

# DeepTrack - Example 4 - Tracking multiple particles

March 8, 2019

## Example 4: Tracking of one of two kinds of multiple particles with DeepTrack 1.0

Example code to use DeepTrack to track one of two kinds of multiple particles. See also Figure 4a.

DeepTrack 1.0

Digital Video Microscopy enhanced with Deep Learning version 1.0

30 November 2018 © Saga Helgadóttir, Aykut Argun & Giovanni Volpe

[Soft Matter Lab](#)

### 1. INITIALIZATION

```
In [1]: import deeptrack
```

### 2. PLAY VIDEO TO BE TRACKED

The video to be tracked is played.

Video file: DeepTrack - Example 4 - Brownian particles + bacteria.mp4

Note that the video file must be in the same folder as this notebook.

```
In [2]: %%HTML
```

```
<video width="400" height="400" controls>
<source src="DeepTrack - Example 4 - Brownian particles + bacteria.mp4" type="video/mp4"
</video>
```

```
<IPython.core.display.HTML object>
```

### 3. CHECK IMAGE GENERATION ROUTINE

Here, we simulate images of multiple particles similar to those we want to track.

Comments:

1. The `image_parameters_function` is a lambda function that determines the kind of particle images for which the deep learning network will be trained. Tuning its parameters is the simplest way to improve the tracking performance.
2. The `image_generator` is a lambda function that works as image generator. It does not need to be changed in most cases.
3. The parameter `number_of_images_to_show` determines the number of sample images that are shown.
4. The red symbol superimposed to the images represents the ground truth particle position.

## BACTERIA

```
In [3]: ### Define image properties
        %matplotlib inline
        from numpy.random import randint, uniform, normal, choice
        from math import pi

        particle_number = 4
        first_particle_range = 10
        other_particle_range = 25
        particle_distance = 10

        def get_image_parameters_optimized():
            (particles_center_x, particles_center_y) = deeptack.particle_positions(particle_number)
            image_parameters = {}

            image_parameters['Particle Center X List'] = particles_center_x
            image_parameters['Particle Center Y List'] = particles_center_y
            image_parameters['Particle Radius List'] = uniform(2.5, 4, particle_number)
            image_parameters['Particle Bessel Orders List'] = [[1, ],
                                                                [1, ],
                                                                [1, ],
                                                                [1, ]]
            image_parameters['Particle Intensities List'] = [[uniform(0.5, 0.7, 1), ],
                                                             [uniform(0.5, 0.7, 1), ],
                                                             [uniform(0.5, 0.7, 1), ],
                                                             [uniform(0.5, 0.7, 1), ]]

            image_parameters['Image Half-Size'] = 25
            image_parameters['Image Background Level'] = uniform(.2, .4)
            image_parameters['Signal to Noise Ratio'] = uniform(3,6)
            image_parameters['Gradient Intensity'] = uniform(0, 0.2)
            image_parameters['Gradient Direction'] = uniform(-pi, pi)
            image_parameters['Ellipsoid Orientation'] = uniform(-pi, pi, particle_number)
            image_parameters['Ellipticity'] = 1

            return image_parameters
```

```

image_parameters_function = lambda : get_image_parameters_optimized()

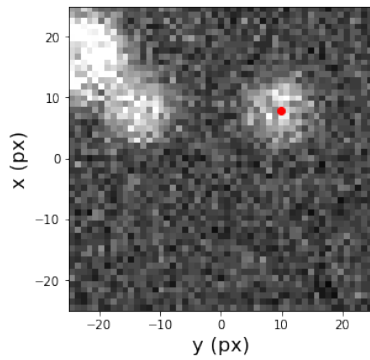
### Define image generator
image_generator = lambda : deeptack.get_image_generator(image_parameters_function)

### Show some examples of generated images
number_of_images_to_show = 10

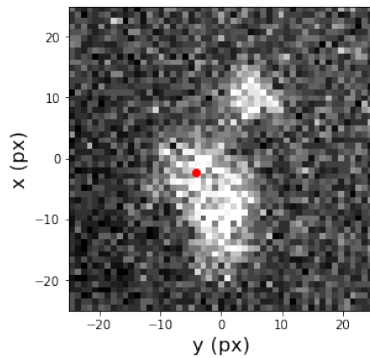
for image_number, image, image_parameters in image_generator():
    if image_number >= number_of_images_to_show:
        break

    deeptack.plot_sample_image(image, image_parameters)

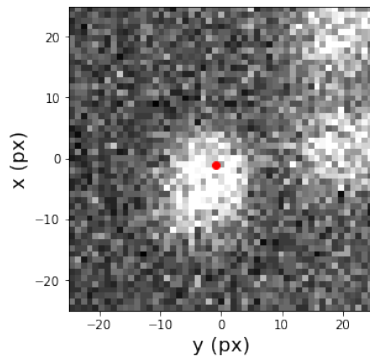
```



particle center x = 7.93 px  
 particle center y = 9.83 px  
 particle radius = 2.71 px  
 Bessel order = 1.00  
 particle intensity = 0.59  
 ellipsoidal\_orientation = -1.26  
 ellipticity = 1.00  
 image half size = 25.00 px  
 image background level = 0.28  
 signal to noise ratio = 5.85  
 gradient intensity = 0.01  
 gradient direction = 1.89

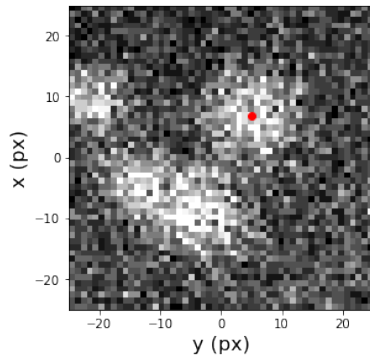


particle center x = -2.34 px  
 particle center y = -4.09 px  
 particle radius = 3.42 px  
 Bessel order = 1.00  
 particle intensity = 0.57  
 ellipsoidal\_orientation = -1.41  
 ellipticity = 1.00  
 image half size = 25.00 px  
 image background level = 0.25  
 signal to noise ratio = 3.95  
 gradient intensity = 0.19  
 gradient direction = 0.61



