fps)

    def wait(self, duration):
        for _ in range(self.duration_to_number(duration)):
            self.new_frame()



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.wait(5)
    vis.make_video()
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  - Alternatively, this can also be done by calling `image.set_visible(False)`.

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- We import this matrix as in image in our figure by calling `image = self.ax.imshow(X, ...)`.
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  - For example, we make it invisible by calling `image.set(visible=False)`.
  - Alternatively, this can also be done by calling `image.set_visible(False)`.

Q2: Import an image into the figure.

Adding an image

```
    def set_boundary(self, boundary=1):
        self.ax.set_xlim(-boundary, boundary)
        self.ax.set_ylim(-boundary, boundary)

    def add_image(self, filename, shift=0, *args, **kwargs):
        X = plt.imread(filename)
        self.image = self.ax.imshow(
            X=X,
            extent=(
                shift - 1 - 2*X.shape[0]/X.shape[1],
                shift + 1,
                -1,
                1,
            ),
            *args,
            **kwargs,
        )
```

Adding an image

```
if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.add_image(filename='singapore.jpg', shift=0.4)
    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)`.
- We import this matrix as in image in our figure by calling `image = self.ax.imshow(X, ...)`.
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  - Alternatively, this can also be done by calling `image.set_visible(False)`.

Q3: Make an image fade in.

Making the image appear

```
    def image_appear(self, duration):
        n_steps = self.duration_to_number(duration)
        for step in range(n_steps):
            self.image.set_alpha((1 + step)/n_steps)
            self.new_frame()



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.add_image(filename='singapore.jpg', shift=0.4)
    vis.image.set_alpha(0)
    vis.new_frame()
    vis.image_appear(0.1)
```

Making the image appear

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    def image_appear(self, duration):
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if __name__ == '__main__':
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Table of contents

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

Shapes in matplotlib

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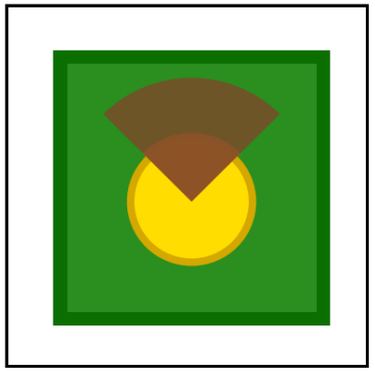

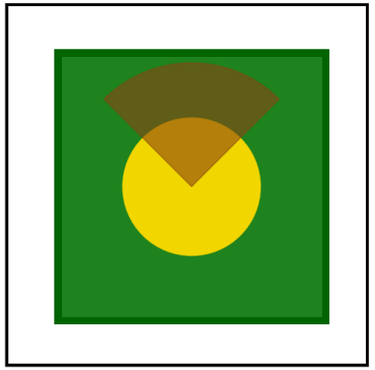

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Shapes in matplotlib

```
if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary(1.1)
    vis.ax.add_patch(Rectangle(
        xy=(-1, -1),
        width=2,
        height=2,
        edgecolor='darkgreen',
        facecolor='forestgreen',
        linewidth=4,
        capstyle='round',
        joinstyle='round',
    ))
```

Shapes in matplotlib

```
    vis.ax.add_patch(Circle(
        xy=(0, 0),
        radius=0.5,
        ec='darkgoldenrod',
        fc='gold',
        lw=2,
    ))
    vis.ax.add_patch(Wedge(
        center=(0, 0),
        theta1=45,
        theta2=135,
        r=1,
        color='crimson',
        lw=0,
        alpha=0.5,
    ))
    vis.new_frame()
```

3D effect

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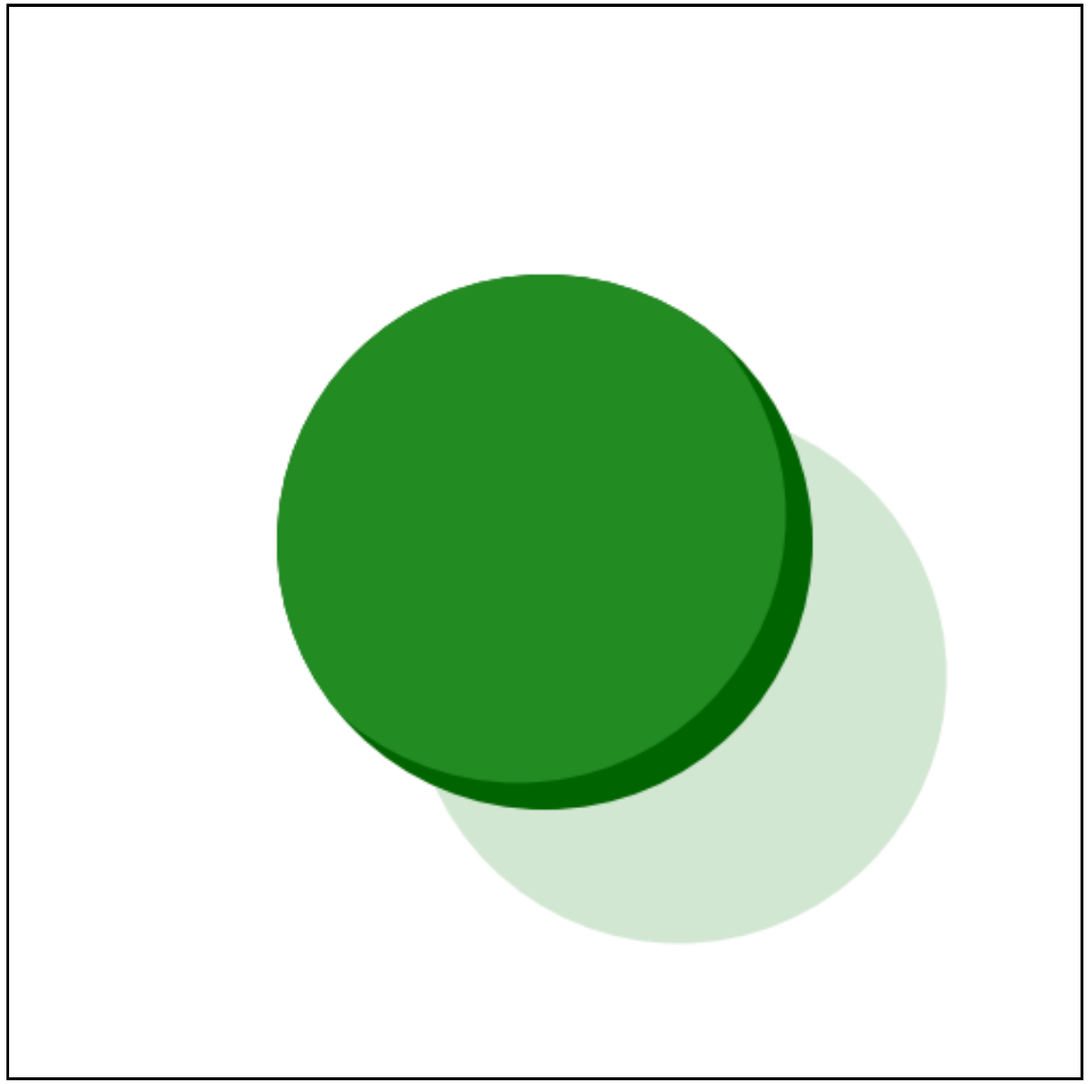

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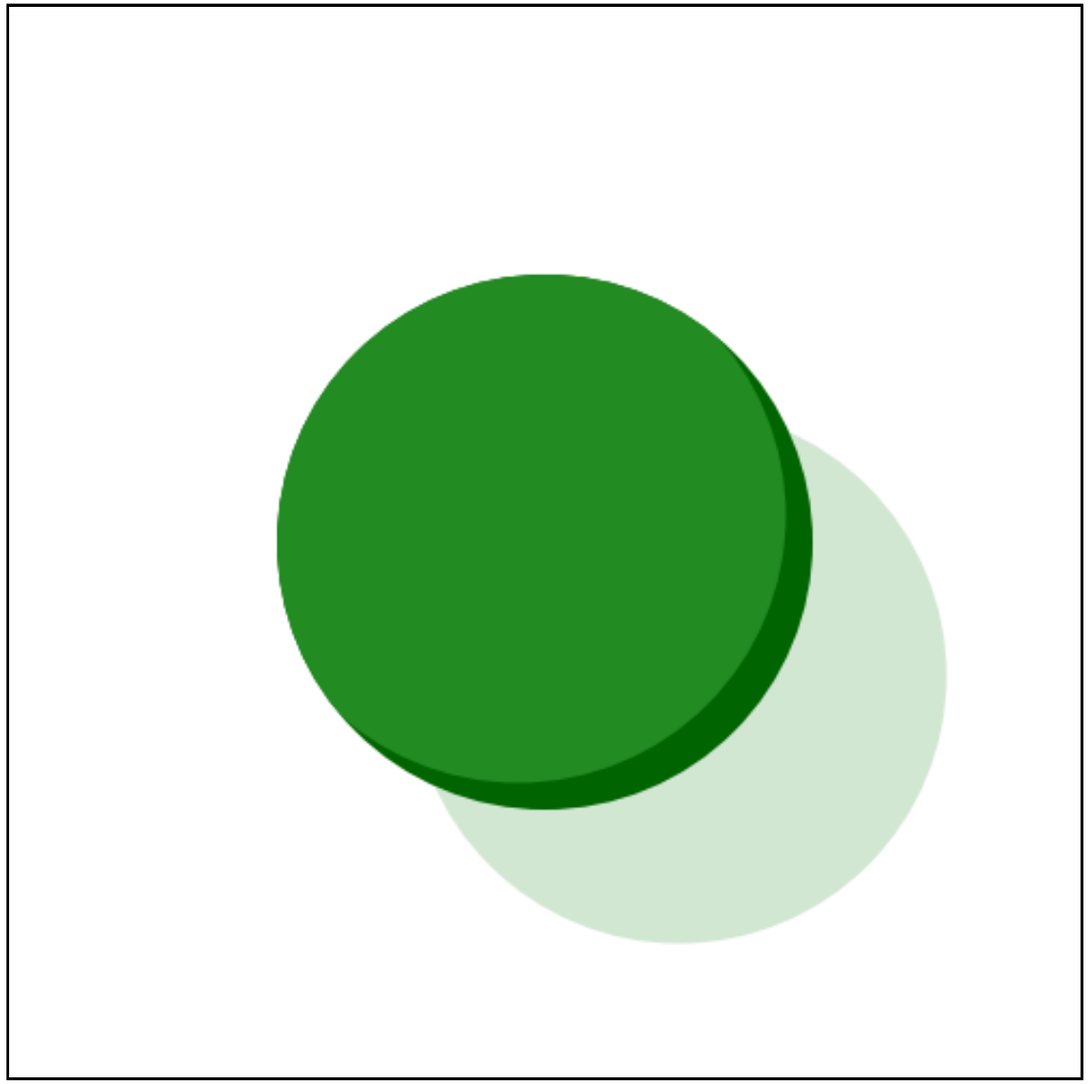

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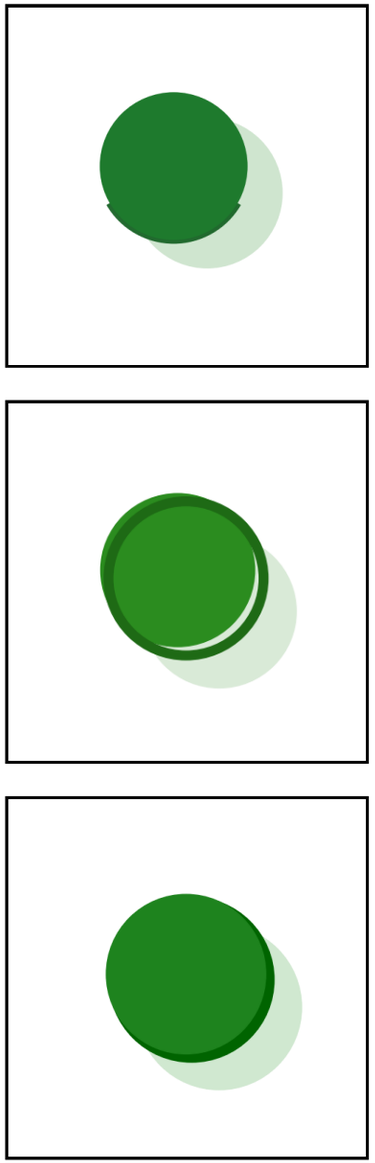

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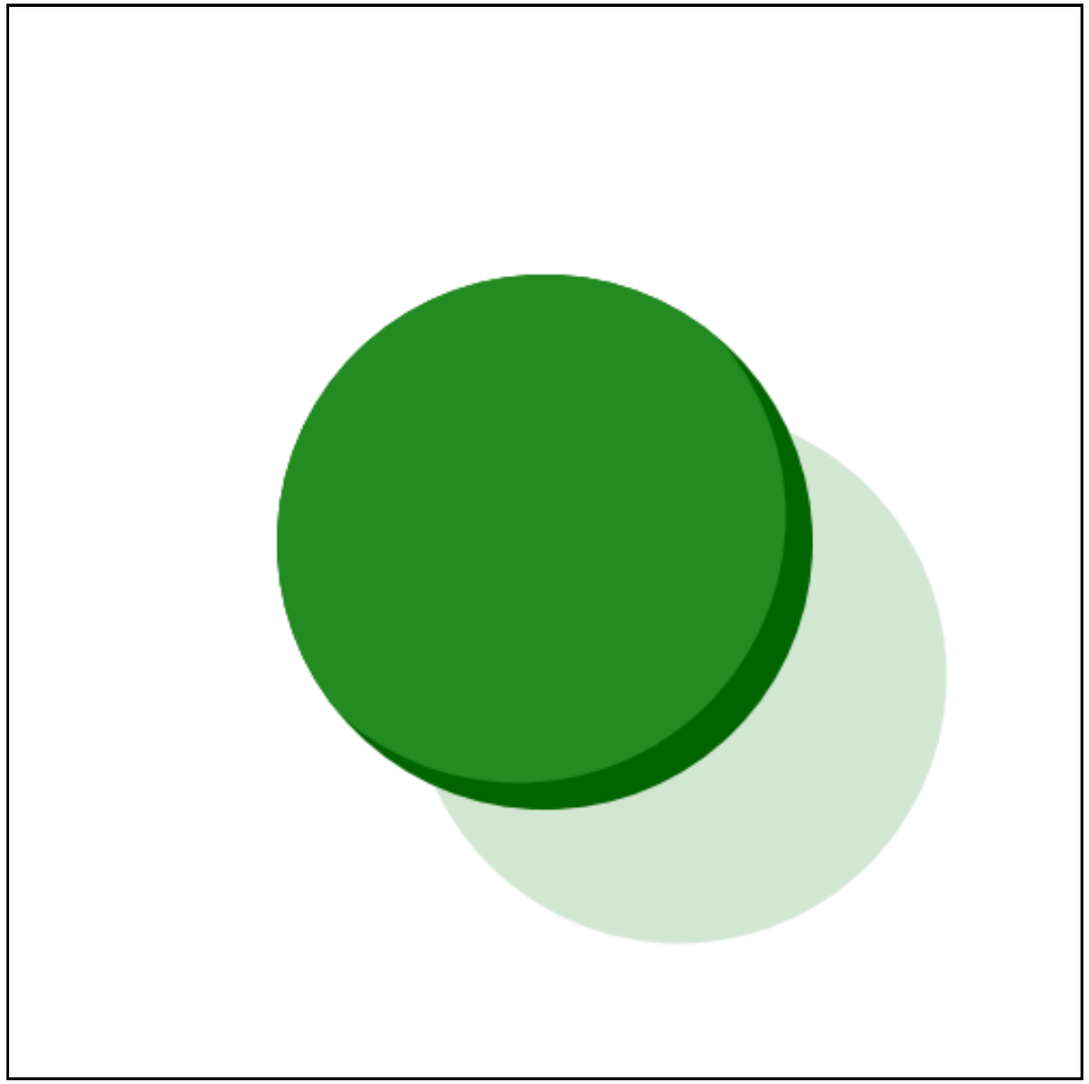
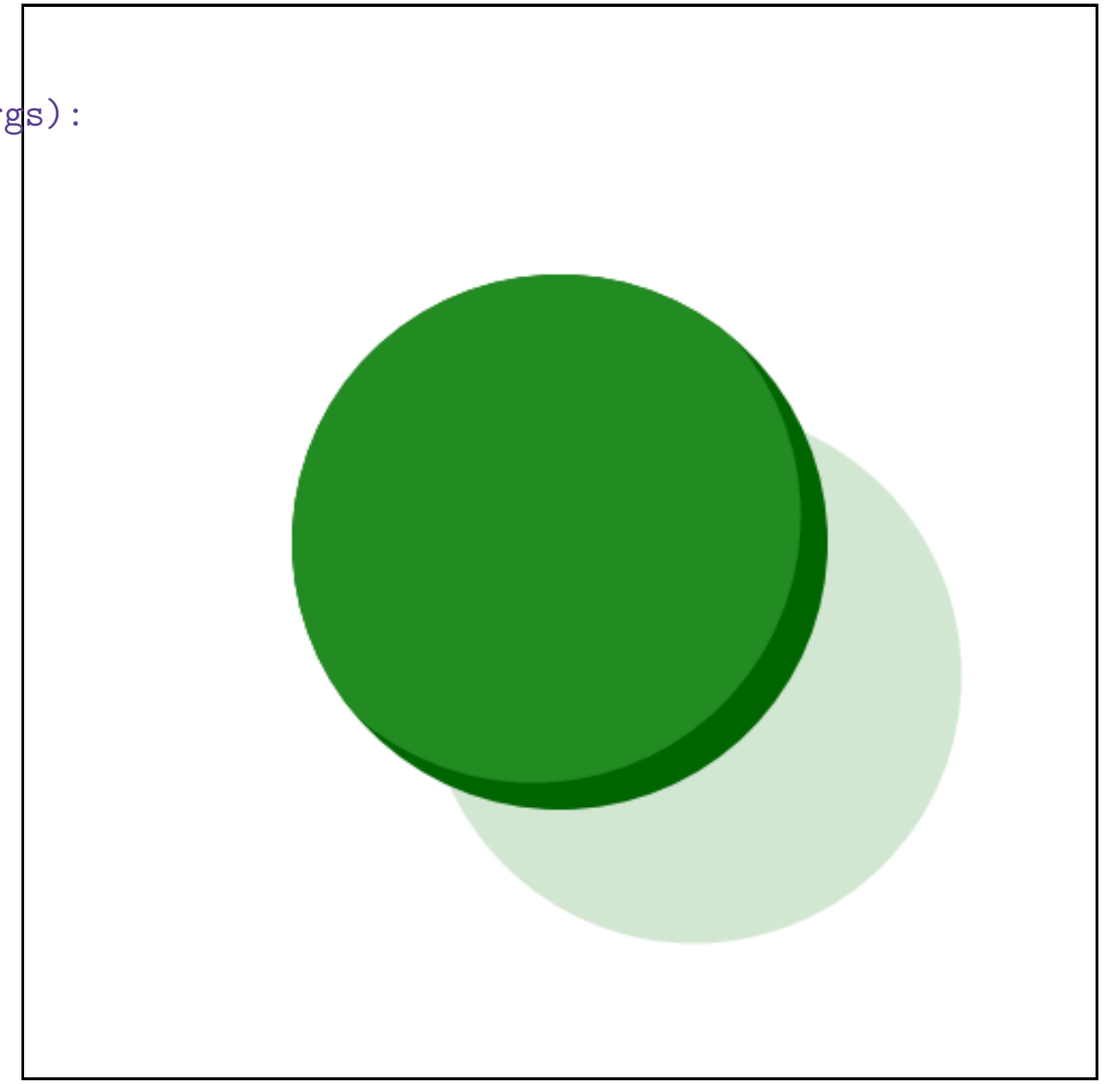


3D effect

