MAI4CAREU

Master programmes in Artificial Intelligence 4 Careers in Europe

Visual Computing Group

CYENS CENTRE OF EXCELLENCE

University of Cyprus – MSc Artificial Intelligence

MAI644 – COMPUTER VISION

Lecture 4: Interpolation – Resizing

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Last time

- Pinhole Camera model
  - Aperture
  - Camera Obscura
- Cameras with lenses
  - Thin lens equation
  - Depth of field
  - Field of view
- Digital cameras
  - Bayer filters
  - Debayering

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Today’s Agenda

- Image basics
  - What is an image – addressing pixels
  - Image as a function – image coordinates
- Image interpolation
  - Nearest neighbor
  - Bilinear
  - Bicubic
- Image resizing
  - Enlarge
  - Shrink

[material based on Joseph Redmon’s course]

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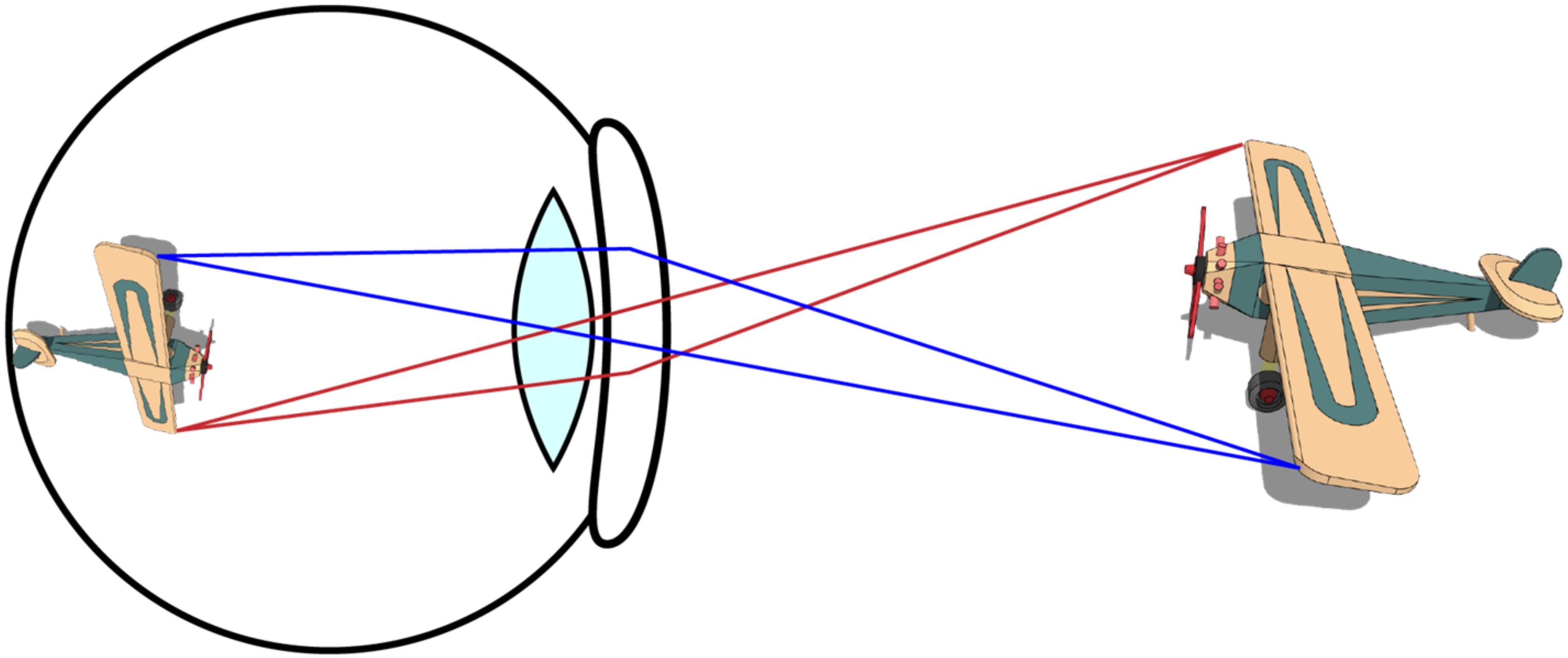
Eyes: projection onto retina



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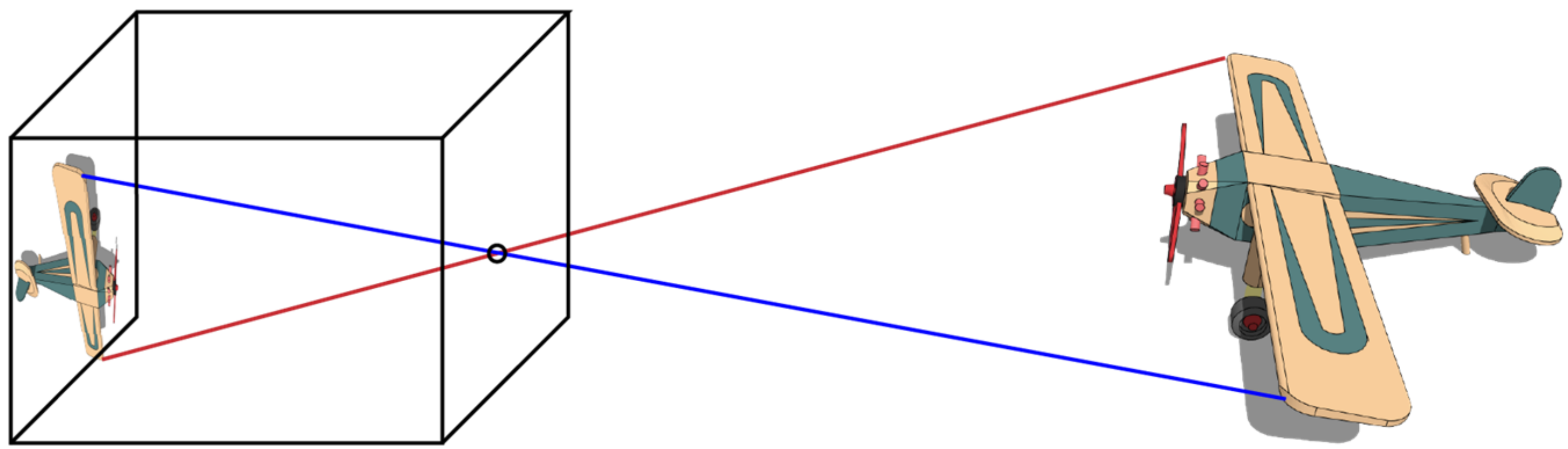
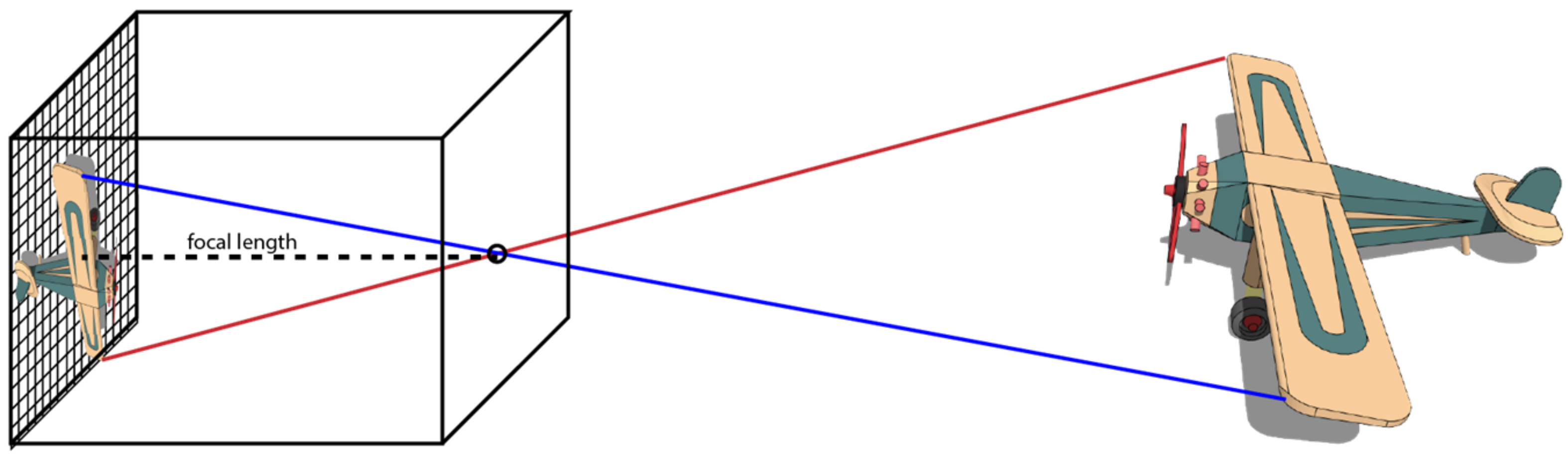
Model: pinhole camera



At each point we record incident light



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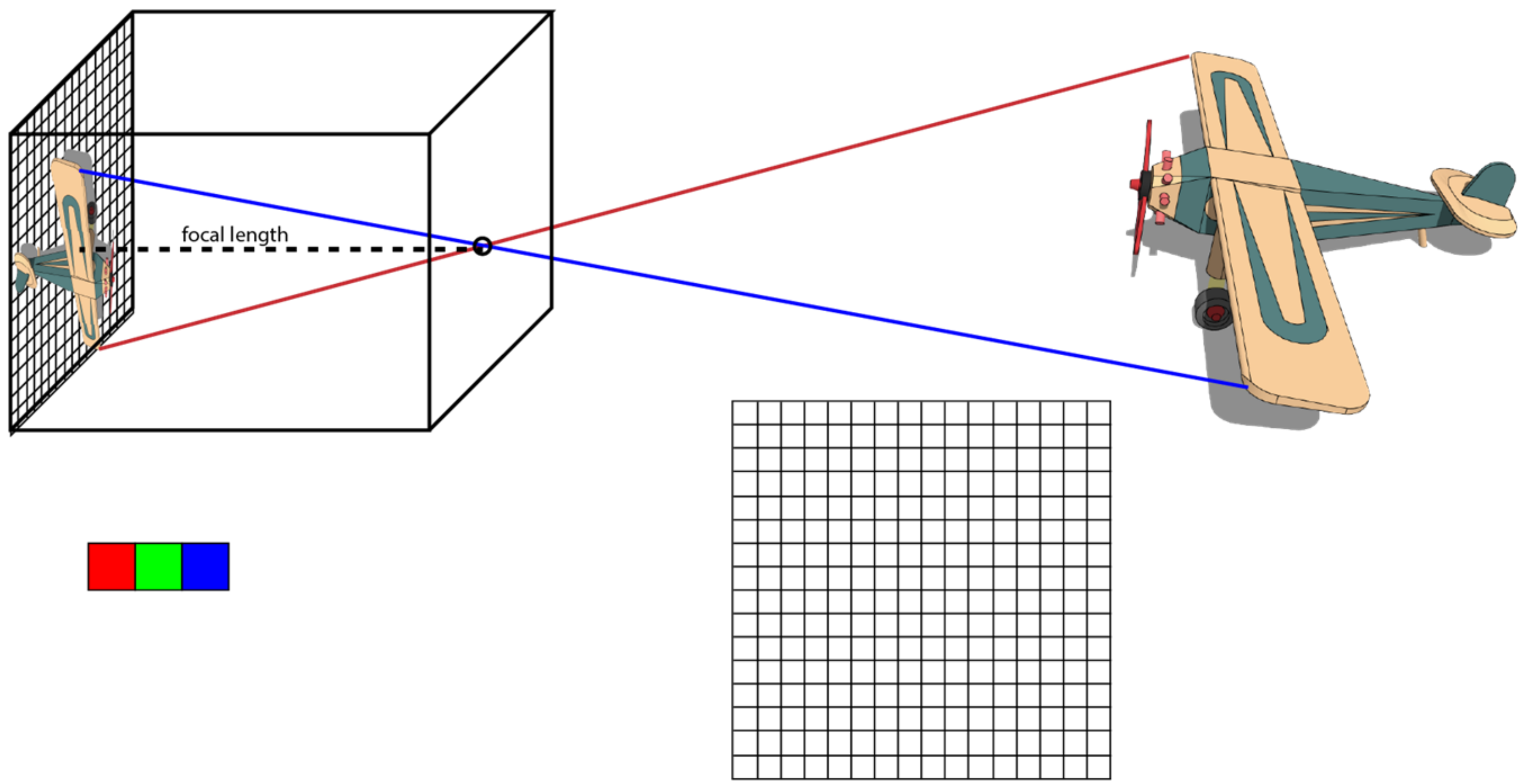
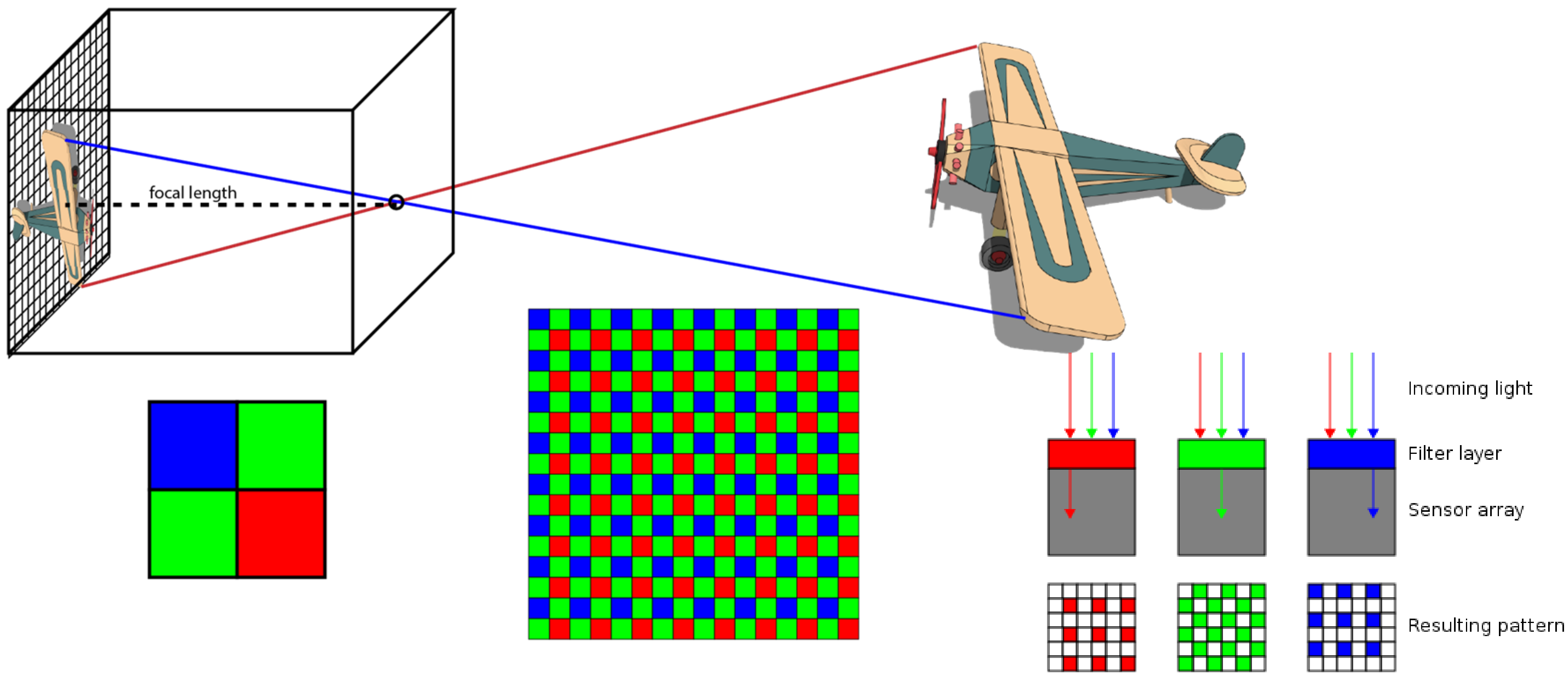
How do we record color?



