# Prediction of Cloud Movement from Satellite Images using Neural Networks

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*Abstract*—**Predicting cloud movement and dynamics is an important aspect in several areas, including prediction of solar energy generation. Knowing where a cloud will be or how it evolves over a given geographical area can help energy providers to better estimate their production levels. In this paper we propose a novel approach to predicting cloud movement based on satellite imagery. It combines techniques of generating motion vectors from sequential images with neural networks. First, the images are masked to isolate cloud pixels, then Farneback's version of the Optical Flow algorithm is used to detect motion from one image to the next and generate motion vector flow for each pair of images. After that, a feed forward back propagation neural network is trained with the vector data derived from the dataset imagery. Different parameters for the duration of the training, size of the input, and the neighborhood radius of one**

took it a step further by detecting and masking out cloud and cloud shadow pixels from the image in order to make use of the clear pixels instead of discarding the entire image. More details will be given in Section II.

Harnessing the power of solar irradiation is a task entirely dependent on weather conditions, specifically on the absence of cloud cover. As clouds passing over a solar power plant cannot be eradicated, a solution is to identify clouds and predict their near future position by analyzing their movement. This way, plant operators can benefit from the cover of shadow by performing maintenance on the installed equipment, and not restrict it from running when the sky is clear.

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# TALKING POINTS

- Motivation

- State of the Art

- Solution

- Experiments

- Conclusions

# Motivation

- Solar energy generation

- Solar irradiance

- Insight into weather processes

# State of the Art

- Cloud Detection: Fmask, Escrig
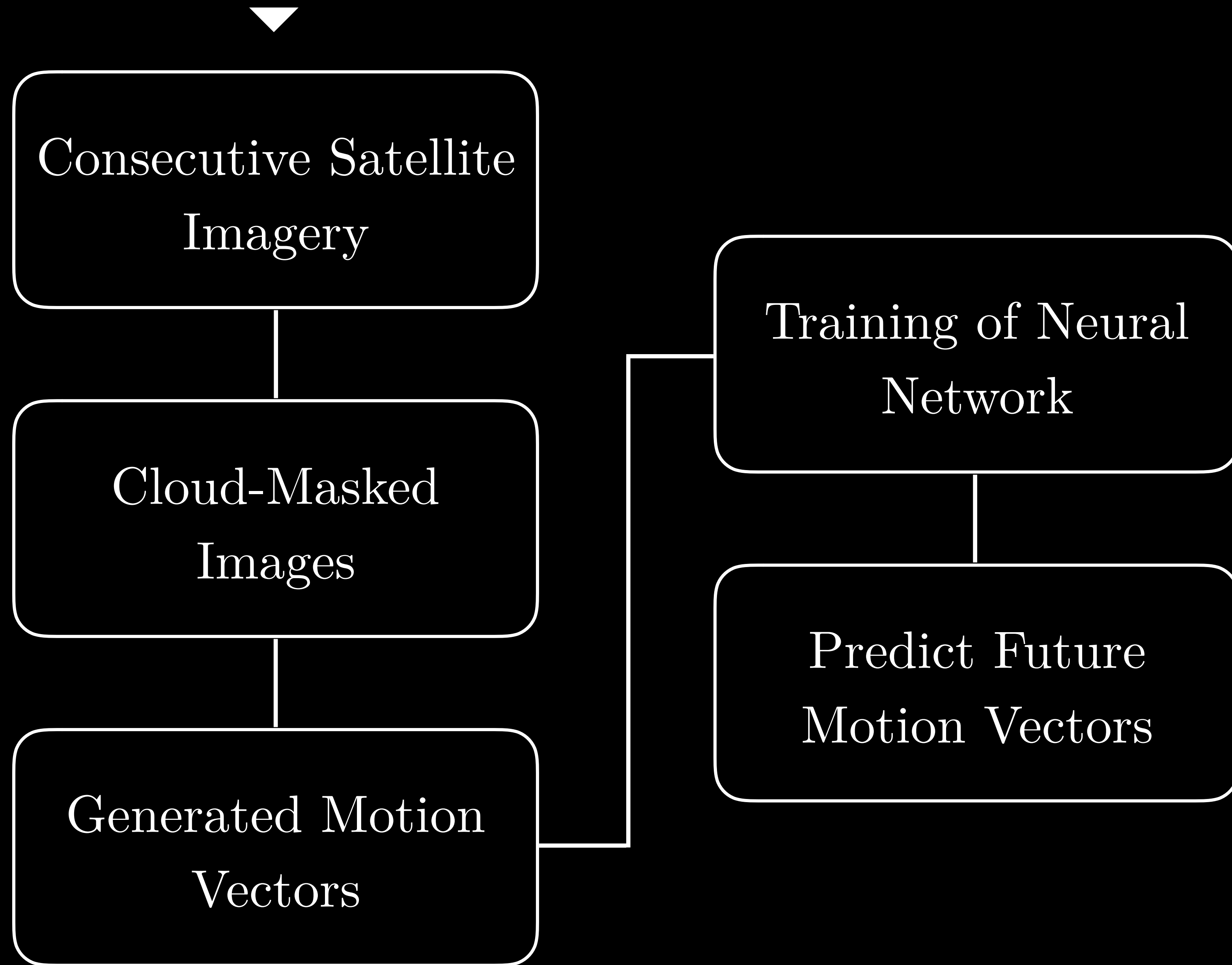
- Cloud Motion: Escrig, Hamill

# Fmask

- Input: Top of Atmosphere (TOA) reflectance values for Bands 1, 2, 3, 4, 5, 7 and the Brightness Temperature (BT) Band 6.

- Series of tests and probabilities for cloud, shadow, and snow.

- Output: three binary masks for clouds, cloud shadows, and snow.

# Hamill

- Input: two infrared images 30 minutes apart

- Multiple cross-correlations for motion vectors

- Output: realistic, forecast IR pixel images

# Escrig

- Input: VIS 0.6, VIS 0.8, IR 3.9, IR 10.8, IR 12.0

- Test for snow and two common threshold tests

- Reflectance test for visible and infrared bands

- Cross-correlation to generate motion vectors

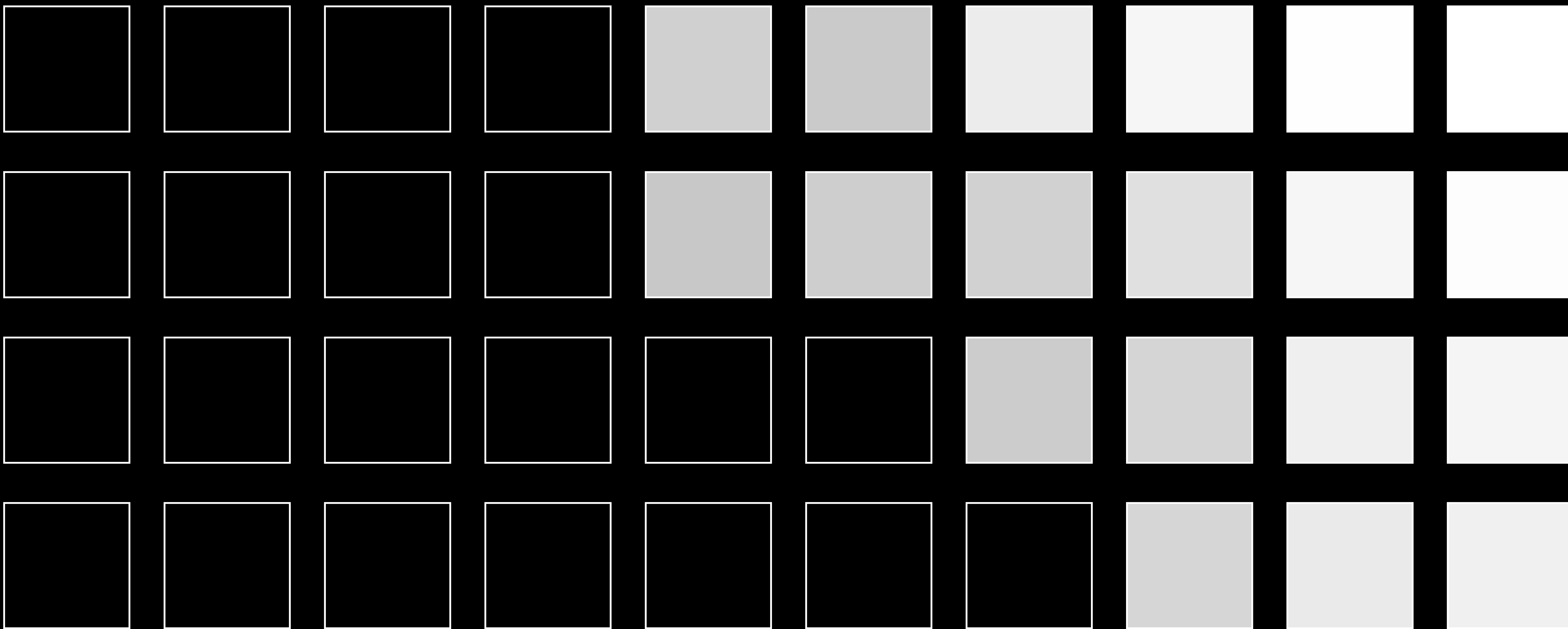- Output: short-term forecasting of cloud cover

```
┌─────────────────────────┐
│  Consecutive Satellite  │
│        Imagery          │
└─────────────────────────┘
                                      ┌─────────────────────────┐
                                      │   Training of Neural    │
                                      │        Network          │
┌─────────────────────────┐          └─────────────────────────┘
│      Cloud-Masked       │
│         Images          │
└─────────────────────────┘          ┌─────────────────────────┐
                                      │     Predict Future      │
                                      │     Motion Vectors      │
┌─────────────────────────┐          └─────────────────────────┘
│    Generated Motion     │
│         Vectors         │
└─────────────────────────┘
```

| 105 | 130 | 176 | 192 | 208 | 222 | 236 | 246 | 254 | 255 |
| 112 | 135 | 168 | 199 | 200 | 206 | 209 | 224 | 246 | 254 |
| 133 | 147 | 173 | 184 | 191 | 197 | 204 | 213 | 239 | 246 |
| 123 | 132 | 145 | 154 | 167 | 176 | 189 | 214 | 234 | 240 |

**Thresholding to zero from 199**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 208 | 222 | 236 | 246 | 254 | 255 |
| 0 | 0 | 0 | 0 | 200 | 206 | 209 | 224 | 246 | 254 |
| 0 | 0 | 0 | 0 | 0 | 0 | 204 | 213 | 239 | 246 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 214 | 234 | 240 |

**Thresholding to zero from 199**

GETTING DATA

$x$

$y$

$x$ | 1 |  |  |  |  |  |  |  |  |  |
$y$ | 0 |  |  |  |  |  |  |  |  |  |

$x$ | 1 | | | | | | | | |
$y$ | 0 | | | | | | | | |

| $x$ | 1 | 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $y$ | 0 | 0 | | | | | | | | |