```
    def add_circle(self, xy=(0, 0), radius=1, *args, **kwargs):
        return self.ax.add_patch(Circle(
            xy=xy,
            radius=radius,
            *args,
            **kwargs,
        ))



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary(2)
    sphere = vis.add_circle(color='darkgreen')
    vis.new_frame()
```



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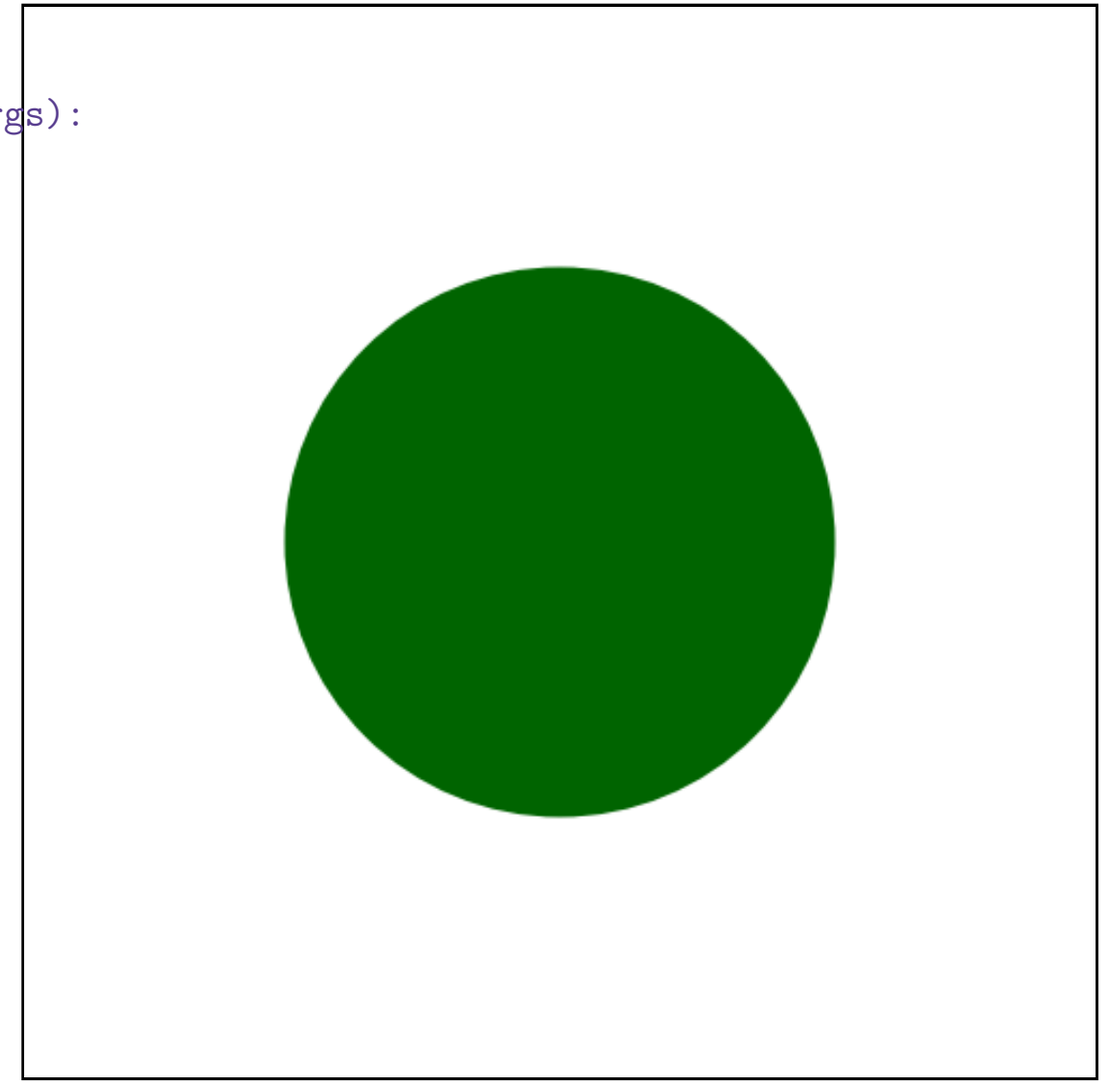
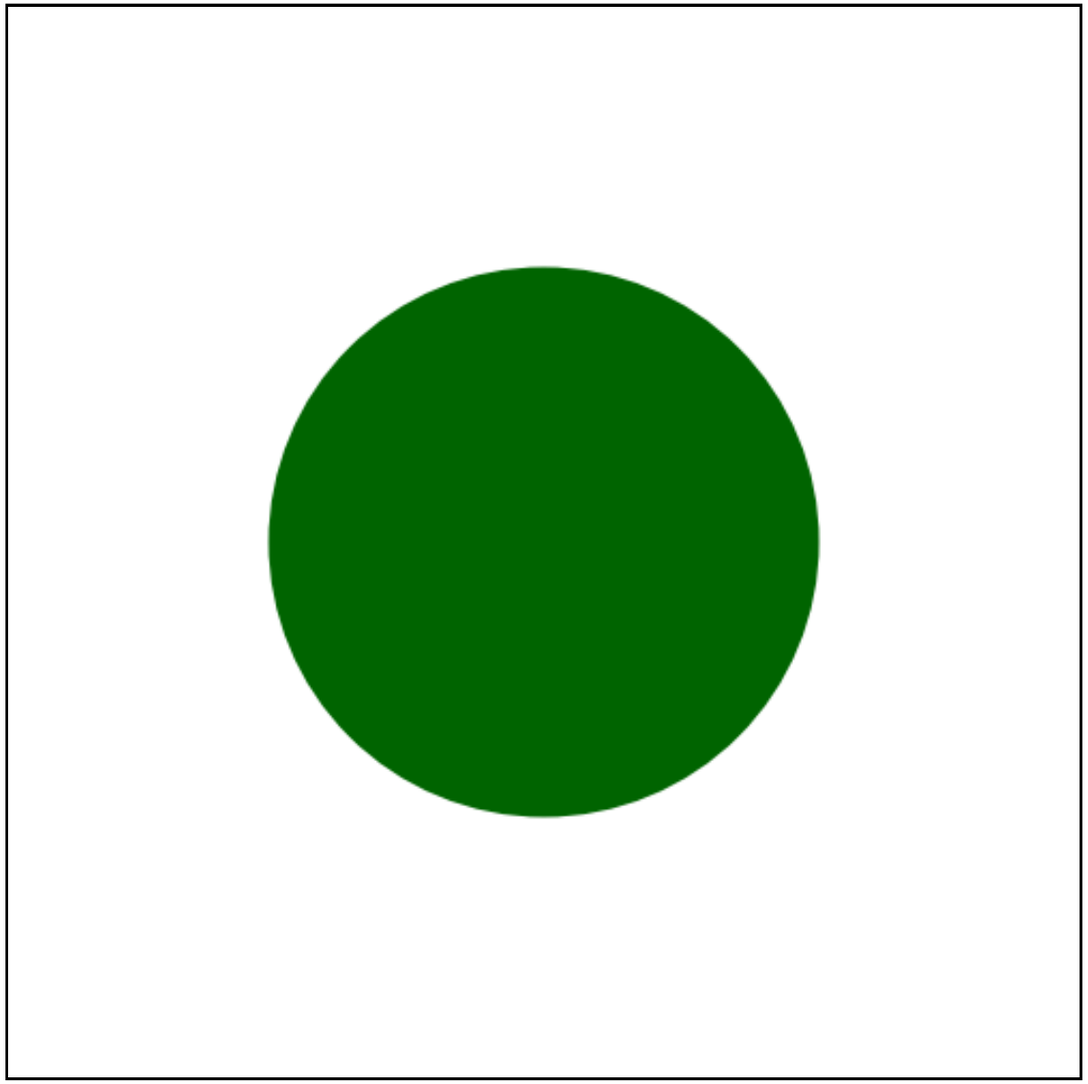


3D effect