Bayer pattern for CMOS sensors



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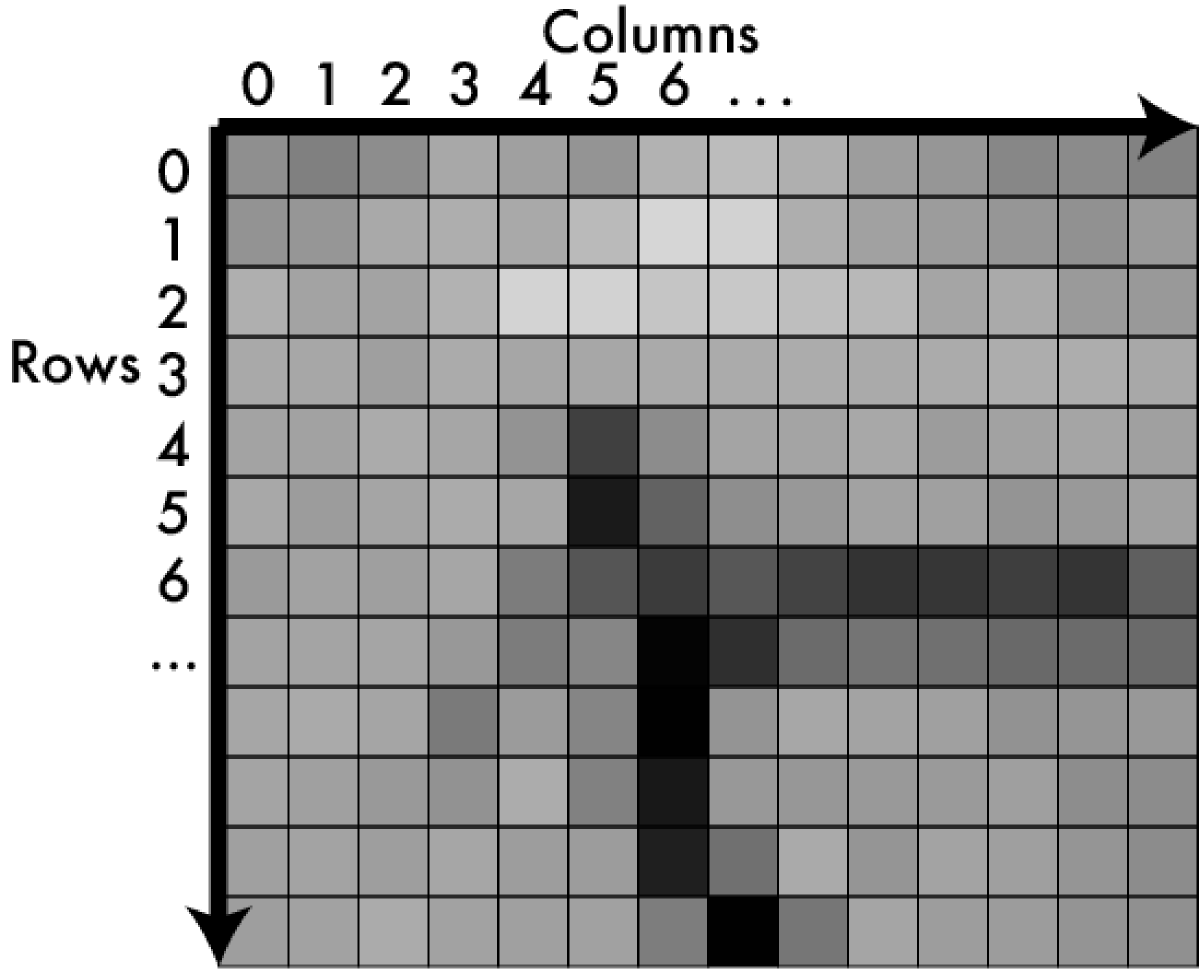
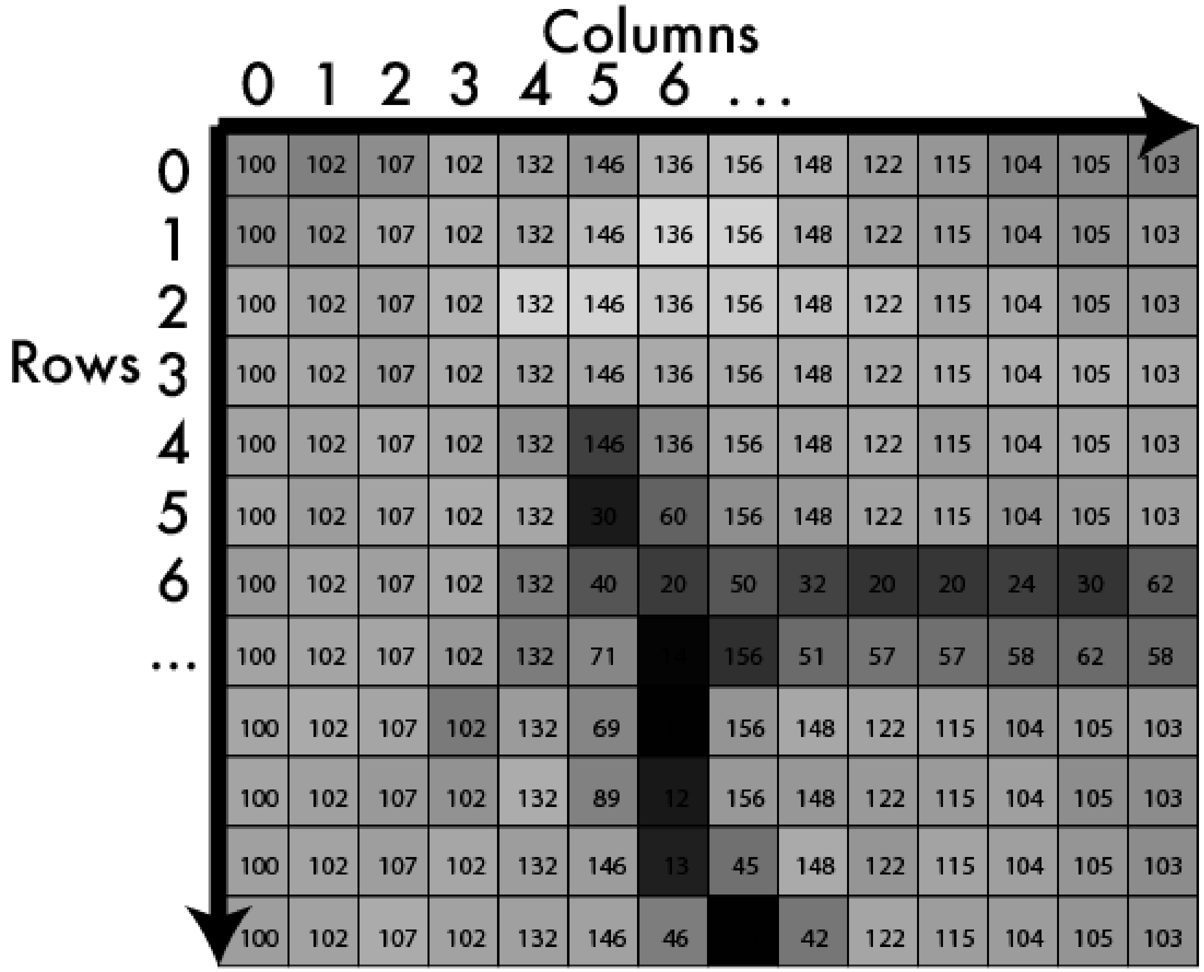
An image is a matrix of light



Values in matrix = how much light



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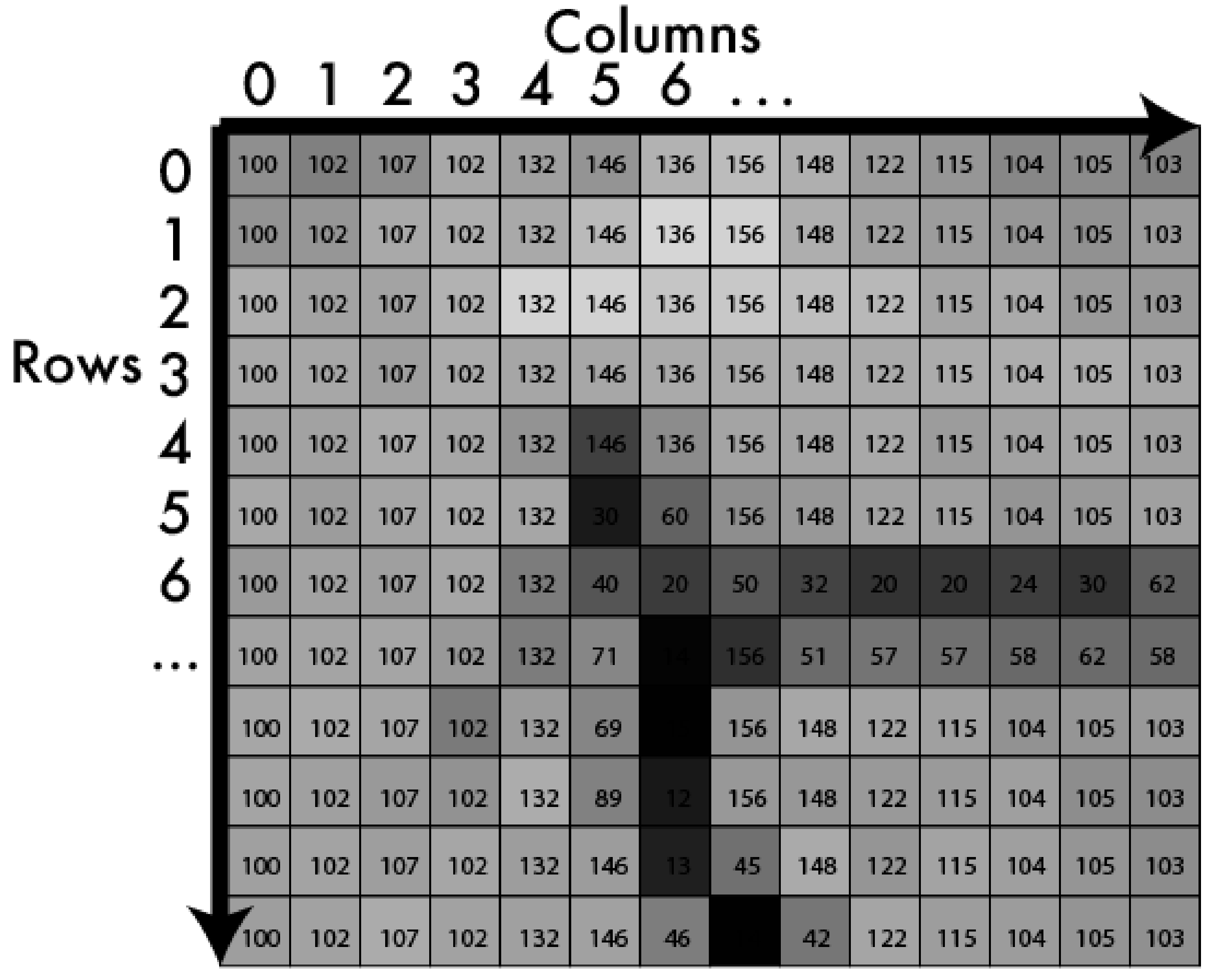
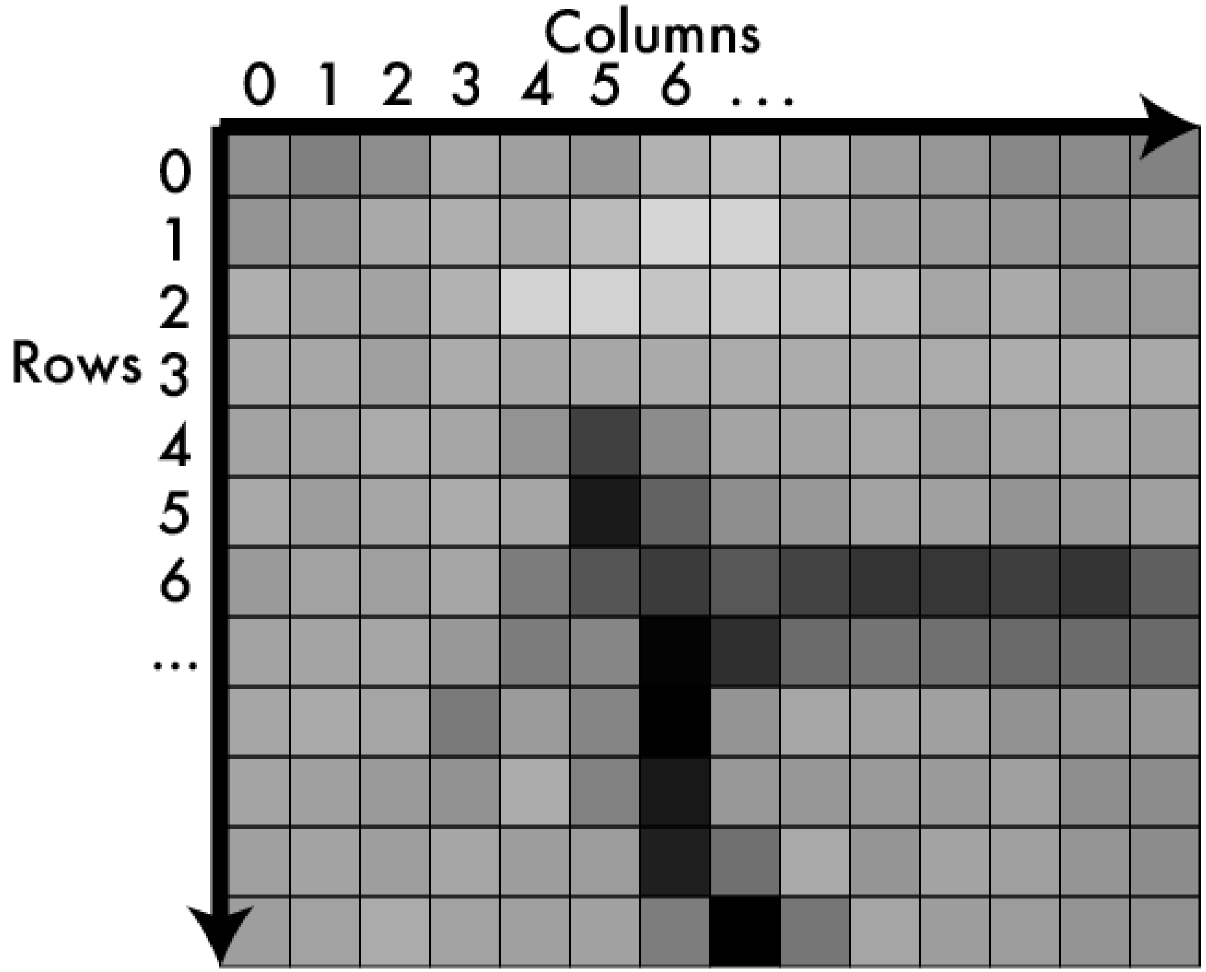
Values in matrix = how much light

- Higher = more light
- Lower = less light
- Bounded
  - No light = 0
  - Sensor/device limit = max
  - Typical ranges:
    - [0-255], fit into byte
    - [0-1], floating point
- Called pixels

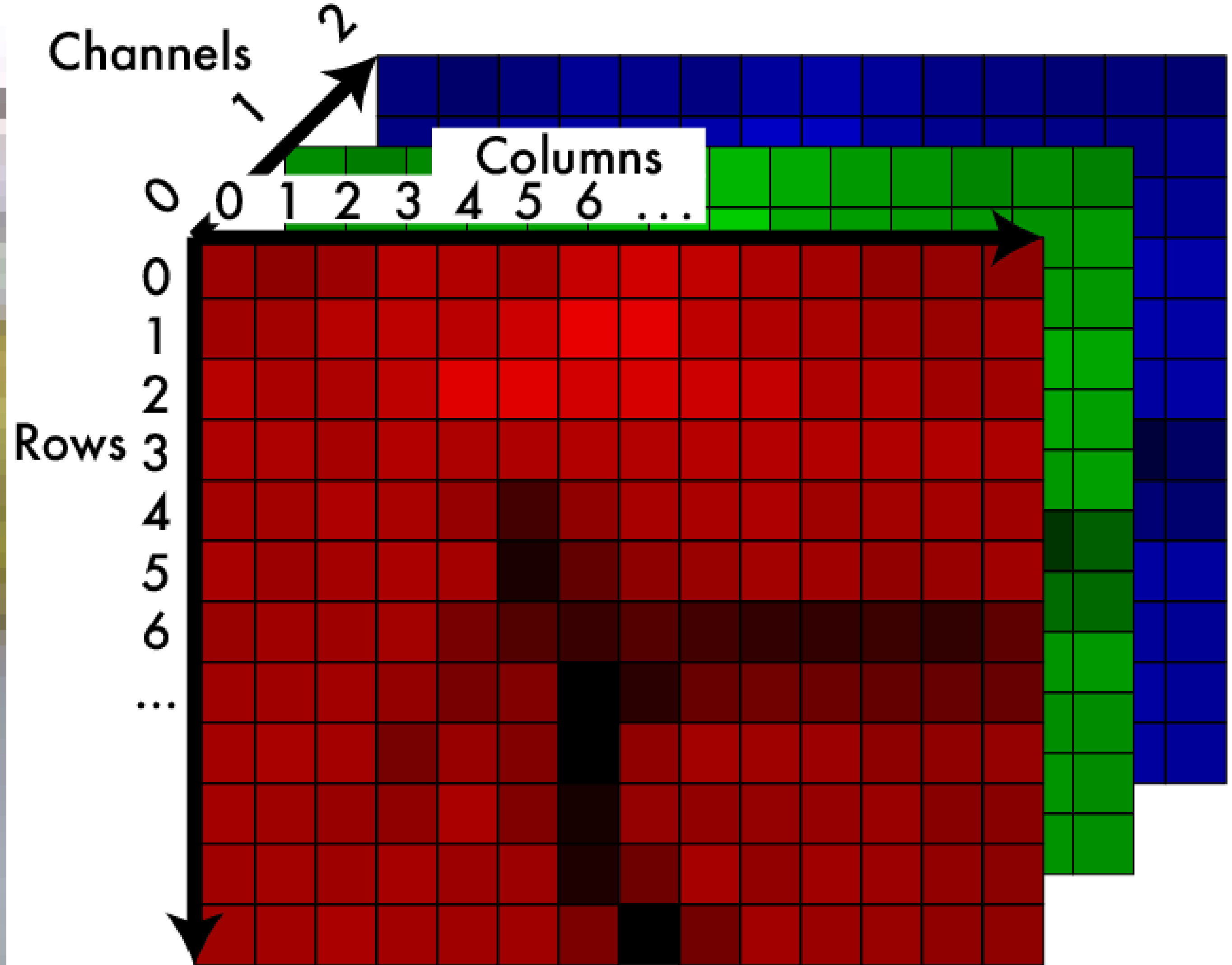


Addressing pixels

- Ways to index:
    - (x,y)
        - Like cartesian coordinates
        - (3,6) is column 3 row 6
    - (r,c)
        - Like matrix notation
        - (3,6) is row 3 column 6
- We use (x,y)
    - Arbitrary
    - Only thing that matters is consistency