$$x \quad \boxed{1} \quad \boxed{1}$$
$$y \quad \boxed{0} \quad \boxed{0}$$

$x$ | 1 | 1 | 1 | | | | | | |
$y$ | 0 | 0 | 0 | | | | | | |
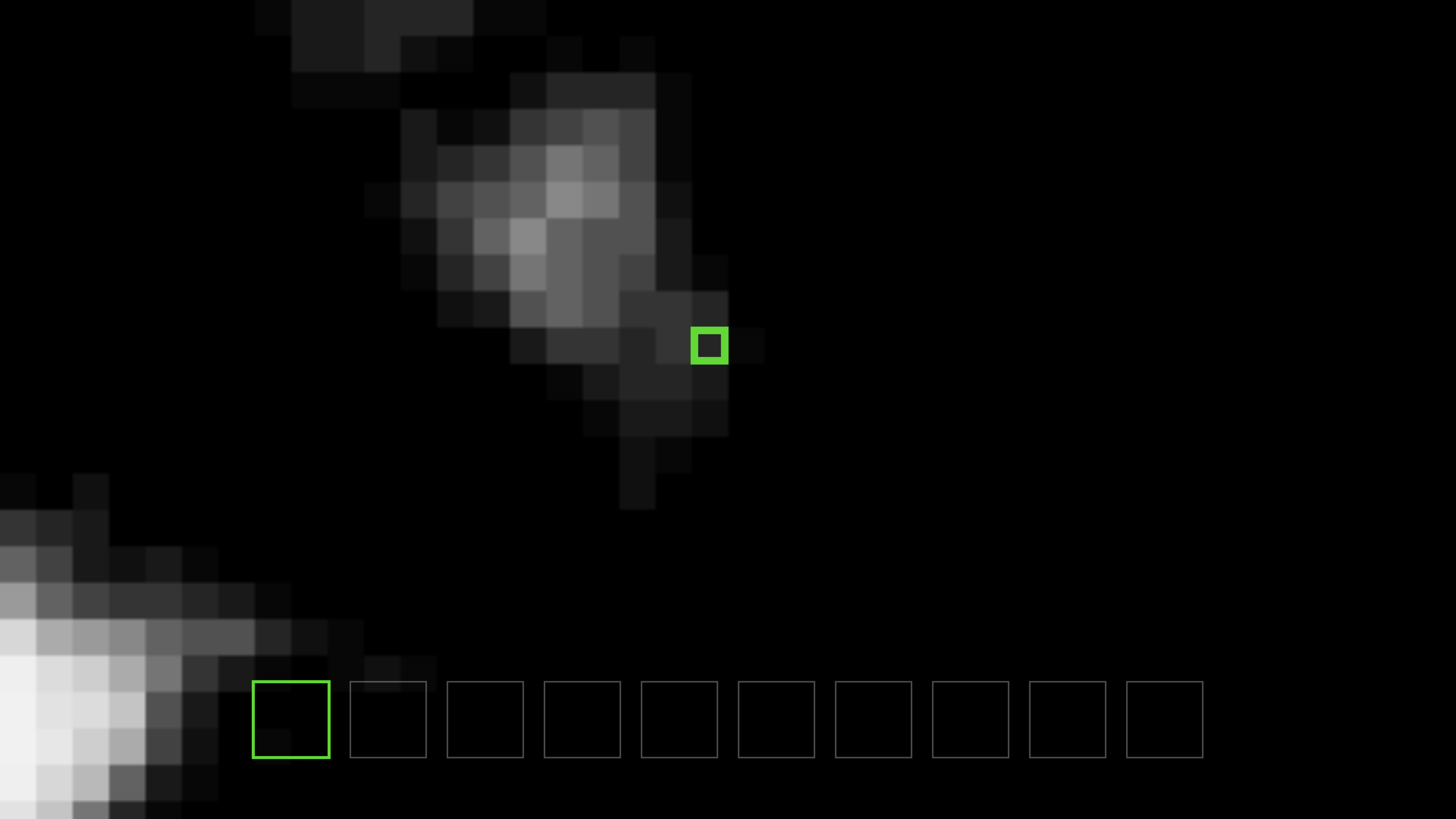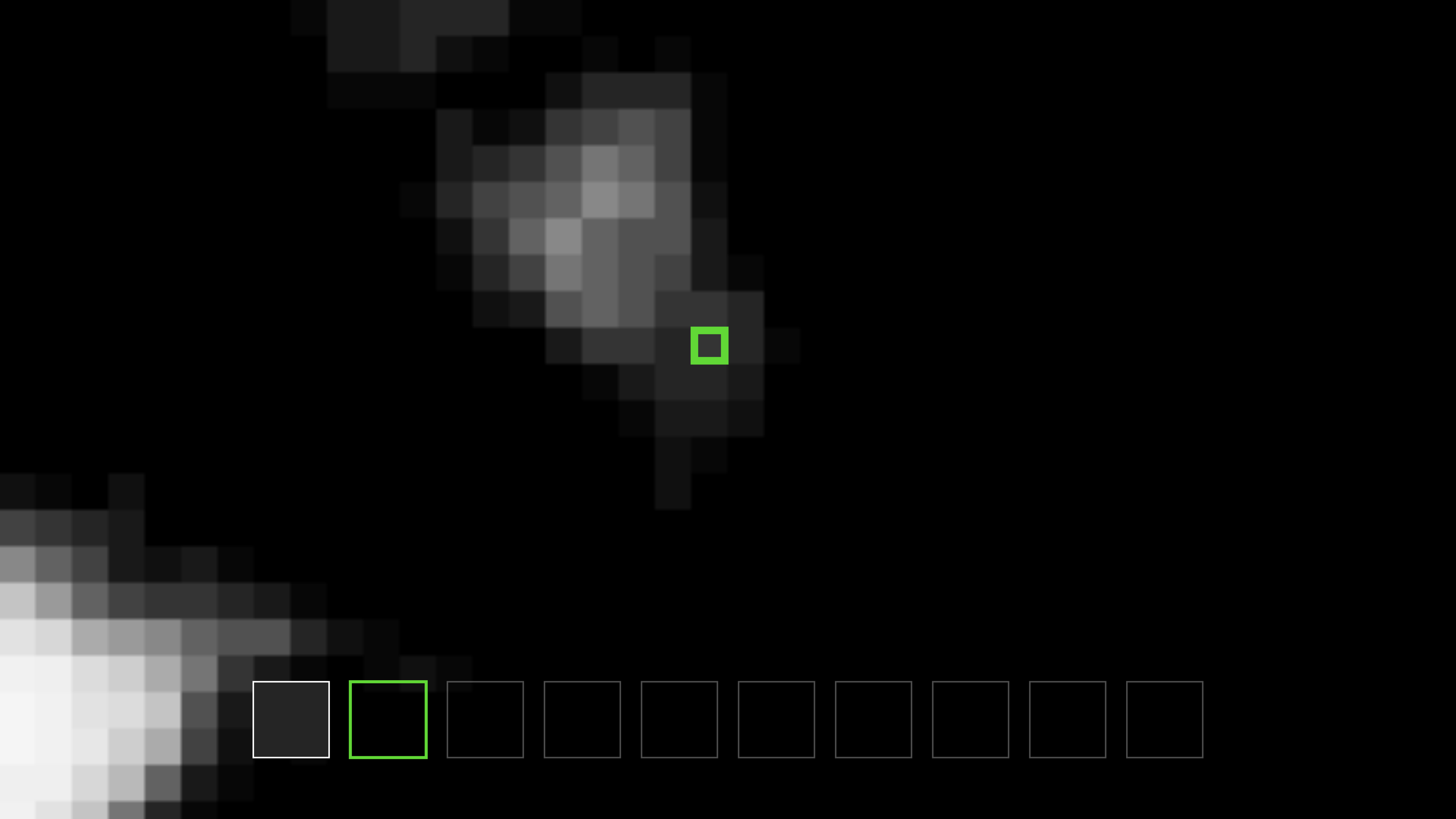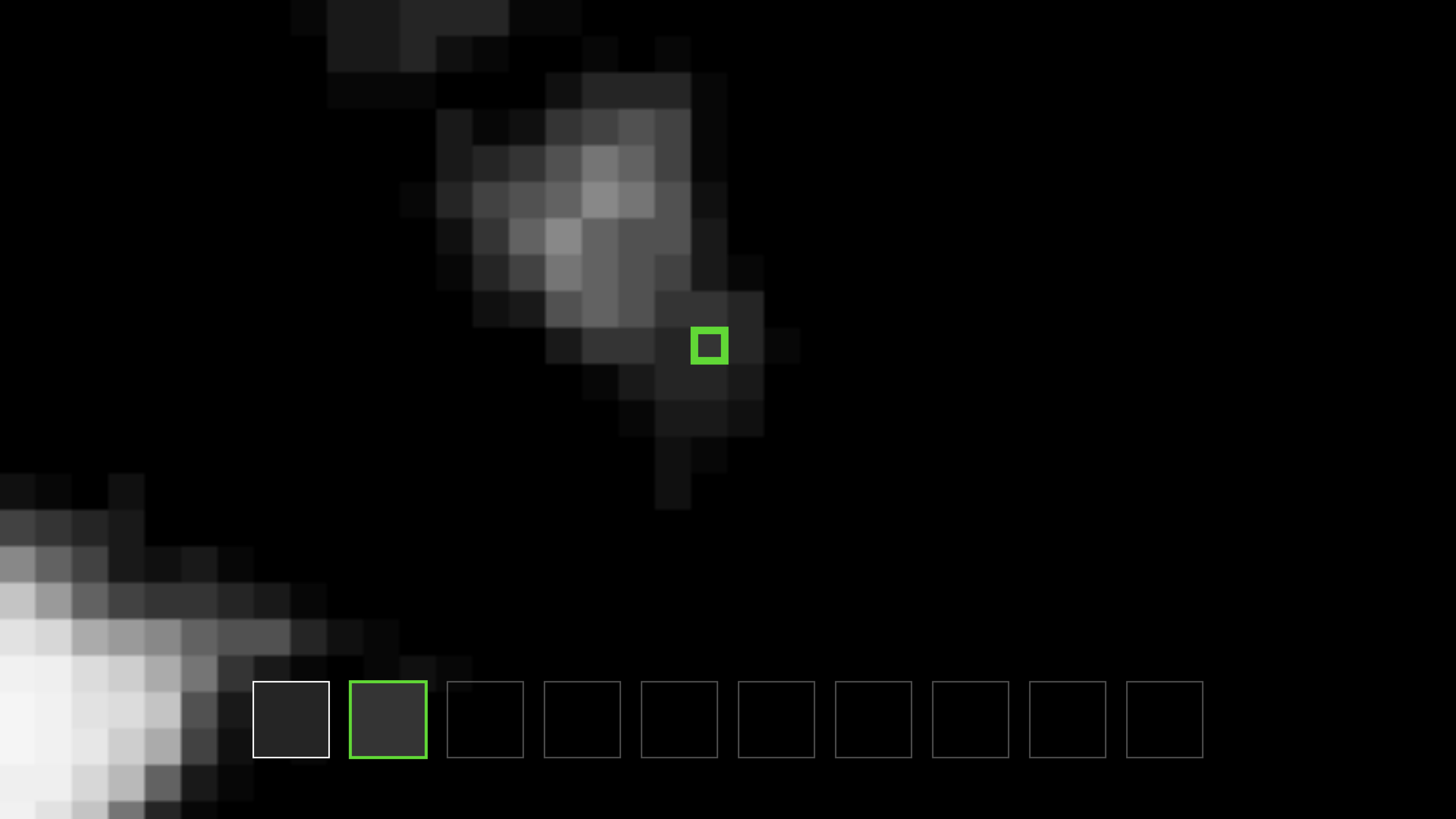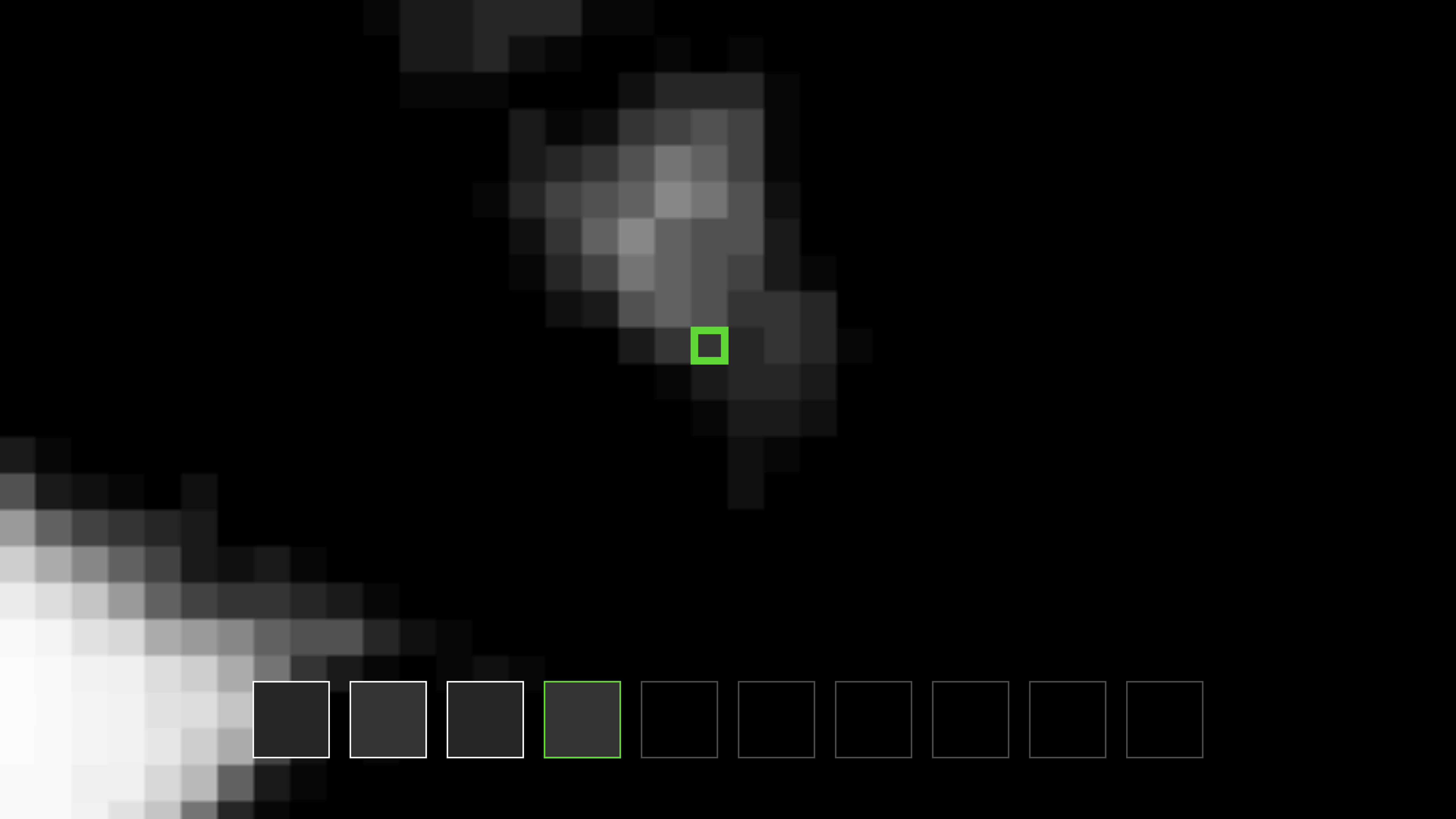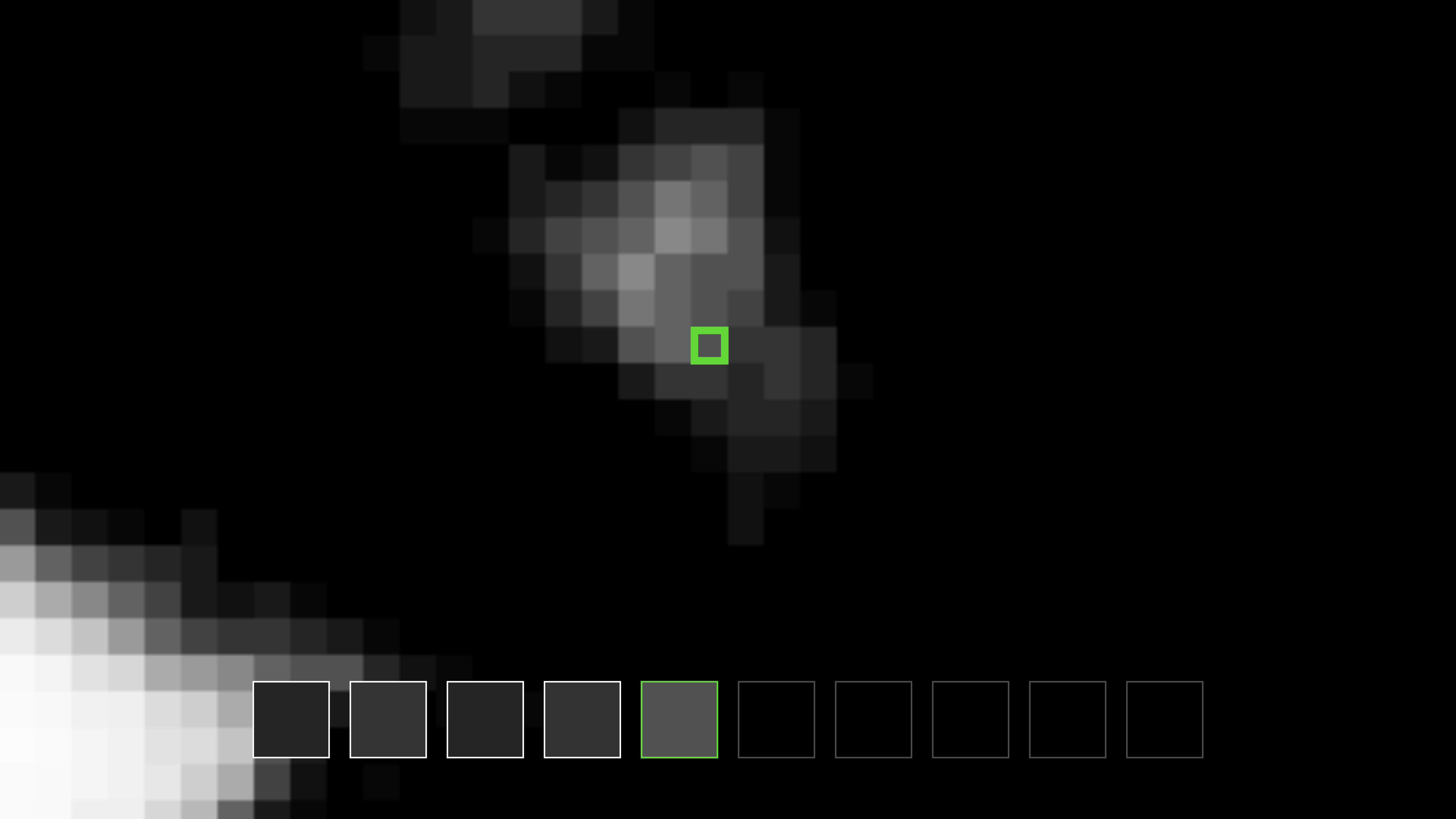