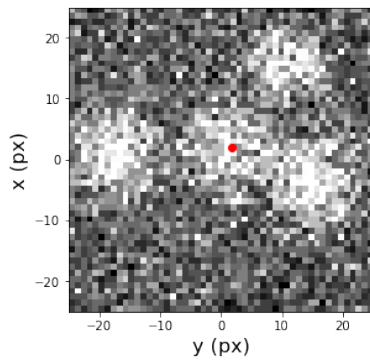
particle center x = -1.13 px  
 particle center y = -0.92 px  
 particle radius = 2.52 px  
 Bessel order = 1.00  
 particle intensity = 0.65  
 ellipsoidal\_orientation = -0.87  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.34  
 signal to noise ratio = 4.66  
 gradient intensity = 0.16  
 gradient direction = 0.17



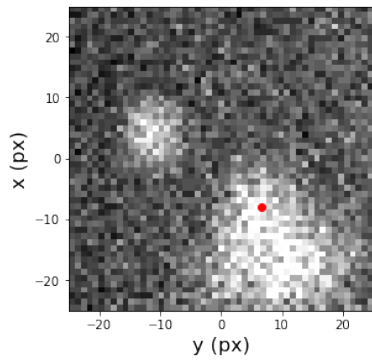
particle center x = 6.88 px  
 particle center y = 4.94 px  
 particle radius = 3.76 px  
 Bessel order = 1.00  
 particle intensity = 0.68  
 ellipsoidal\_orientation = -1.87  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.27  
 signal to noise ratio = 3.53  
 gradient intensity = 0.16  
 gradient direction = -1.13



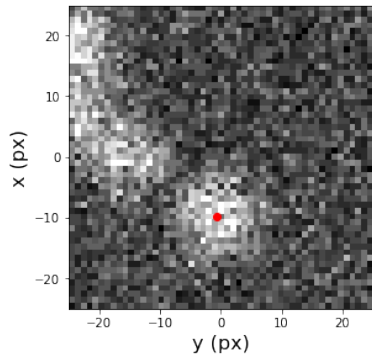
particle center x = 2.05 px  
 particle center y = 1.84 px  
 particle radius = 3.75 px  
 Bessel order = 1.00  
 particle intensity = 0.55  
 ellipsoidal\_orientation = 0.55  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.37  
 signal to noise ratio = 3.49  
 gradient intensity = 0.03  
 gradient direction = 1.87



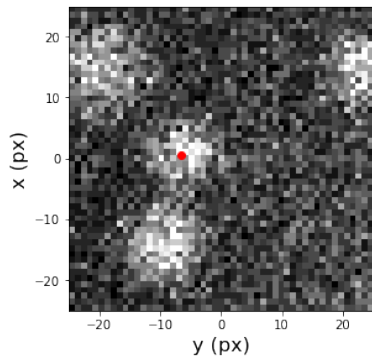
particle center x = -7.99 px  
 particle center y = 6.57 px  
 particle radius = 3.32 px  
 Bessel order = 1.00  
 particle intensity = 0.54  
 ellipsoidal\_orientation = -0.00  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.32  
 signal to noise ratio = 5.03  
 gradient intensity = 0.15  
 gradient direction = -0.23



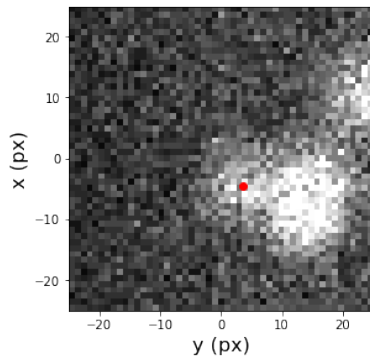
particle center x = -9.85 px  
 particle center y = -0.76 px  
 particle radius = 3.40 px  
 Bessel order = 1.00  
 particle intensity = 0.62  
 ellipsoidal\_orientation = -1.61  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.28  
 signal to noise ratio = 4.26  
 gradient intensity = 0.03  
 gradient direction = -0.58



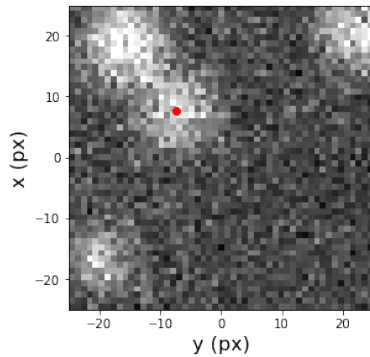
particle center x = 0.63 px  
 particle center y = -6.61 px  
 particle radius = 2.72 px  
 Bessel order = 1.00  
 particle intensity = 0.63  
 ellipsoidal\_orientation = -2.78  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.23  
 signal to noise ratio = 3.71  
 gradient intensity = 0.20  
 gradient direction = -0.43



particle center x = -4.59 px  
 particle center y = 3.50 px  
 particle radius = 3.21 px  
 Bessel order = 1.00  
 particle intensity = 0.51  
 ellipsoidal\_orientation = -0.16  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.26  
 signal to noise ratio = 5.12  
 gradient intensity = 0.14  
 gradient direction = 0.06



particle center x = 7.72 px  
 particle center y = -7.35 px  
 particle radius = 3.46 px  
 Bessel order = 1.00  
 particle intensity = 0.51  
 ellipsoidal\_orientation = 2.16  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.29  
 signal to noise ratio = 5.86  
 gradient intensity = 0.05  
 gradient direction = -2.87

## PARTICLES

In [4]: *### Define image properties*

```

%matplotlib inline
from numpy.random import randint, uniform, normal, choice
from math import pi

```

```

particle_number = 6
first_particle_range = 12.5
other_particle_range = 27.5
particle_distance = 50

```

```

def get_image_parameters_optimized():
    (particles_center_x, particles_center_y) = deeptack.particle_positions(particle_number)
    image_parameters = {}
    image_parameters['Particle Center X List'] = particles_center_x
    image_parameters['Particle Center Y List'] = particles_center_y
    image_parameters['Particle Radius List'] = uniform(2, 3, particle_number)