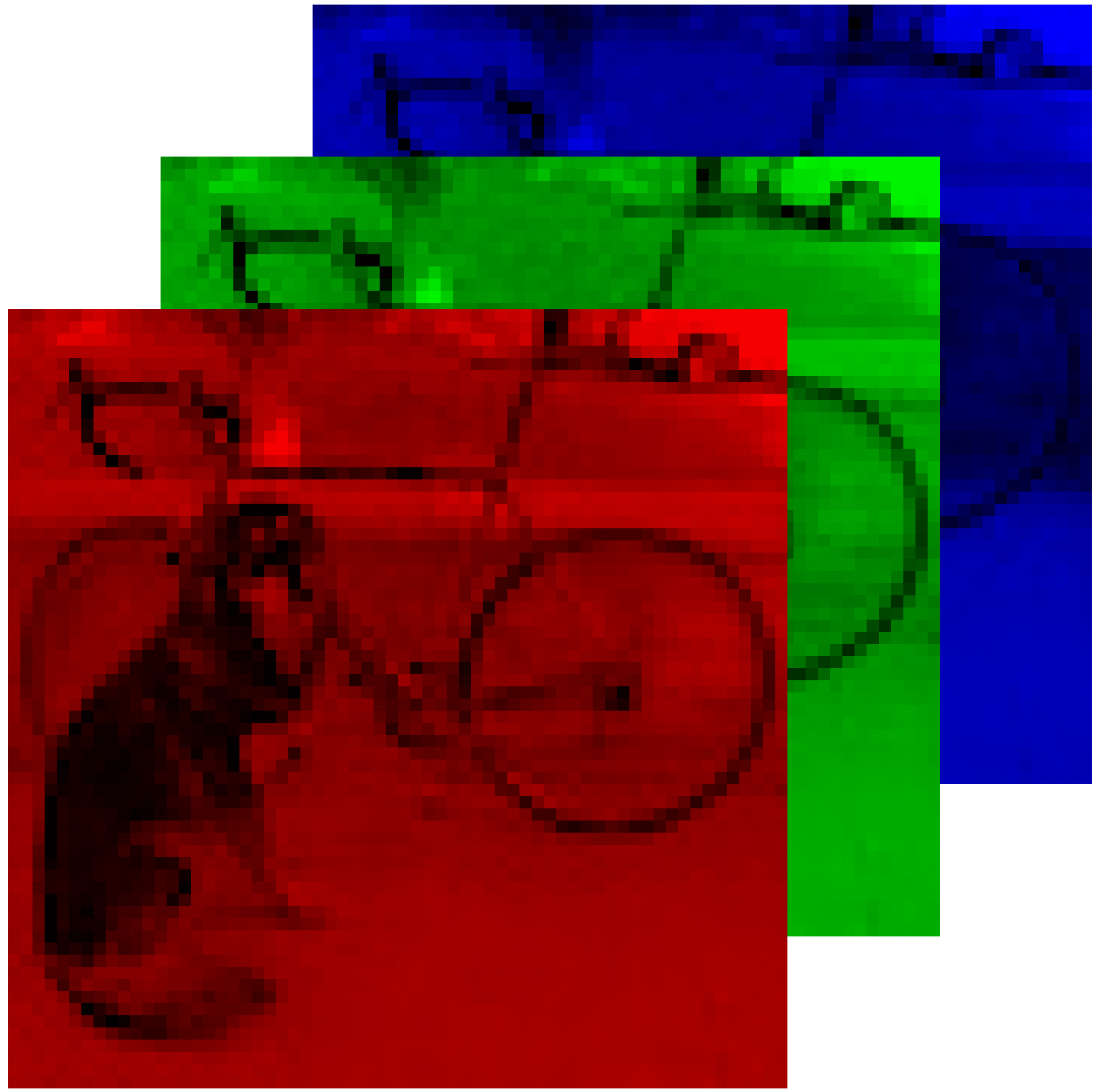
Color image: 3d tensor in colorspace



RGB information in separate "channels"

Remember: we can match "real" colors using a mix of primaries.

Each channel encodes one primary. Adding the light produced from each primary mimics the original color.



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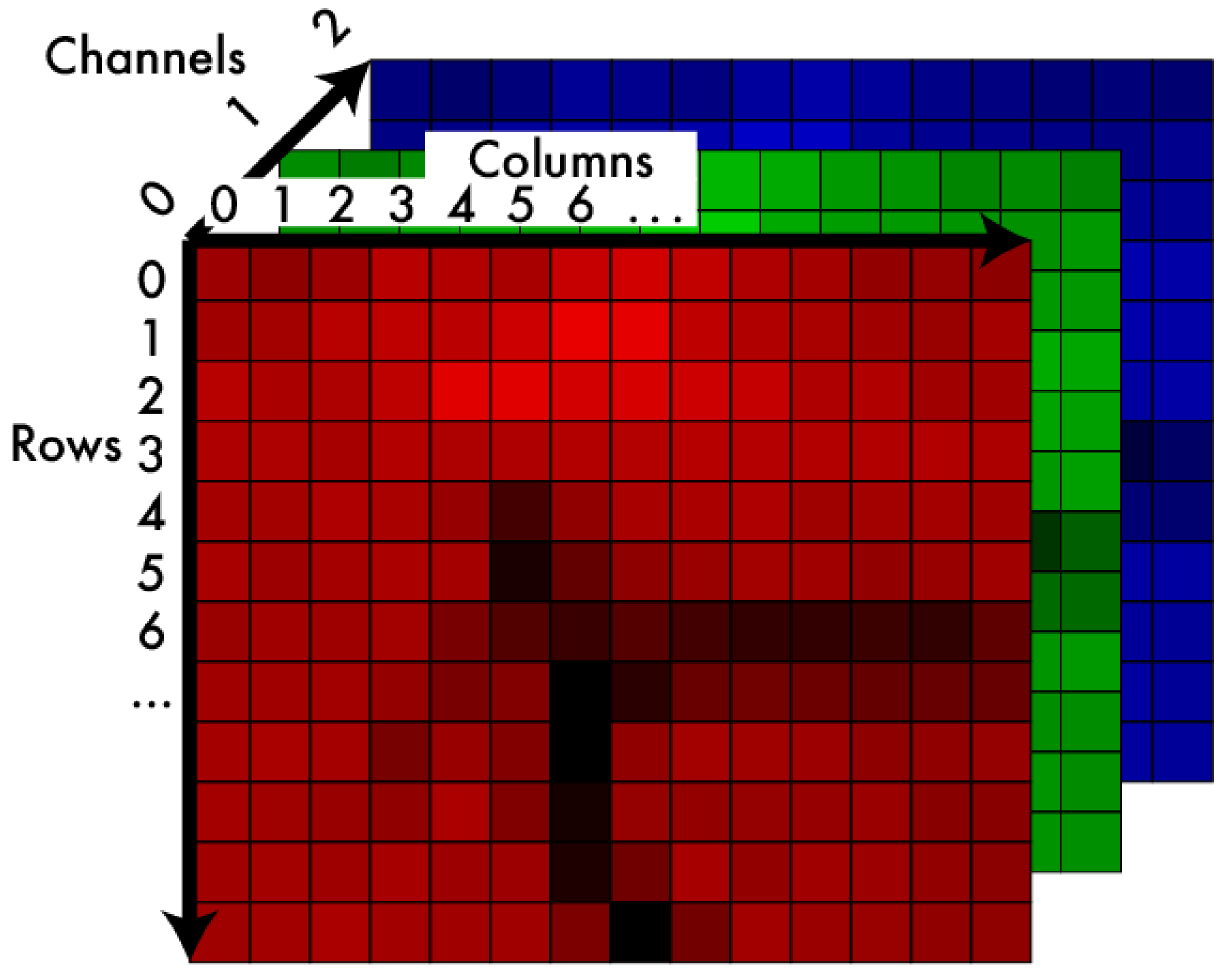
Addressing pixels

- We use (x,y,c)
  - (1,2,0):
    - column 1, row 2, channel 0
- Still doesn’t matter, just be consistent
- Also for size:
  - 1920 x 1080 x 3 image:
    - 1920 px wide
    - 1080 px tall
    - 3 channels



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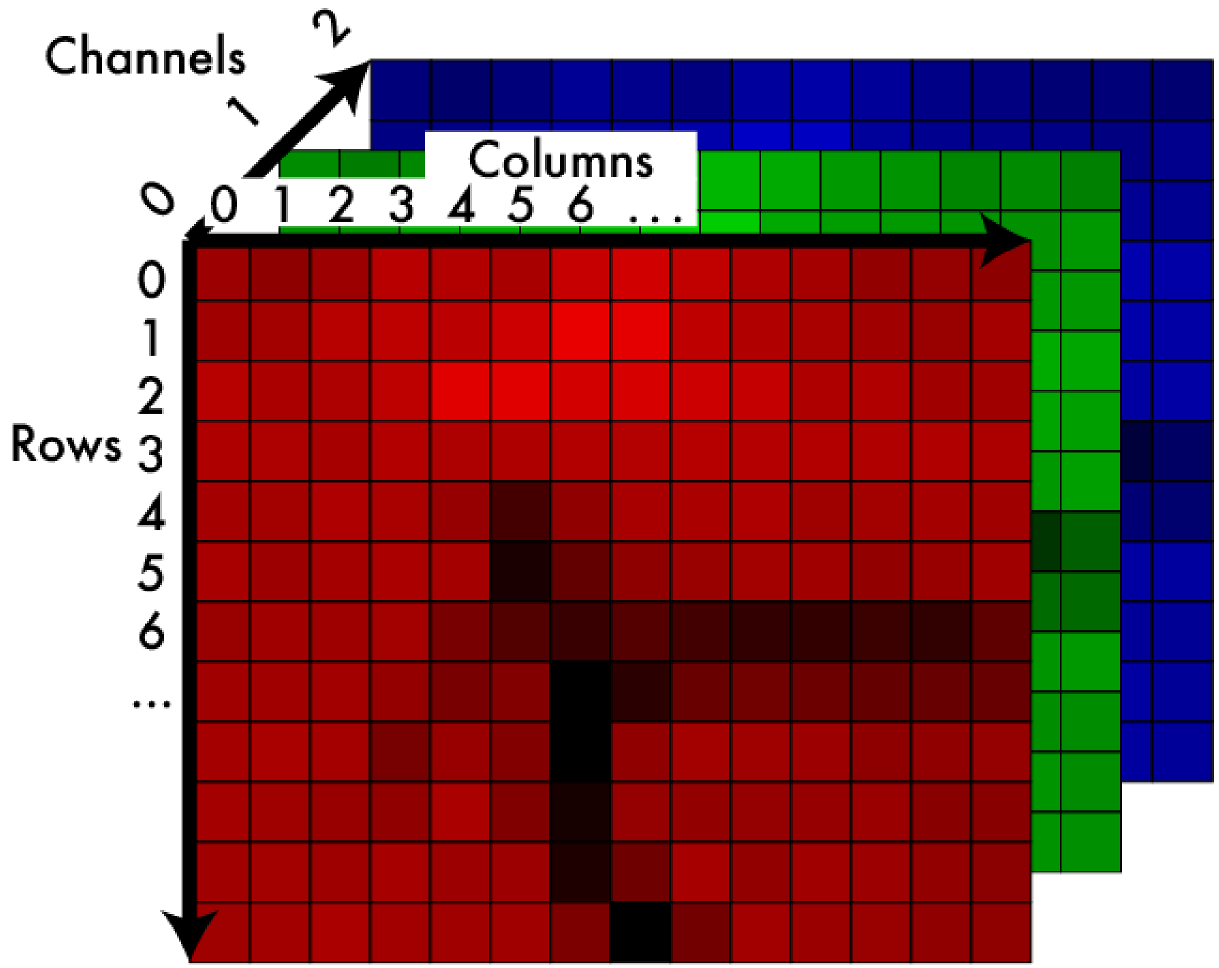
An image is like a function

An image is a mapping from indices to pixel value:

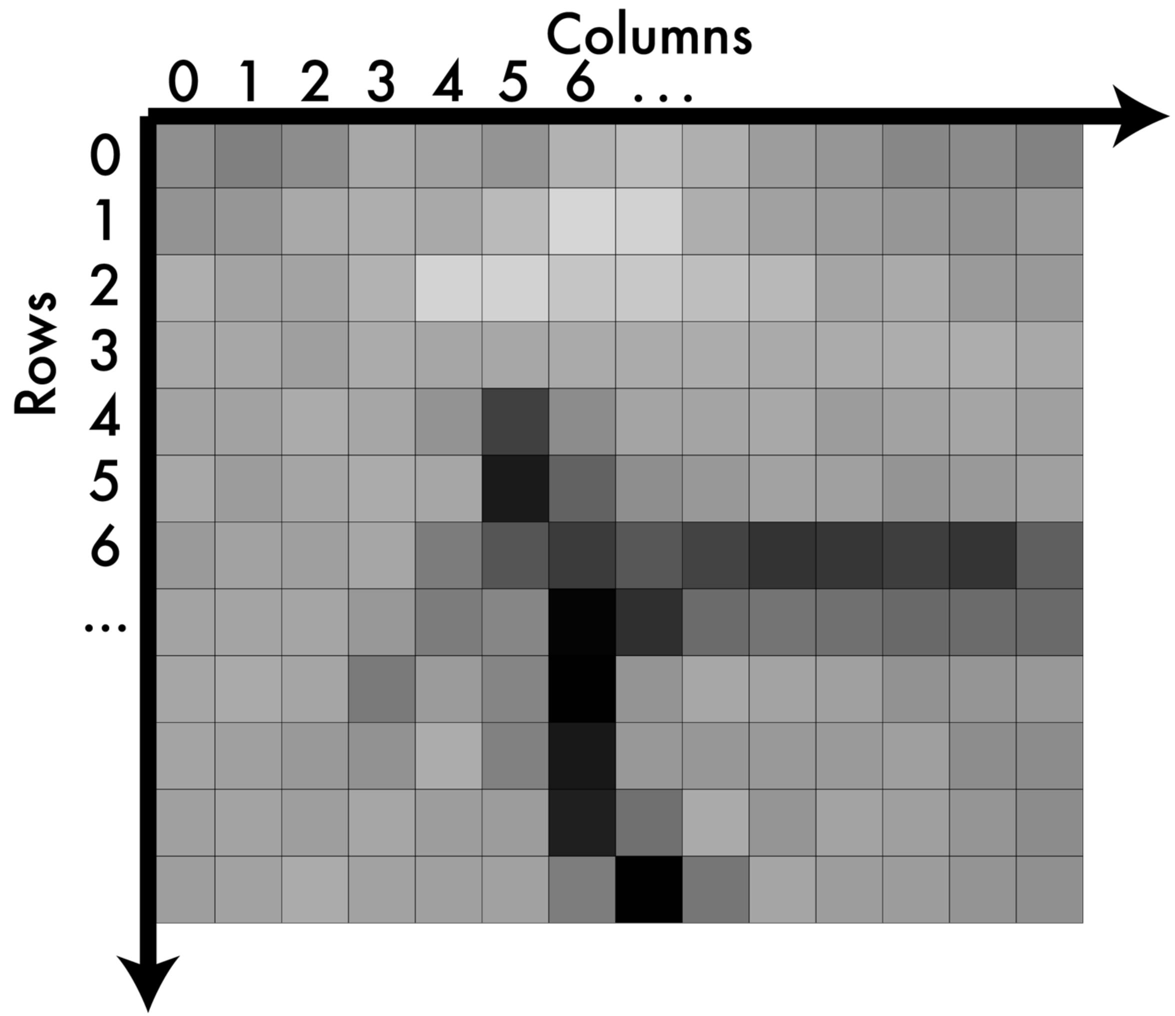
- Im: I x I x I -> R

We may want to pass in non-integers:

- Im': R x R x I -> R



A note on coordinates in images



integer pixels

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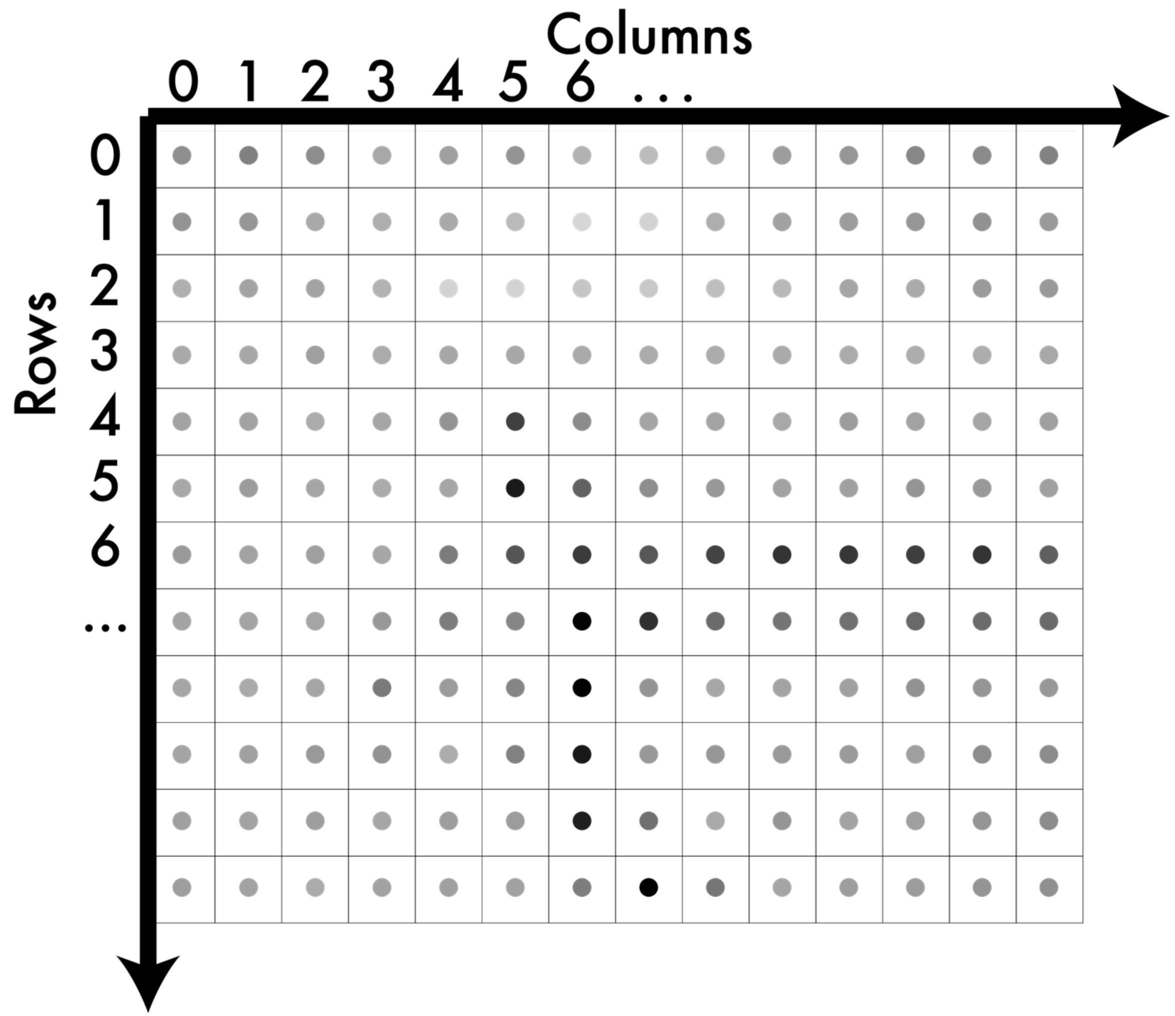
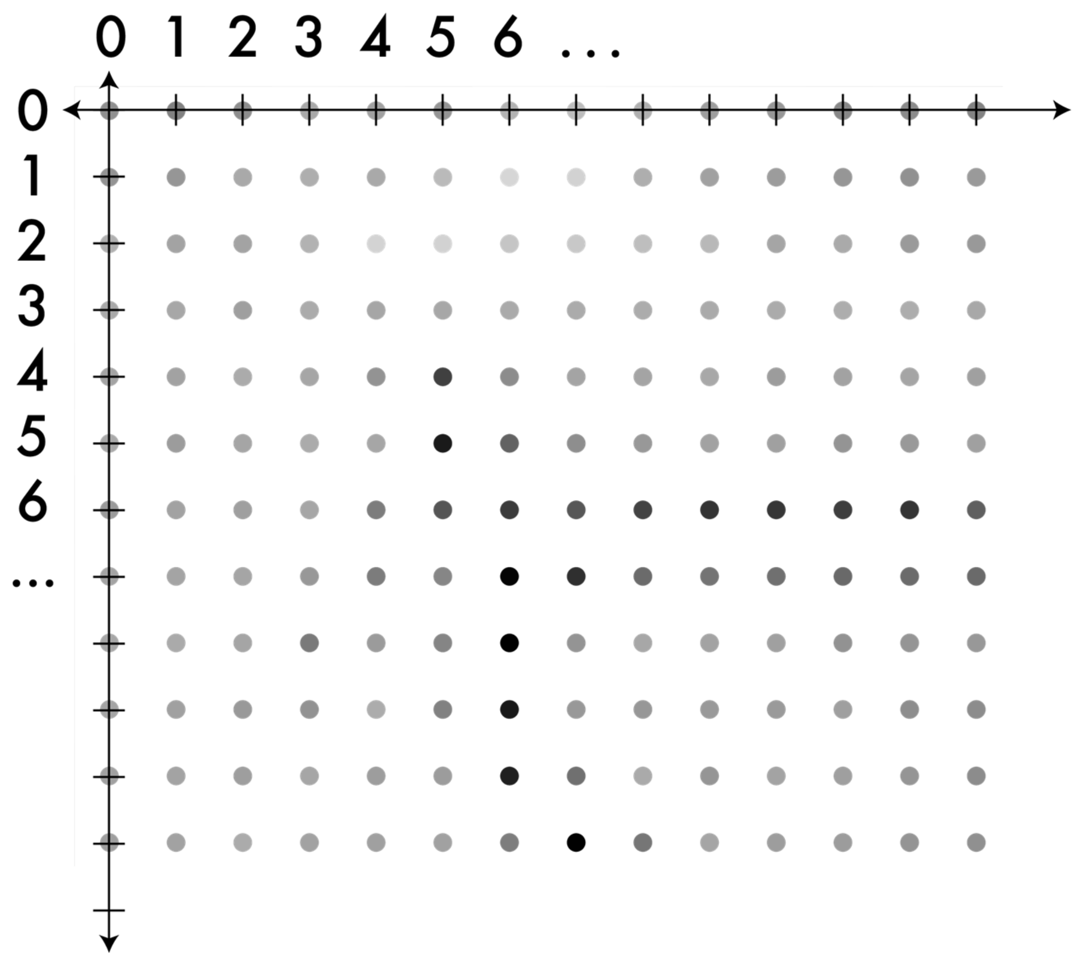


We can think of their values as being at the centers.

A note on coordinates in images



Now we can move to a real coordinate system.

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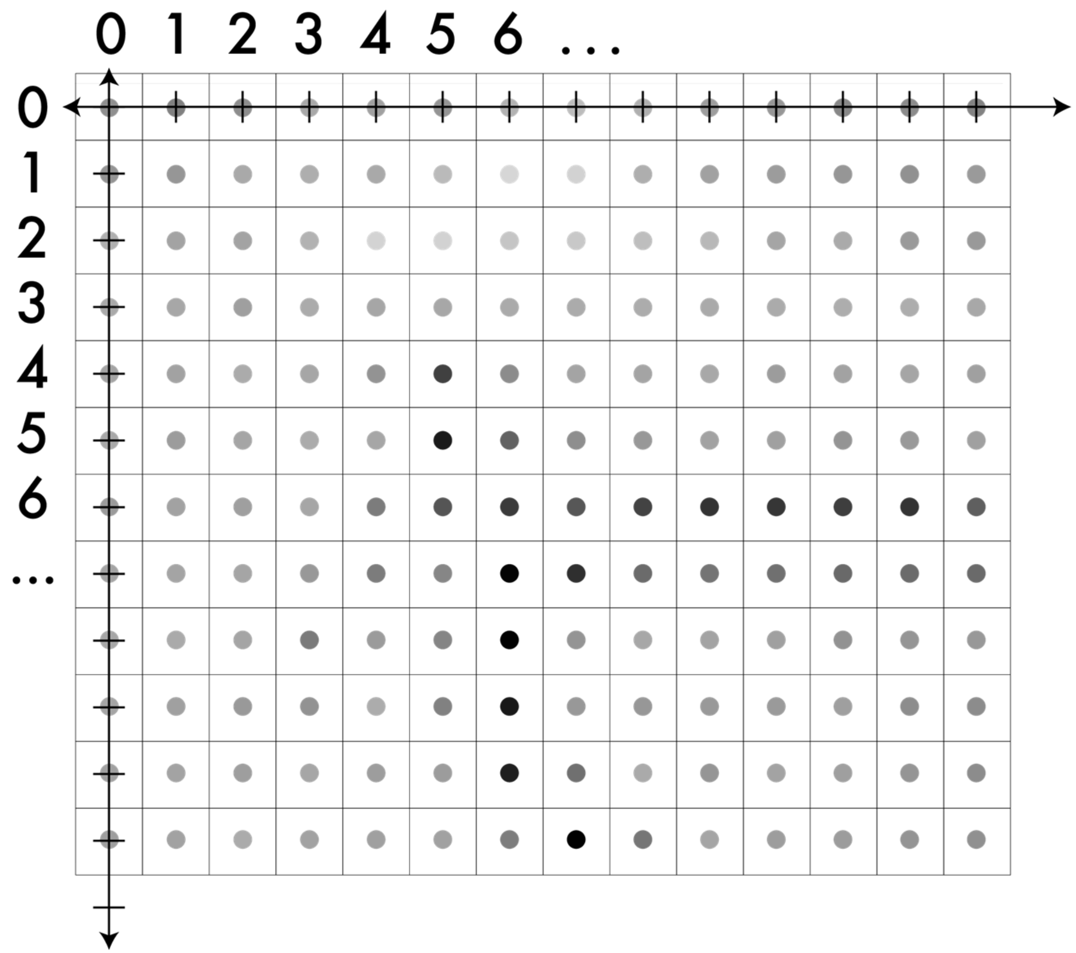

On the image

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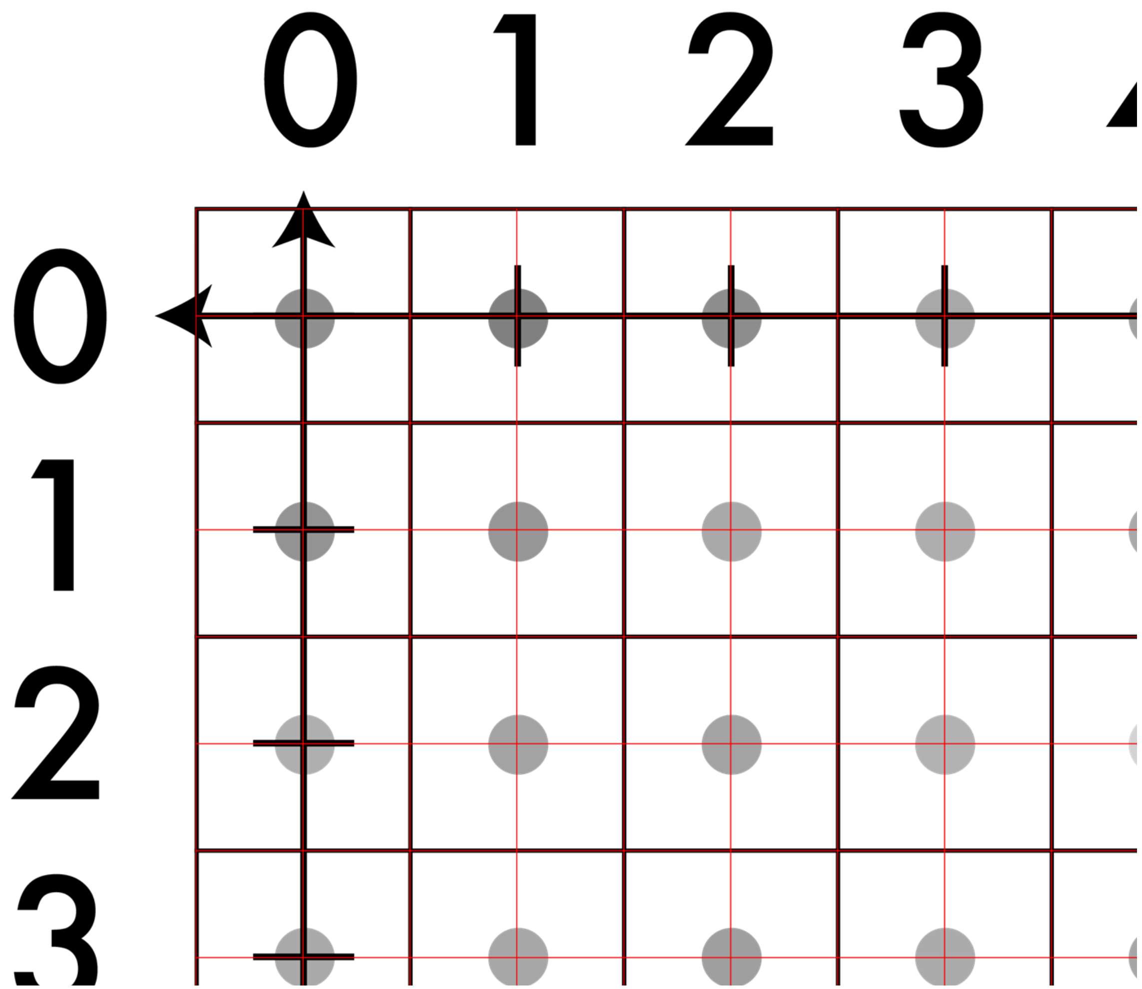
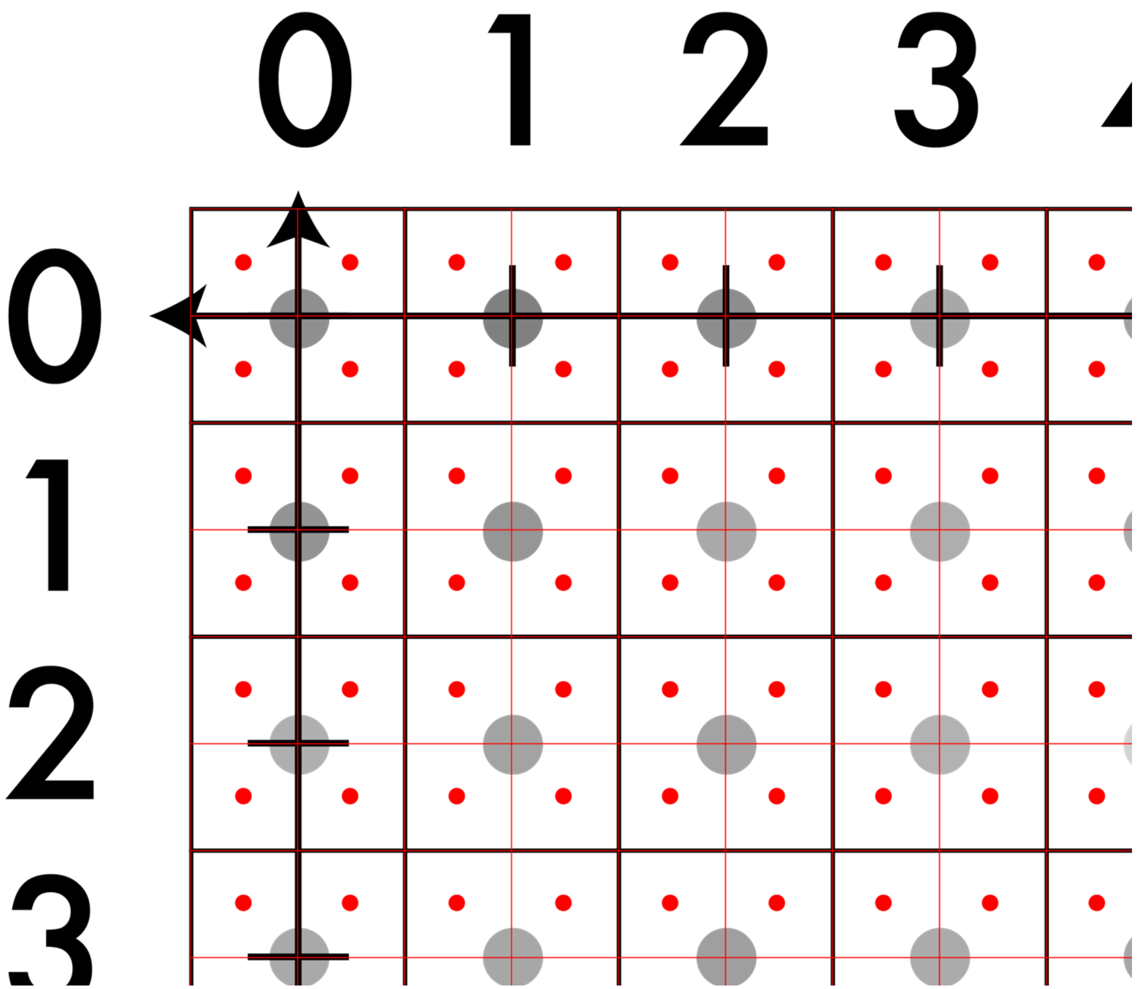
A note on coordinates in images

So, the value of the pixel (x,y) is now centered at (x,y).