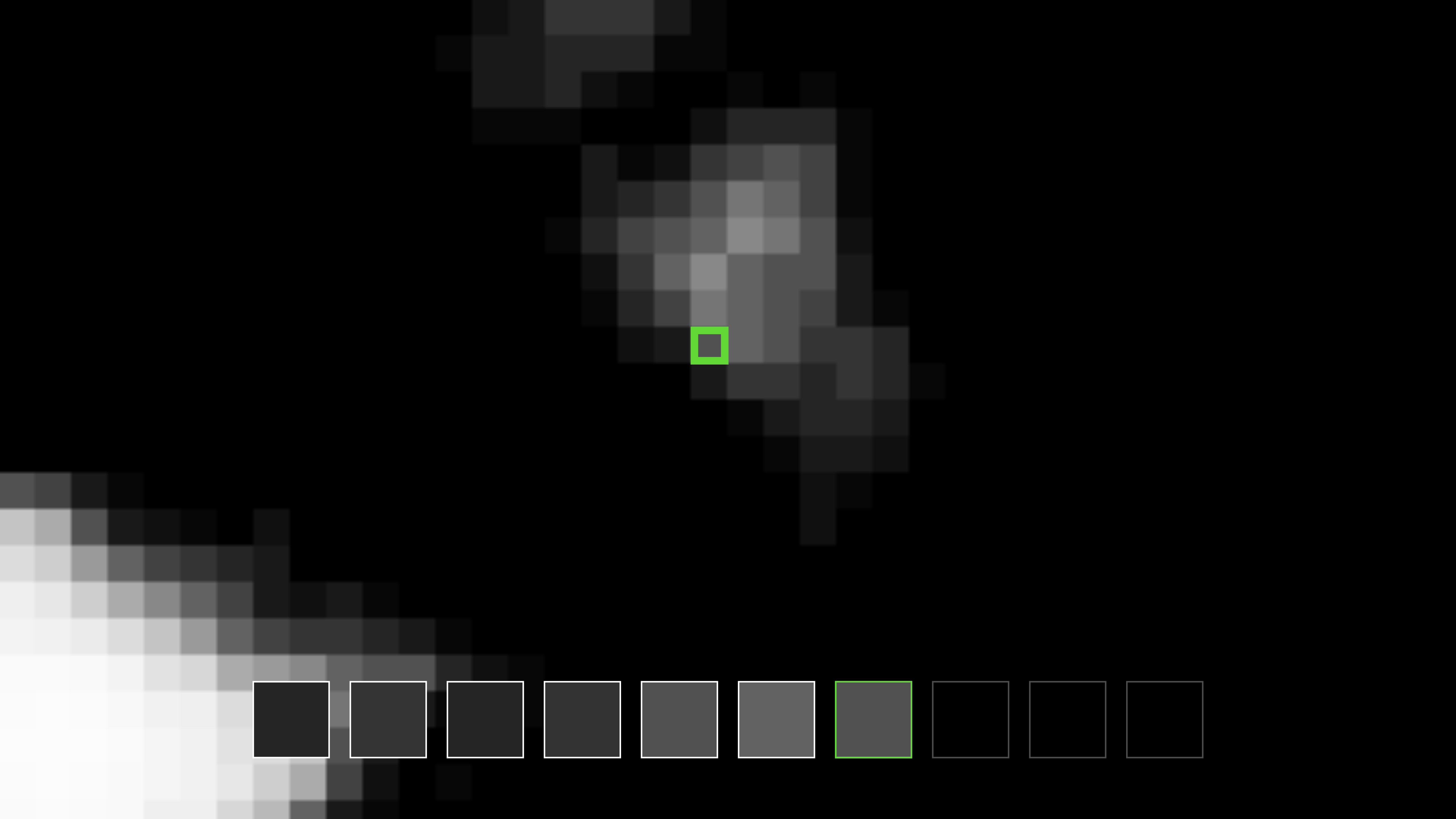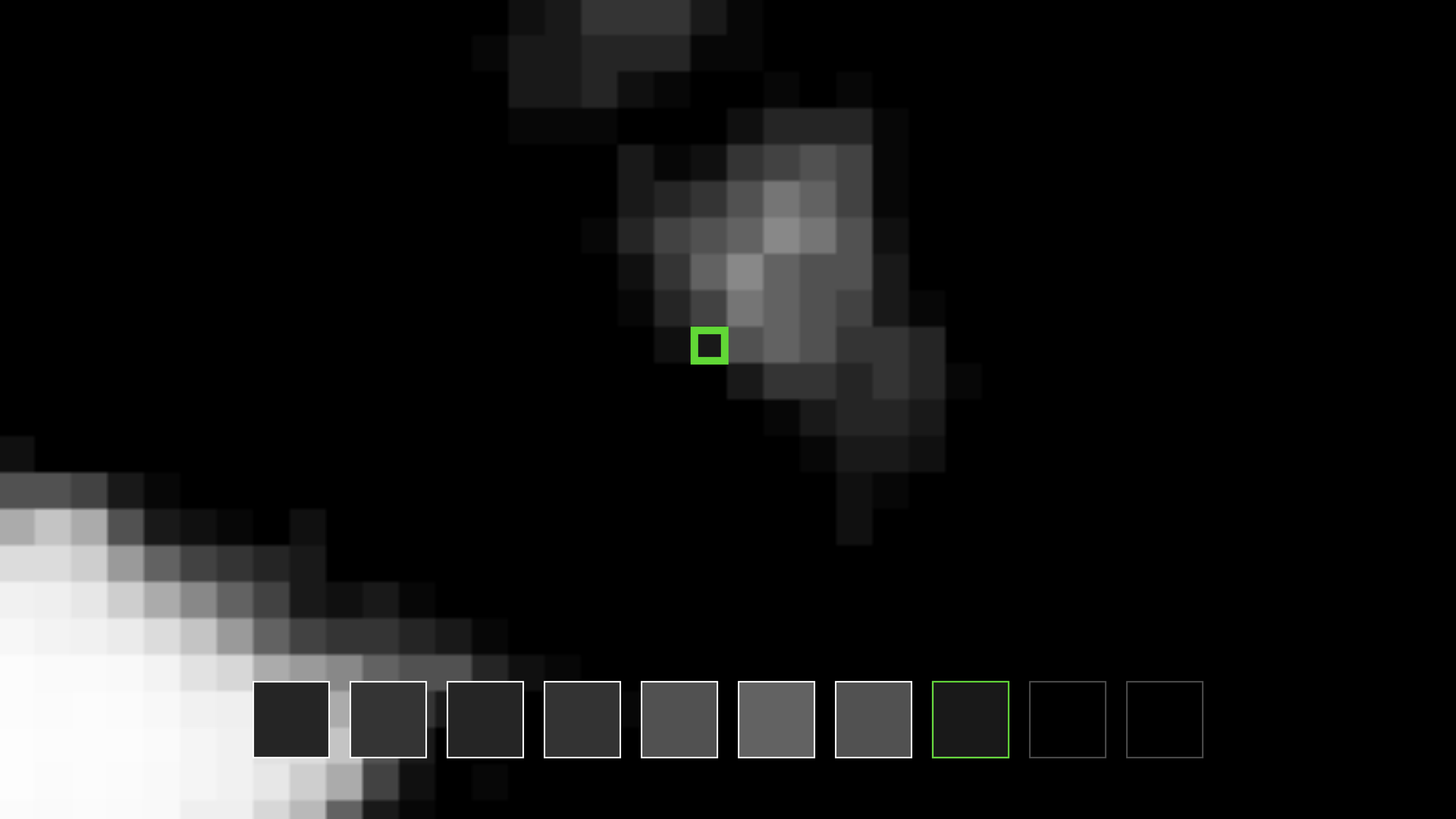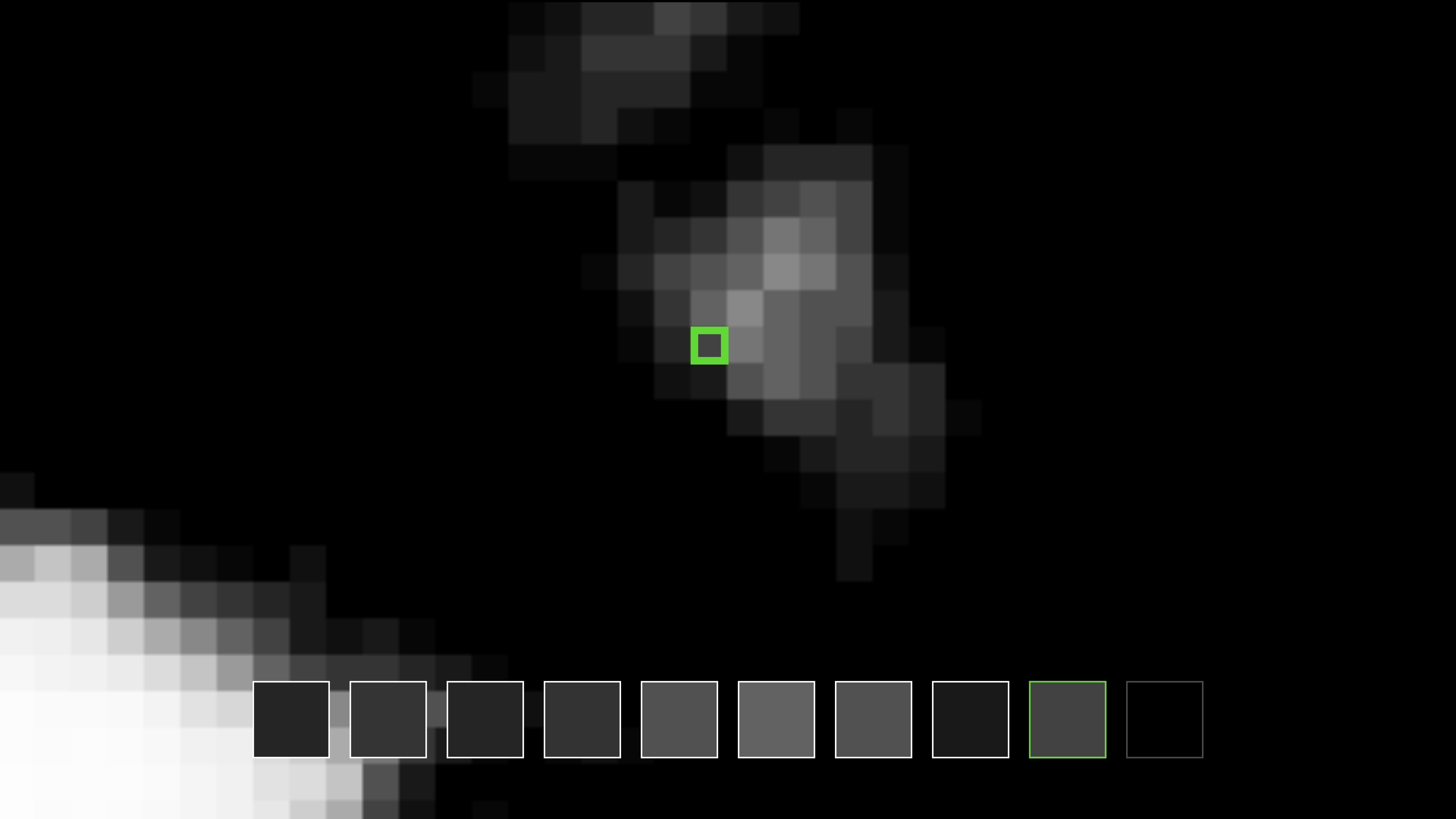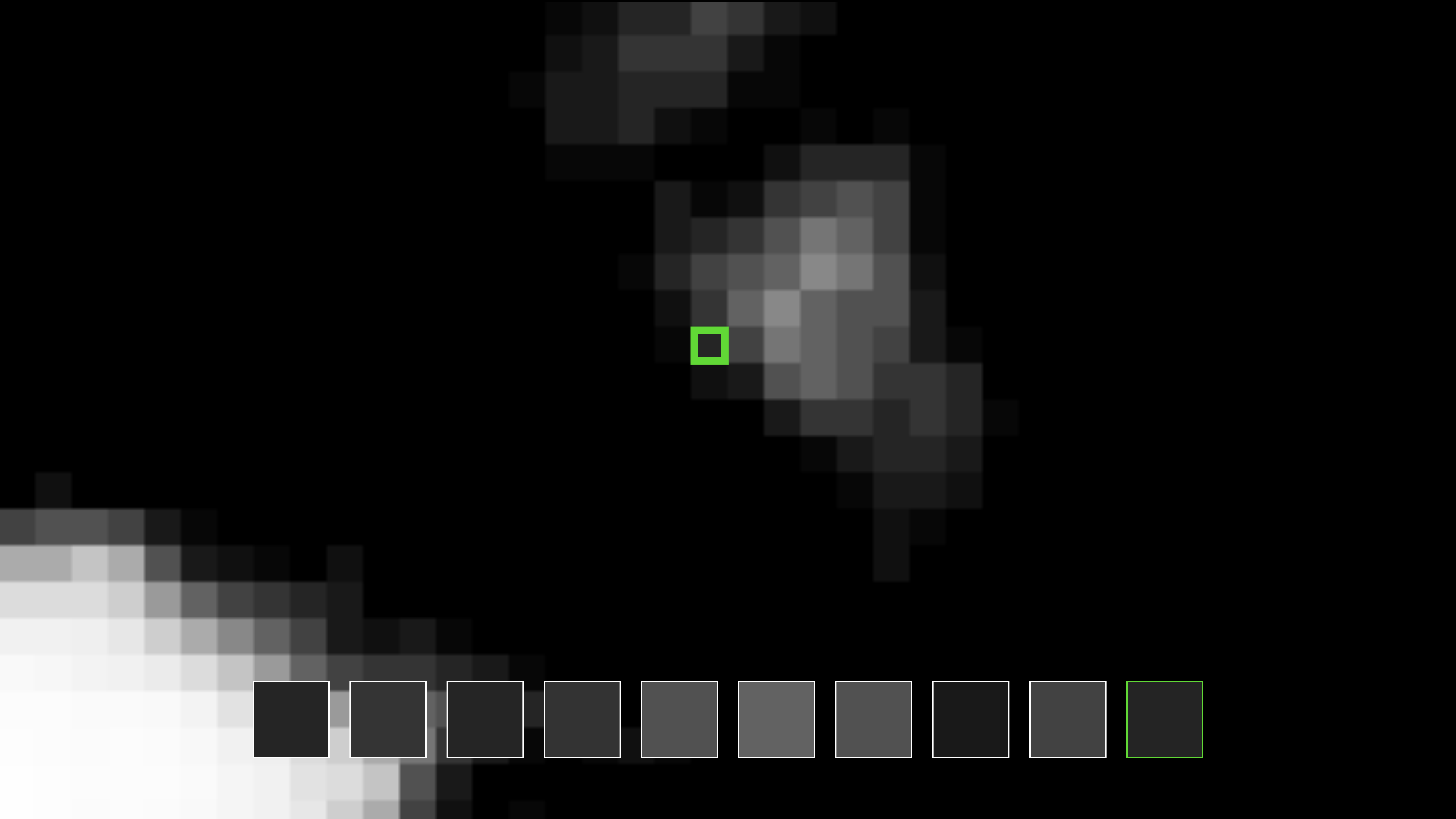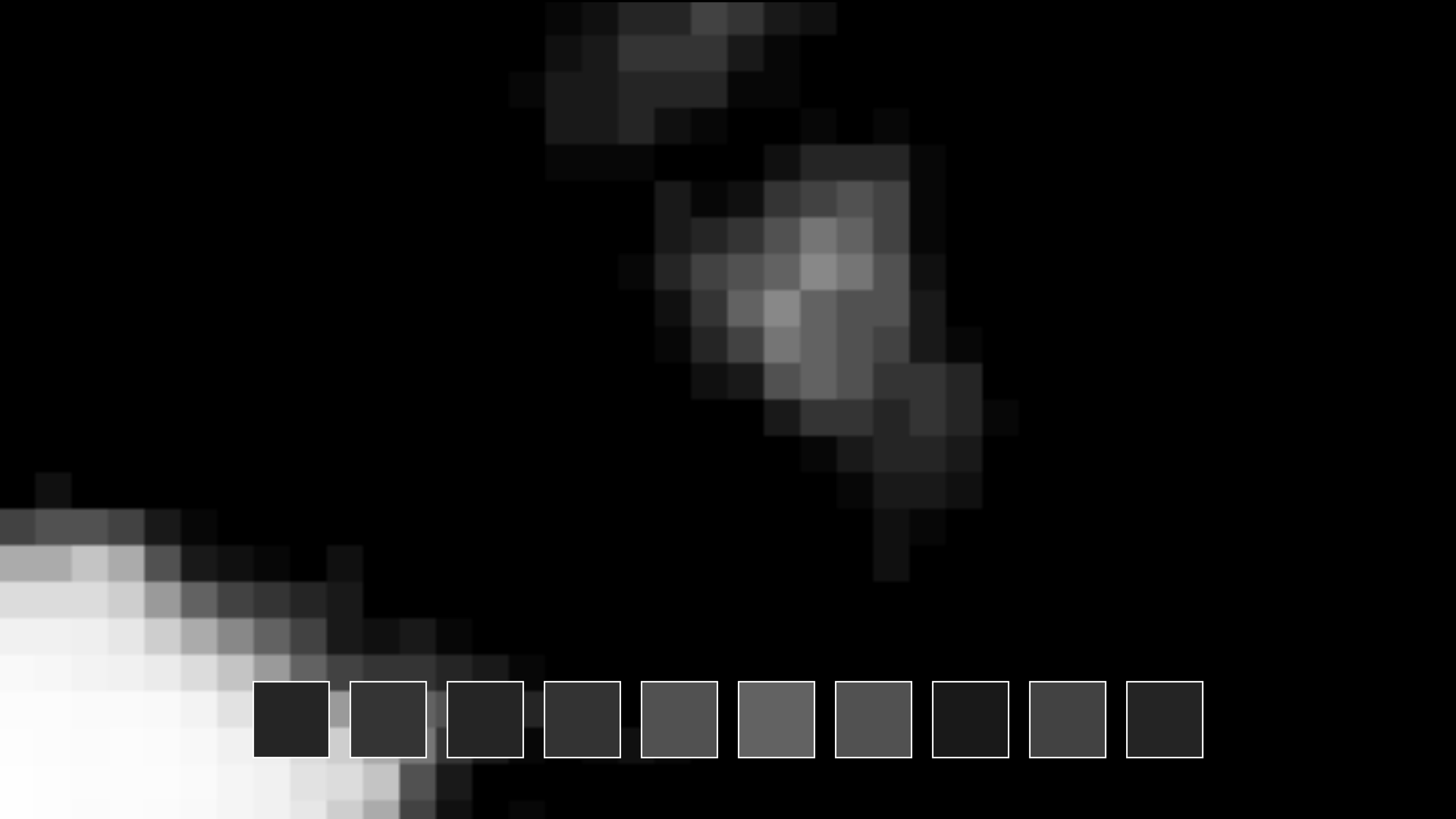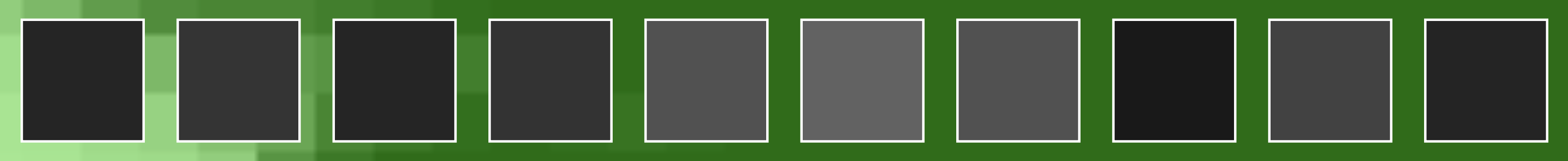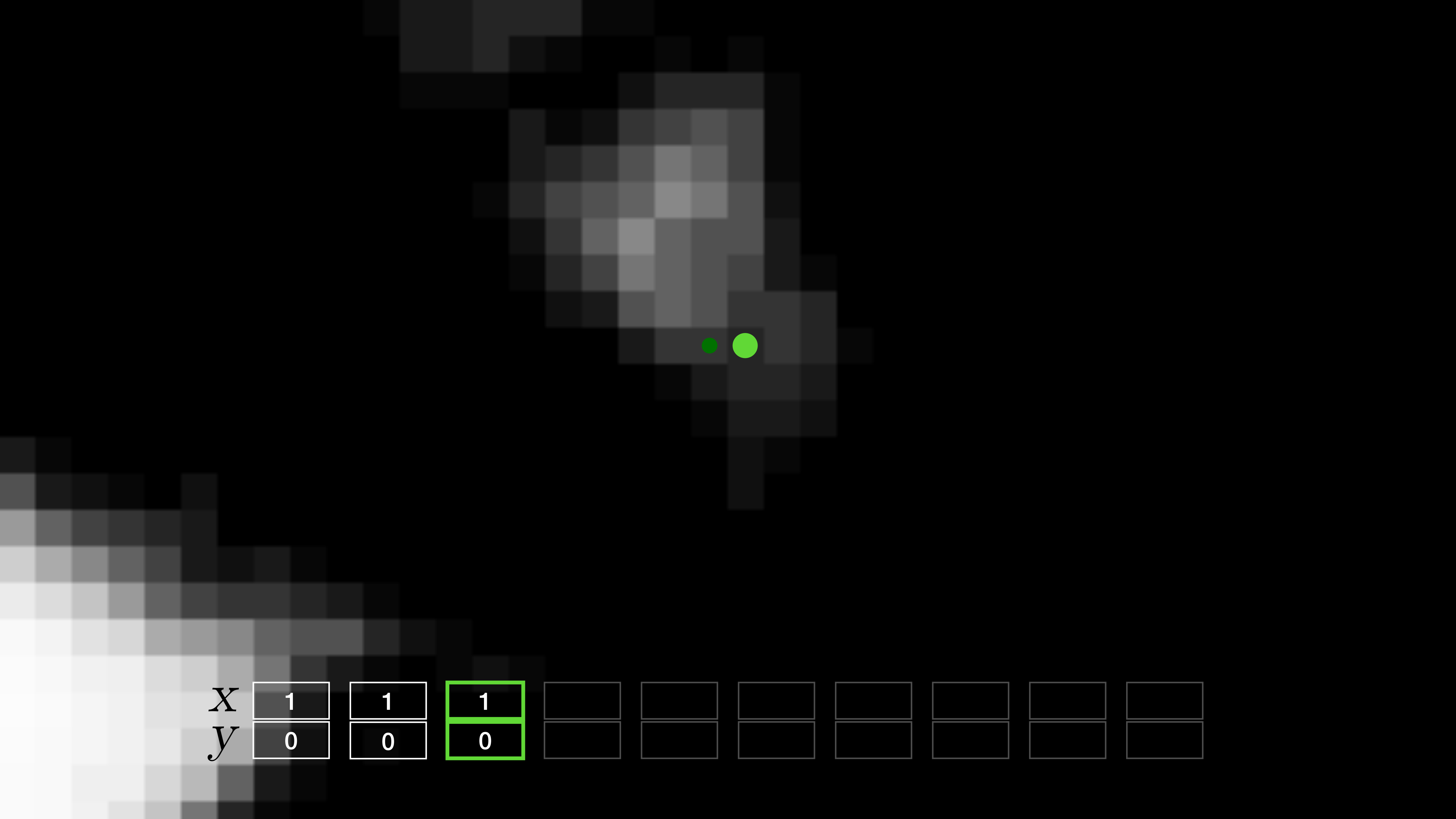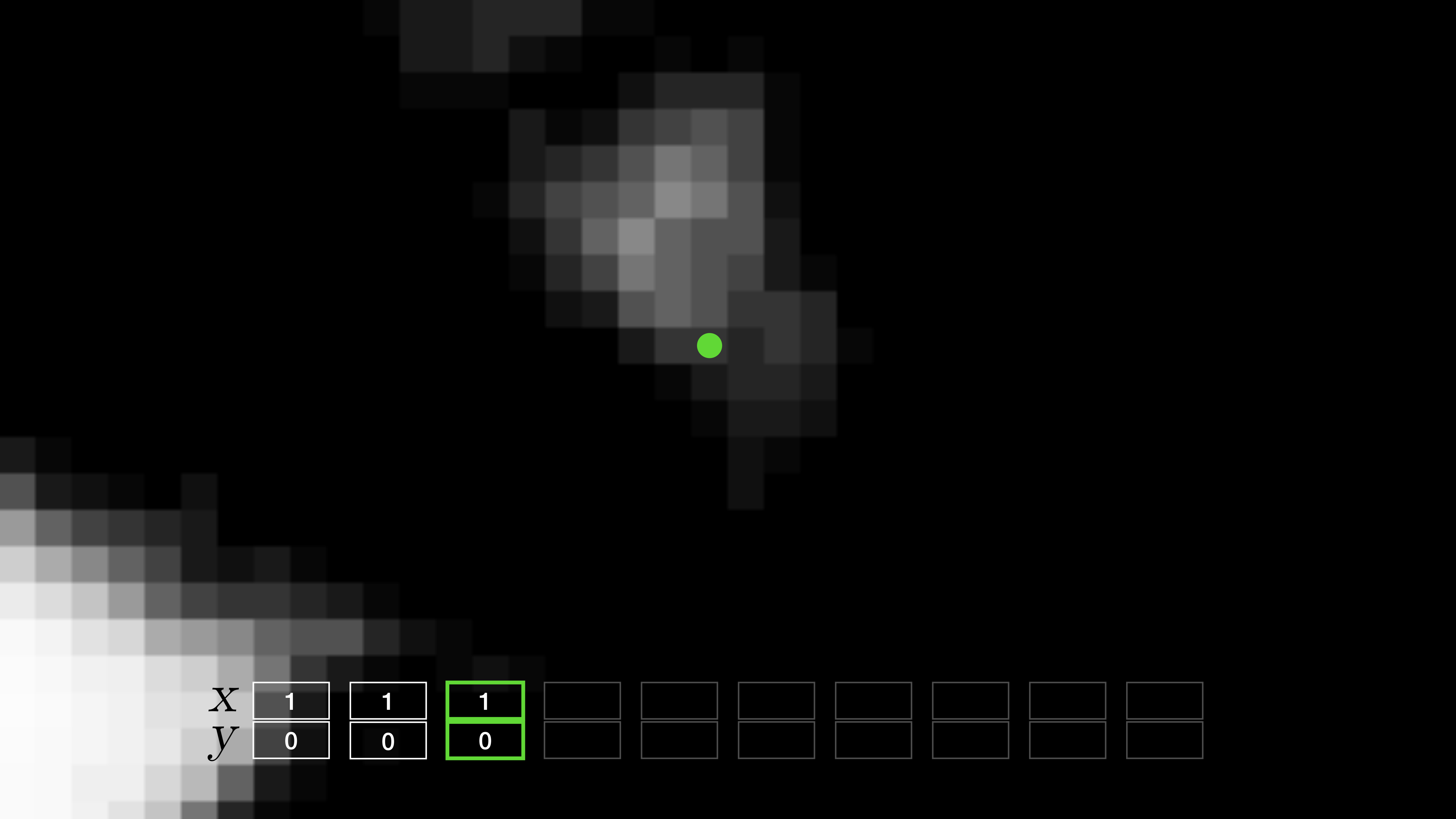