```
side_shift = 0.1
light = vis.add_circle(
    xy=(-side_shift, side_shift),
    color='forestgreen',
)
vis.new_frame()
light.set_clip_path(sphere)
vis.new_frame()
sphere.set_lw(0)
light.set_lw(0)
vis.new_frame()
```



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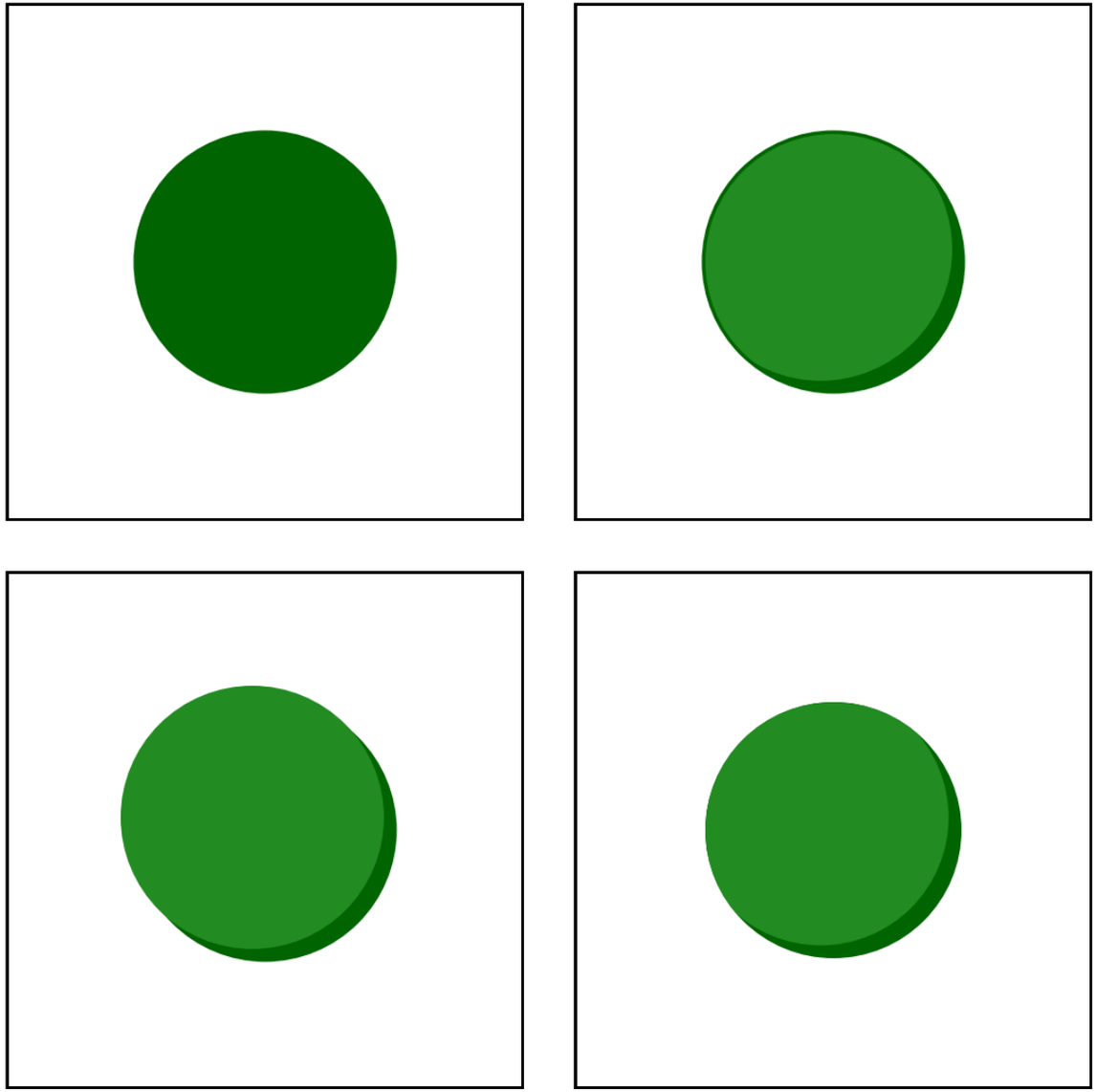
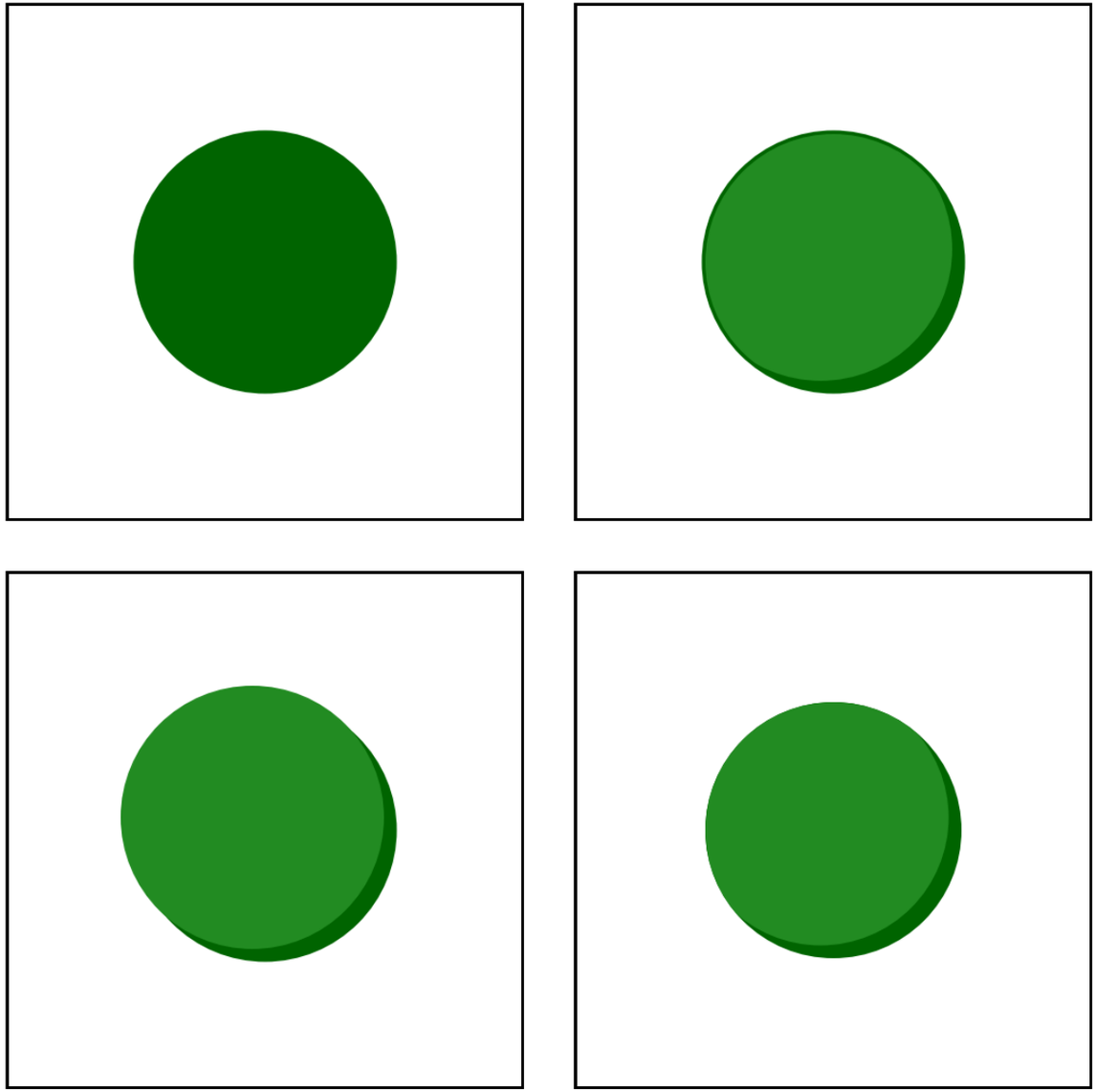


3D effect