A note on coordinates in images

But there are other real-valued points.



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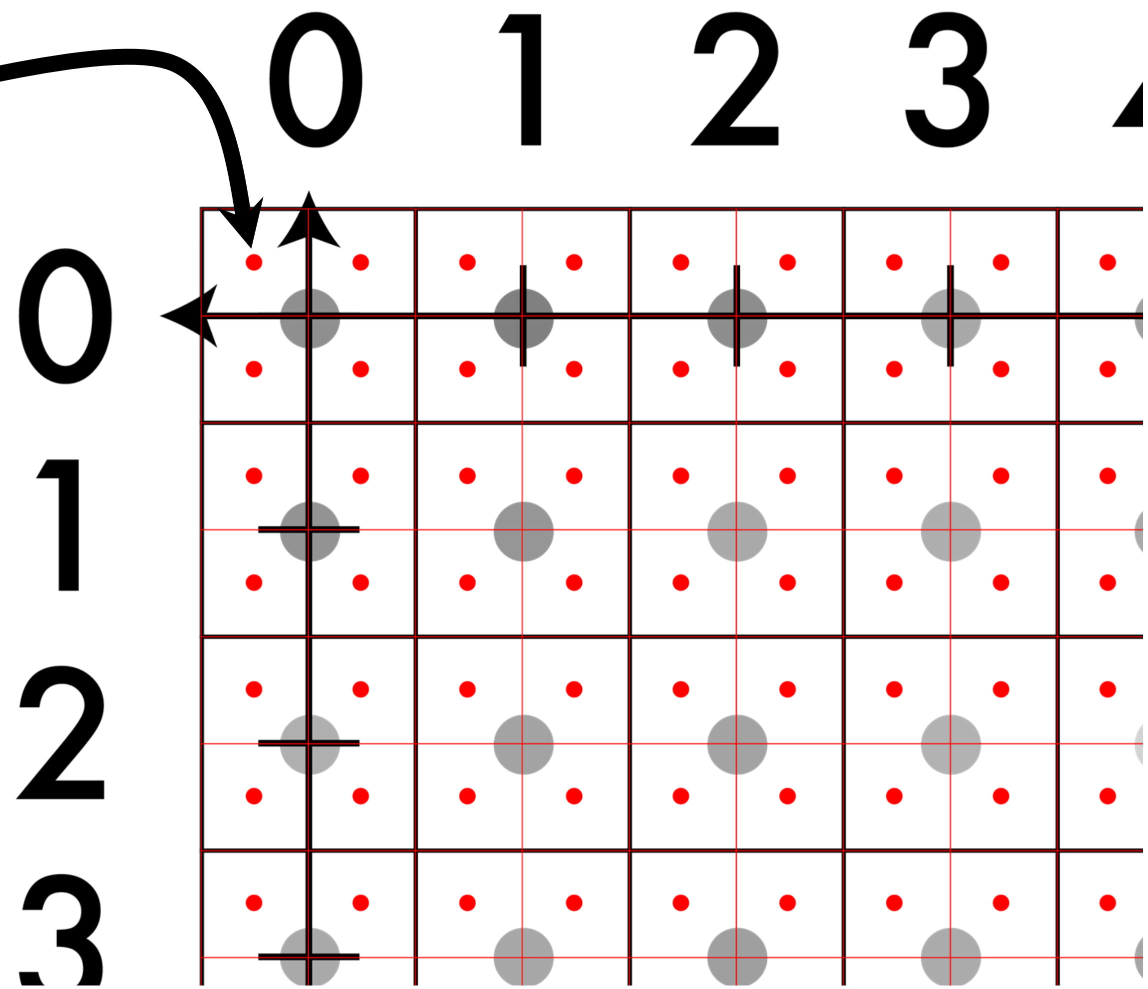
A note on coordinates in images

This point is:
(-.25, -.25)



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Interpolation

How do we find out the VALUE of a non-integer point, when the image only comes with integer points, i.e. (25,45,3).

Two simple ideas:

1. Nearest-Neighbor Interpolation
2. Bilinear Interpolation

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Nearest neighbor: what it sounds like

f(x,y,z) = Im(round(x), round(y), z)

- Looks blocky
- Note: z is still int

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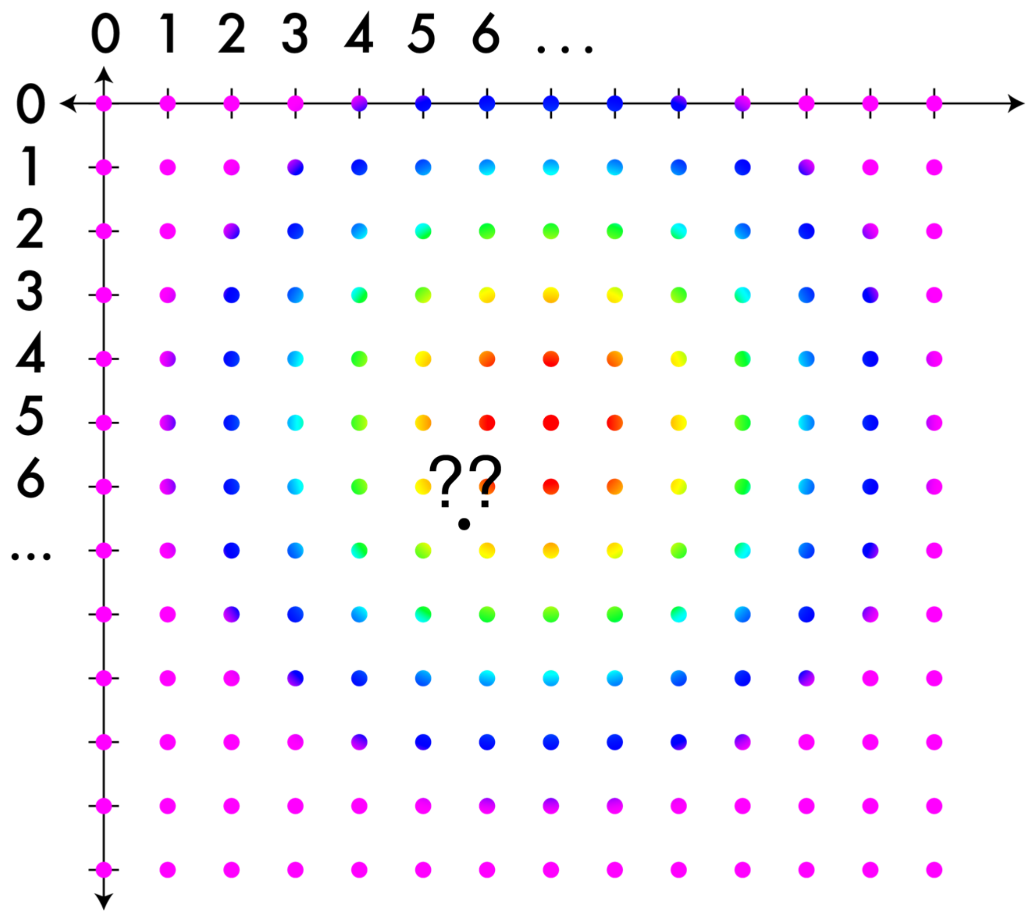
Bilinear interpolation: for grids, pretty good

This time find the closest pixels in a box



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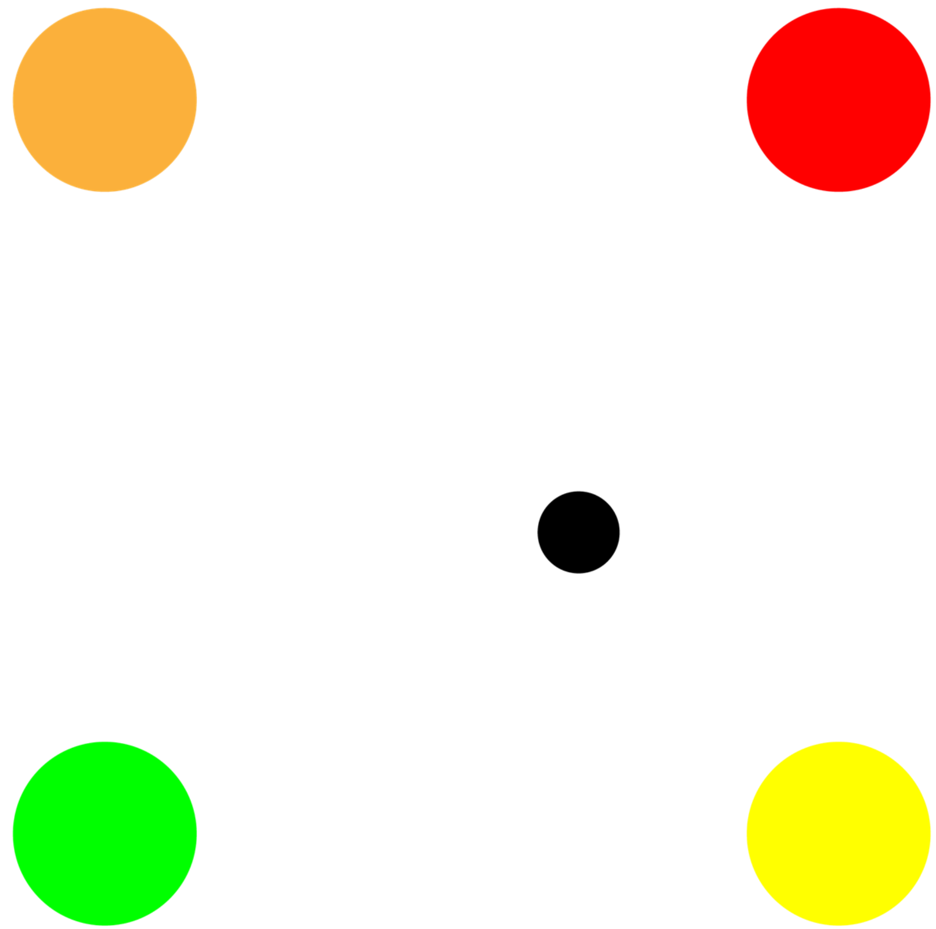

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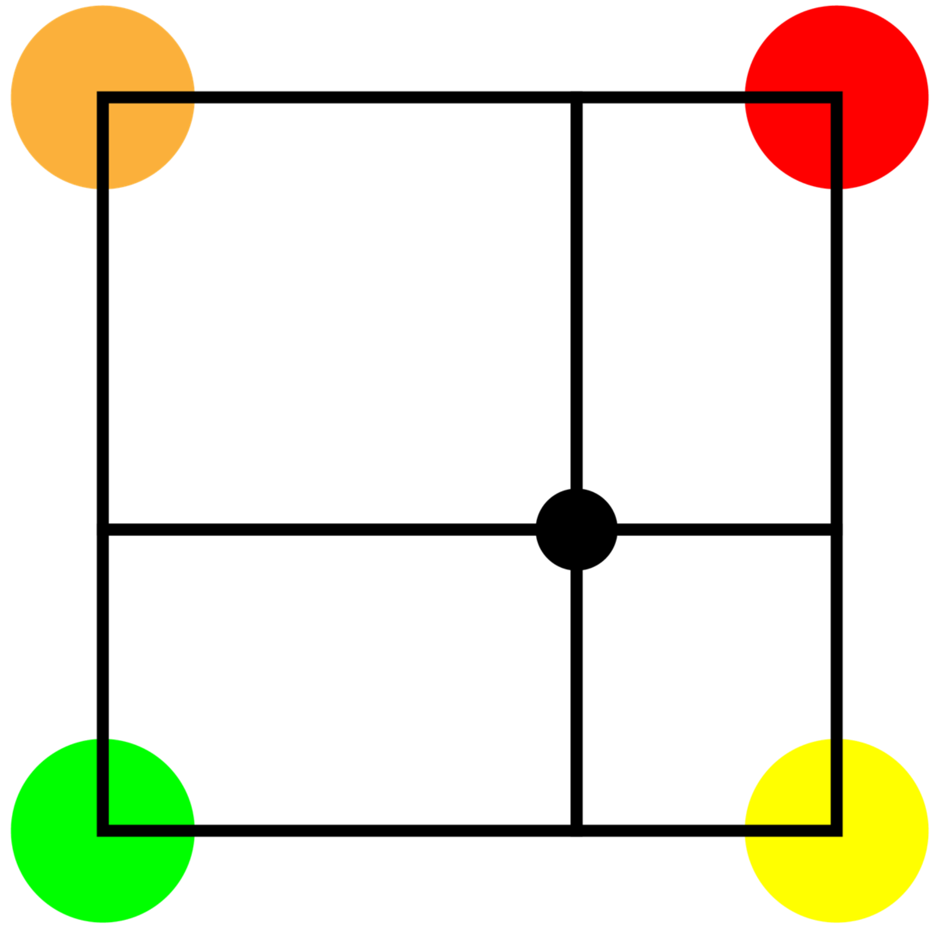


Bilinear interpolation: for grids, pretty good

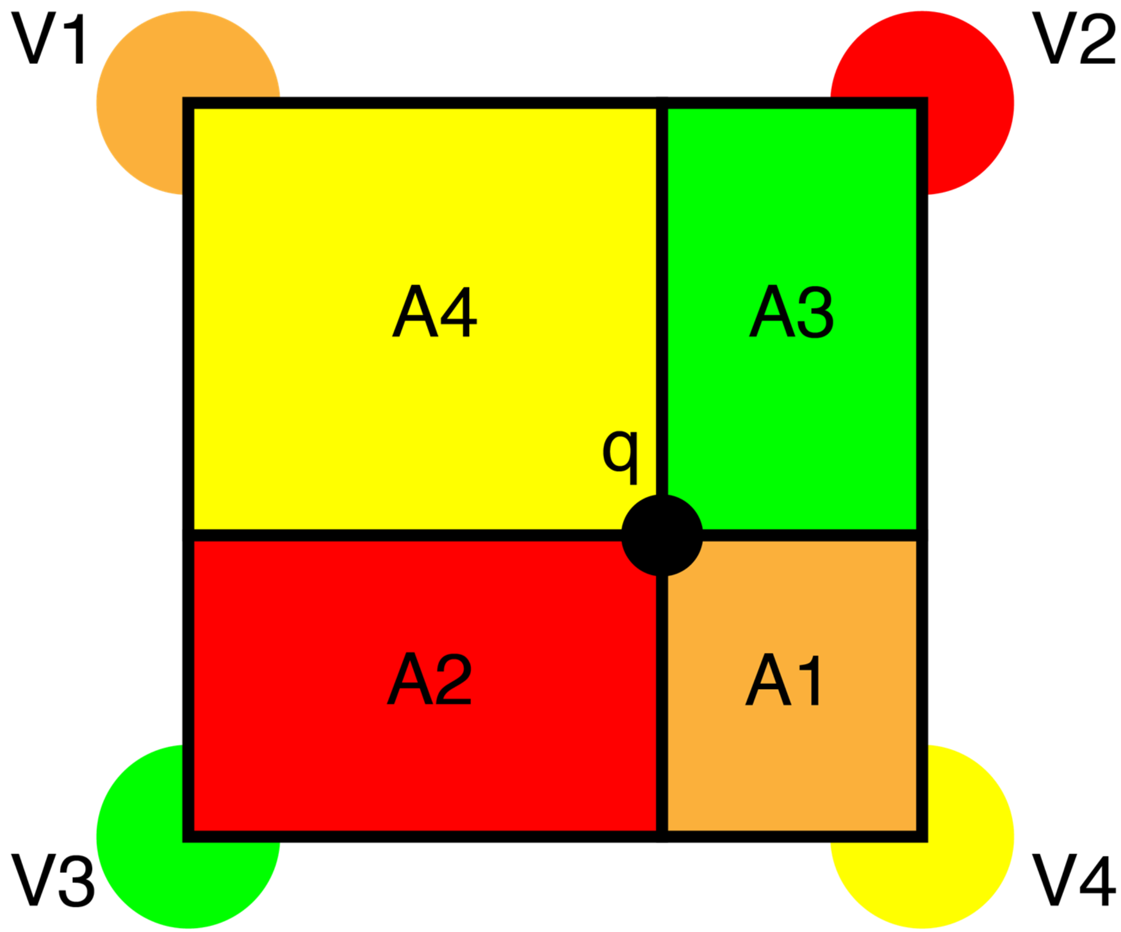
This time find the closest pixels in a box

Weighted sum based on area of opposite rectangle

q = V1*A1 + V2*A2 + V3*A3 + V4*A4

Need to normalize!

Or do we?