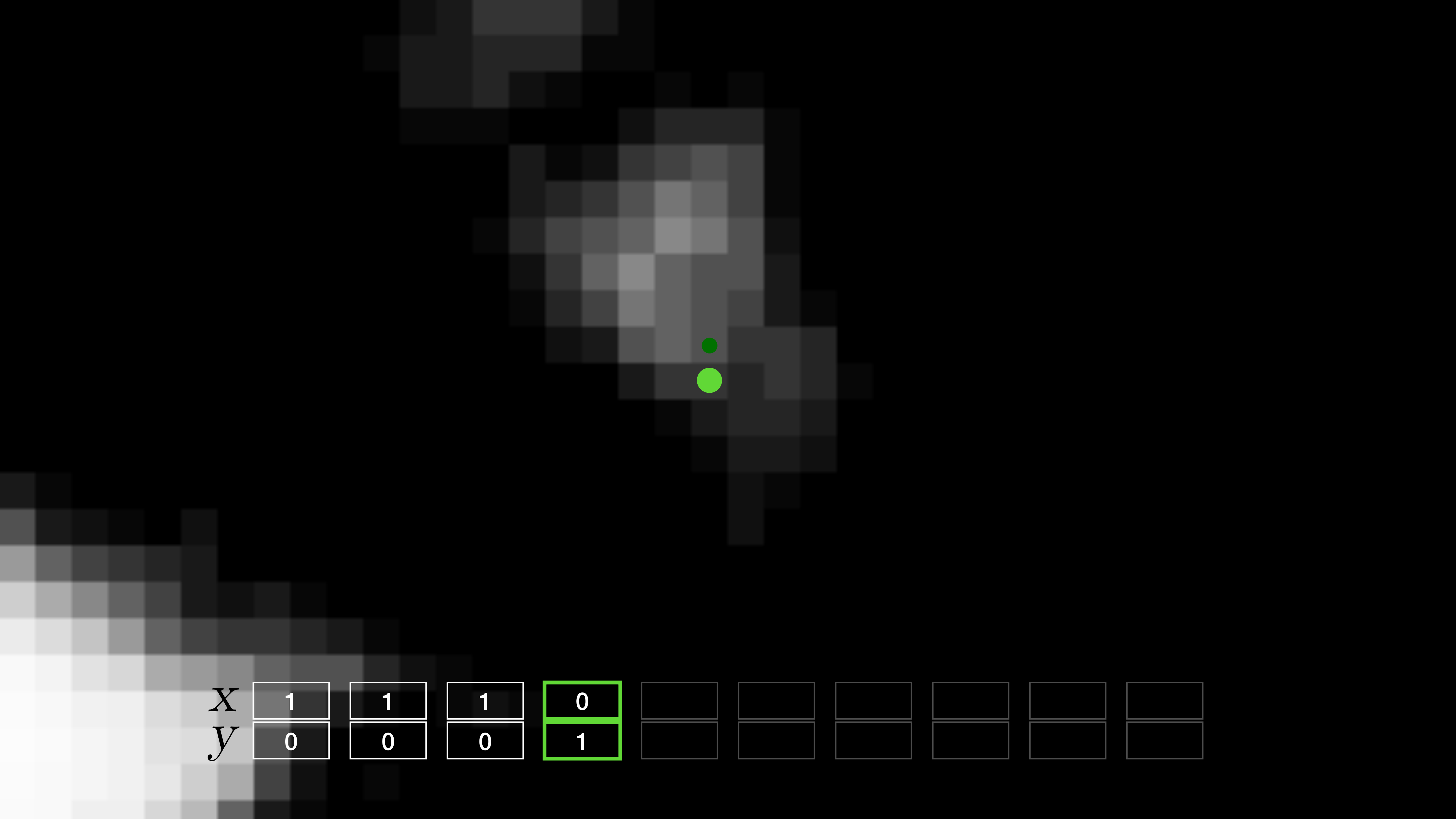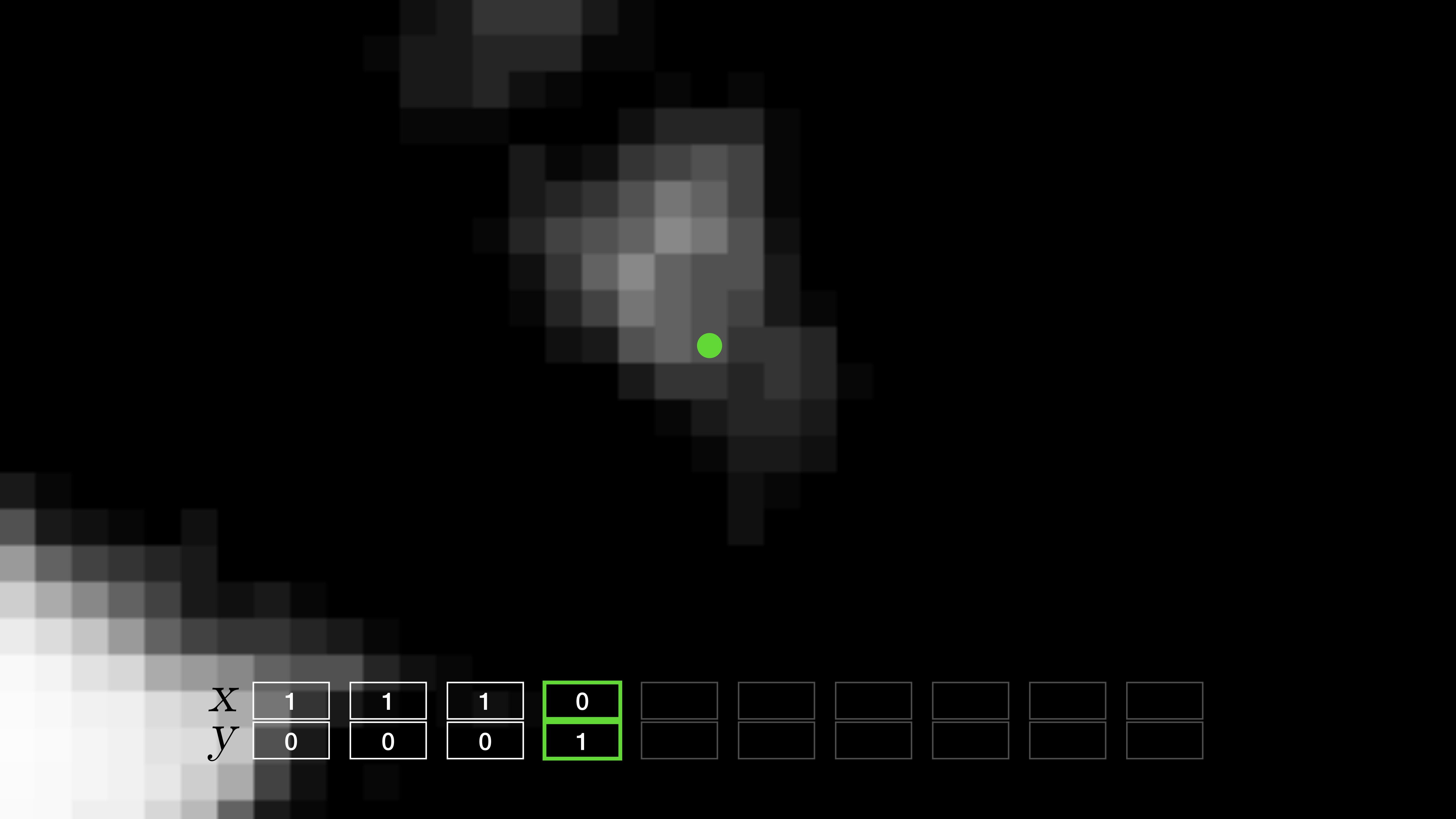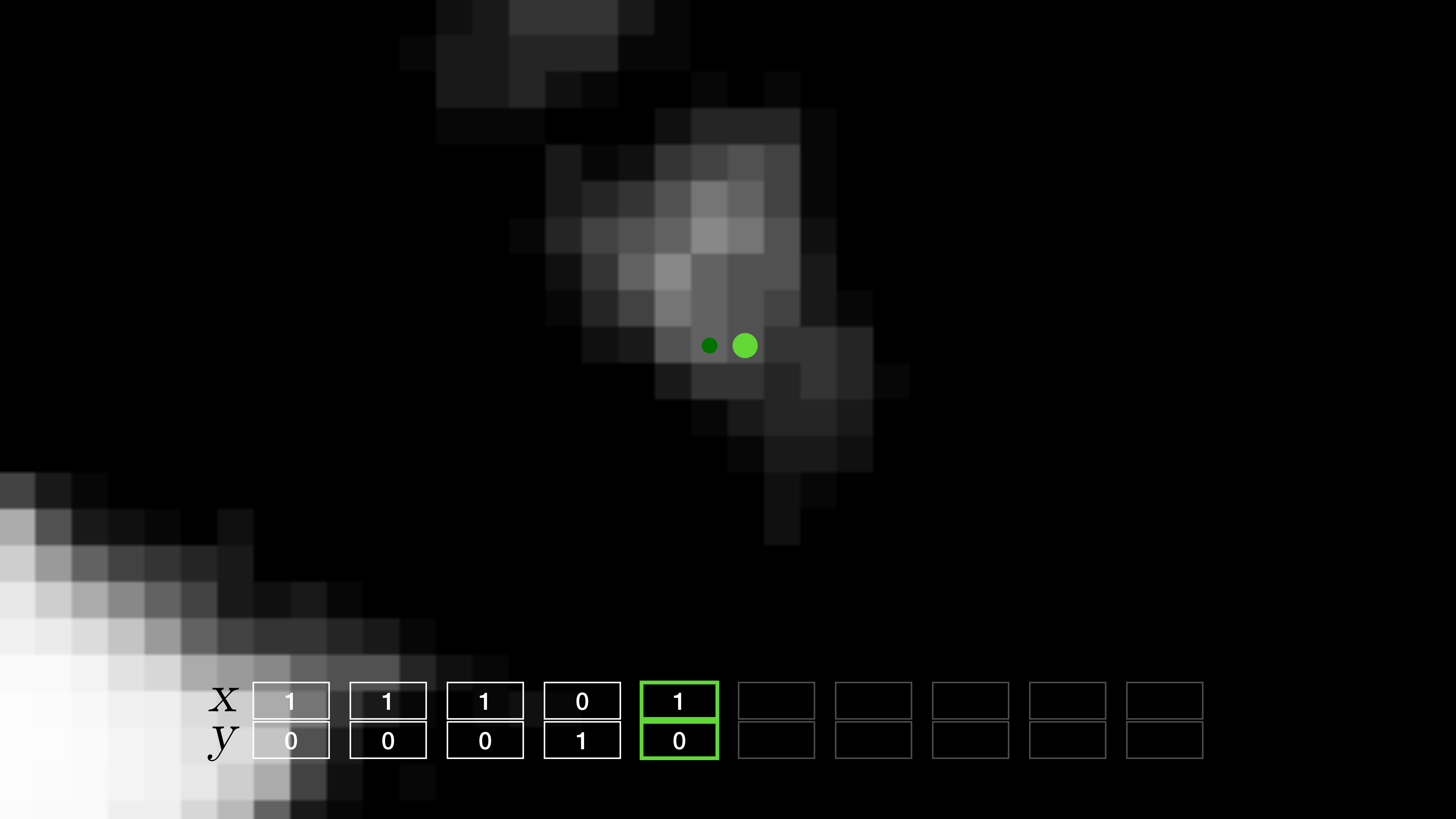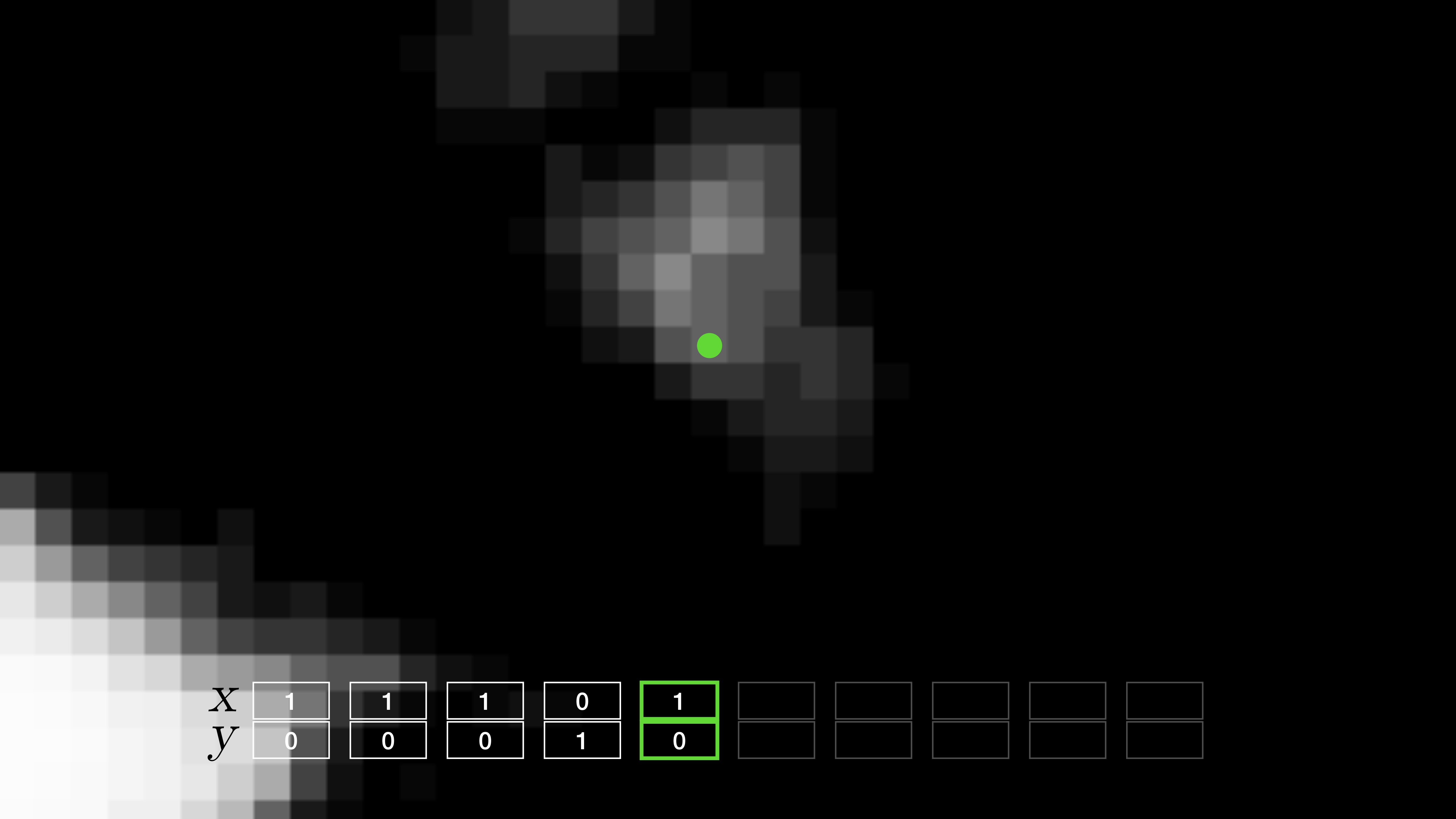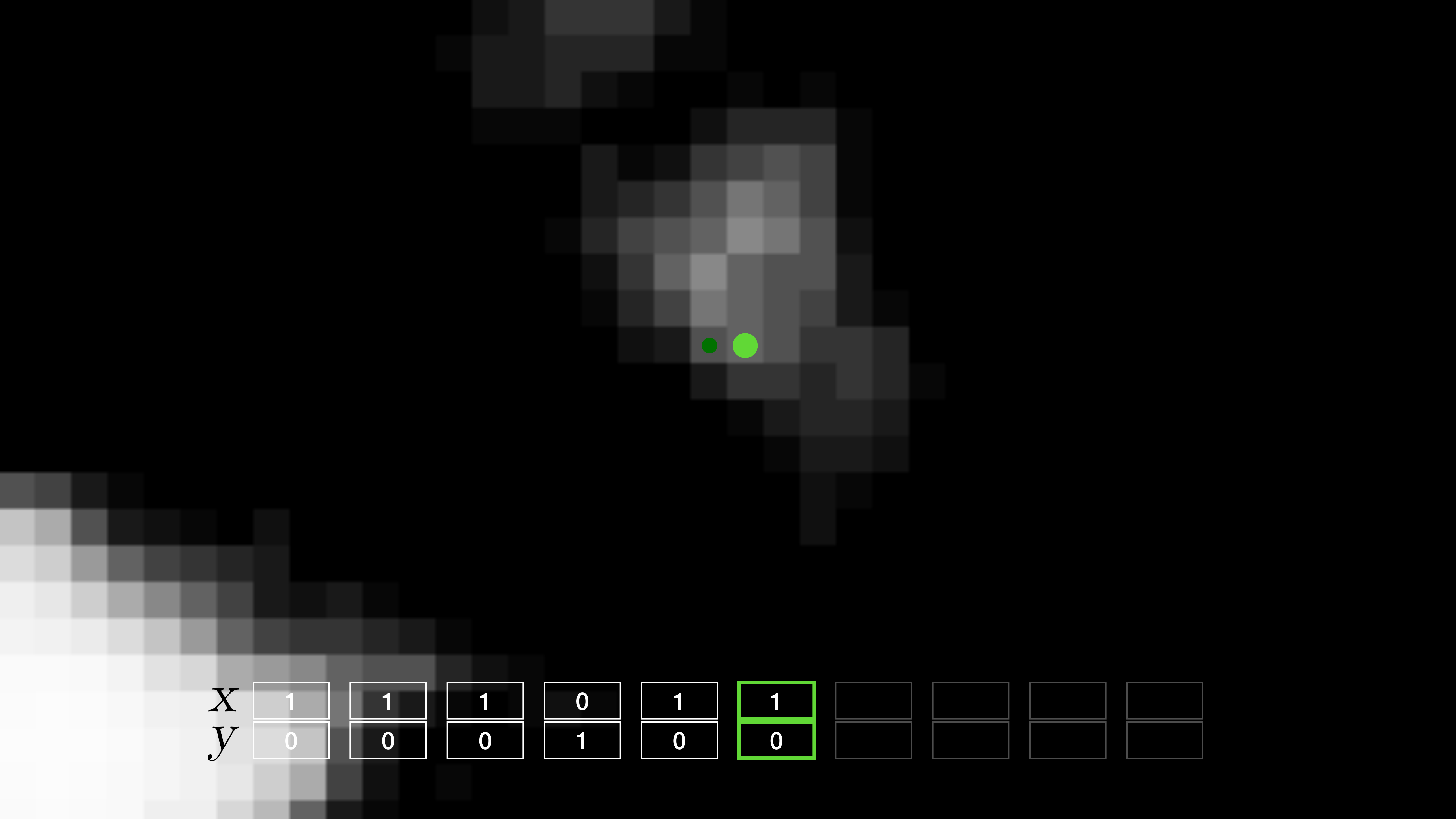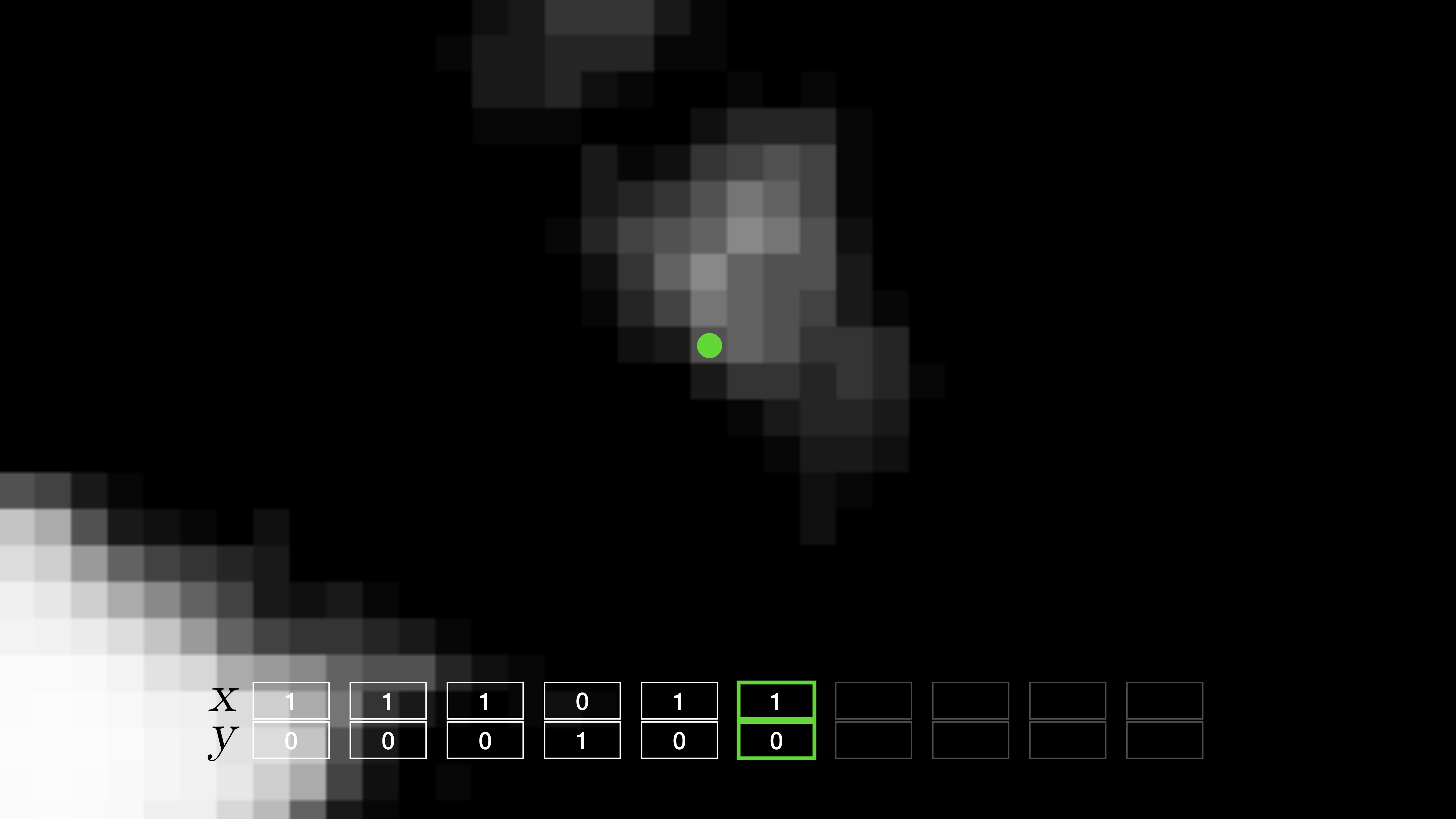
$x$ | 1 | 1 | 1 | | | | | | | |
$y$ | 0 | 0 | 0 | | | | | | | |