```
shade = vis.add_circle(
xy=(0.5, -0.5),
    color='forestgreen',
    lw=0,
)
vis.new_frame()
shade.set_zorder(0)
vis.new_frame()
shade.set_alpha(0.2)
vis.new_frame()
```



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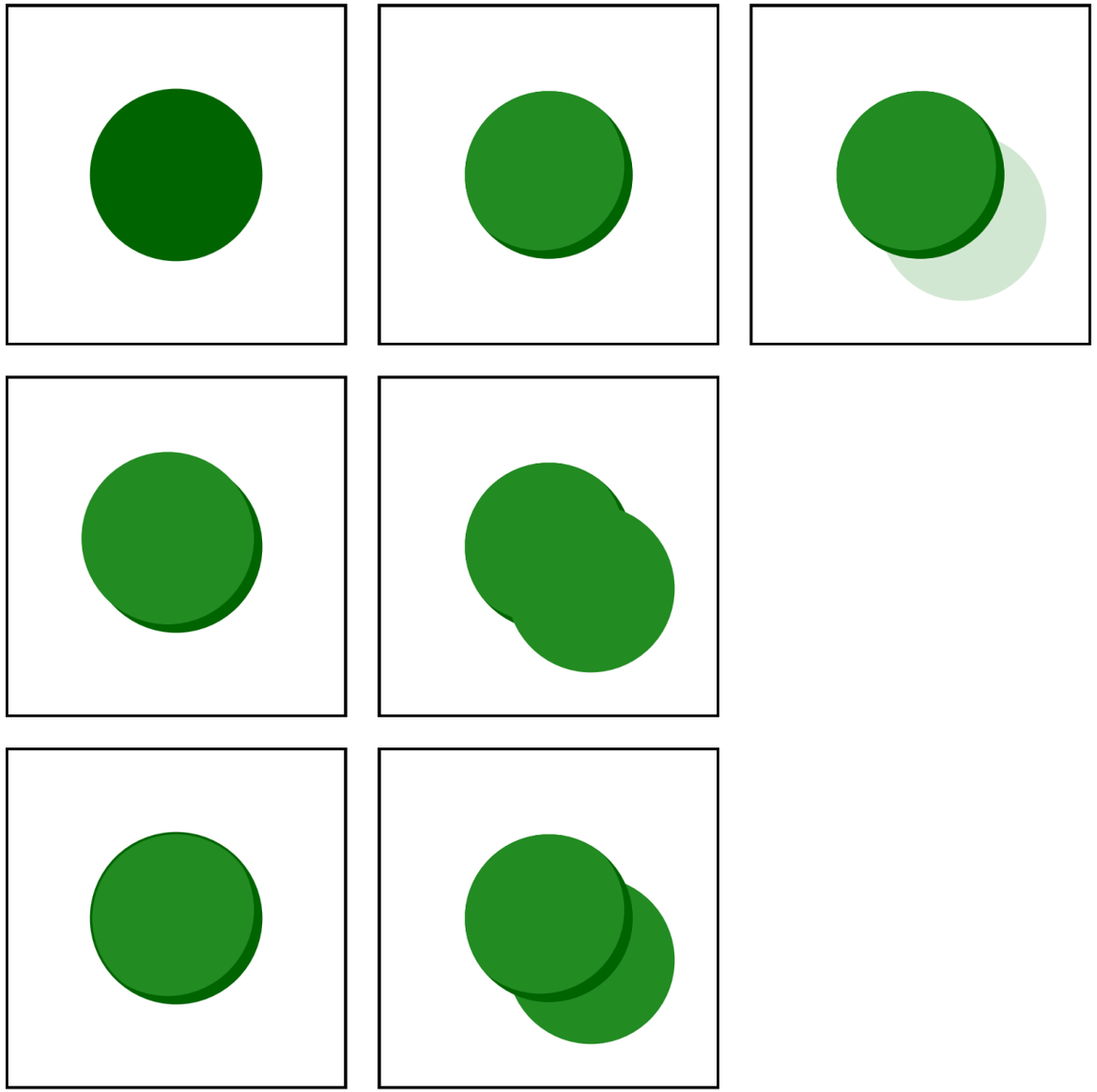

Creating a sphere

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).
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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

```
    def new_sphere(self,
            color='forestgreen',
            dark='darkgreen',
            alpha=0.2,
            **kwargs,
        ):
        sphere = {
            key :  vis.add_circle(color=color, lw=0)
            for key in ['main', 'light', 'shade']
        }
        sphere.update(**kwargs)
        sphere['main'].set_color(dark)
        sphere['shade'].set(alpha=alpha, zorder=0)
        return sphere
```

Creating a sphere

```
    def new_sphere(self,
            color='forestgreen', ..... the front color of the sphere
            dark='darkgreen',
            alpha=0.2,
            **kwargs,
        ):
        sphere = {
            key :  vis.add_circle(color=color, lw=0)
            for key in ['main', 'light', 'shade']
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        sphere['main'].set_color(dark)
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        return sphere
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Creating a sphere

```
    def new_sphere(self,
            color='forestgreen', ..... the front color of the sphere
            dark='darkgreen', ..... the color of the side shade of the sphere
            alpha=0.2,
            **kwargs,
        ):
        sphere = {
            key :  vis.add_circle(color=color, lw=0)
            for key in ['main', 'light', 'shade']
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        sphere.update(**kwargs)
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Creating a sphere

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

Creating a sphere

```
    def new_sphere(self,
            color='forestgreen', ..... the front color of the sphere
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            key :  vis.add_circle(color=color, lw=0) ..... each key leads to a circle patch
            for key in ['main', 'light', 'shade'] ..... the sphere is composed of three circles: main, light, and shade
        }
        sphere.update(**kwargs) ..... adds the input of the function as items of the dictionnary sphere
        sphere['main'].set_color(dark)
        sphere['shade'].set(alpha=alpha, zorder=0)
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Creating a sphere

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        sphere = {
            key :  vis.add_circle(color=color, lw=0) ..... each key leads to a circle patch
            for key in ['main', 'light', 'shade'] ..... the sphere is composed of three circles: main, light, and shade
        }
        sphere.update(**kwargs) ..... adds the input of the function as items of the dictionnary sphere
        sphere['main'].set_color(dark) ..... the main sphere is the background and darker one
        sphere['shade'].set(alpha=alpha, zorder=0)
        return sphere
```

Creating a sphere

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    def new_sphere(self,
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            for key in ['main', 'light', 'shade'] ..... the sphere is composed of three circles: main, light, and shade
        }
        sphere.update(**kwargs) ..... adds the input of the function as items of the dictionnary sphere
        sphere['main'].set_color(dark) ..... the main sphere is the background and darker one
        sphere['shade'].set(alpha=alpha, zorder=0) ..... the shade sphere is the one on the floor
        return sphere
```

Creating a sphere

```
    def update_sphere(self, main, light, shade,
            xy=(0, 0),
            radius=1,
            height=0,
            shift=(0.4, -0.8),
            side=0.15,
            shadow=0.5,
        ):
        xy = np.array(xy)
        shift = np.array(shift)
        for circle in [main, light, shade]:
            circle.set_radius(radius)
        main.set_center(xy + np.array([0, height]))
        light.set_center(xy - radius*side*shift + np.array([0, height]))
        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
        shade.set_center(xy + shade_shift*shift)
        light.set_clip_path(main)
```

Creating a sphere

```
    def update_sphere(self, main, light, shade, ..... the three circles of the sphere
            xy=(0, 0),
            radius=1,
            height=0,
            shift=(0.4, -0.8),
            side=0.15,
            shadow=0.5,
        ):
        xy = np.array(xy)
        shift = np.array(shift)
        for circle in [main, light, shade]:
            circle.set_radius(radius)
        main.set_center(xy + np.array([0, height]))
        light.set_center(xy - radius*side*shift + np.array([0, height]))
        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
        shade.set_center(xy + shade_shift*shift)
        light.set_clip_path(main)
```

Creating a sphere

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            xy=(0, 0), ..... the planar position of the sphere
            radius=1,
            height=0,
            shift=(0.4, -0.8),
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        ):
        xy = np.array(xy)
        shift = np.array(shift)
        for circle in [main, light, shade]:
            circle.set_radius(radius)
        main.set_center(xy + np.array([0, height])) ..... main is vertically shifted by height from xy
        light.set_center(xy - radius*side*shift + np.array([0, height]))
        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
        shade.set_center(xy + shade_shift*shift)
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```

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        ):
        xy = np.array(xy)
        shift = np.array(shift)
        for circle in [main, light, shade]:
            circle.set_radius(radius)
        main.set_center(xy + np.array([0, height])) ..... main is vertically shifted by height from xy
        light.set_center(xy - radius*side*shift + np.array([0, height])) ..... light is shifted from main using shift
        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
        shade.set_center(xy + shade_shift*shift)
        light.set_clip_path(main)
```

Creating a sphere

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        xy = np.array(xy)
        shift = np.array(shift)
        for circle in [main, light, shade]:
            circle.set_radius(radius)
        main.set_center(xy + np.array([0, height])) ..... main is vertically shifted by height from xy
        light.set_center(xy - radius*side*shift + np.array([0, height])) ..... light is shifted from main using shift
        shade_shift = height*shadow + radius/np.sum(shift**2)**0.5
        shade.set_center(xy + shade_shift*shift) ..... shade is shifted from xy using shift
        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
```

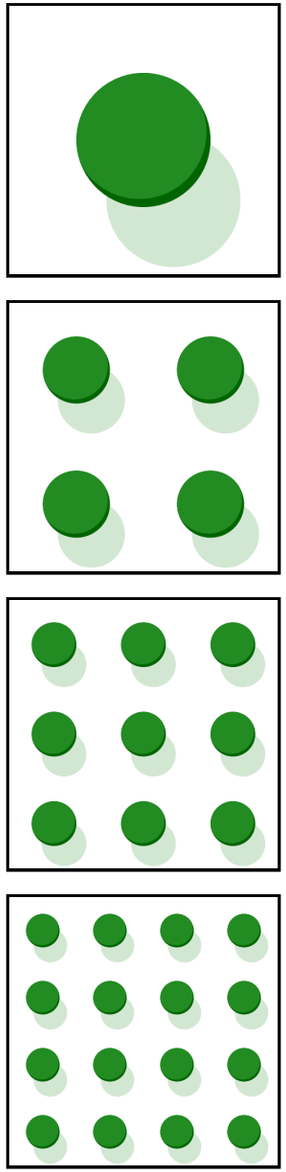
Creating spheres

Creating spheres

Q6: Create a custom number of spheres.

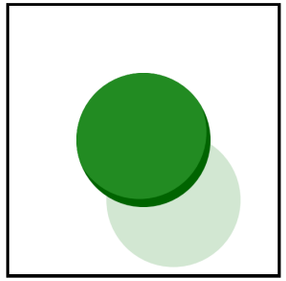
Creating spheres

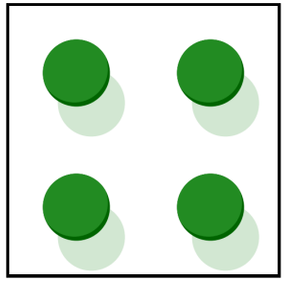
Q6: Create a custom number of spheres.

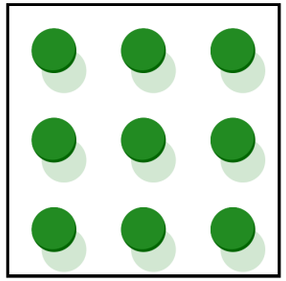


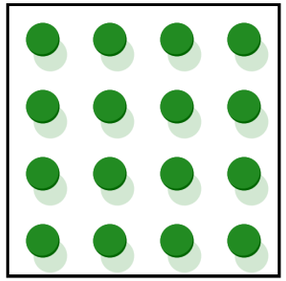
Creating spheres

```
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)
```



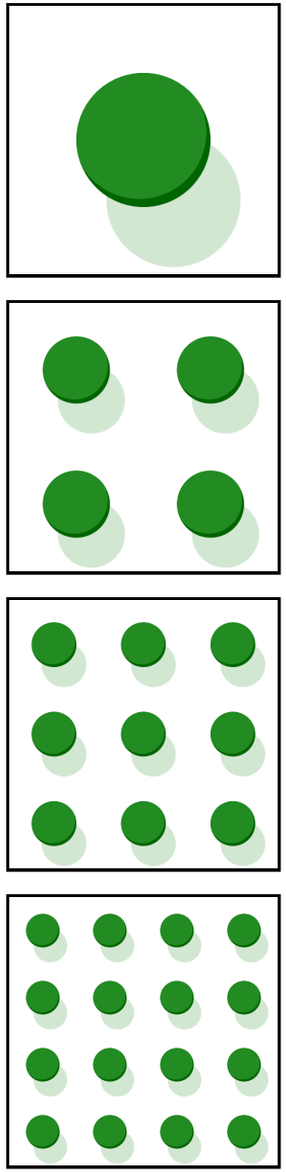






Creating spheres

```
if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    for n in range(1, 5):
        vis.make_spheres(n)
        vis.new_frame()
        for sphere in vis.spheres:
            sphere['main'].set_visible(False)
            sphere['light'].set_visible(False)
            sphere['shade'].set_visible(False)
```



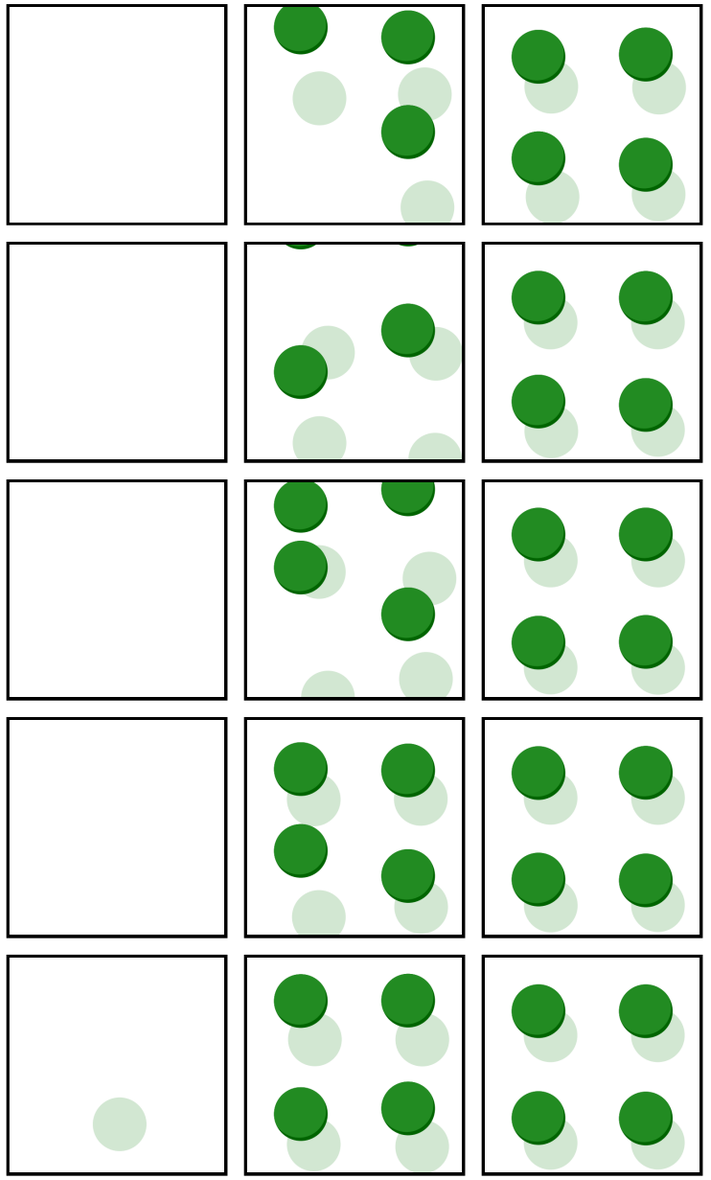
Dropping spheres

Dropping spheres

Q7: Create dropping spheres.