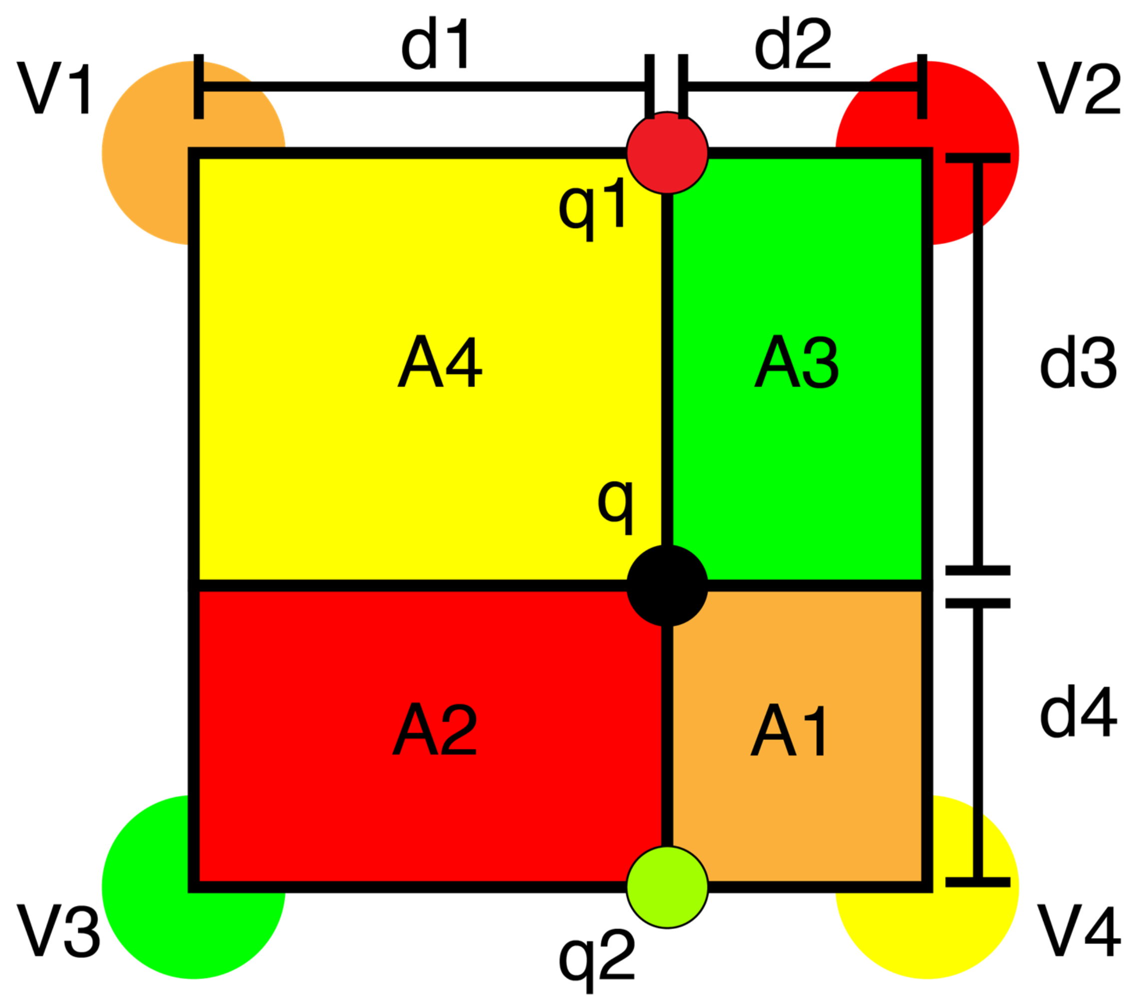


Bilinear interpolation: for grids, pretty good

q = V1*A1 + V2*A2 + V3*A3 + V4*A4

A1 = d2*d4
A2 = d1*d4
A3 = d2*d3
A4 = d1*d3

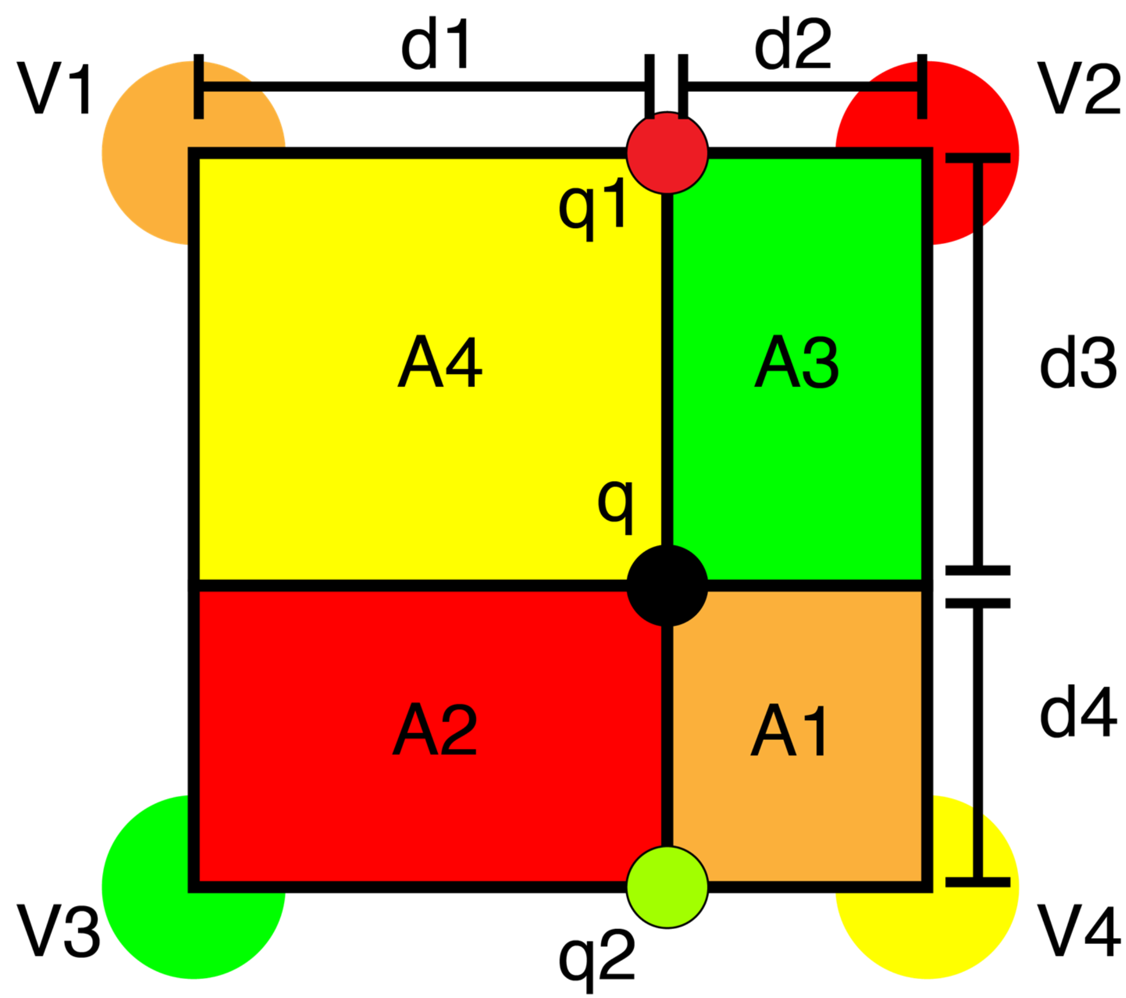
=> q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3



Bilinear interpolation: for grids, pretty good

Alternatively, linear interpolation of linear interpolates

q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3



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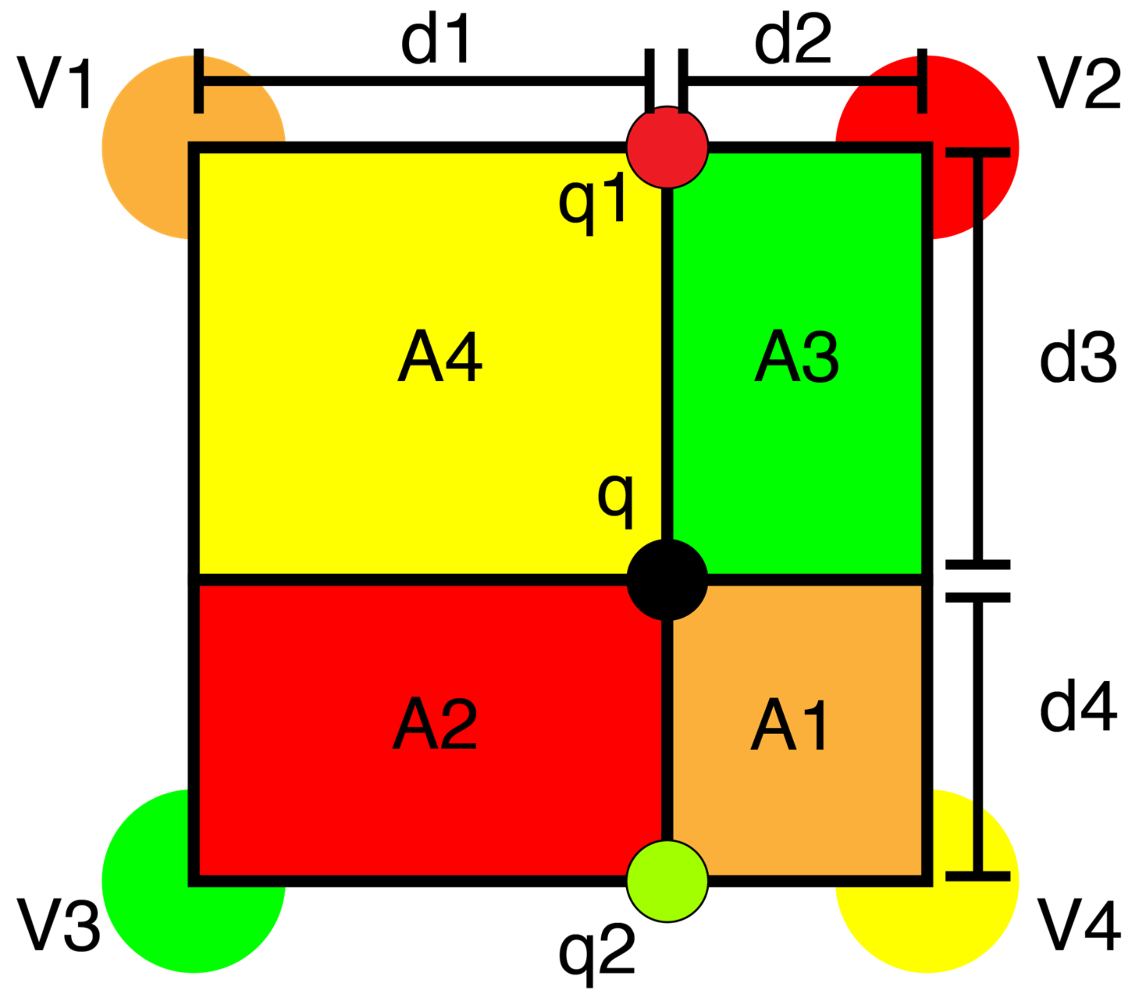
Bilinear interpolation: for grids, pretty good

q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3

Equivalent:

q = q1*d4 + q2*d3



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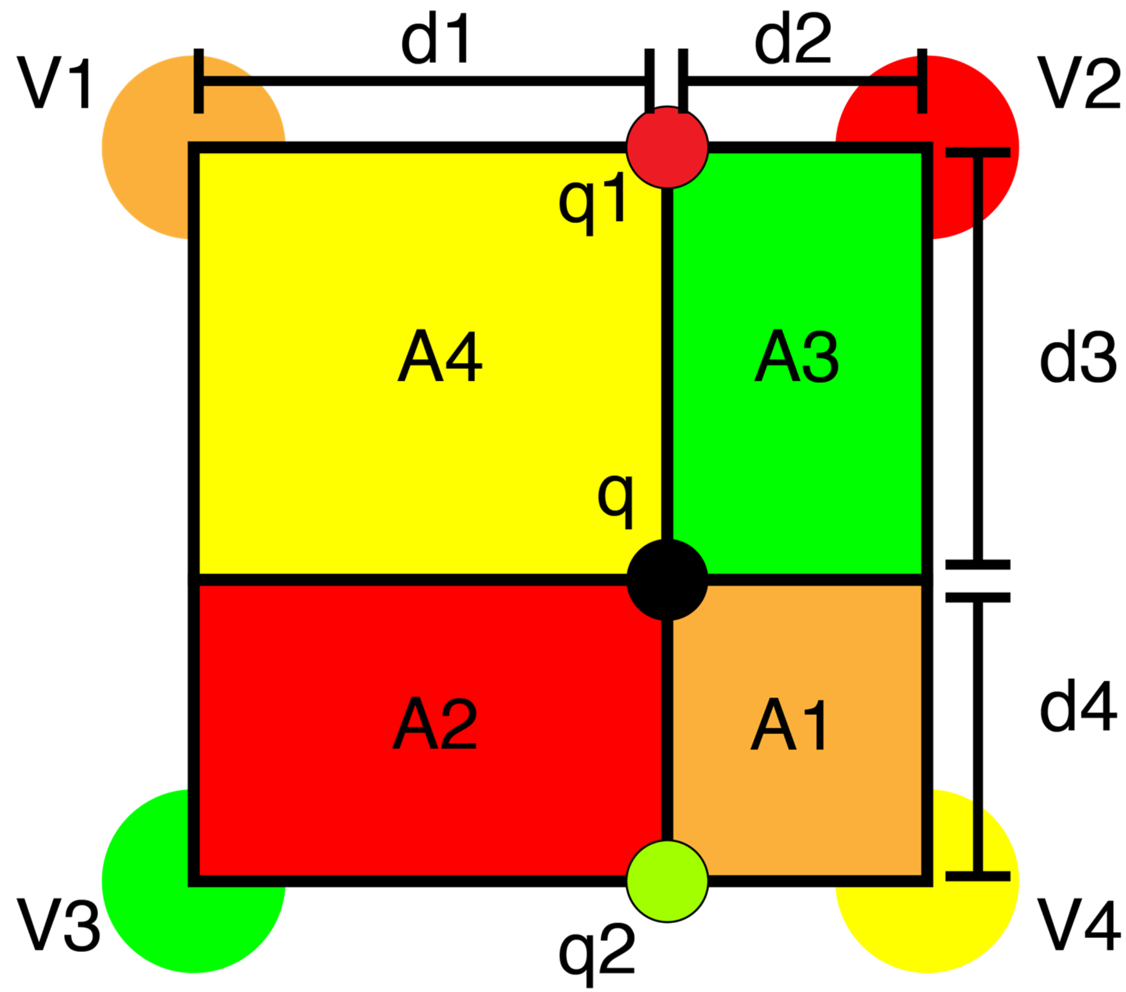
Bilinear interpolation: for grids, pretty good

q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3

Equivalent:

q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)