| $x$ | 1 | 1 | 1 | 0 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $y$ | 0 | 0 | 0 | 1 | | | | | | |

| $x$ | 1 | 1 | 1 | 0 | | | | | | |
| $y$ | 0 | 0 | 0 | 1 | | | | | | |

| $x$ | 1 | 1 | 1 | 0 | 1 | | | | | |
|-----|---|---|---|---|---|---|---|---|---|---|
| $y$ | 0 | 0 | 0 | 1 | 0 | | | | | |

|   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | 1 | 1 | 1 | 0 | 1 |   |   |   |   |   |
| $y$ | 0 | 0 | 0 | 1 | 0 |   |   |   |   |   |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | | | | |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | | | | |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | | | | |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | | | | |

$x$

| 1 | 1 | 1 | 0 | 1 | 1 | 1 | | | |
|---|---|---|---|---|---|---|---|---|---|

$y$
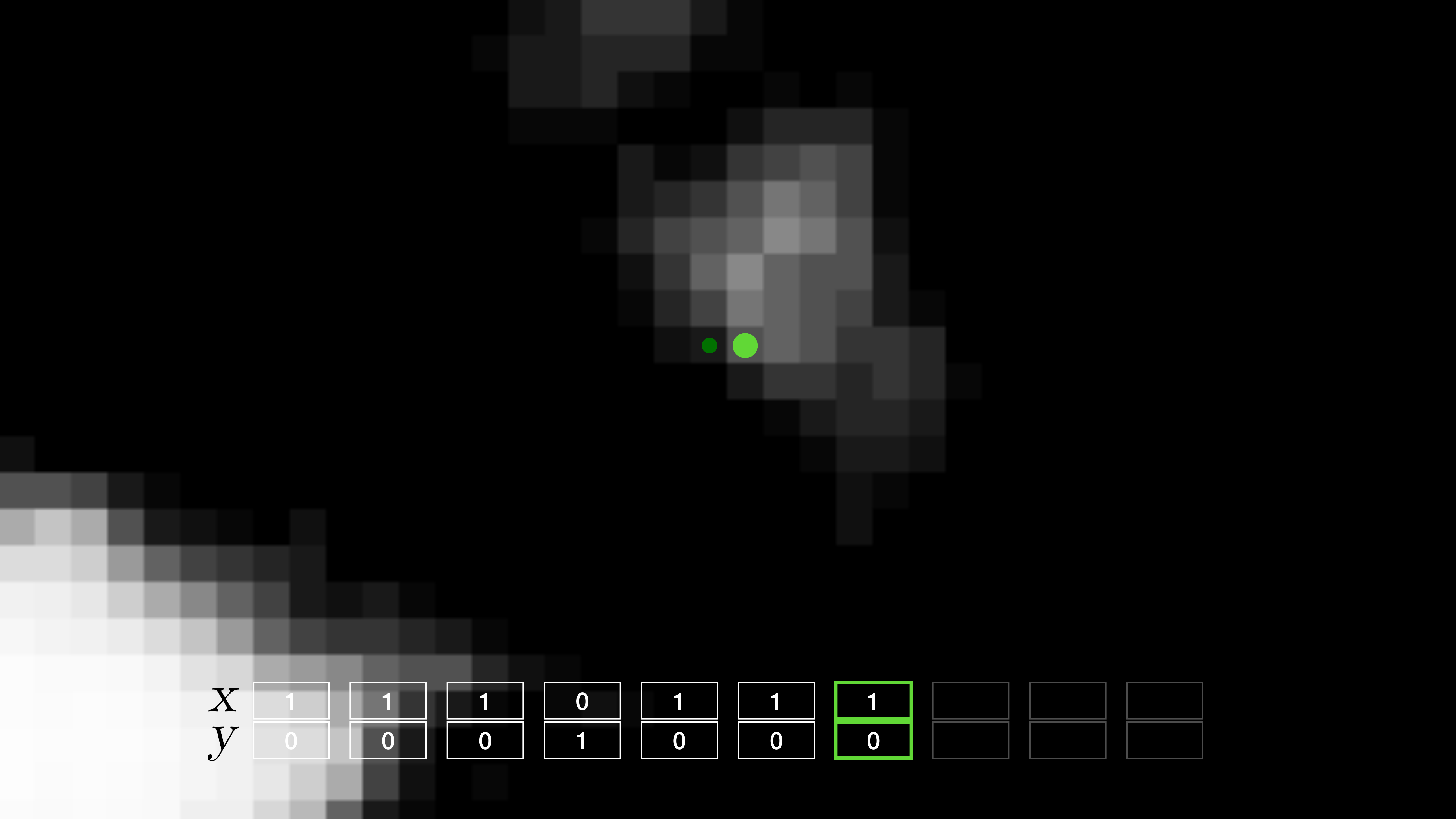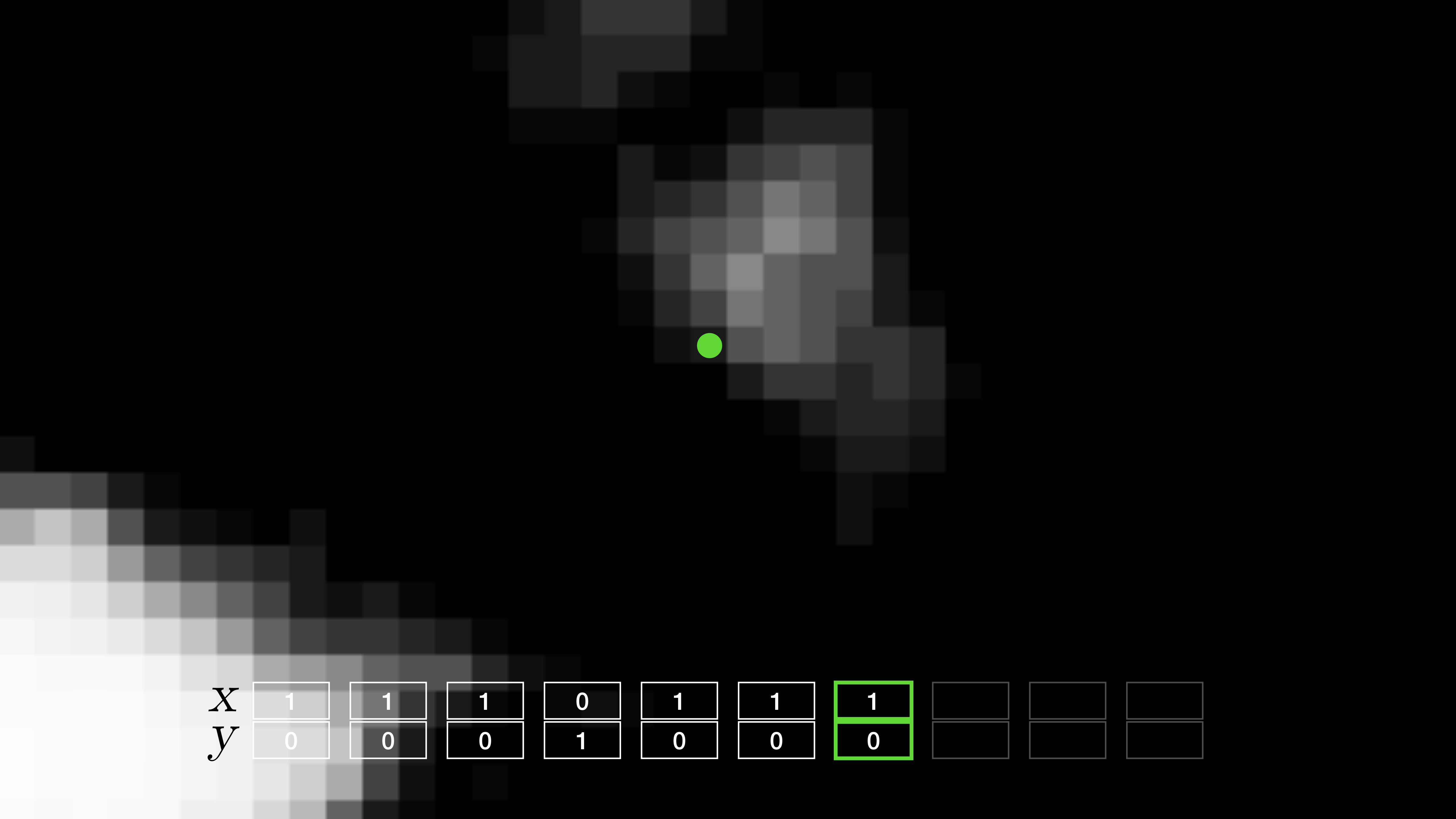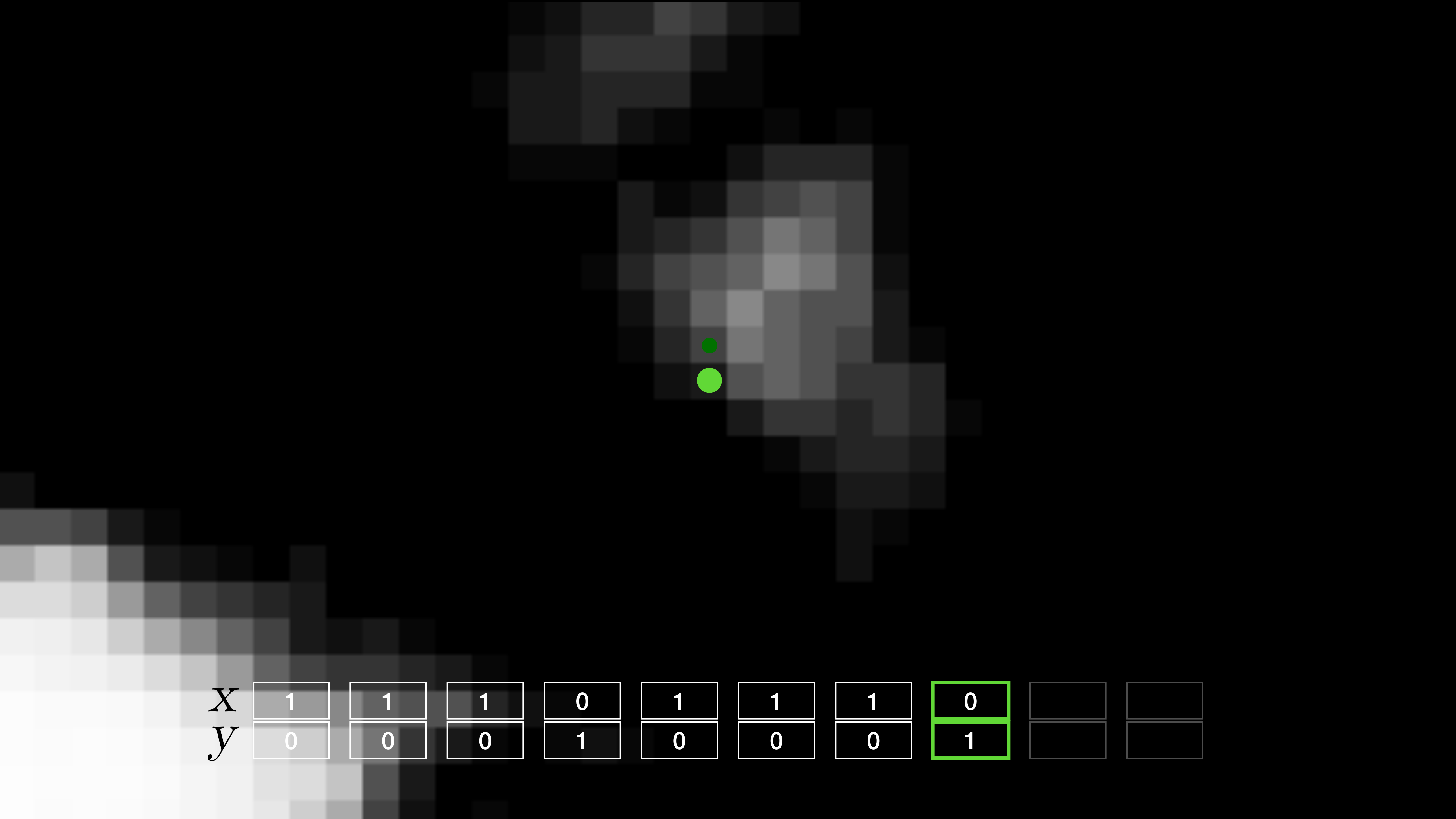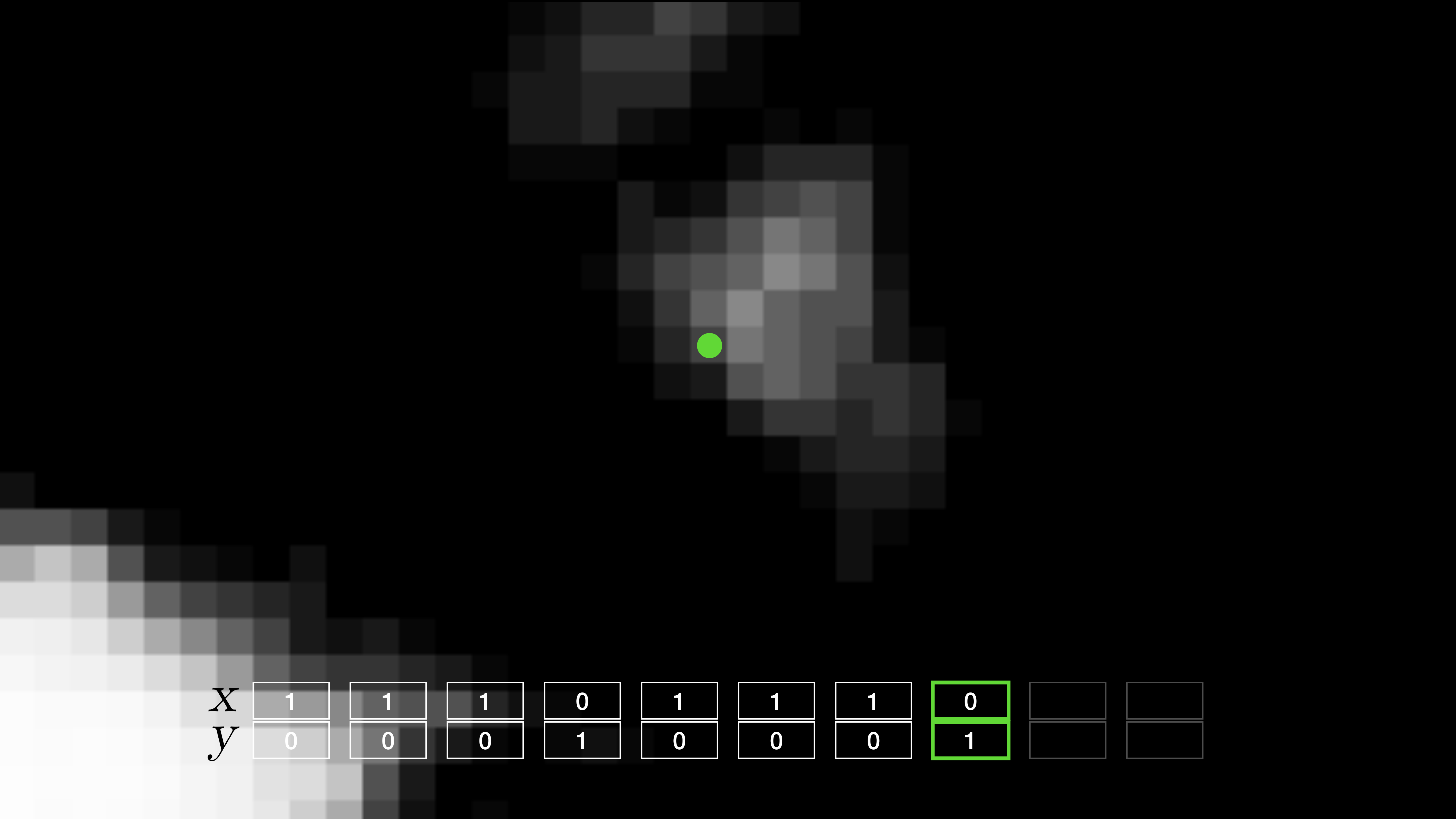
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | | | |
|---|---|---|---|---|---|---|---|---|---|