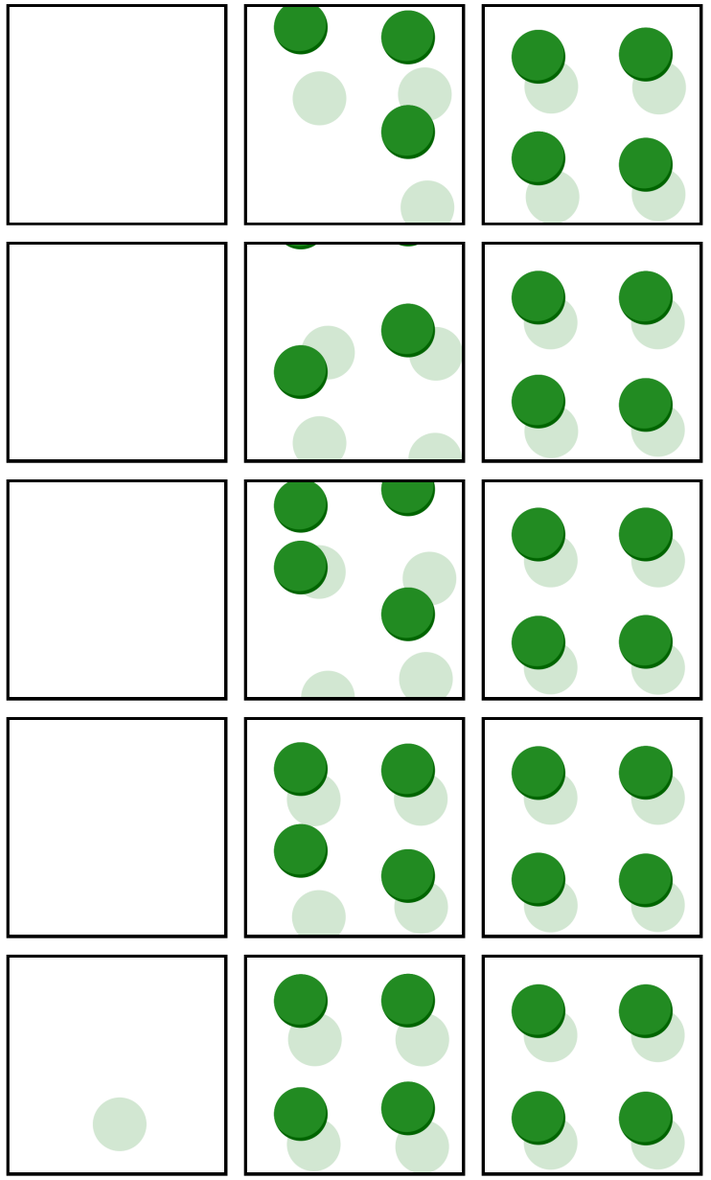
Dropping spheres

Q7: Create dropping spheres.



Dropping spheres

```
    def get_height(self,
            index=0,
            height_spread=1,
            height_period=0.5,
            height_drop=0.25,
            max_height=4.5,
        ):
        if not hasattr(self, 'height_shifts'):
            self.height_shifts = np.random.rand(len(self.spheres))
        shifts = index - self.fps*height_spread*self.height_shifts
        shifts = shifts*(shifts >= 0)
        flucts = np.abs(np.cos(np.pi*shifts/self.fps/height_period))
        heights = np.exp(-shifts/self.fps/height_drop)
        return max_height*flucts*heights
```

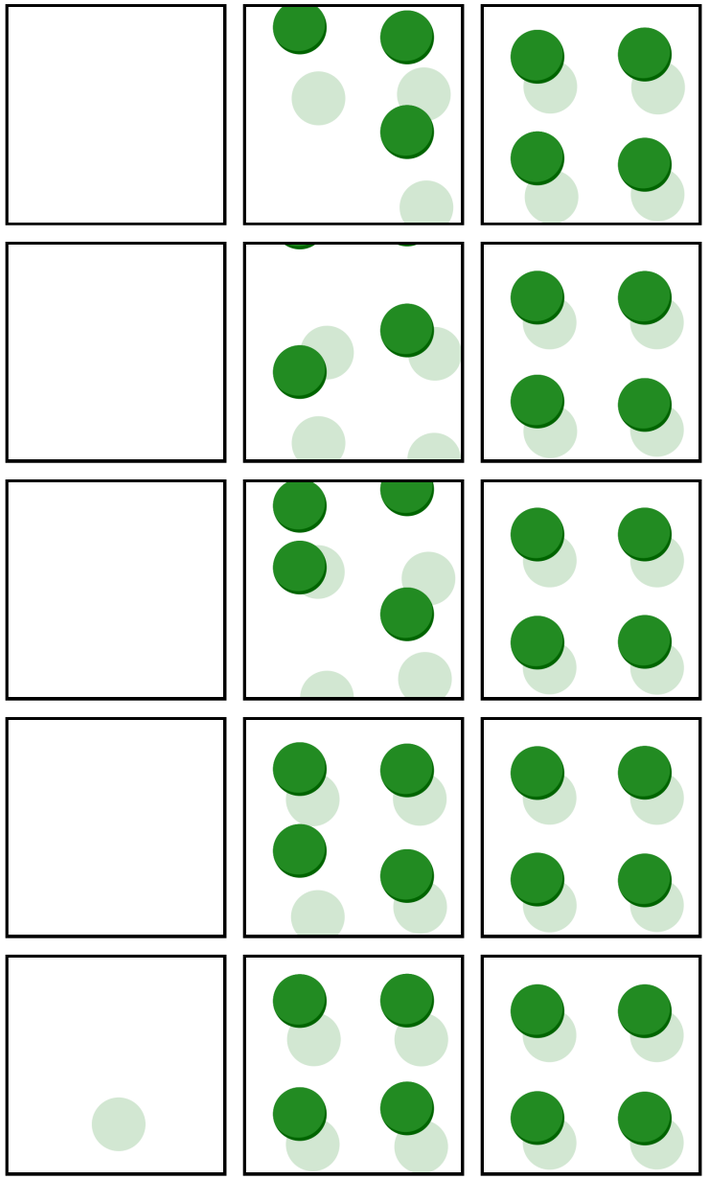


Dropping spheres

```
    def drop_spheres(self, duration, *args, **kwargs):
        for index in range(self.duration_to_number(duration)):
            heights = self.get_height(index, *args, **kwargs)
            for sphere, height in zip(self.spheres, heights):
                self.update_sphere(height=height, **sphere)
            self.new_frame()



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.make_spheres(2)
    vis.drop_spheres(0.5,
        height_spread=0.2,
        height_period=0.1,
        height_drop=0.05,
    )
```



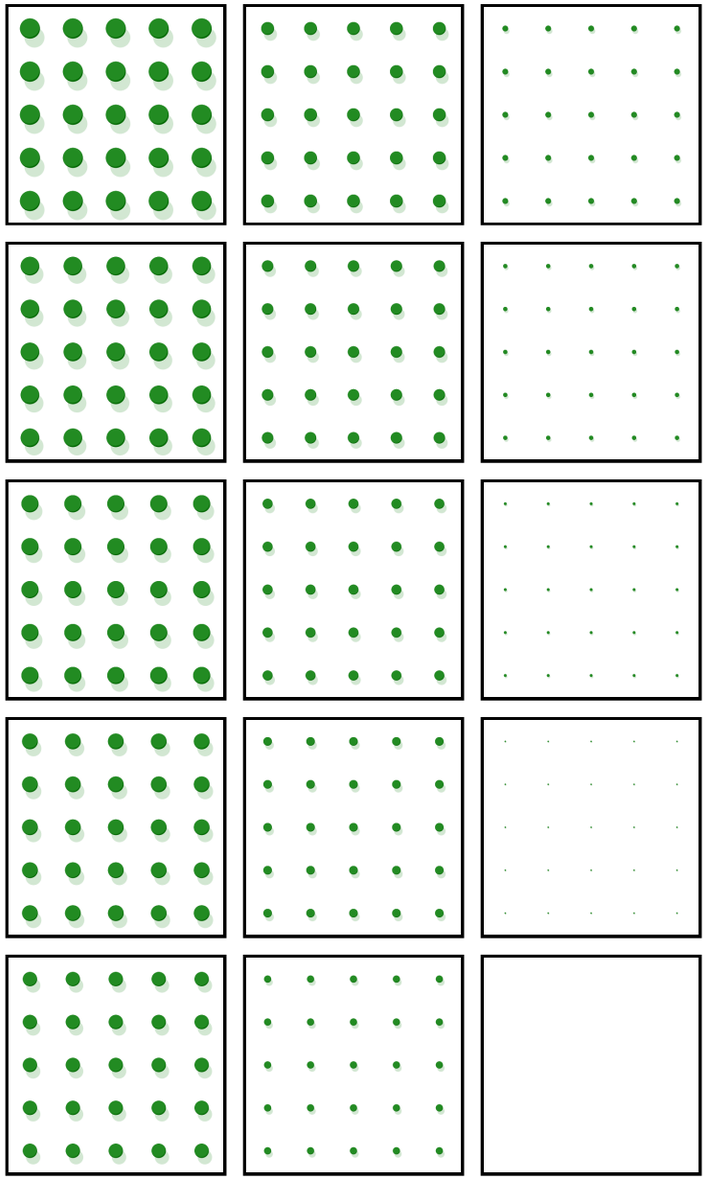
Schrinking spheres

Schrinking spheres

Q8: Create schrinking spheres.

Schrinking spheres

Q8: Create schrinking spheres.