```

```

image_parameters['Particle Bessel Orders List'] = [[2, ],
                                                    [1, ],
                                                    [2, ],
                                                    [2, ],
                                                    [1, ],
                                                    [2, ]]

image_parameters['Particle Intensities List'] = [[-uniform(0.12, 0.16, 1), ],
                                                  [uniform(0.1, 0.8, 1), ],
                                                  [-uniform(0.1, 0.12, 1), ],
                                                  [-uniform(0.1, 0.12, 1), ],
                                                  [uniform(0.1, 0.8, 1), ],
                                                  [-uniform(0.1, 0.12, 1), ]]

image_parameters['Image Half-Size'] = 25
image_parameters['Image Background Level'] = uniform(.1, .5)
image_parameters['Signal to Noise Ratio'] = uniform(10, 15)
image_parameters['Gradient Intensity'] = uniform(0, 0.05)
image_parameters['Gradient Direction'] = uniform(-pi, pi)
image_parameters['Ellipsoid Orientation'] = uniform(-pi, pi, particle_number)
image_parameters['Ellipticity'] = 1

return image_parameters

```

```

image_parameters_function = lambda : get_image_parameters_optimized()

```

```

### Define image generator

```

```

image_generator = lambda : deeptack.get_image_generator(image_parameters_function)

```

```

### Show some examples of generated images

```

```

number_of_images_to_show = 10

```

```

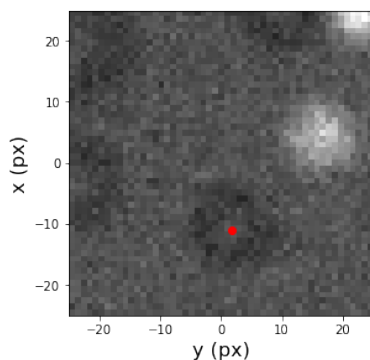
for image_number, image, image_parameters in image_generator():
    if image_number >= number_of_images_to_show:
        break

```

```

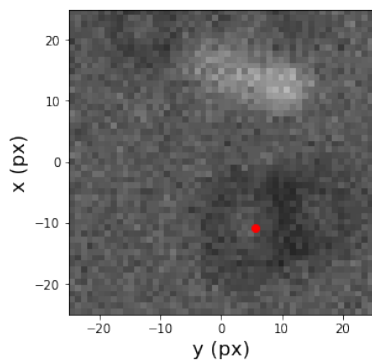
deeptack.plot_sample_image(image, image_parameters)

```



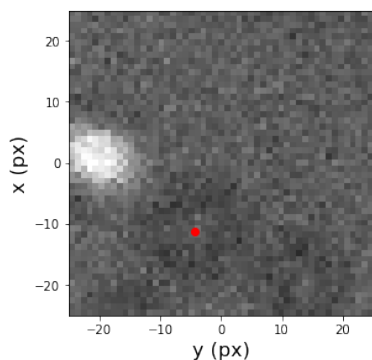
particle center x = -10.99 px  
 particle center y = 1.87 px  
 particle radius = 2.03 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = 0.05  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.32  
 signal to noise ratio = 14.01  
 gradient intensity = 0.03  
 gradient direction = -2.01



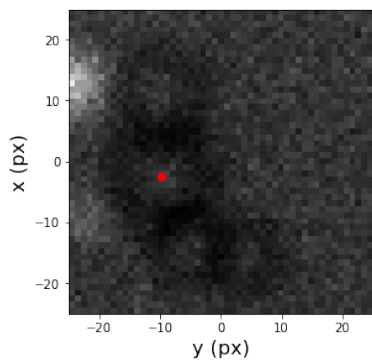
particle center x = -10.80 px  
 particle center y = 5.53 px  
 particle radius = 2.87 px  
 Bessel order = 2.00  
 particle intensity = -0.12  
 ellipsoidal\_orientation = 3.10  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.35  
 signal to noise ratio = 14.43  
 gradient intensity = 0.00  
 gradient direction = -0.08



particle center x = -11.22 px  
 particle center y = -4.27 px  
 particle radius = 2.61 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = 1.67  
 ellipticity = 1.00

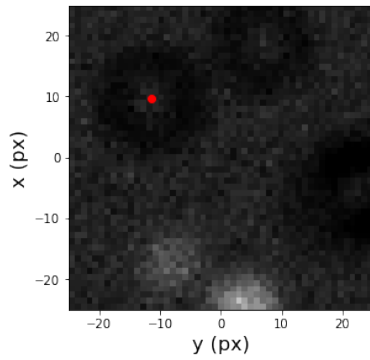
image half size = 25.00 px  
 image background level = 0.38  
 signal to noise ratio = 12.44  
 gradient intensity = 0.04  
 gradient direction = -2.18



particle center x = -2.51 px  
 particle center y = -9.74 px  
 particle radius = 2.94 px  
 Bessel order = 2.00  
 particle intensity = -0.14  
 ellipsoidal\_orientation = -2.96  
 ellipticity = 1.00

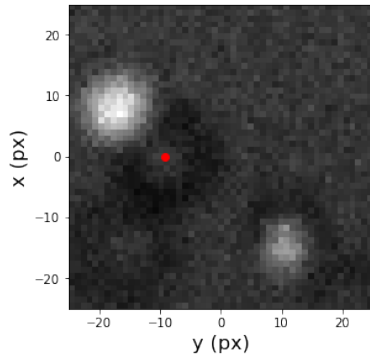
image half size = 25.00 px  
 image background level = 0.21  
 signal to noise ratio = 11.10  
 gradient intensity = 0.02  
 gradient direction = 1.67





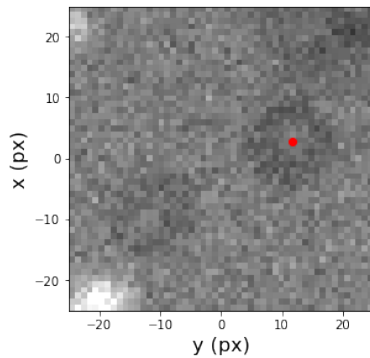
particle center x = 9.61 px  
 particle center y = -11.49 px  
 particle radius = 2.74 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = -2.99  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.14  
 signal to noise ratio = 11.75  
 gradient intensity = 0.01  
 gradient direction = 1.27