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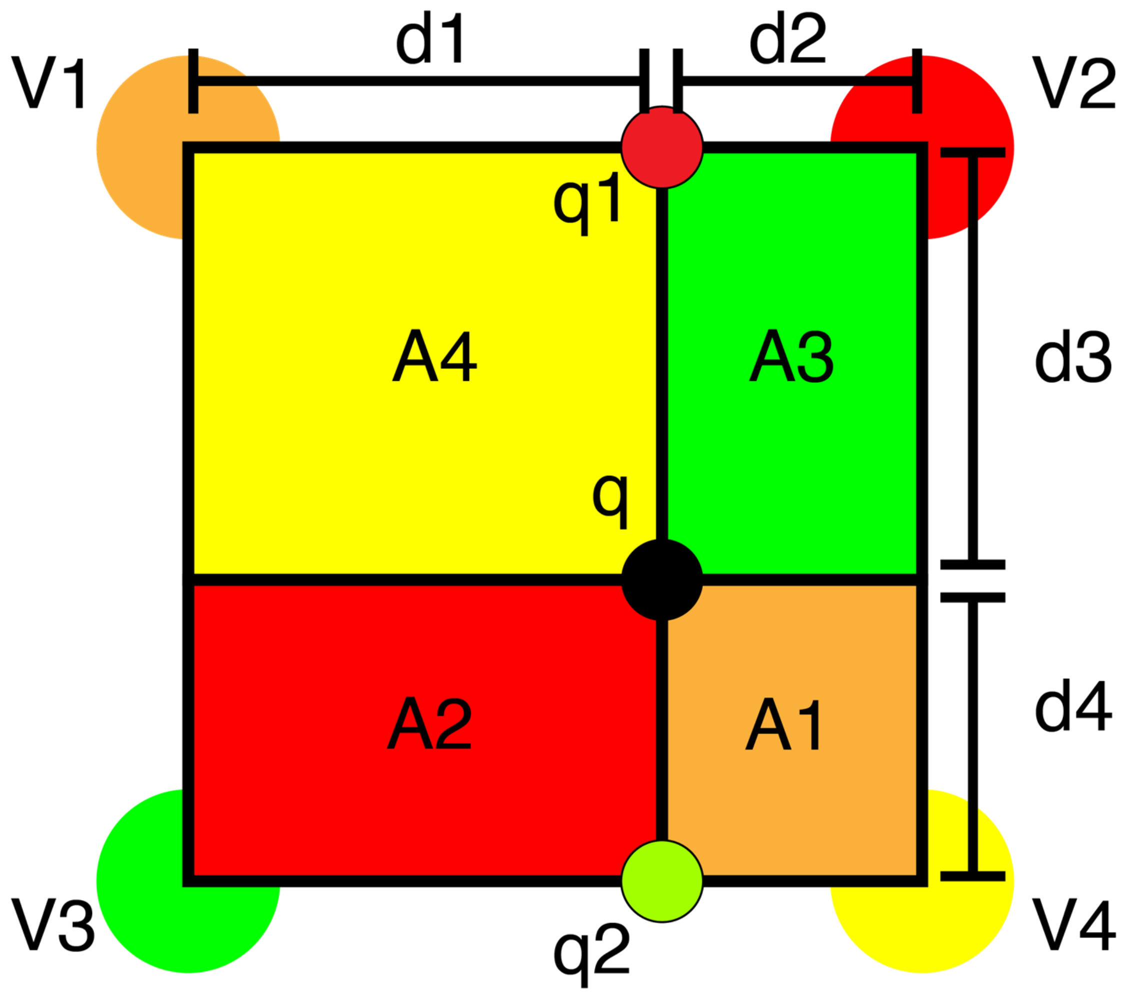
Bilinear interpolation: for grids, pretty good

q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3

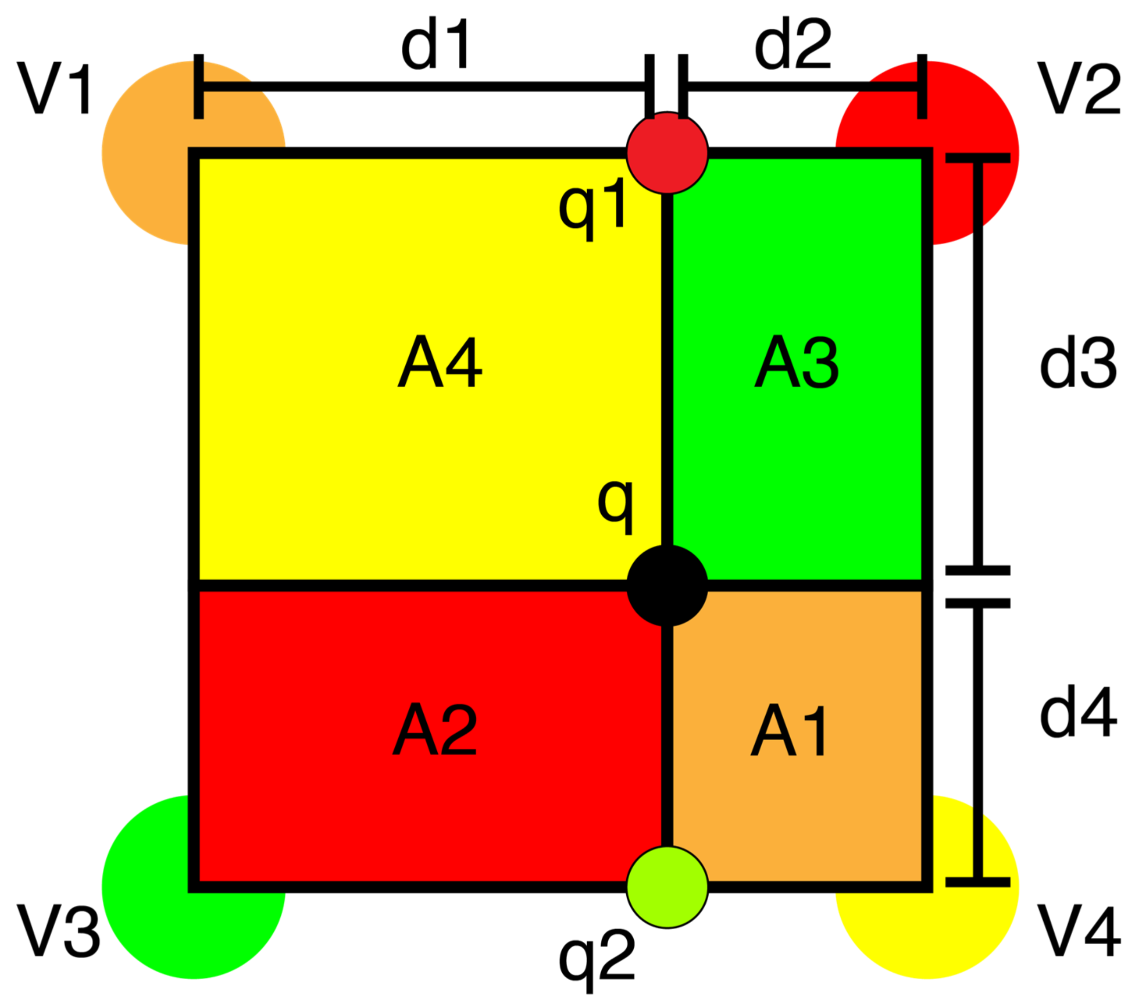
Equivalent:

q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3 (distribution)



Bilinear interpolation: for grids, pretty good

q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3



Equivalent:

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Recall:
A1 = d2*d4
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A3 = d2*d3
A4 = d1*d3

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Equivalent:

q = q1*d4 + q2*d3
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Recall:
A1 = d2*d4
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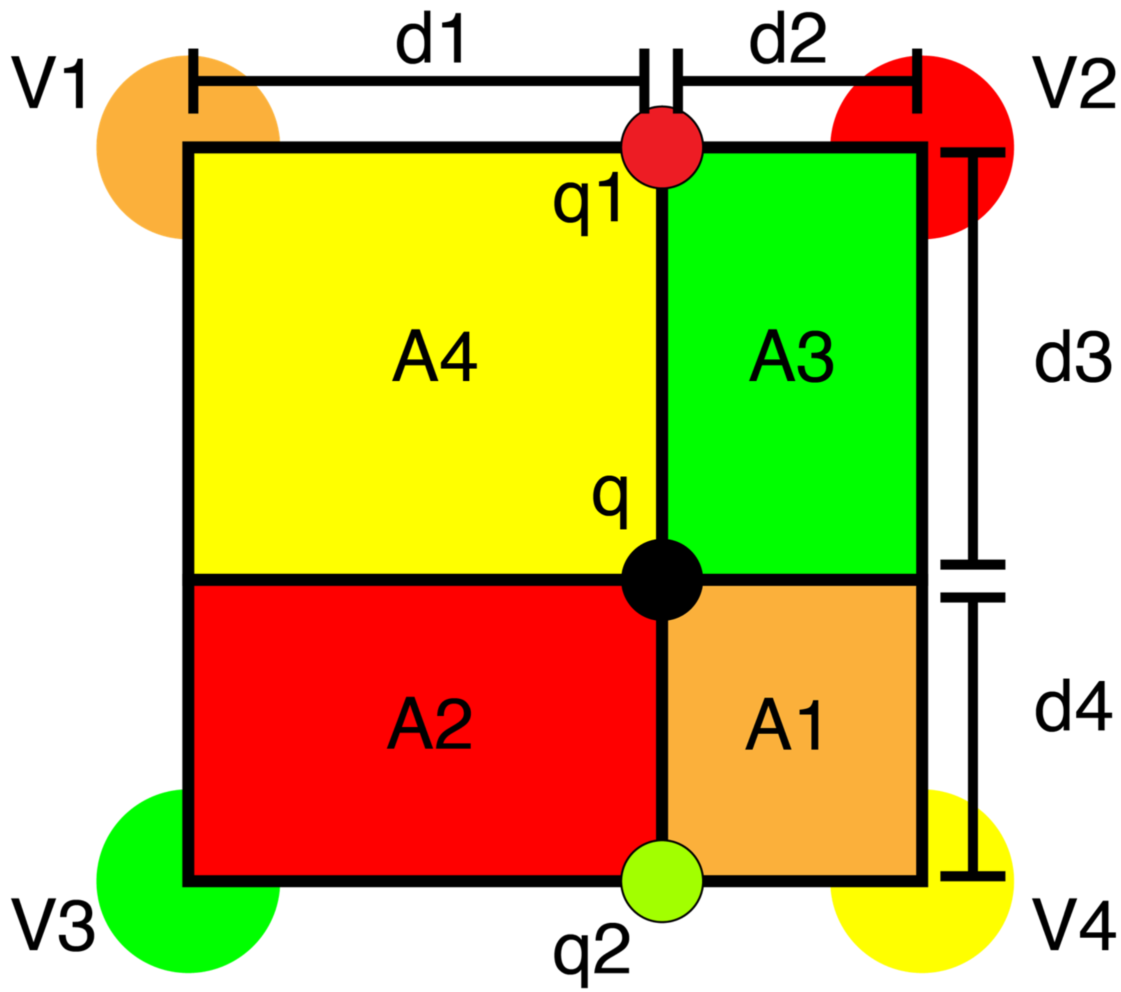
q = V1*A1 + V2*A2 + V3*A3 + V4*A4



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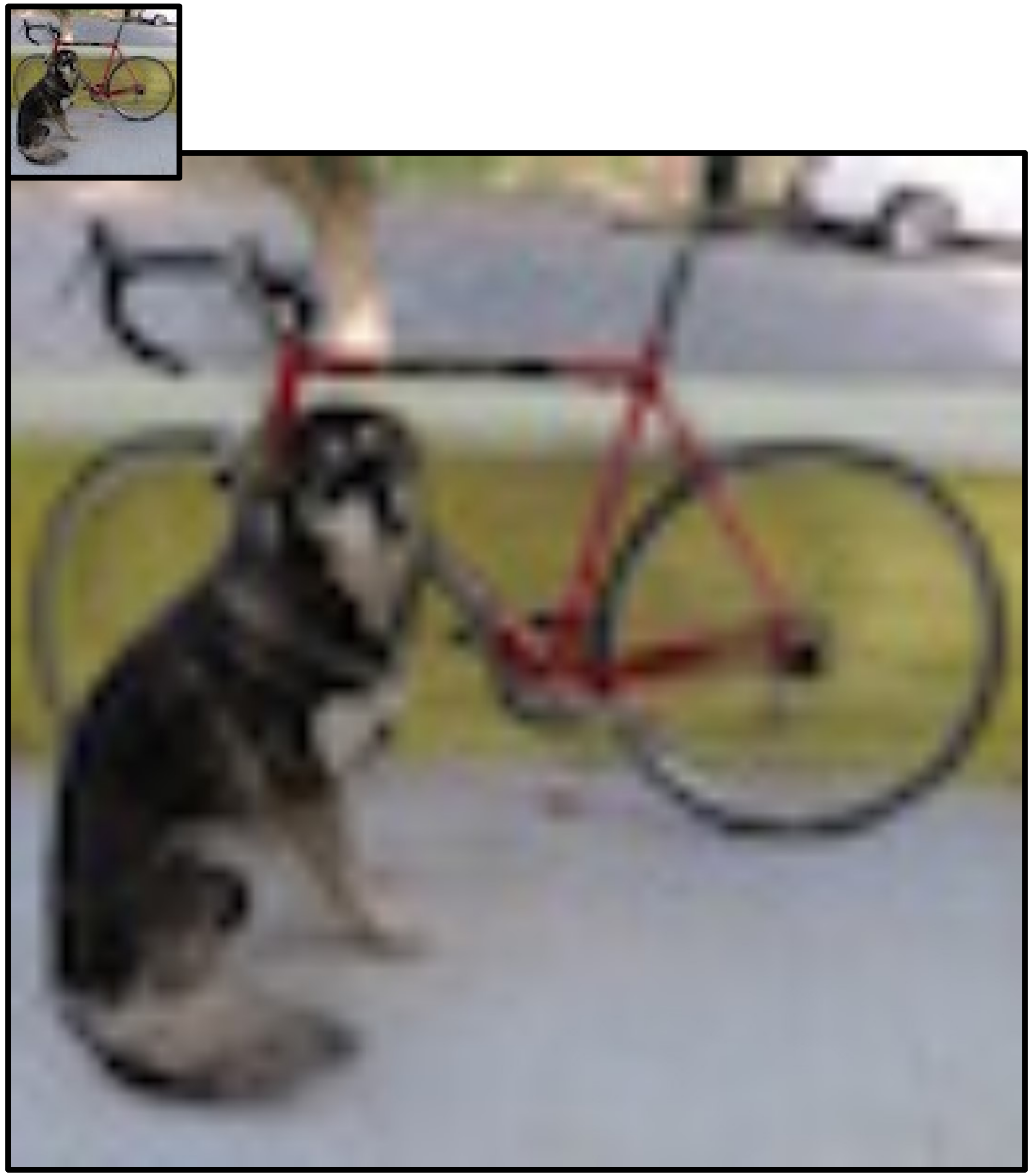
Bilinear interpolation: for grids, pretty good

- Smoother than NN
- More complex
  - 4 lookups
  - Some math
- Often the right tradeoff of speed vs final result



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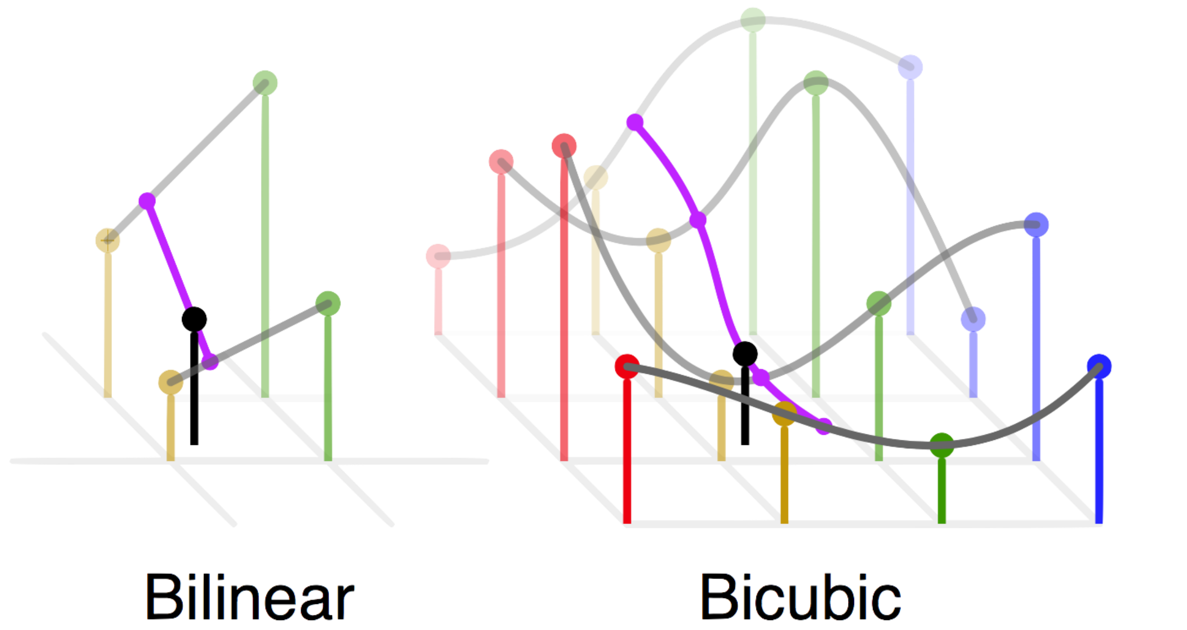
Bicubic sampling: more complex, maybe better?