Schrinking spheres

```
    def schrink_spheres(self, duration):
        n_steps = self.duration_to_number(duration)
        radius = self.spheres[0]['main'].get_radius()
        for index in range(n_steps):
            ratio = 1 - (1 + index)/n_steps
            for sphere in self.spheres:
                sphere['radius'] = ratio*radius
                self.update_sphere(**sphere)
            self.new_frame()


if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.make_spheres(5)
    vis.schrink_spheres(0.5)
```

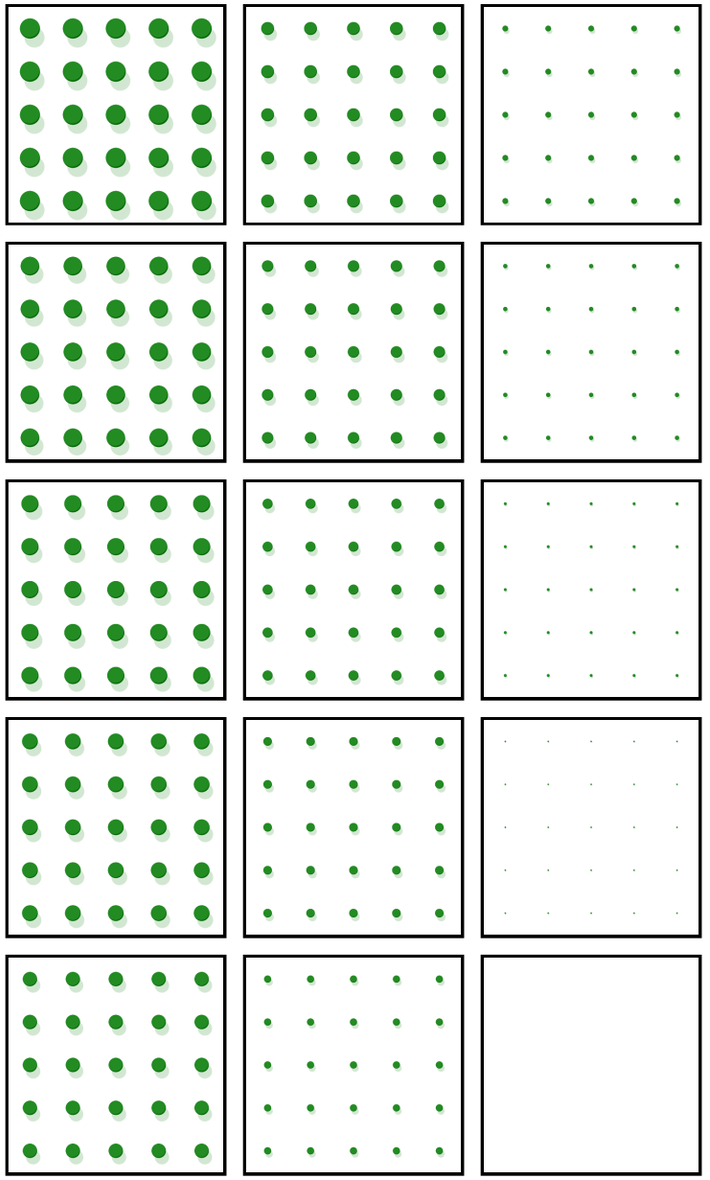


Table of contents

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

Drawings

Drawings

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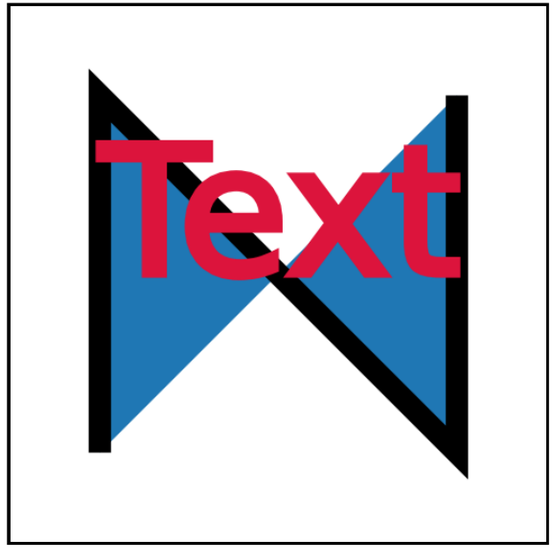

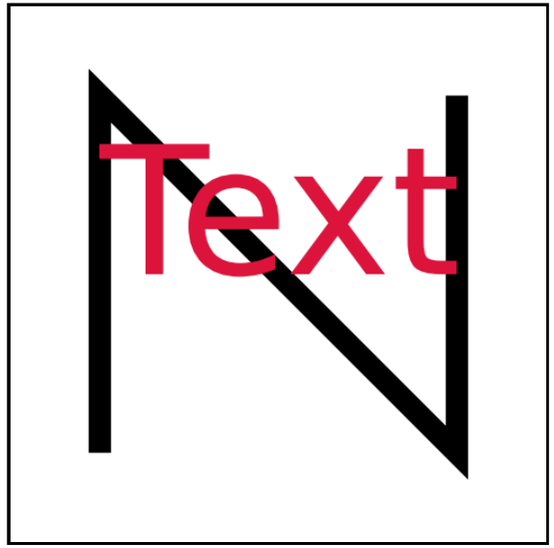

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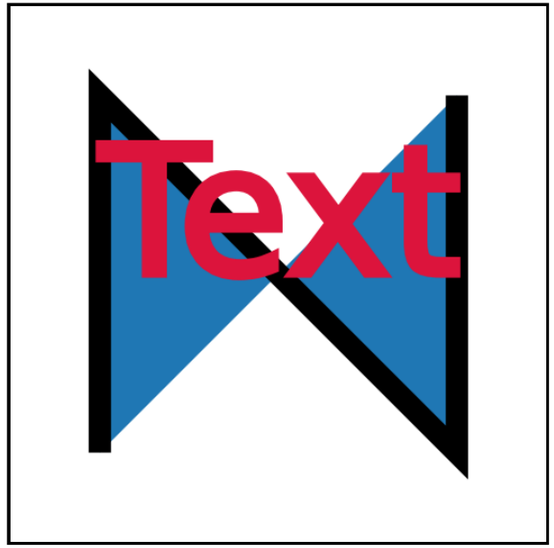
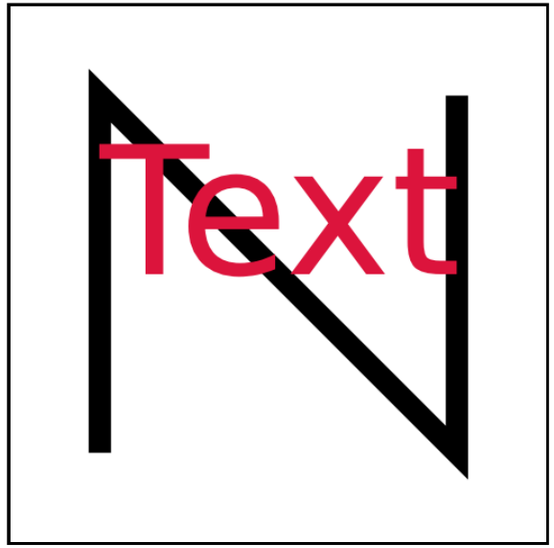
Q9: Create these two images.





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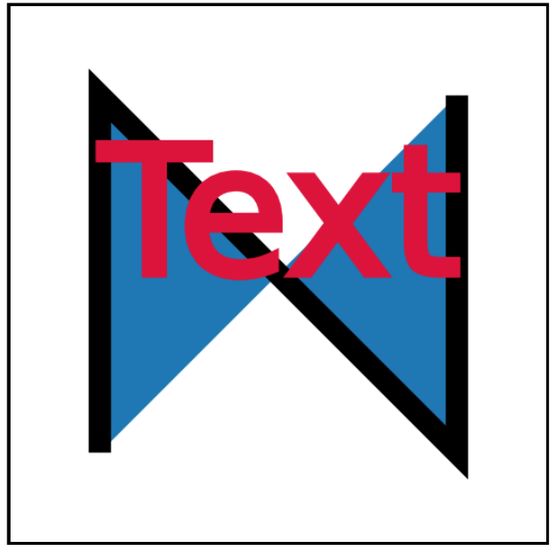

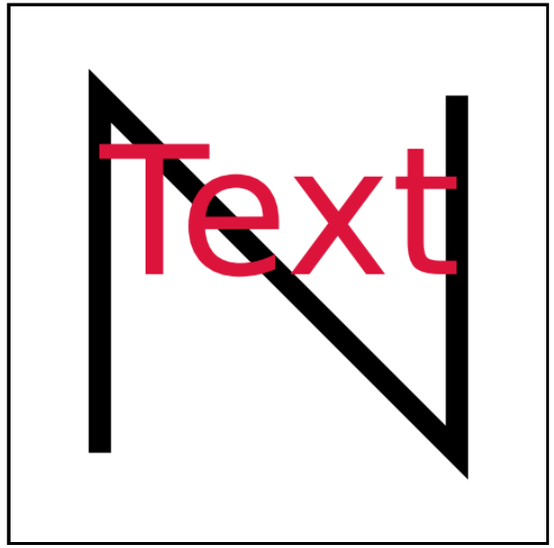

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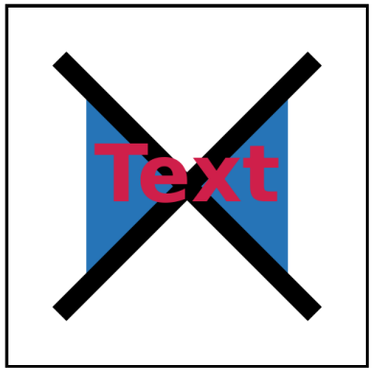

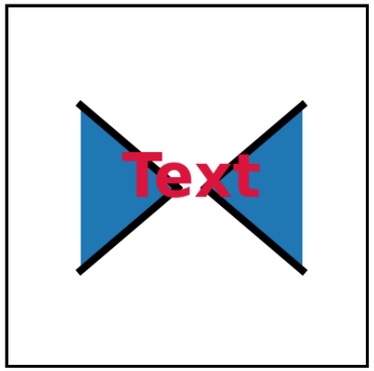

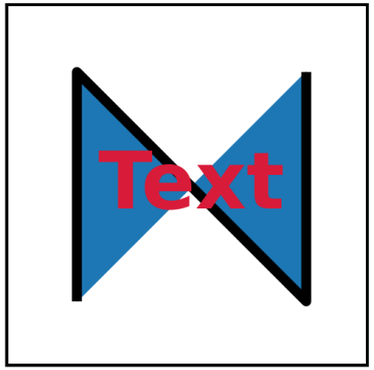

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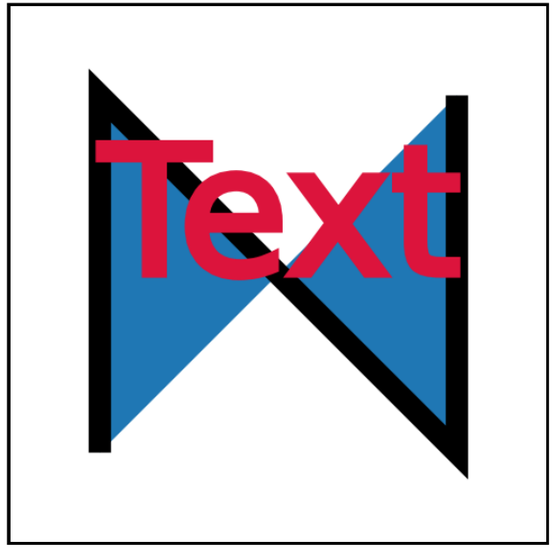