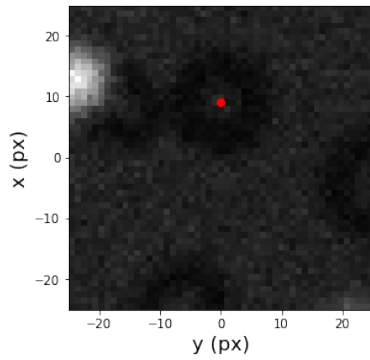
particle center x = -0.00 px  
 particle center y = -9.28 px  
 particle radius = 2.71 px  
 Bessel order = 2.00  
 particle intensity = -0.16  
 ellipsoidal\_orientation = -2.11  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.21  
 signal to noise ratio = 13.71  
 gradient intensity = 0.01  
 gradient direction = 1.44



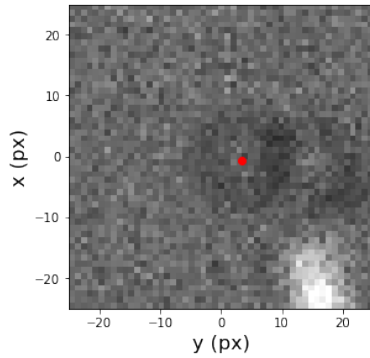
particle center x = 2.74 px  
 particle center y = 11.78 px  
 particle radius = 2.13 px  
 Bessel order = 2.00  
 particle intensity = -0.15  
 ellipsoidal\_orientation = 0.32  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.50  
 signal to noise ratio = 12.17  
 gradient intensity = 0.03  
 gradient direction = -1.79



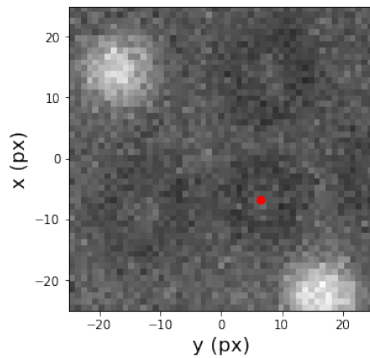
particle center x = 9.11 px  
 particle center y = 0.04 px  
 particle radius = 2.47 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = -1.76  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.14  
 signal to noise ratio = 13.55  
 gradient intensity = 0.01  
 gradient direction = 2.29



particle center x = -0.67 px  
 particle center y = 3.39 px  
 particle radius = 2.46 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = -1.46  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.42  
 signal to noise ratio = 10.44  
 gradient intensity = 0.02  
 gradient direction = 0.20



particle center x = -6.86 px  
 particle center y = 6.49 px  
 particle radius = 2.18 px  
 Bessel order = 2.00  
 particle intensity = -0.13  
 ellipsoidal\_orientation = -1.72  
 ellipticity = 1.00

image half size = 25.00 px  
 image background level = 0.36  
 signal to noise ratio = 12.38  
 gradient intensity = 0.05  
 gradient direction = -2.09

#### 4. USE A PRETRAINED DEEP LEARNING NETWORK

The pretrained networks saved in the files "DeepTrack - Example 4 - Bacteria - Pretrained network.h5" and "DeepTrack - Example 4 - Particles - Pretrained network.h5" are loaded and their

performance on selected video is tested.

Video file: DeepTrack - Example 4 - Brownian particles + bacteria.mp4

Note that the pretrained network files and the video file must be in the same folder as this notebook.

Comments:

1. number\_frames\_to\_be\_tracked can be changed to track different number of frames. If number\_frames is equal to 0 then the whole video is tracked.
2. box\_half\_size is half the size of the box to be scanned over the frames. The resulting sample should be comparable to the training image.
3. box\_scanning\_step is the step that is used to scan the box over the frame. It can be increased for higher accuracy or decreased for lower computational time.
4. frame\_normalize gives the option to normalize the frames. Set to 1 to normalize, 0 otherwise.
5. frame\_enhance gives the option to enhance the frames. Set to 1 to track the original frames.

## BACTERIA

```
In [5]: ### Define the video file to be tracked
        video_file_name = 'DeepTrack - Example 4 - Brownian particles + bacteria.mp4'

        ### Define the number of frames to be tracked
        number_frames_to_be_tracked = 2

        ### Define the size of the box to be scanned over the frames
        box_half_size = 25

        ### Define the scanning step over the frame
        box_scanning_step = 5

        ### Preprocess the images
        frame_normalize = 0
        frame_enhance = 2

        ### Load the pretrained network
        saved_network_file_name = 'DeepTrack - Example 4 - Bacteria - Pretrained network.h5'
        network = deeptack.load(saved_network_file_name)

        ### Track the video
        (number_tracked_frames, frames, predicted_positions_wrt_frame, predicted_positions_wrt_b
         video_file_name,
         network,
         number_frames_to_be_tracked,
         box_half_size,
         box_scanning_step,
```

```
frame_normalize,  
frame_enhance)
```

Using TensorFlow backend.

## PARTICLES

```
In [6]: ### Define the video file to be tracked  
video_file_name = 'DeepTrack - Example 4 - Brownian particles + bacteria.mp4'  
  
### Define the number of frames to be tracked  
number_frames_to_be_tracked = 2  
  
### Define the size of the box to be scanned over the frames  
box_half_size = 25  
  
### Define the scanning step over the frame  
box_scanning_step = 3  
  
frame_normalize = 0  
frame_enhance = 1.5  
  
### Load the pretrained network  
saved_network_file_name = 'DeepTrack - Example 4 - Particles - Pretrained network.h5'  
network = deeptack.load(saved_network_file_name)  
  
### Track the video  
(number_tracked_frames, frames, predicted_positions_wrt_frame, predicted_positions_wrt_b  
    video_file_name,  
    network,  
    number_frames_to_be_tracked,  
    box_half_size,  
    box_scanning_step,  
    frame_normalize,  
    frame_enhance)
```

## 5. SHOW EXAMPLES OF TRACKED SCANNING BOXES

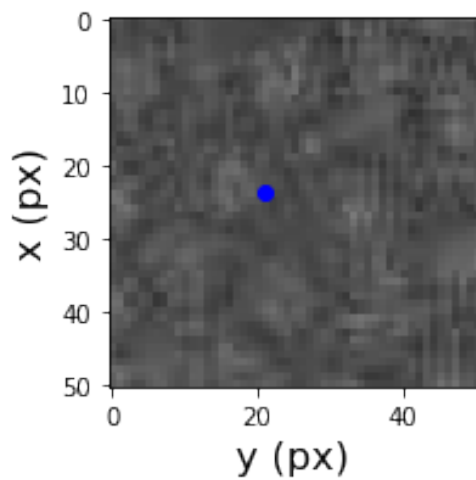
The tracked scanning boxes are plotted over a range of frames, rows and columns. It shows the case of either tracking the bacteria or the particles, which ever was tracked the latest above.