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | | | |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | | | |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | | |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | | |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | | |
|-----|---|---|---|---|---|---|---|---|---|---|
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | | |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | |
| --- | - | - | - | - | - | - | - | - | - | - |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | |

|   | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | |

| | $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| --- | - | - | - | - | - | - | - | - | - | - |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

| $x$ | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| $y$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
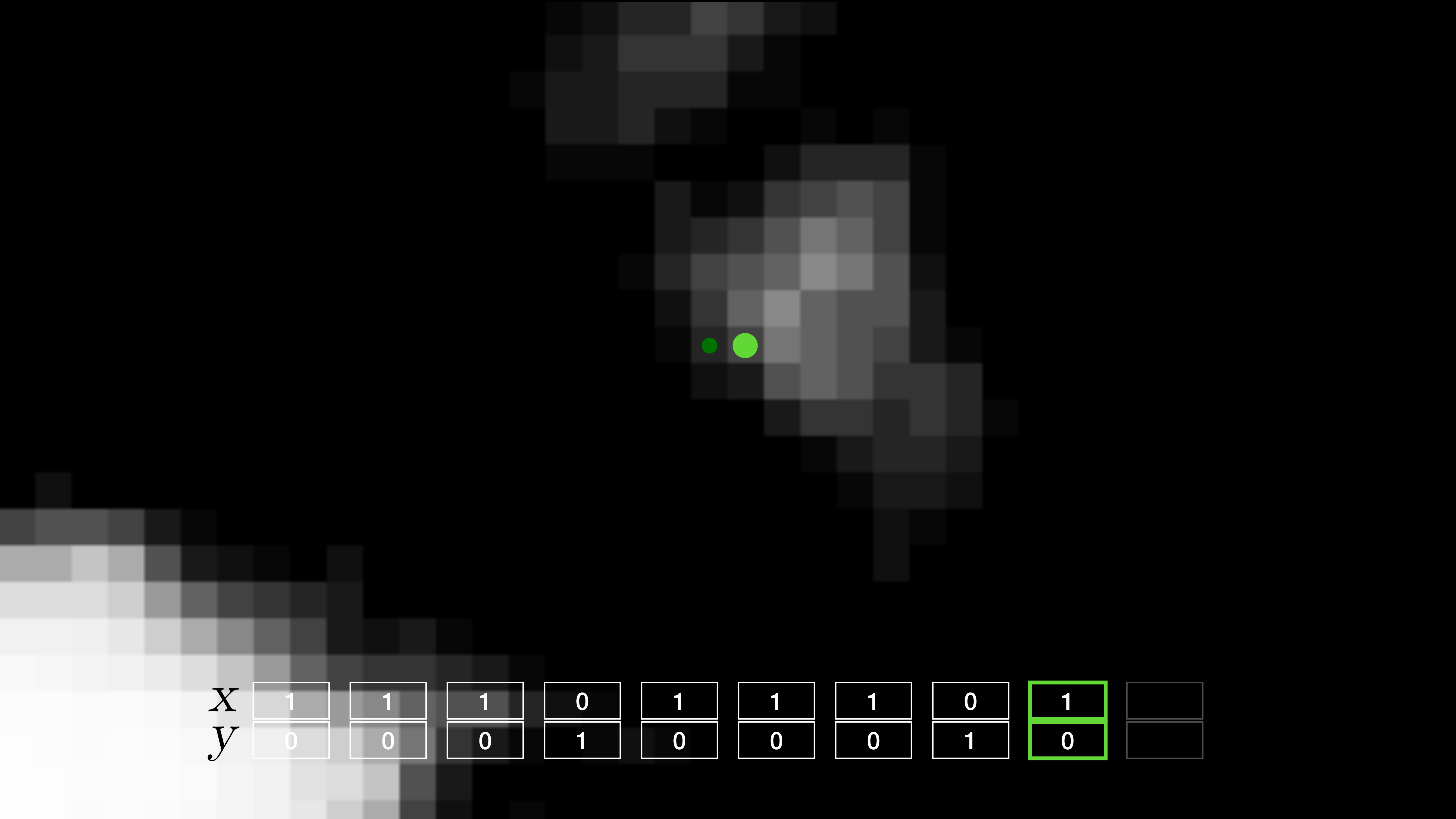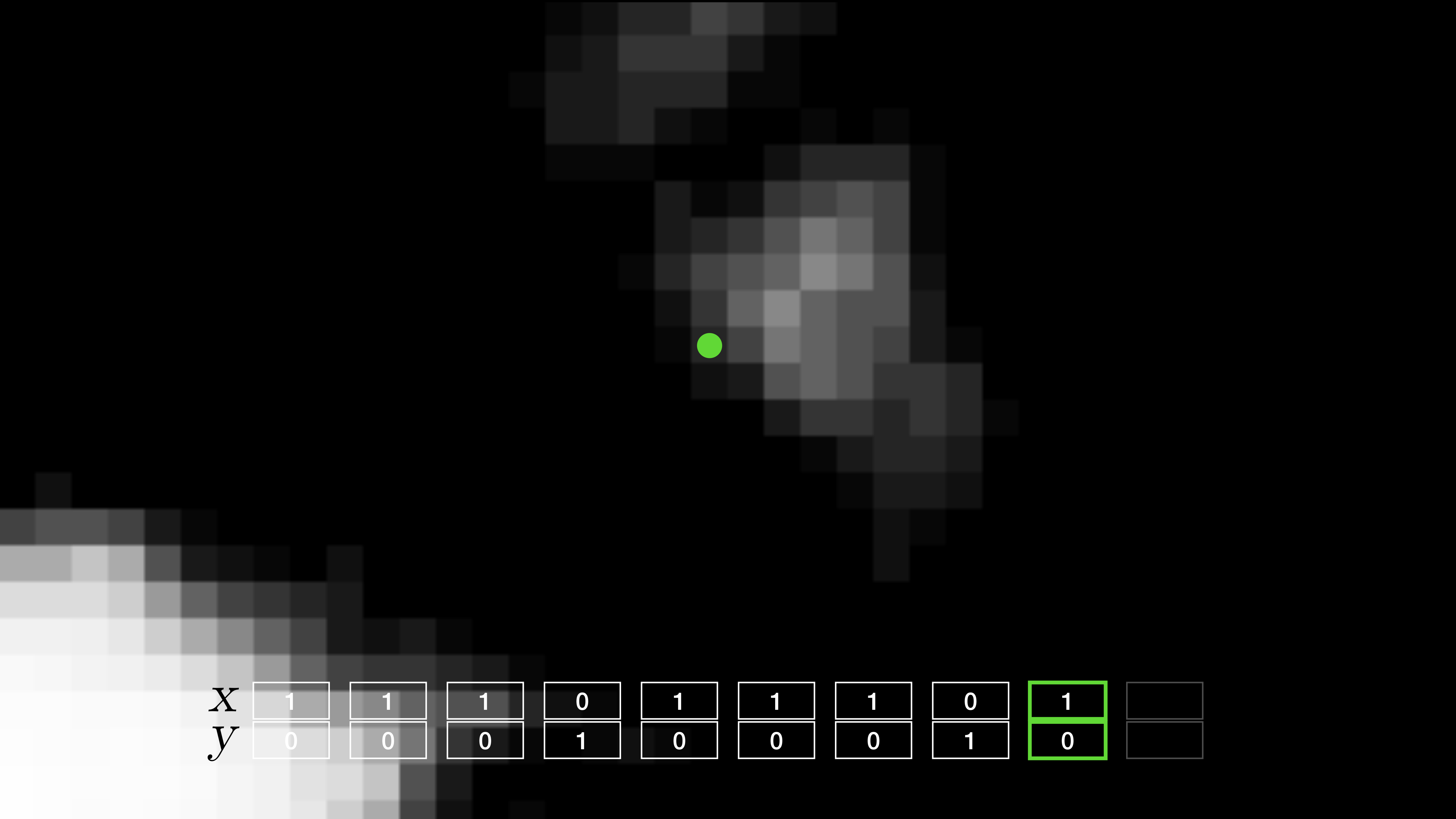
# Pixel brightness data