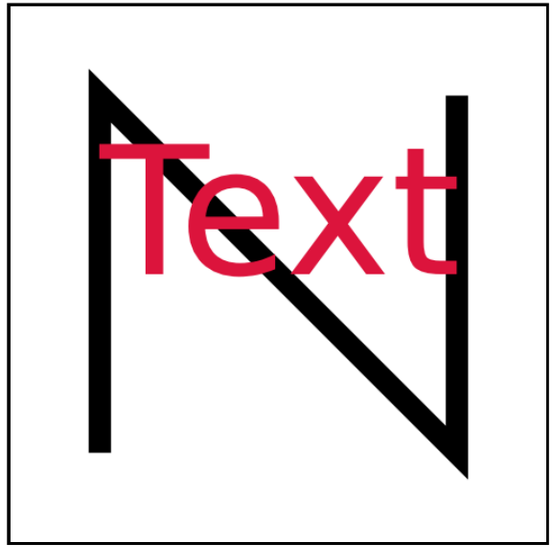

Drawings

```
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)]),
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183.     vis.new_frame()
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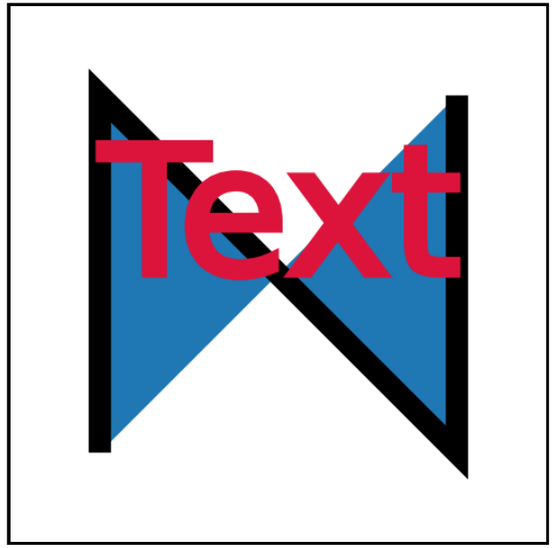

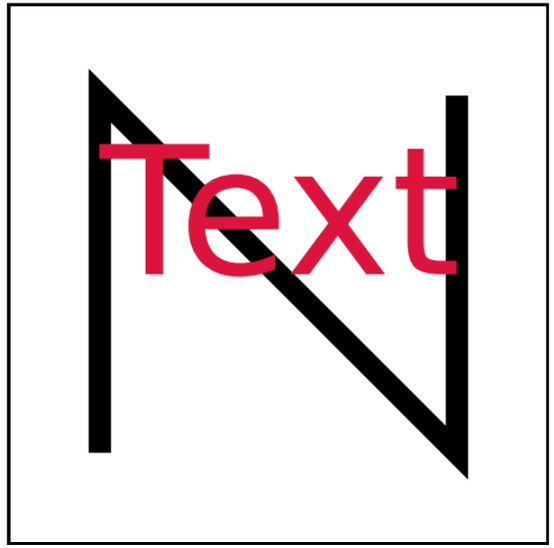

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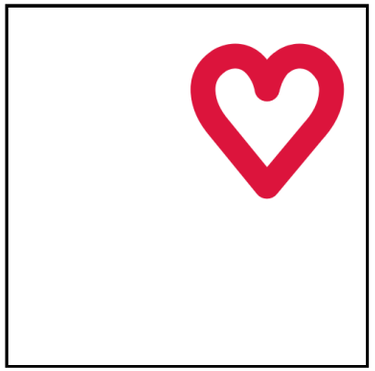

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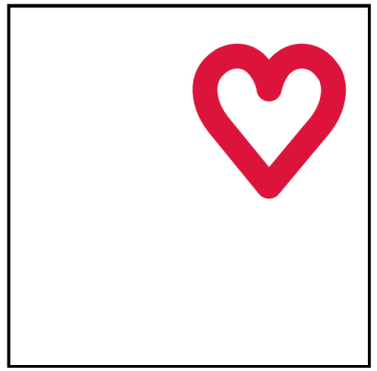

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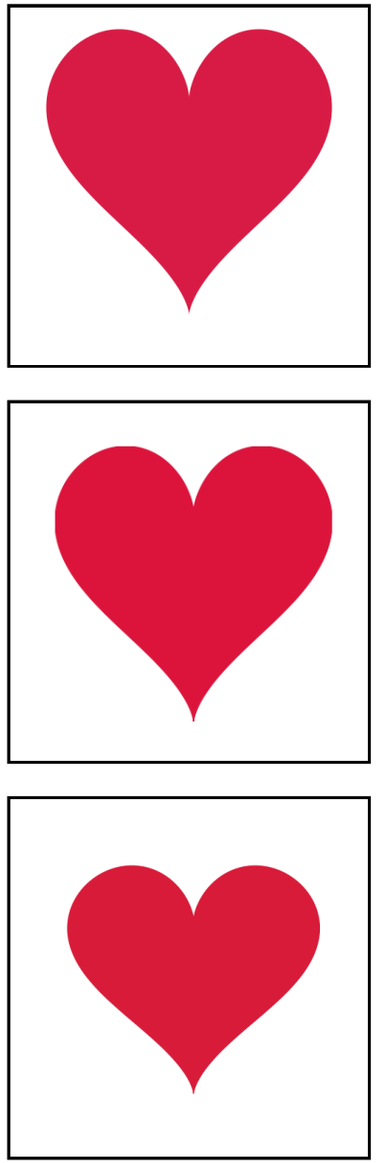

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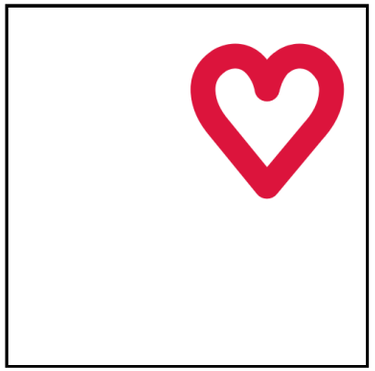
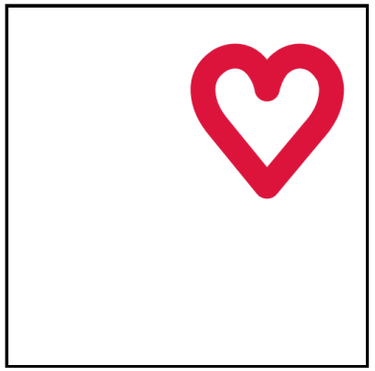


Drawings

```
if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    path = TextPath(xy=(0, 0), s='\u2665', size=1)
    patch = vis.ax.add_patch(PathPatch(path=path))
    patch.set(lw=5, color='crimson', fill=False, joinstyle='round')
    vis.new_frame()
    bbox = path.get_extents()
    vertices = (path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size
    path = Path(vertices=vertices, codes=path.codes)
    patch.set(path=path)
    vis.new_frame()
    vis.set_boundary(0.5)
    patch.set(lw=0, fill=True)
    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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```
    def add_heart(self, size=1, *args, **kwargs):
        path = TextPath(xy=(0, 0), s='\u2665', size=1)
        bbox = path.get_extents()
        vertices = size*(path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size
        path = Path(vertices=vertices, codes=path.codes)
        self.heart = vis.ax.add_patch(PathPatch(path=path, *args, **kwargs))
```

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        bbox = path.get_extents()
        vertices = size*(path.vertices - (bbox.p0 + bbox.p1)/2)/bbox.size ........ resizes the vertices around the origin
        path = Path(vertices=vertices, codes=path.codes)
        self.heart = vis.ax.add_patch(PathPatch(path=path, *args, **kwargs))
```

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Q11: Create the drawn heart effect.

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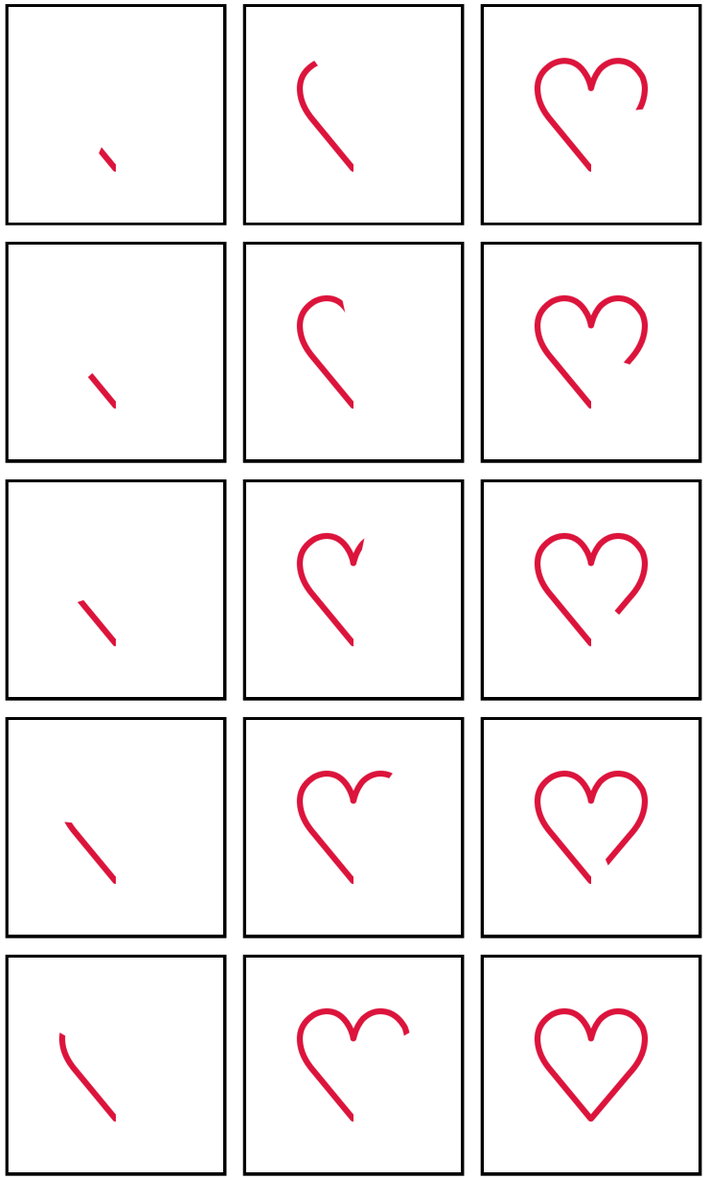
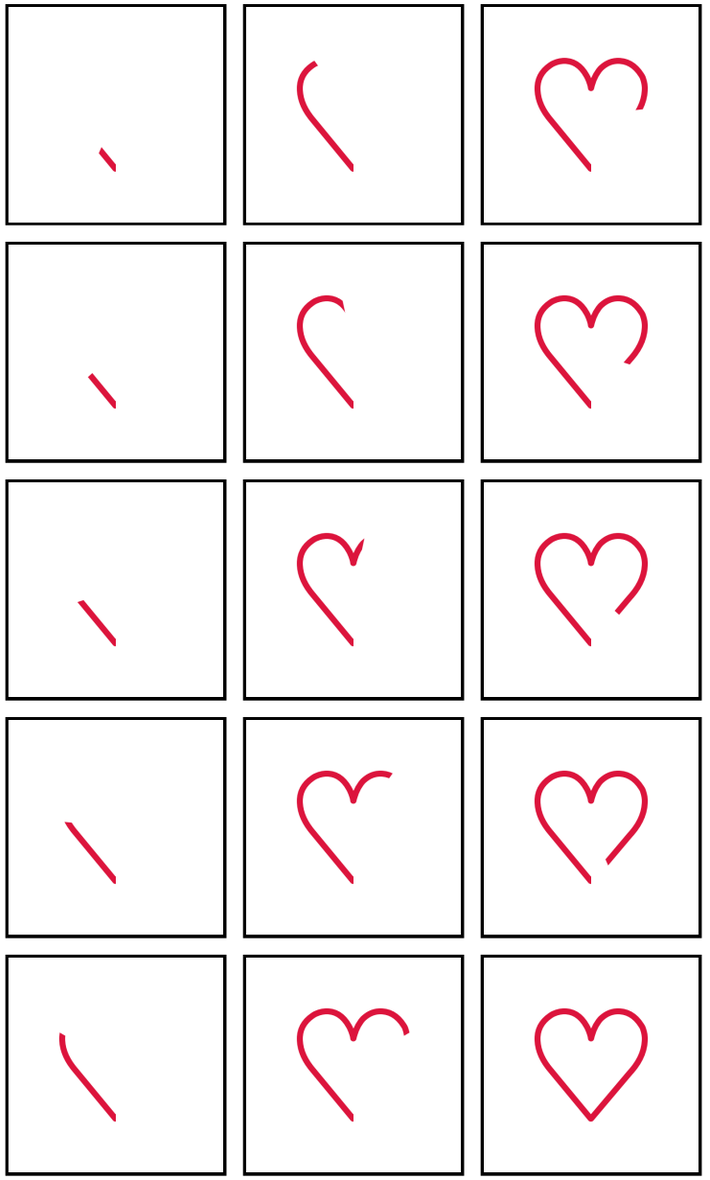


Drawing a heart

```
    def draw_heart(self, duration, *args, **kwargs):
        n_steps = self.duration_to_number(duration)
        wedge = self.ax.add_patch(
            Wedge((0, 0), 1, 270, 270, visible=False)
        )
        self.heart.set_clip_path(wedge)
        for index in range(n_steps):
            wedge.set_theta1(270 - 360*(1 + index)/n_steps)
            self.new_frame()



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.add_heart(ec='crimson', lw=2, fill=False, joinstyle='round')
    vis.draw_heart(0.5)
```



Zooming effect

Zooming effect

Q12: Create a zooming and fading effect.