Comments:

1. frame\_to\_be\_shown can be changed to view different frames.
2. rows\_to\_be\_shown can be changed to view different rows of each of the frames.
3. columns\_to\_be\_shown can be changed to view different columns of each of the frames.
4. The blue symbol is the deep learning network prediction for the position (x, y).

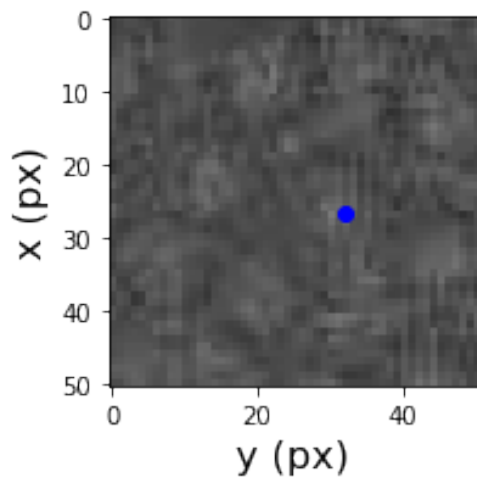
```
In [7]: ### Define frames, rows and columns of the samples to be shown
frames_to_be_shown = range(1)
rows_to_be_shown = range(15,20)
columns_to_be_shown = range(5,10)

### Show boxes
deeptrack.plot_tracked_scanning_boxes(
    frames_to_be_shown,
    rows_to_be_shown,
    columns_to_be_shown,
    boxes_all,
    predicted_positions_wrt_box)
```



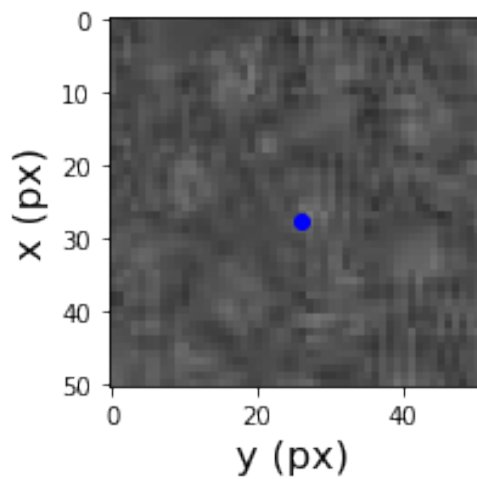
frame = 0  
row = 15  
column = 5

particle center x = 23.52 px  
particle center y = 20.99 px  
particle radius = 8.53 px



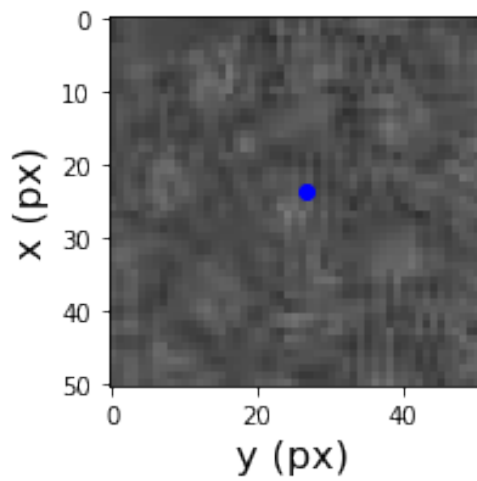
frame = 0  
row = 15  
column = 6

particle center x = 26.69 px  
particle center y = 32.00 px  
particle radius = 7.52 px



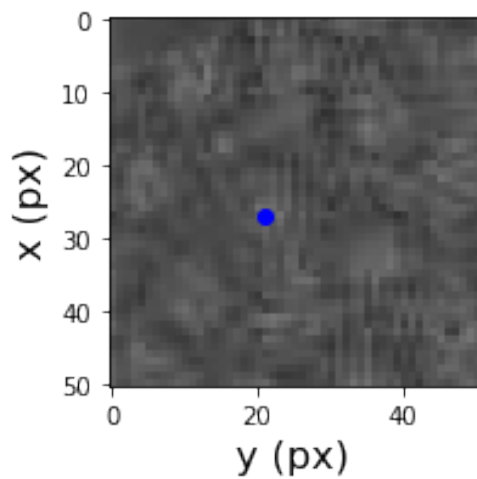
frame = 0  
row = 15  
column = 7

particle center x = 27.70 px  
particle center y = 25.91 px  
particle radius = 3.56 px



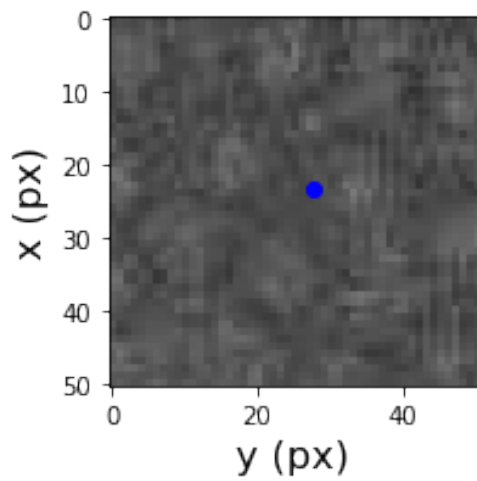
frame = 0  
row = 15  
column = 8

particle center x = 23.49 px  
particle center y = 26.83 px  
particle radius = 2.90 px