| frame 1 | frame 2 | frame 3 | frame 4 | frame 5 | frame 6 | frame 7 | frame 8 | frame 9 | frame 10 |
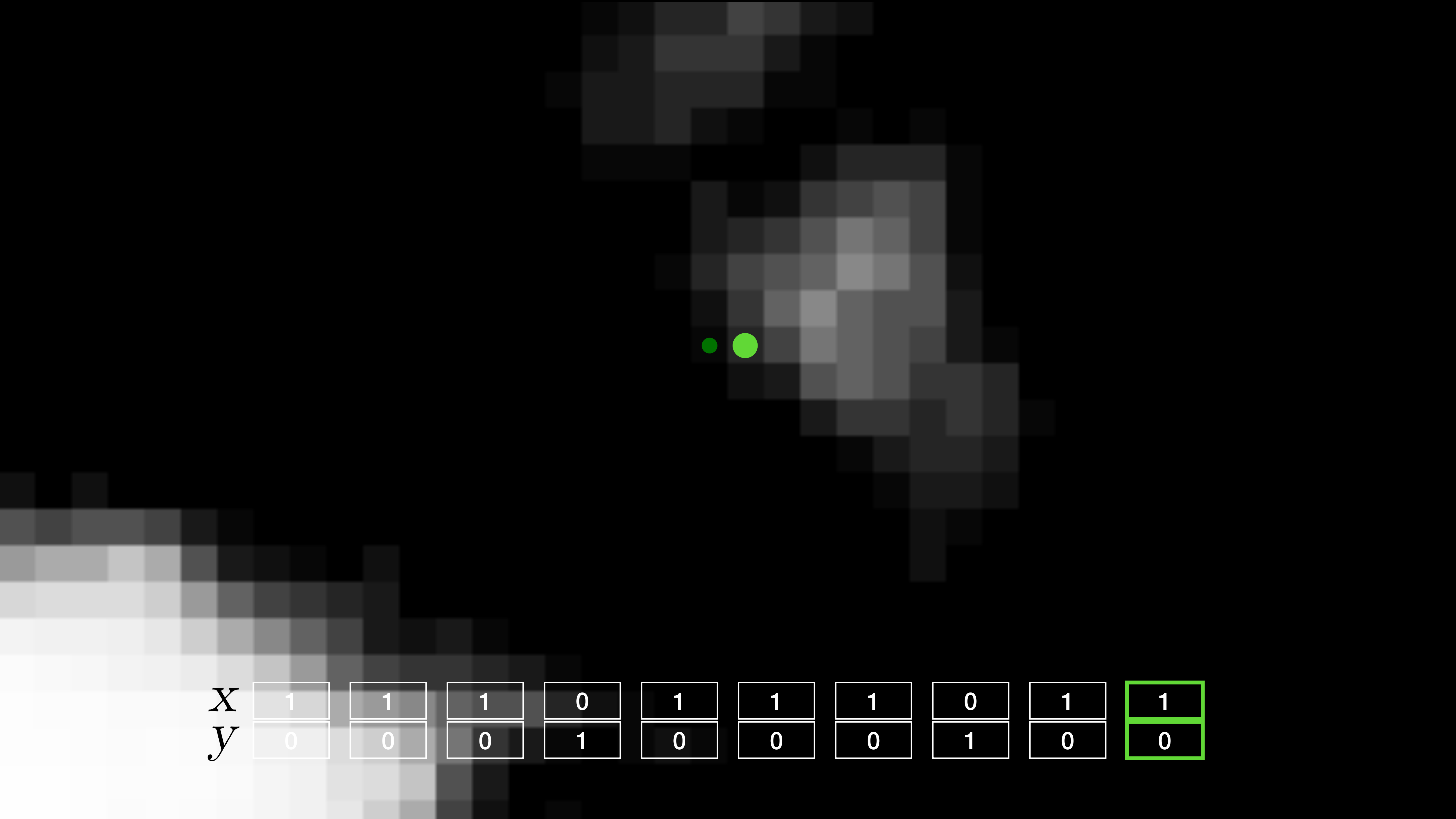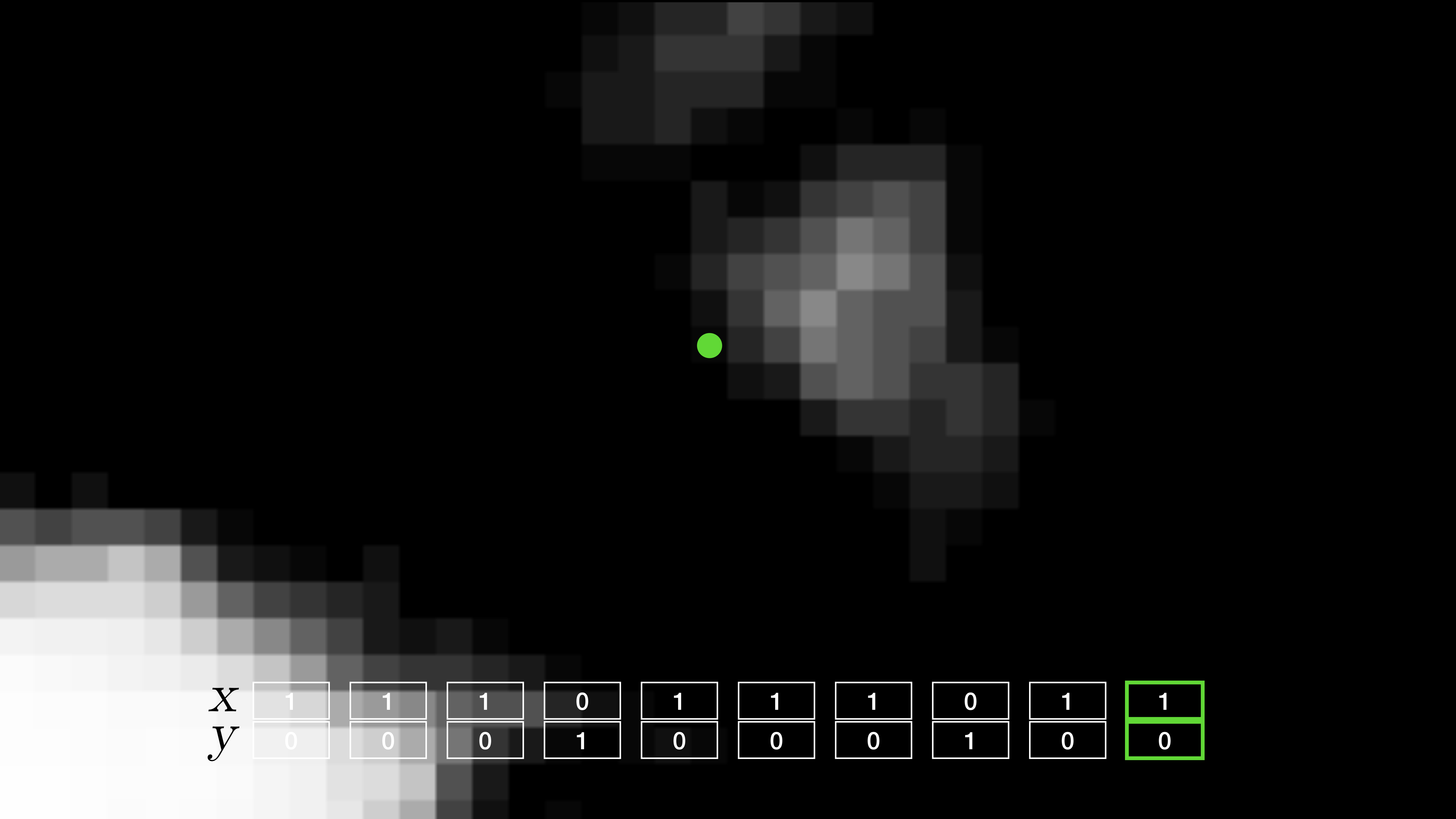
# Pixel motion data
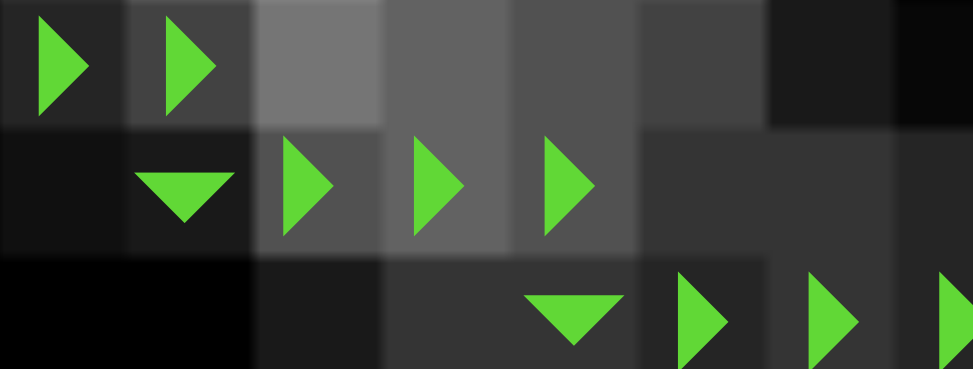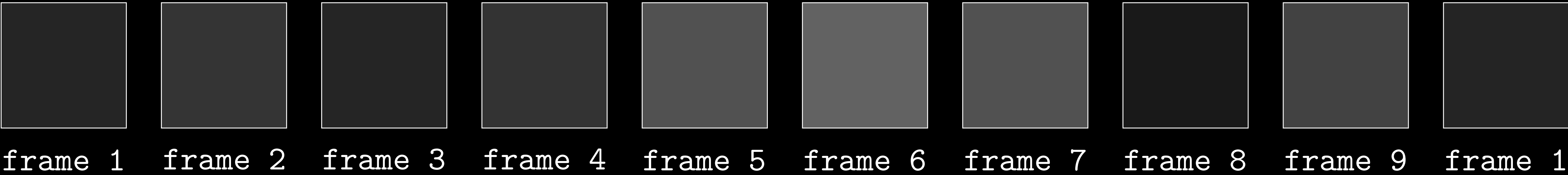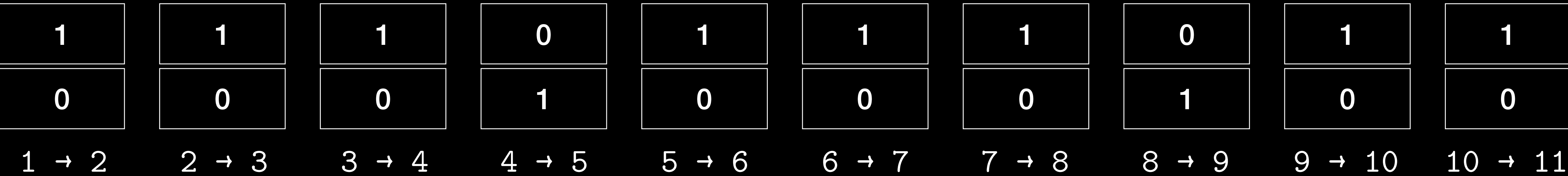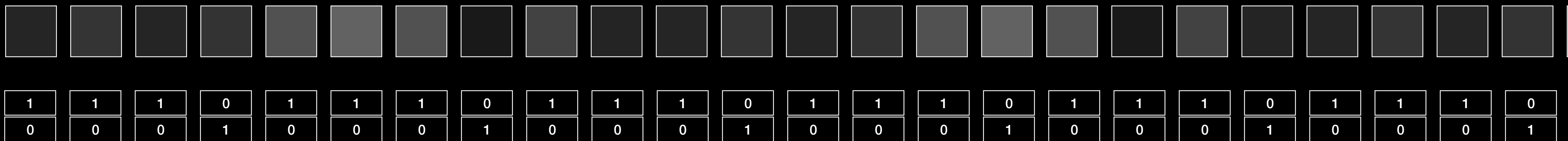
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

| 1 → 2 | 2 → 3 | 3 → 4 | 4 → 5 | 5 → 6 | 6 → 7 | 7 → 8 | 8 → 9 | 9 → 10 | 10 → 11 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

|   | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |
|   | 0 | 0 | 0 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 |
|   | 0 | 0 | 0 | 0 | 1 | 1 |
| 3 | 1 | 1 | 1 | 0 | 0 | 0 |
|   | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 |
|   | 1 | 1 | 1 | 1 | 1 | 1 |

$1 \rightarrow 2$

|   | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.02246 | 1.02576 | 1.01616 | 1.04350 | 1.74782 | 1.06209 |
|   | -0.01143 | -0.4596 | 0.3804 | 1.0055 | 1.64463 | 1.65841 |
| 2 | 1.0232 | 0.9910 | 0.9932 | 1.1044 | 1.5785 | 0.7234 |
|   | 0.0032 | 0.0334 | 0.1890 | 0.3045 | 0.7001 | 1.0033 |
| 3 | 0.5693 | 0.7203 | 0.8993 | 0.4323 | 0.2003 | 0.0234 |
|   | 0.7134 | 0.8024 | 0.9203 | 1.2304 | 1.4403 | 1.5774 |
| 4 | 0.5435 | 0.2232 | 0.1334 | 0.0021 | -0.0043 | -0.0123 |
|   | 0.5463 | 0.5343 | 1.0102 | 1.0324 | 1.1084 | 1.2192 |