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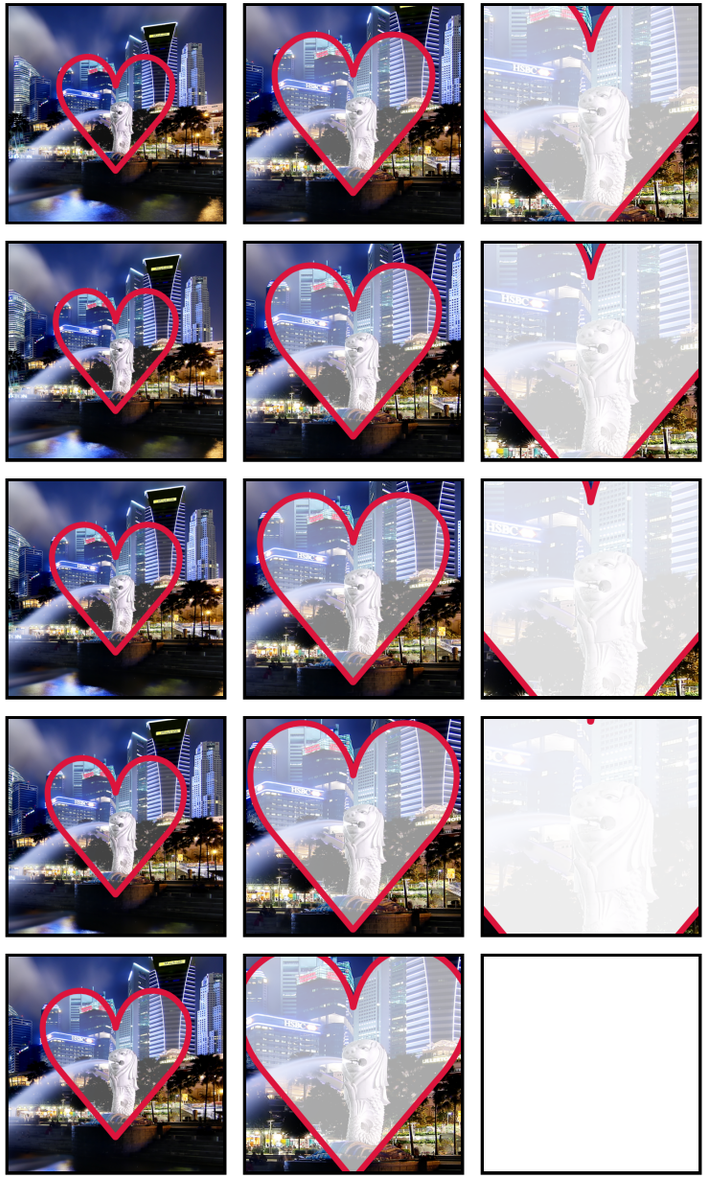

Zooming effect

```
    def zoom_in(self, duration, zoom=0.5):
        n_steps = self.duration_to_number(duration)
        for index in range(n_steps):
            ratio = (1 + index)/n_steps
            self.heart.set_fc((1, 1, 1, ratio))
            self.set_boundary(1 - ratio*(1 - zoom))
            self.new_frame()



if __name__ == '__main__':
    vis = Visual.square(dpi=500)
    vis.set_boundary()
    vis.add_image(filename='singapore.jpg', shift=0.4)
    vis.add_heart(ec='crimson', lw=2, joinstyle='round')
    vis.zoom_in(0.5, zoom=0.2)
```

Table of contents

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

Final video

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Q13: Combine all functions to create the original video.

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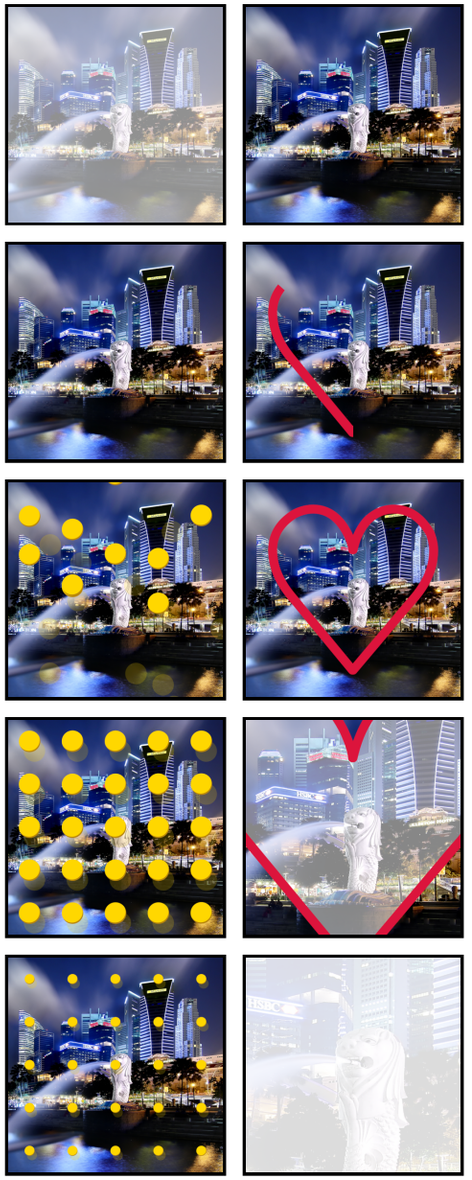
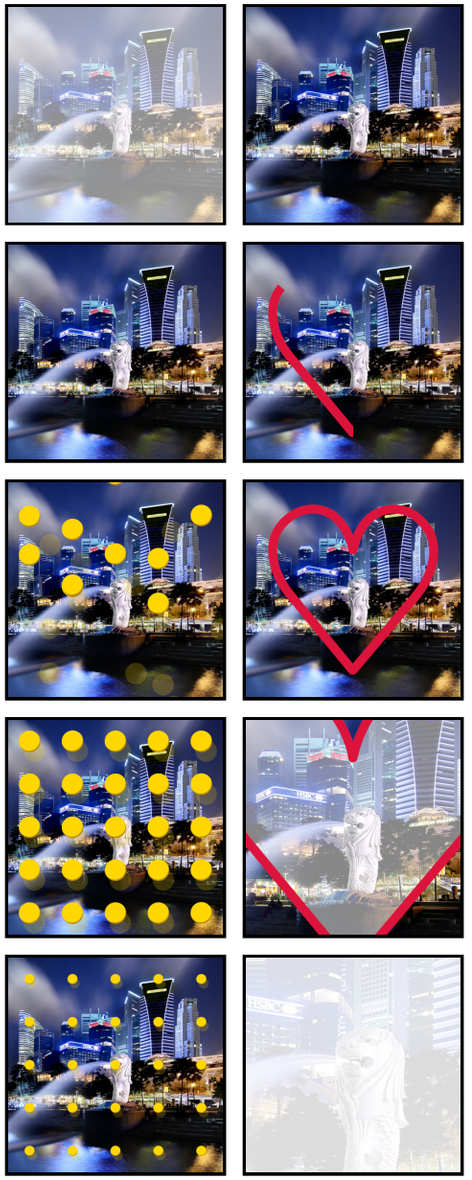


Final video

```
if __name__ == '__main__':
    vis = Visual.square(dpi=1000)
    vis.set_boundary()
    vis.wait(duration=0.5)
    vis.add_image(filename='singapore.jpg', shift=0.4)
    vis.image_appear(duration=1)
    vis.wait(duration=0.5)
    vis.make_spheres(number=5, color='gold', dark='darkgoldenrod')
    vis.drop_spheres(duration=3)
    vis.schrink_spheres(duration=1)
    vis.wait(duration=0.5)
    vis.add_heart(size=1.5)
    vis.heart.set(ec='crimson', fc=4*[0], lw=3, joinstyle='round')
    vis.draw_heart(duration=1)
    vis.wait(duration=0.5)
    vis.zoom_in(duration=1, zoom=0.2)
    vis.make_video()
```



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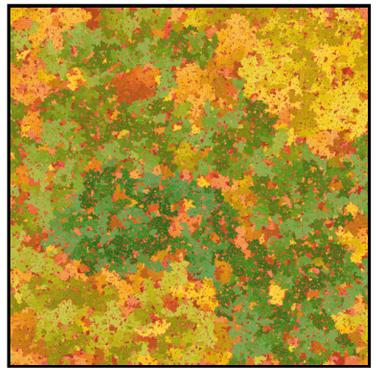

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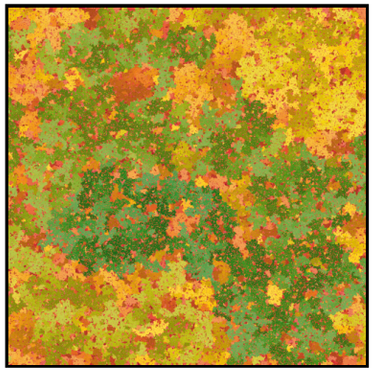

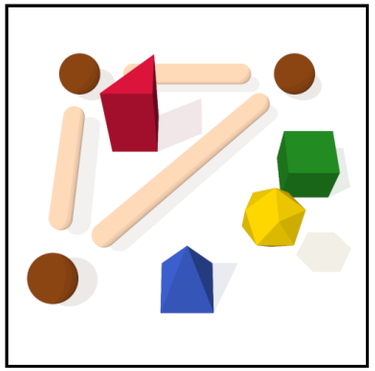

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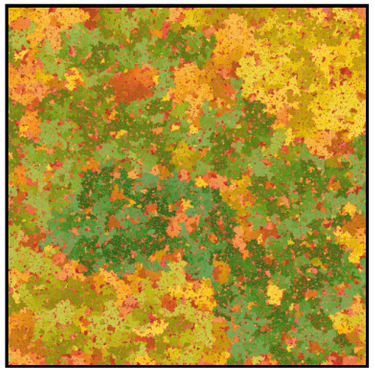

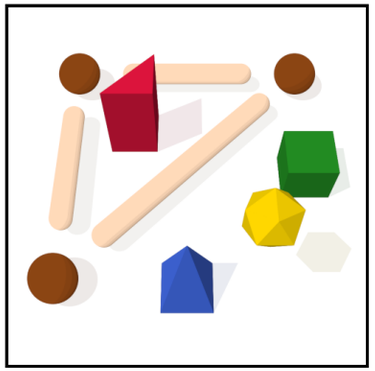

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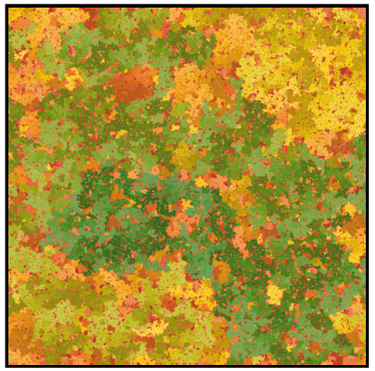

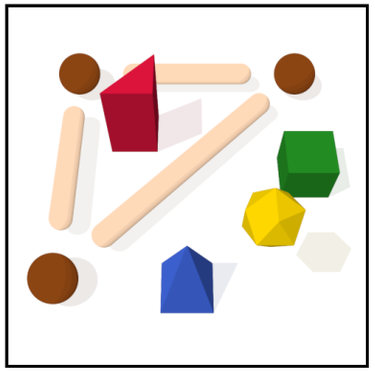

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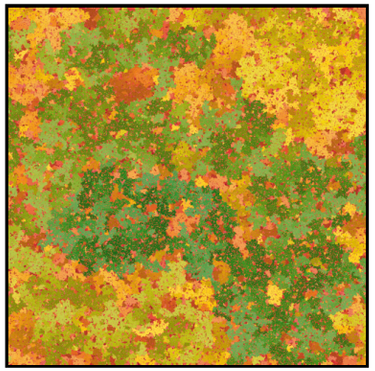

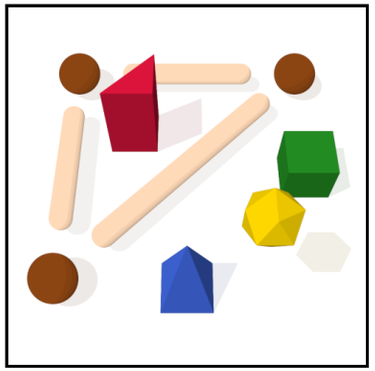

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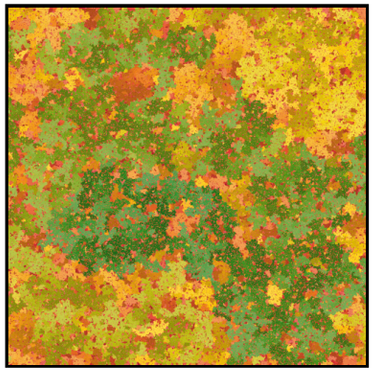

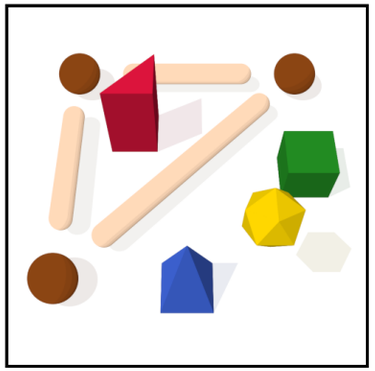

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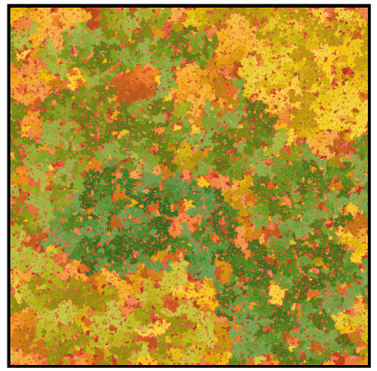
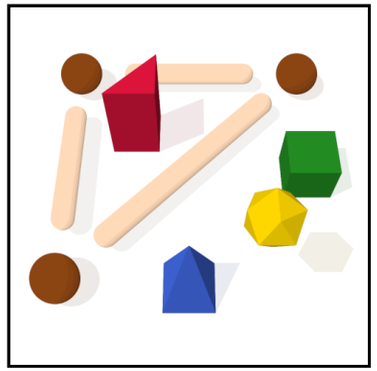
And so much more still remain to be discovered and applied!





Thank you!
Thank you!
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Maybank
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FULLERTON
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