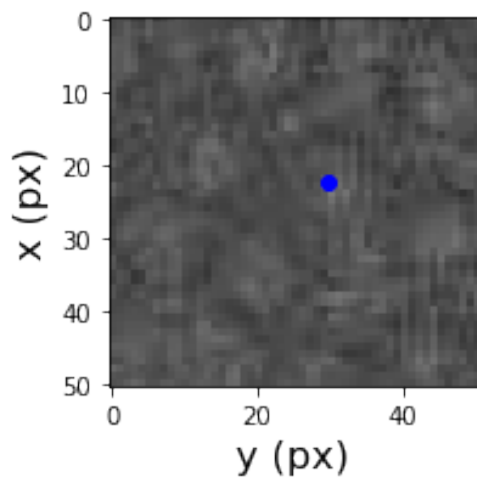
frame = 0  
row = 15  
column = 9

particle center x = 26.88 px  
particle center y = 21.02 px  
particle radius = 4.50 px



frame = 0  
row = 16  
column = 5

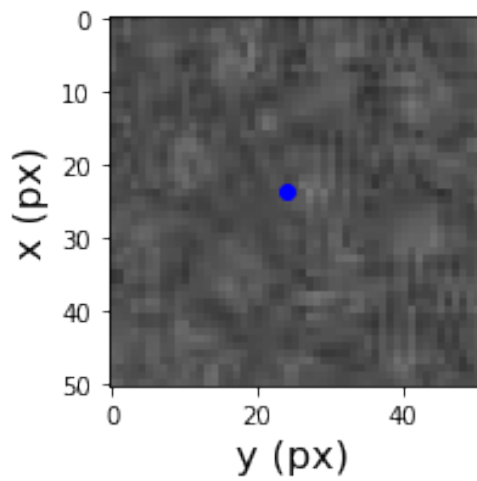
particle center x = 23.44 px  
particle center y = 27.55 px  
particle radius = 9.14 px



frame = 0  
row = 16  
column = 6

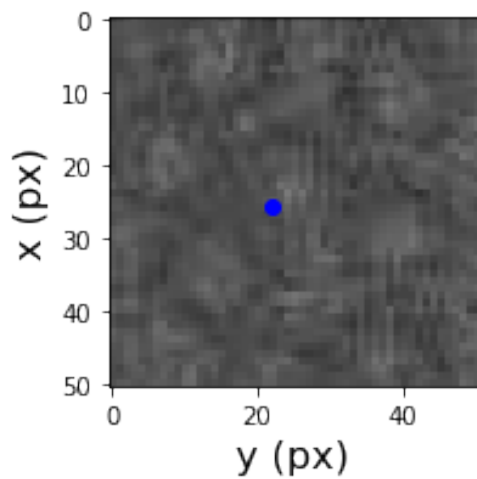
particle center x = 22.20 px  
particle center y = 29.87 px  
particle radius = 7.43 px





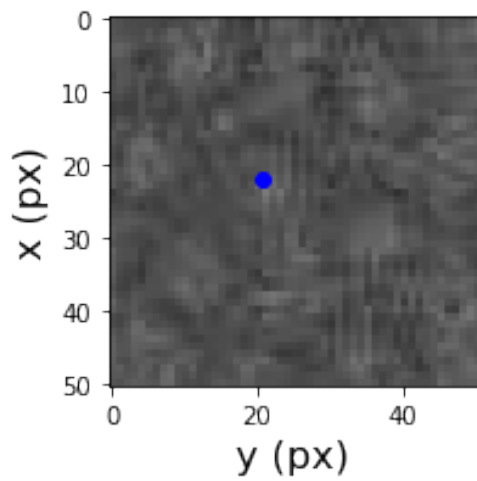
frame = 0  
row = 16  
column = 7

particle center x = 23.58 px  
particle center y = 23.99 px  
particle radius = 4.54 px



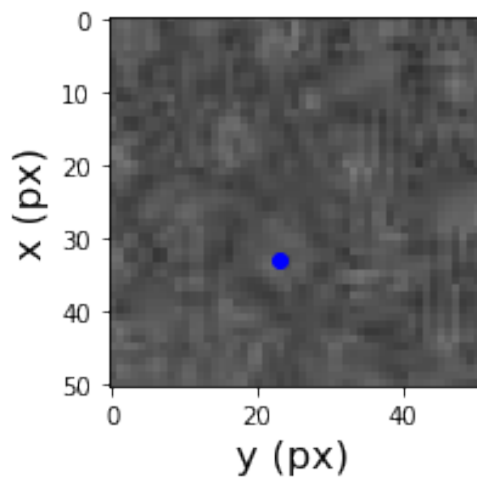
frame = 0  
row = 16  
column = 8

particle center x = 25.64 px  
particle center y = 22.00 px  
particle radius = 5.61 px



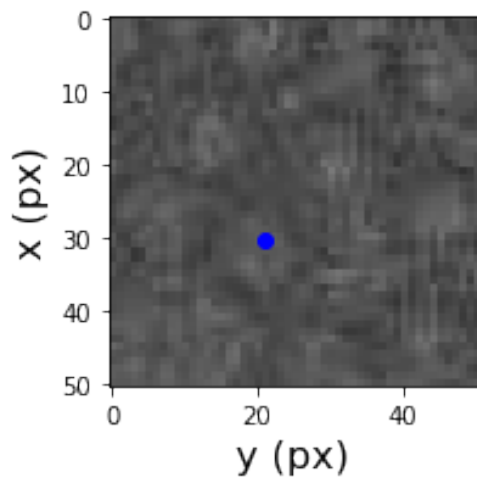
frame = 0  
row = 16  
column = 9

particle center x = 21.96 px  
particle center y = 20.59 px  
particle radius = 6.89 px



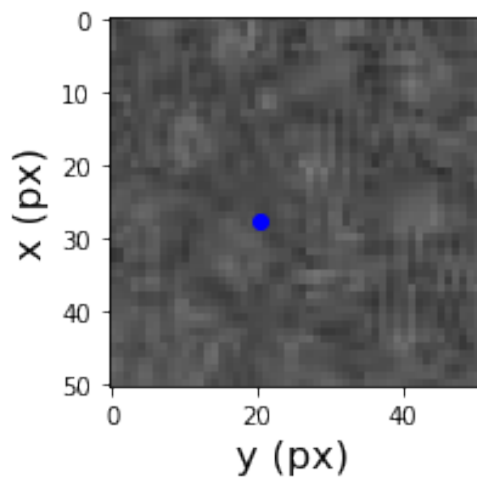
frame = 0  
row = 17  
column = 5

particle center x = 32.97 px  
particle center y = 22.86 px  
particle radius = 7.74 px