1 → 2

frames

2 → 3

frames

$3 \rightarrow 4$

$4 \rightarrow 5$

Input Layer  Hidden Layer  Output Layer
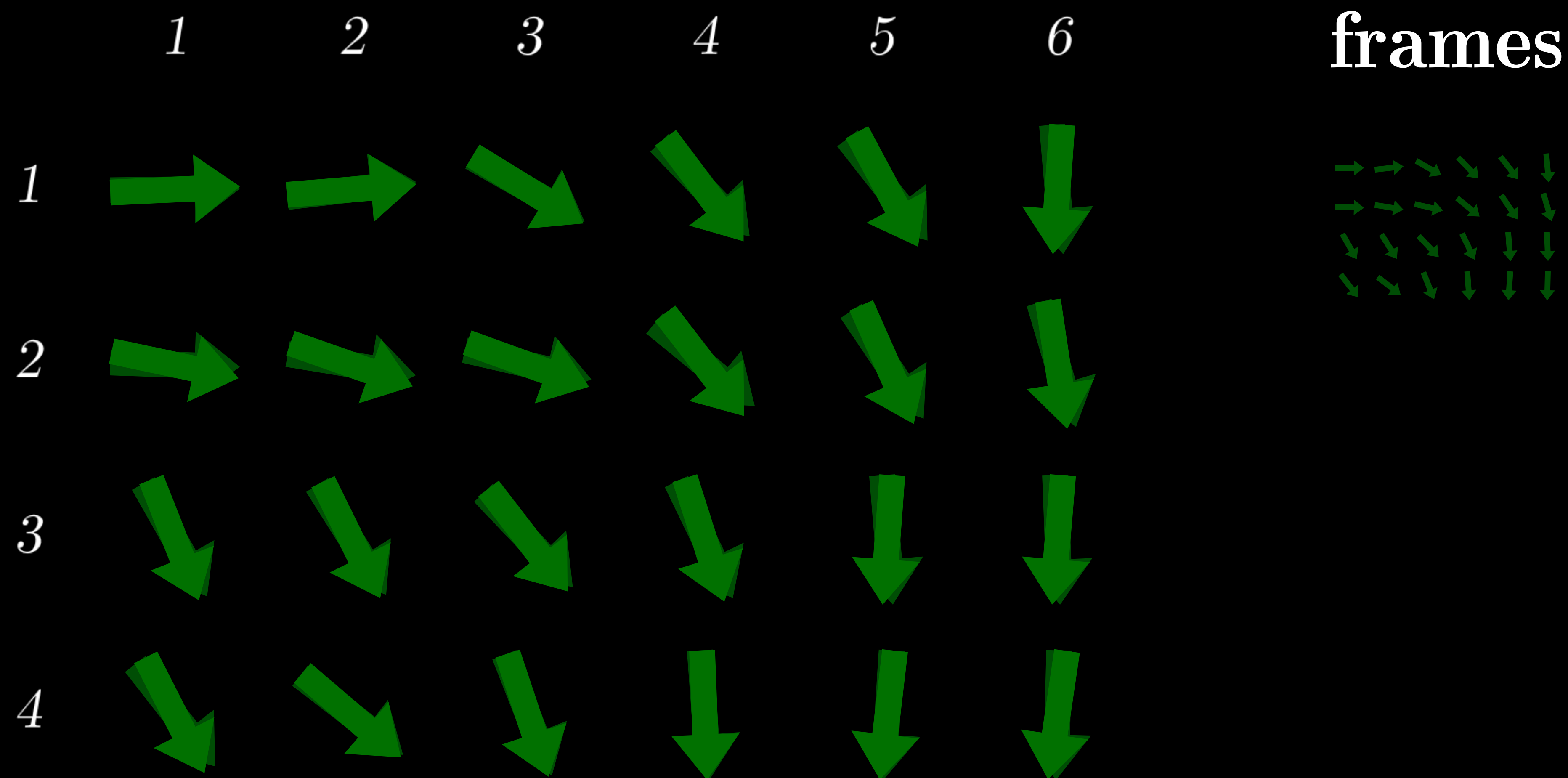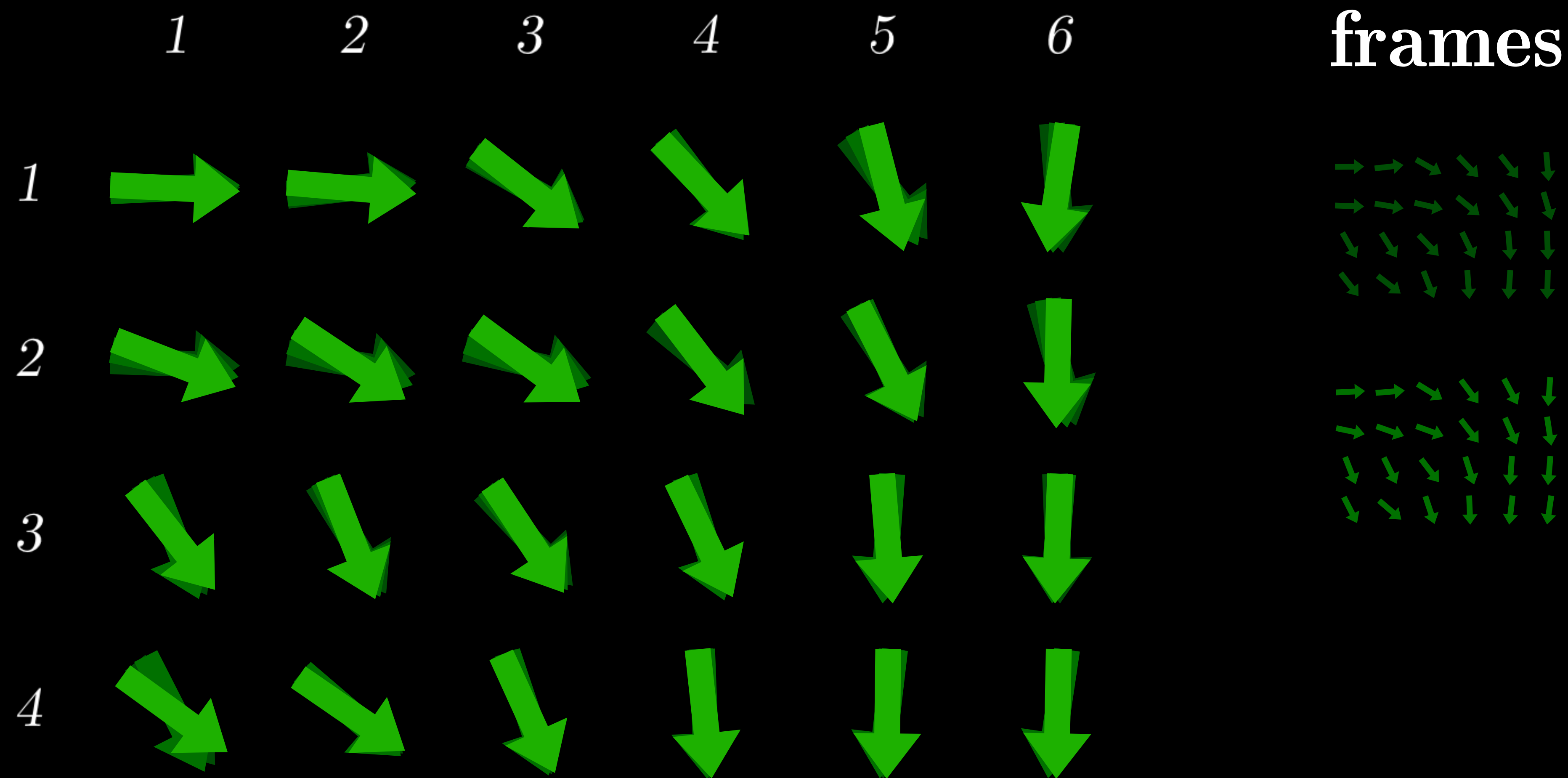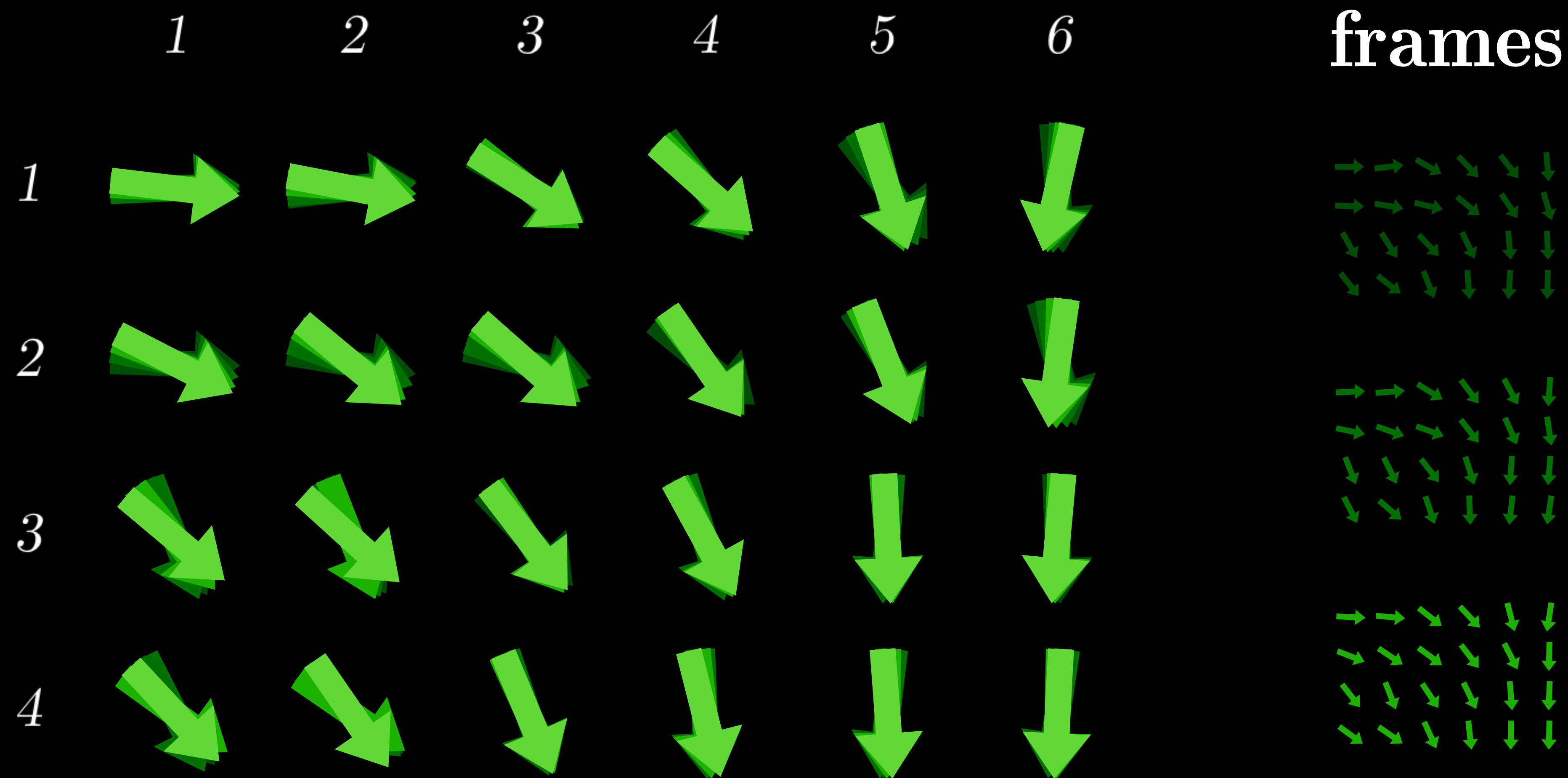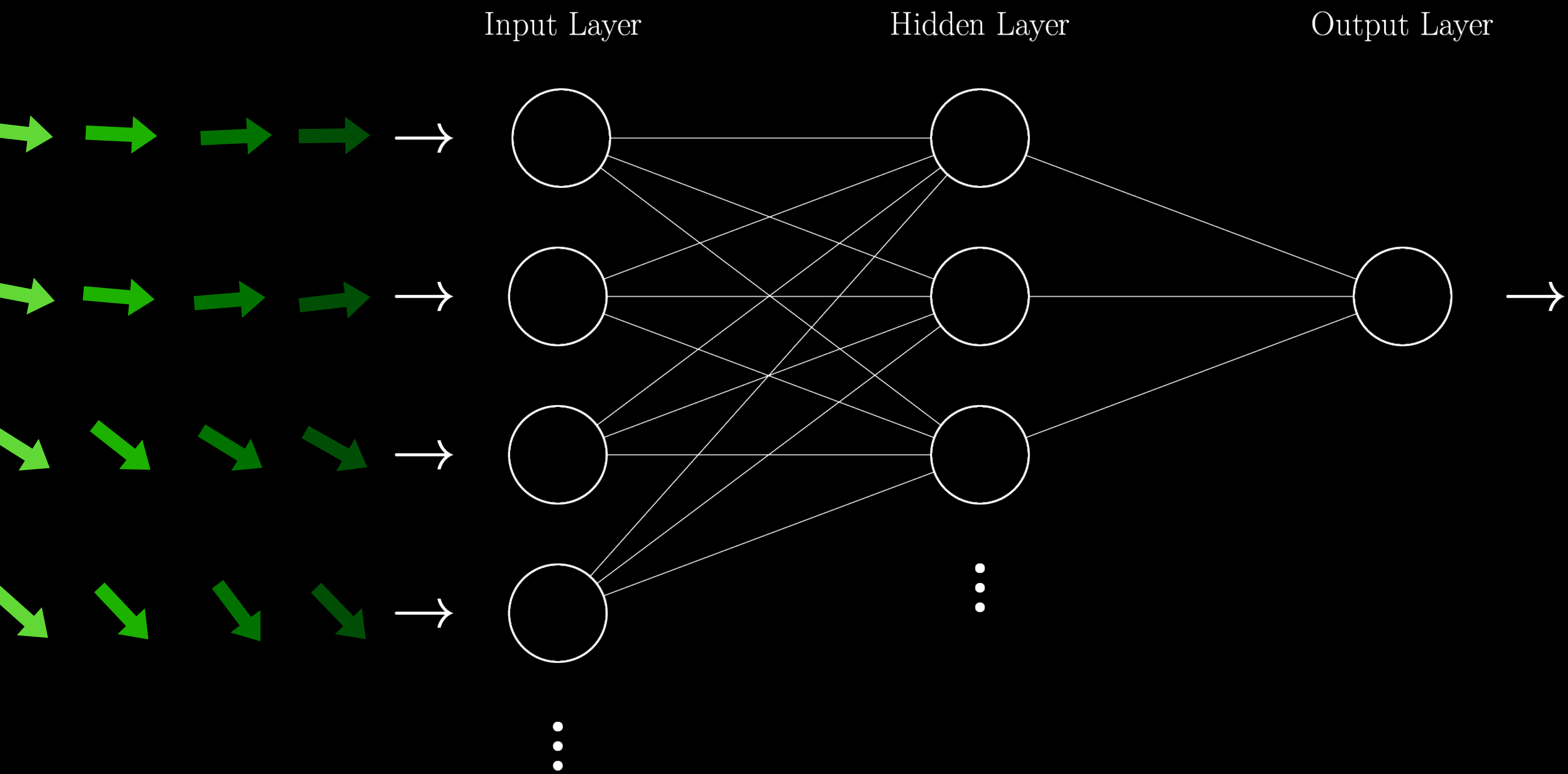
Input Layer          Hidden Layer          Output Layer
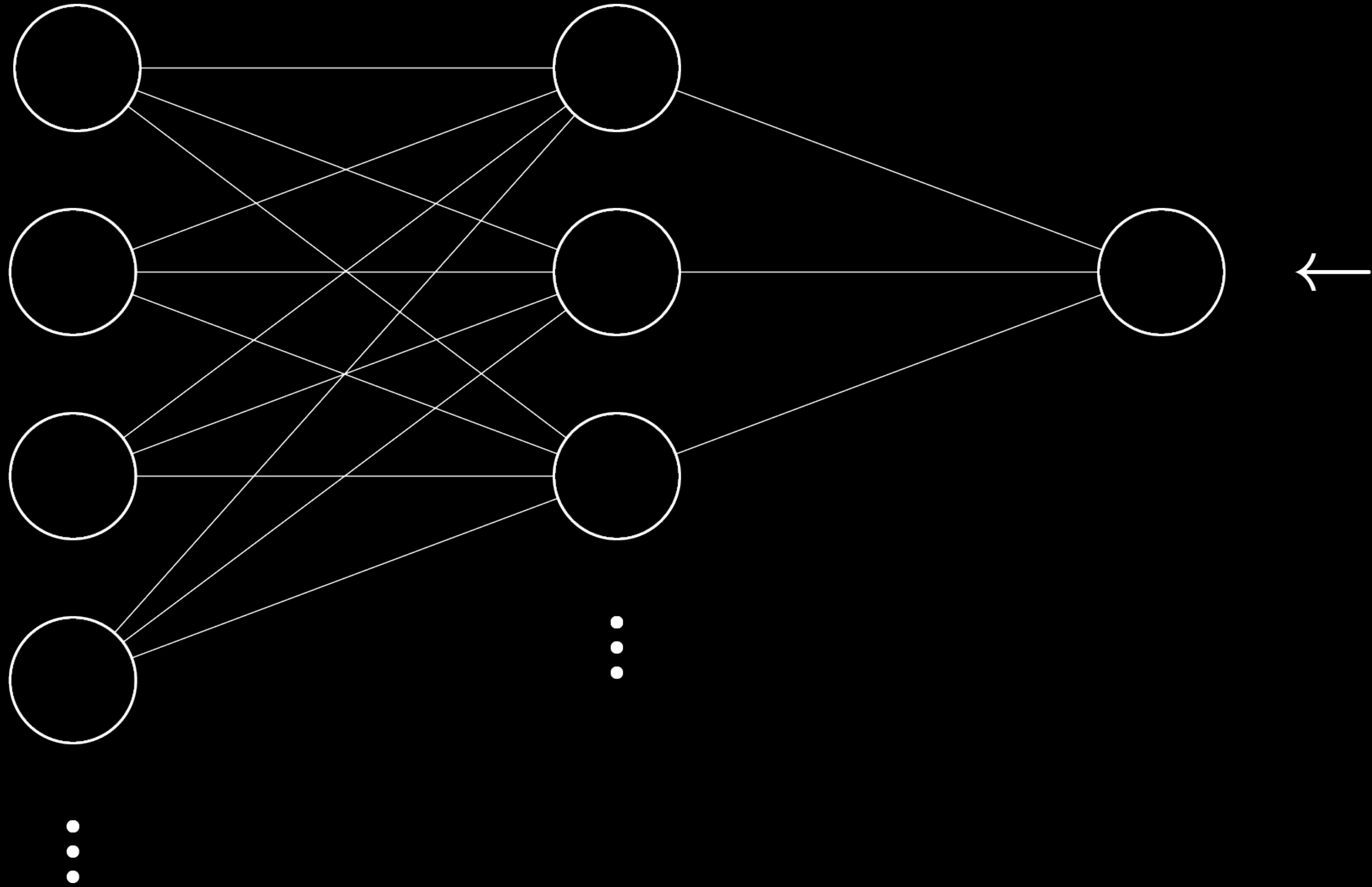
| Input Size | Training Epochs | Neighborhood Radius | Selection Type | Values |
|---|---|---|---|---|
| 4 | 1000 | 0 | Linear | 32 |
| | | | Random | |
| | | 1 | Linear | 288 |
| | | | Random | |
| | | 2 | Linear | 800 |
| | | | Random | |
| | 10 000 | 0 | Linear | 32 |
| | | | Random | |
| | | 1 | Linear | 288 |
| | | | Random | |
| | | 2 | Linear | 800 |
| | | | Random | |
| | 100 000 | 0 | Linear | 32 |
| | | | Random | |
| | | 1 | Linear | 288 |
| | | | Random | |
| | | 2 | Linear | 800 |
| | | | Random | |

| Input Size | Training Epochs | Neighborhood Radius | Selection Type | Mean Error | Training Time |
|---|---|---|---|---|---|
| 4 | 1000 | 0 | Linear | 0.0102 | 00:01.679 |
| | | | Random | 0.0288 | 00:01.618 |
| | | 1 | Linear | 0.0075 | 00:01.625 |
| | | | Random | 0.0227 | 00:01.680 |
| | | 2 | Linear | 0.0041 | 00:01.678 |
| | | | Random | 0.0176 | 00:01.728 |
| | 10 000 | 0 | Linear | 0.0076 | 00:16.124 |
| | | | Random | 0.0062 | 00:15.923 |
| | | 1 | Linear | 0.0055 | 00:15.970 |
| | | | Random | 0.0215 | 00:15.986 |
| | | 2 | Linear | 0.0046 | 00:16.721 |
| | | | Random | 0.0108 | 00:17.510 |
| | 100 000 | 0 | Linear | 0.0024 | 02:41.294 |
| | | | Random | 0.0043 | 02:39.883 |
| | | 1 | Linear | 0.0014 | 02:49.710 |
| | | | Random | 0.0128 | 02:40.887 |
| | | 2 | Linear | 0.0013 | 03:05.169 |
| | | | Random | 0.0071 | 02:49.830 |

| Input Size | Training Epochs | Neighborhood Radius | Selection Type | Mean Error | Training Time |
|---|---|---|---|---|---|
| 16 | 1000 | 0 | Linear | 0.0110 | 00:01.906 |
| | | | Random | 0.0110 | 00:02.029 |
| | | 1 | Linear | 0.5000 | 00:01.979 |
| | | | Random | 0.0085 | 00:02.150 |
| | | 2 | Linear | 0.4999 | 00:02.126 |
| | | | Random | 0.5176 | 00:02.296 |
| | 10 000 | 0 | Linear | 0.0108 | 00:18.734 |
| | | | Random | 0.0025 | 00:19.465 |
| | | 1 | Linear | 0.0105 | 00:18.642 |
| | | | Random | 0.0070 | 00:19.789 |
| | | 2 | Linear | 0.0076 | 00:19.279 |
| | | | Random | 2.35e-06 | 00:20.560 |
| | 100 000 | 0 | Linear | 0.0107 | 03:08.697 |
| | | | Random | 0.0089 | 03:06.621 |
| | | 1 | Linear | 0.0070 | 03:07.029 |
| | | | Random | 0.0190 | 03:38.659 |
| | | 2 | Linear | 0.0052 | 03:11.950 |
| | | | Random | 0.4493 | 03:23.349 |
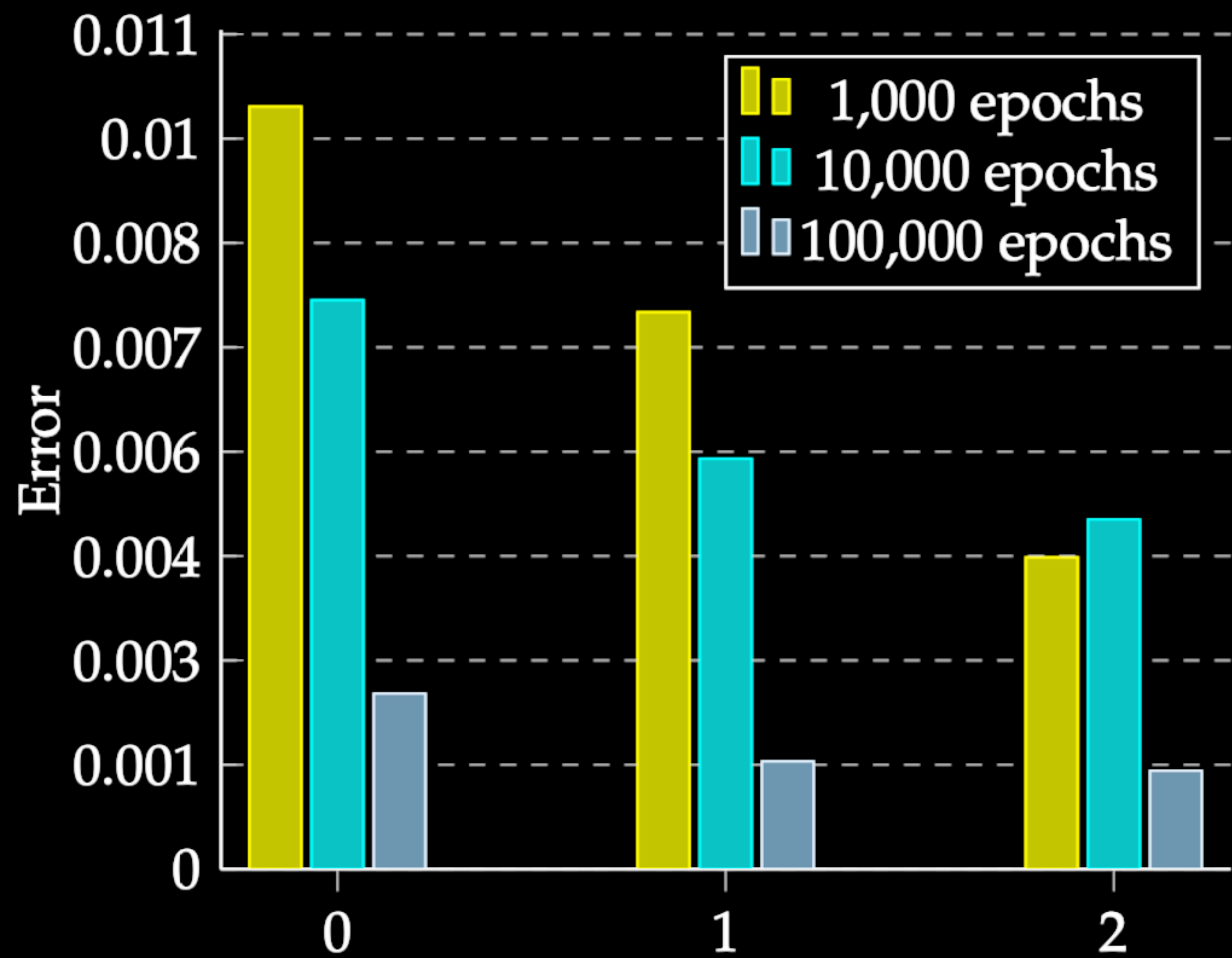
# NOTE

- Now testing with a larger dataset of:
  - 1920 x 1080 pixel images, spanning over
  - two years (about 16 000 images), at
  - 30-minute intervals; and

- Implementing a Convolutional Neural Network

# Conclusions

# THANK YOU!

# Prediction of Cloud Movement from Satellite Images using Neural Networks

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Department of Computer Science

Romania

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