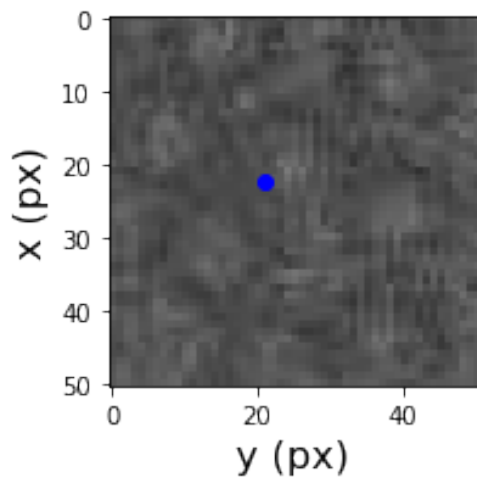
frame = 0  
row = 17  
column = 6

particle center x = 30.48 px  
particle center y = 21.10 px  
particle radius = 8.40 px



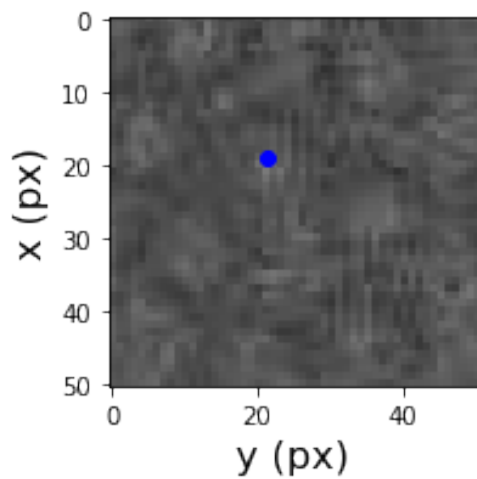
frame = 0  
row = 17  
column = 7

particle center x = 27.75 px  
particle center y = 20.50 px  
particle radius = 8.65 px



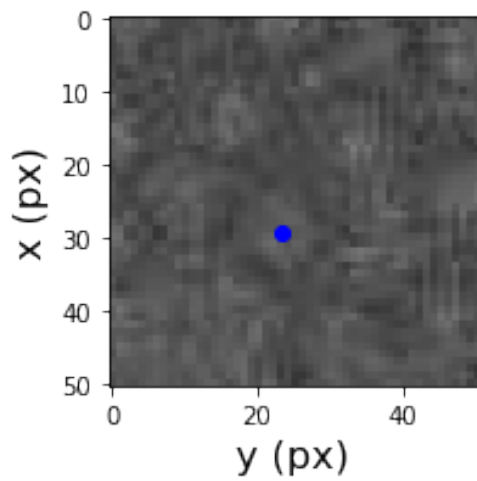
frame = 0  
row = 17  
column = 8

particle center x = 22.22 px  
particle center y = 20.91 px  
particle radius = 7.70 px



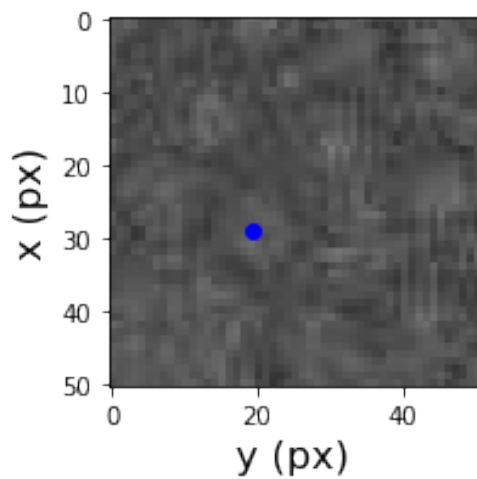
frame = 0  
row = 17  
column = 9

particle center x = 19.08 px  
particle center y = 21.23 px  
particle radius = 7.70 px



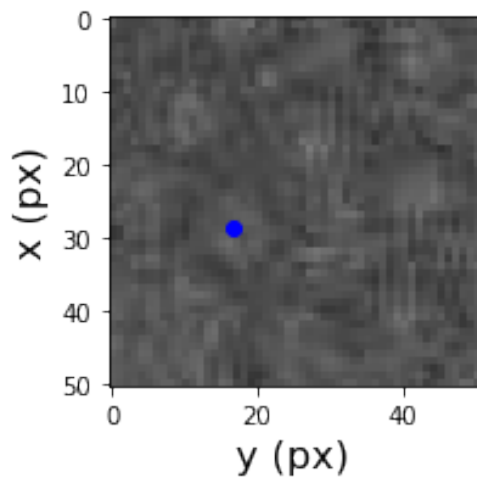
frame = 0  
row = 18  
column = 5

particle center x = 29.39 px  
particle center y = 23.33 px  
particle radius = 4.67 px



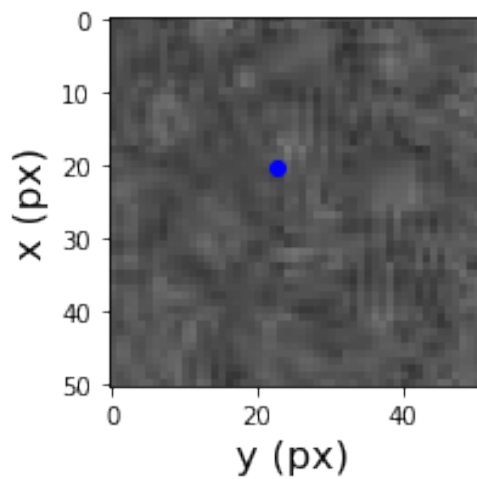
frame = 0  
row = 18  
column = 6

particle center x = 28.91 px  
particle center y = 19.36 px  
particle radius = 6.44 px



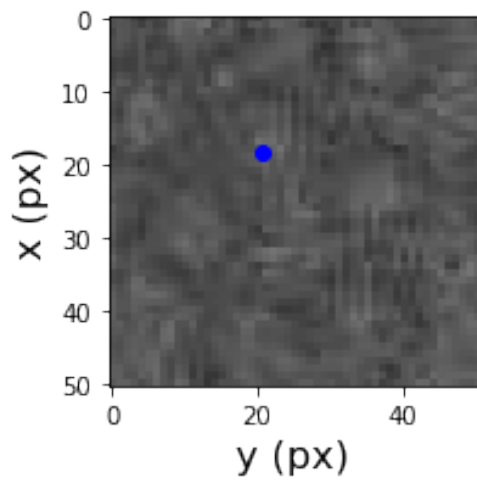
frame = 0  
row = 18  
column = 7

particle center x = 28.77 px  
particle center y = 16.51 px  
particle radius = 9.51 px



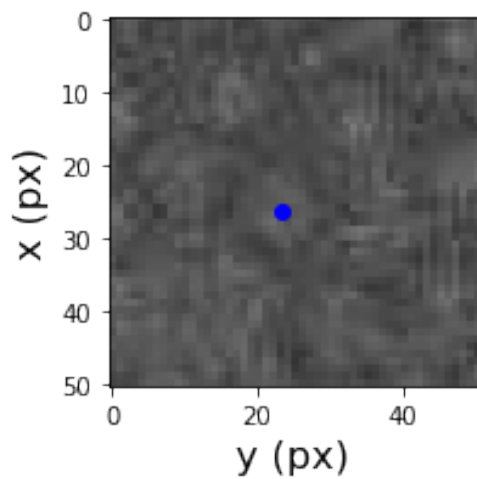
frame = 0  
row = 18  
column = 8

particle center x = 20.28 px  
particle center y = 22.65 px  
particle radius = 9.49 px



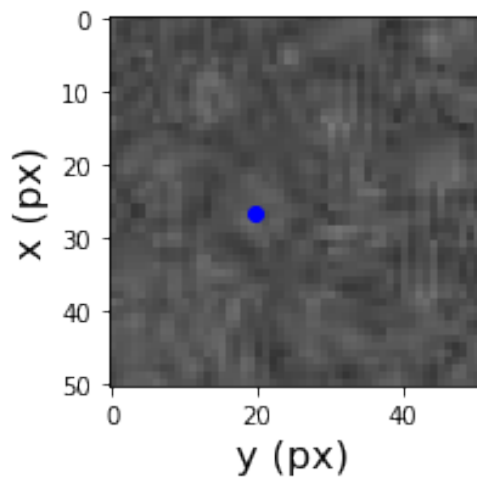
frame = 0  
row = 18  
column = 9

particle center x = 18.28 px  
particle center y = 20.68 px  
particle radius = 9.52 px



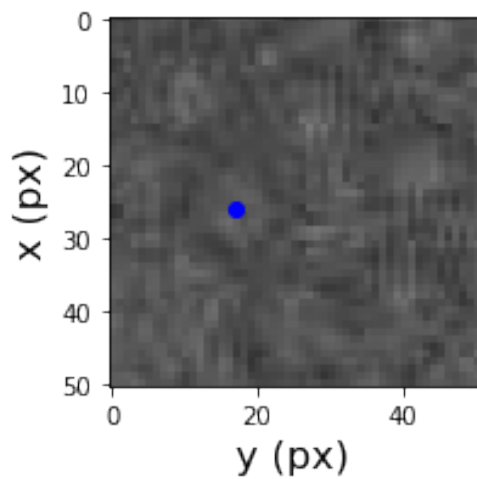
frame = 0  
row = 19  
column = 5

particle center x = 26.45 px  
particle center y = 23.33 px  
particle radius = 2.44 px



frame = 0  
row = 19  
column = 6

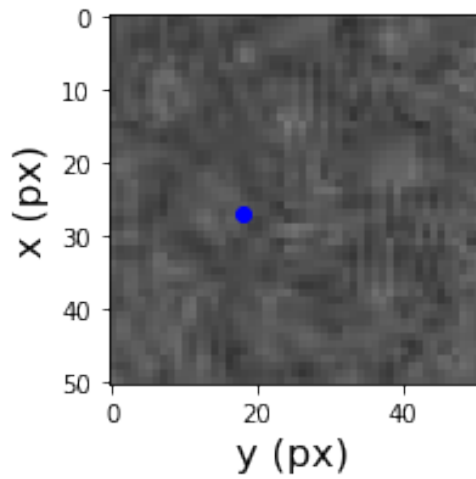
particle center x = 26.52 px  
particle center y = 19.56 px  
particle radius = 5.30 px



frame = 0  
row = 19  
column = 7

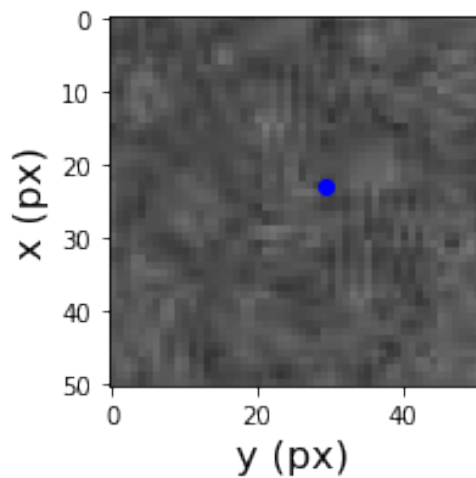
particle center x = 25.92 px  
particle center y = 16.88 px  
particle radius = 8.28 px





frame = 0  
row = 19  
column = 8

particle center x = 27.04 px  
particle center y = 17.98 px  
particle radius = 9.59 px



frame = 0  
row = 19  
column = 9

particle center x = 22.92 px  
particle center y = 29.43 px  
particle radius = 11.08 px

## 6. SHOW EXAMPLES OF TRACKED FRAMES

The tracked frames are shown. It shows the case of either tracking the bacteria or the particles, which ever was tracked the latest above.

Comments:

1. `particle_radial_distance_threshold` can be changed to choose which prediction points (blue dots) are to be used to calculate the centroid positions (orange circles). We used 6 and 3.5 pixels for bacteria and particles, respectively.
2. `particle_maximum_interdistance` can be changed to choose what predicted points (blue dots) belong to the same particle. We used 20 and 8.5 pixels for bacteria and particles, respectively.

```
In [8]: ### Define minimum radial distance from the center of the scanning boxes
        %matplotlib inline
        particle_radial_distance_threshold = 3.5

        ### Define the minimum distance between predicted scanning points for them belonging to
        particle_maximum_interdistance = 8.5

        ### Visualize tracked frames
        deeptack.show_tracked_frames(
            particle_radial_distance_threshold,
            particle_maximum_interdistance,
            number_tracked_frames,
            frames,
            predicted_positions_wrt_frame)
```