- A cubic interpolation of 4 cubic interpolations
- Smoother than bilinear, no "star"
- 16 nearest neighbors
- Fit 3rd order poly:
  - f(x) = a + bx + cx^2 + dx^3
- Interpolate along axis
- Fit another poly to interpolated values



Bicubic vs bilinear

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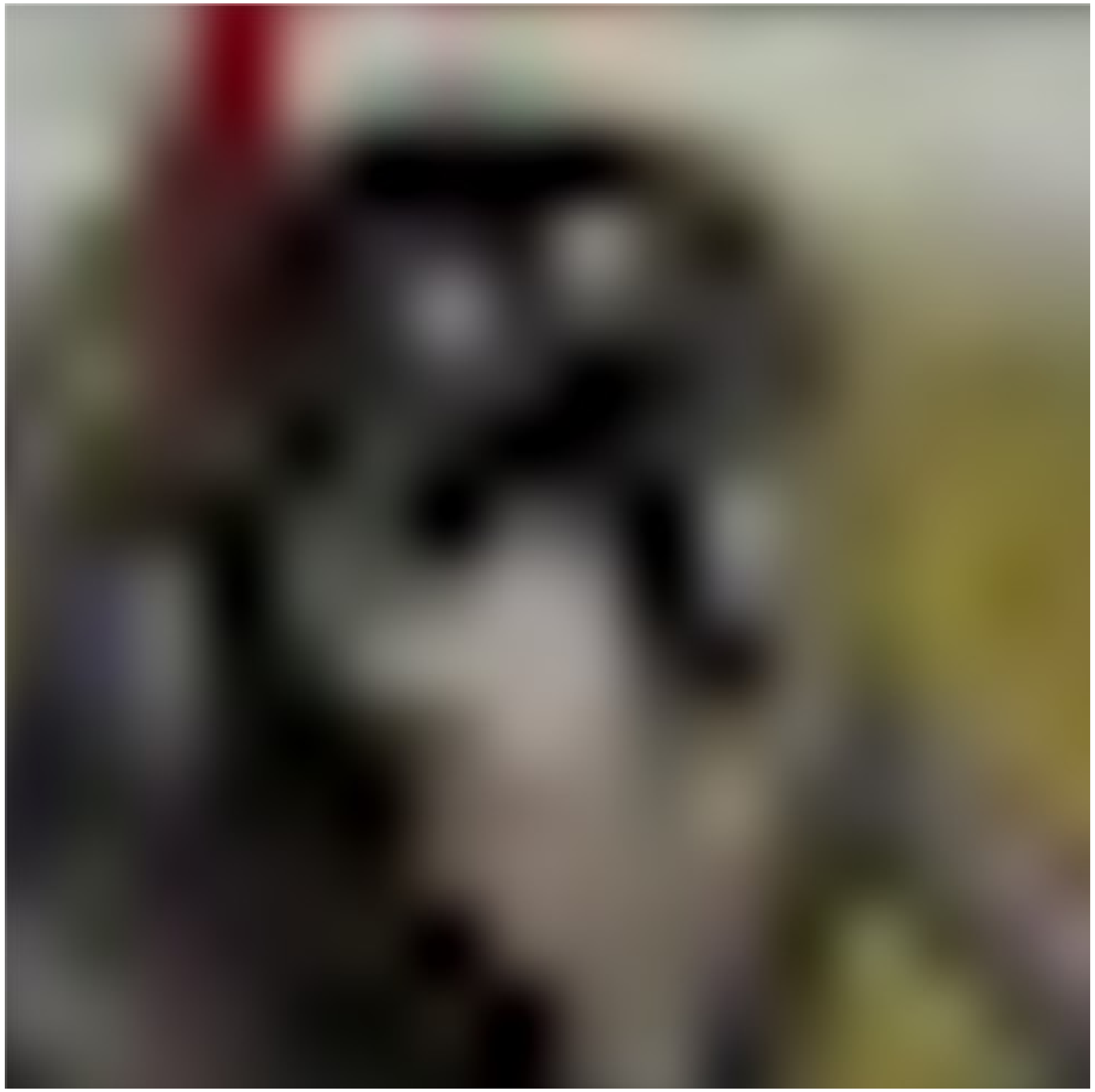
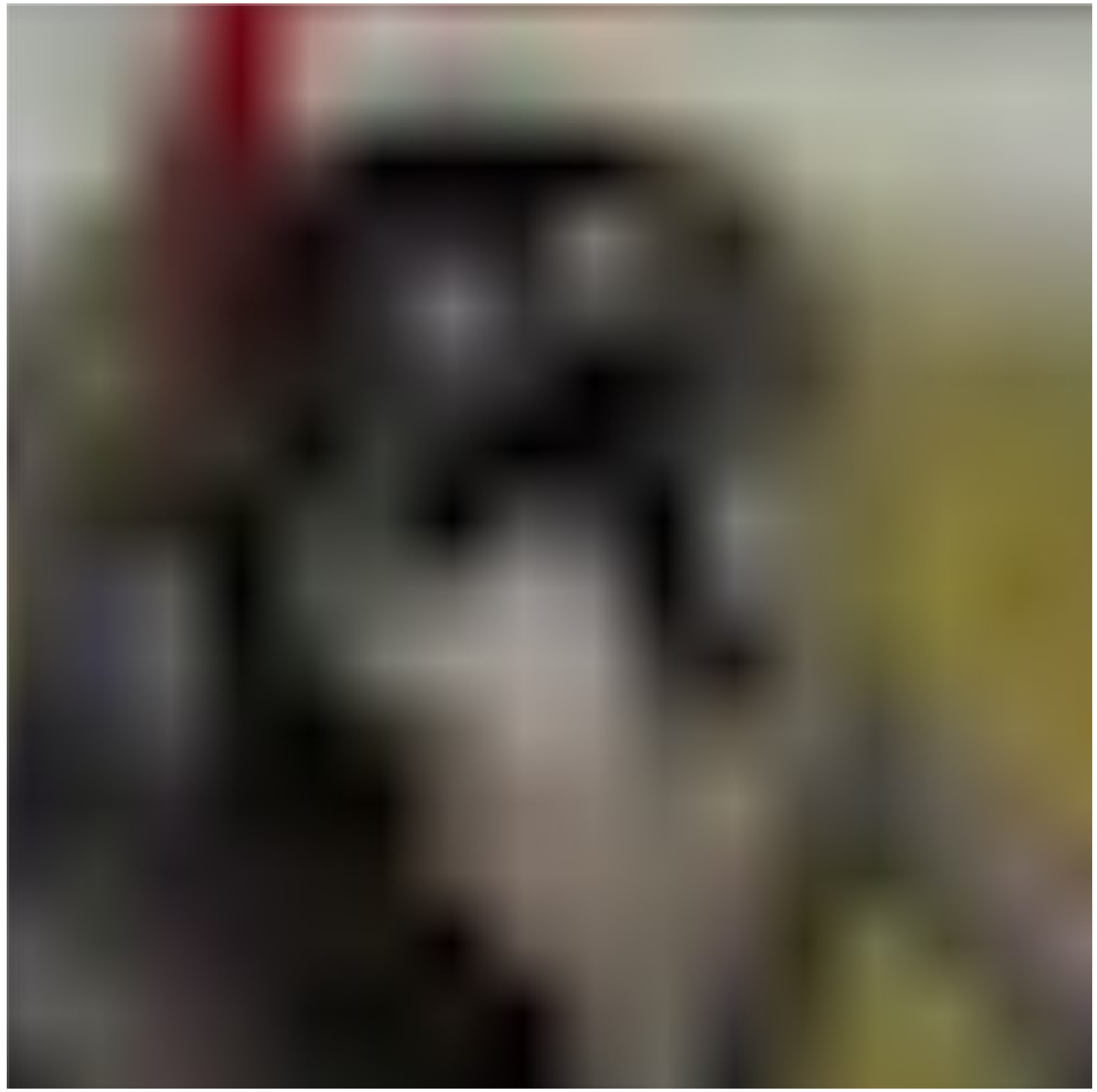
Bicubic vs bilinear





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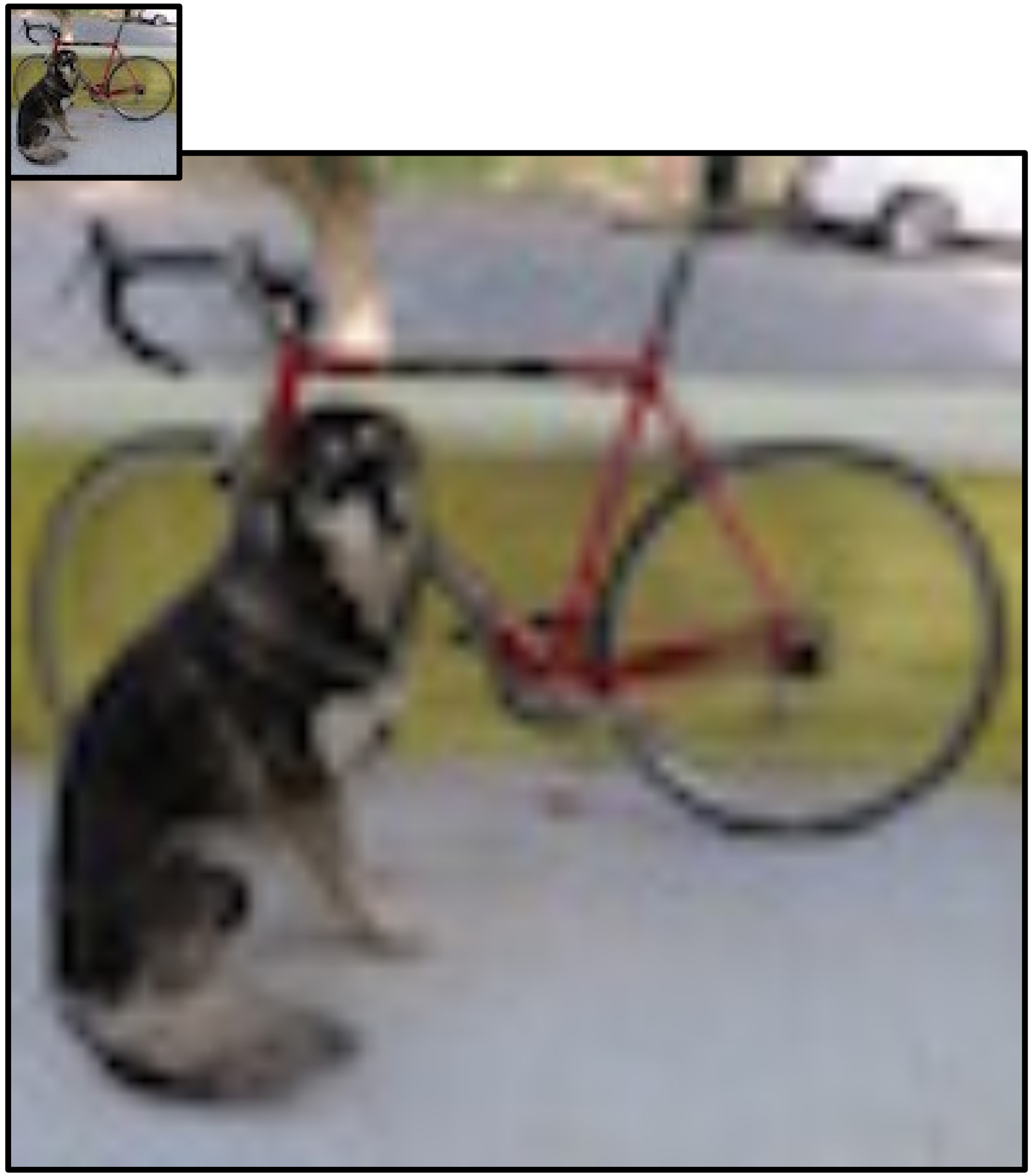
Resize algorithm:

- For each pixel in new image:
  - Map to old im coordinates
  - Interpolate value
  - Set new value in image



So what is this interpolation useful for?

Today's Agenda

- Image basics
  - What is an image – addressing pixels
  - Image as a function – image coordinates
- Image interpolation
  - Nearest neighbor
  - Bilinear
  - Bicubic
- Image resizing
  - Enlarge
  - Shrink

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Image resizing!

Say we want to increase the size of an image...

This is a beautiful image of a sunset... it's just very small...

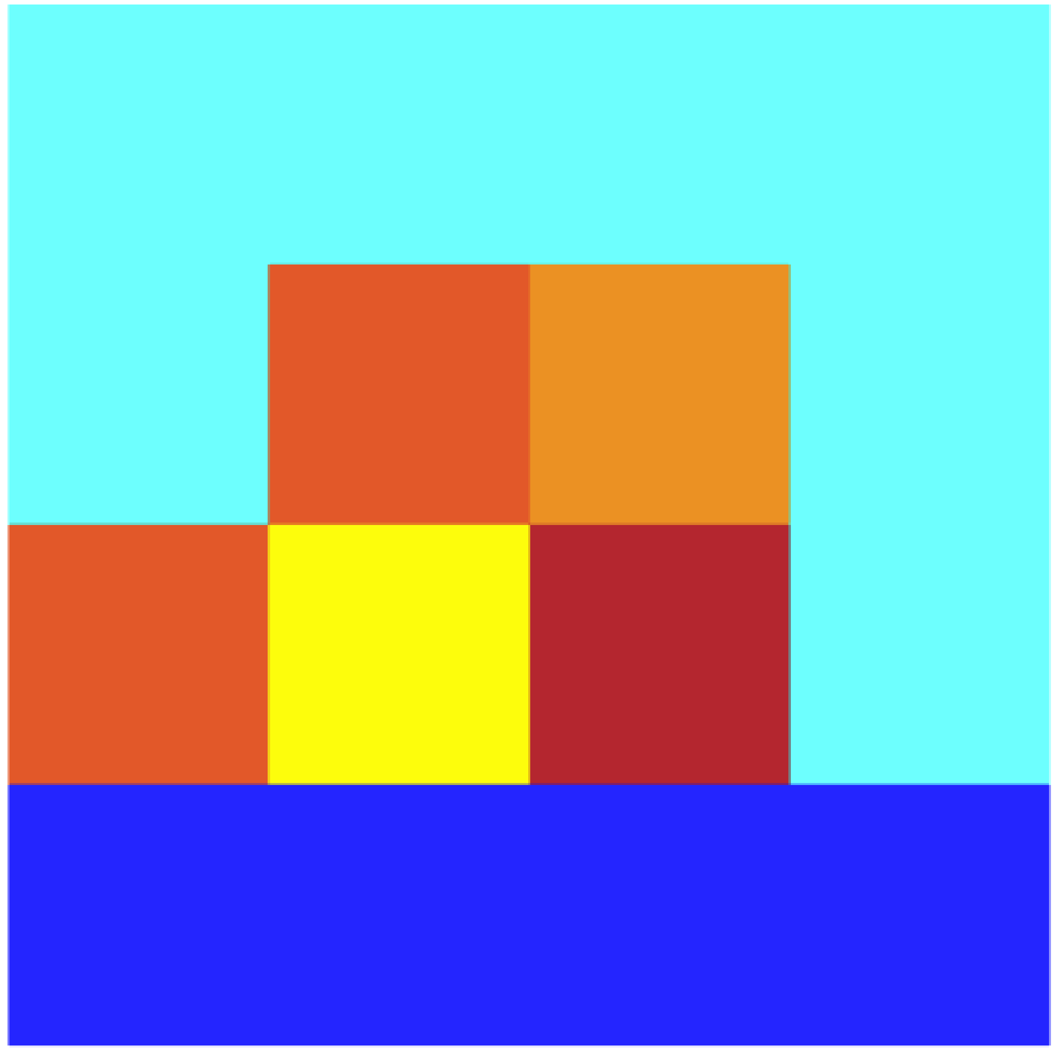
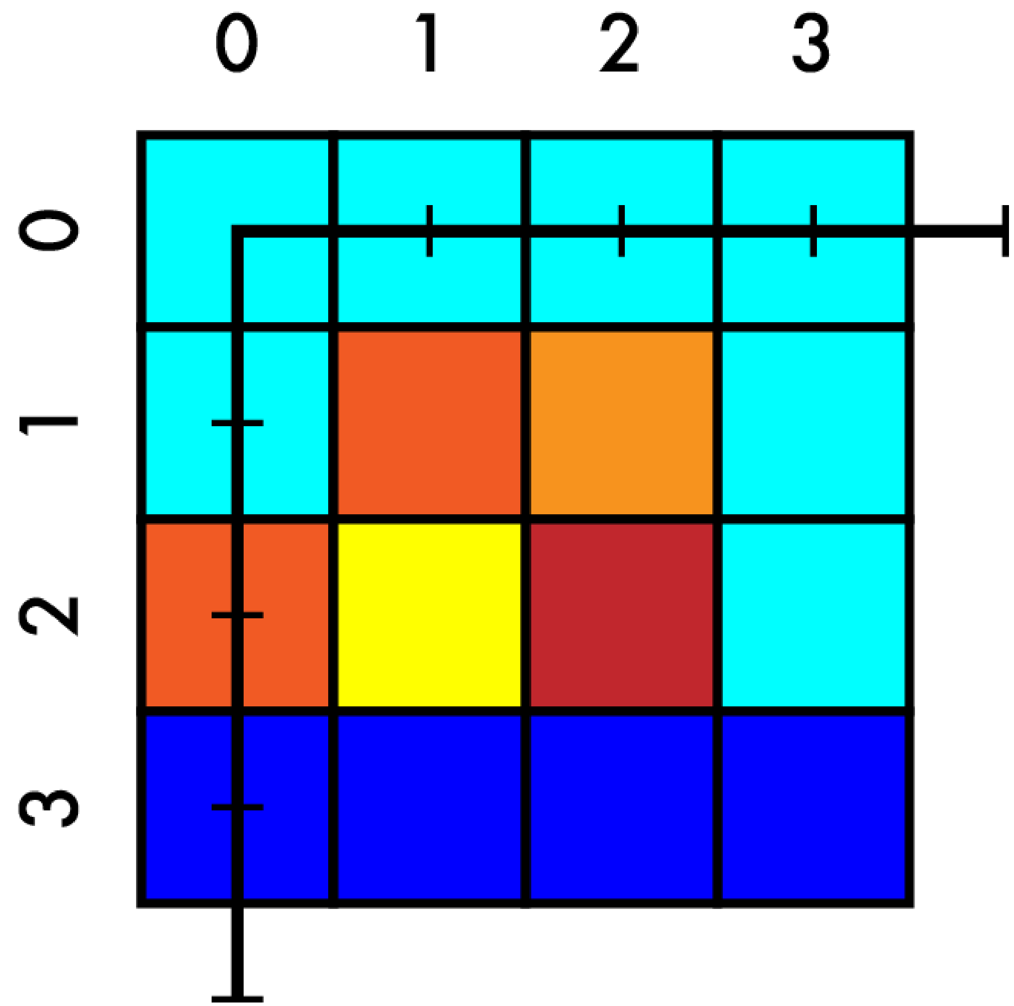


Image resizing!

Say we want to increase the size of an image...

This is a beautiful image of a sunset... it's just very small...

Say we want to increase size 4x4 -> 7x7



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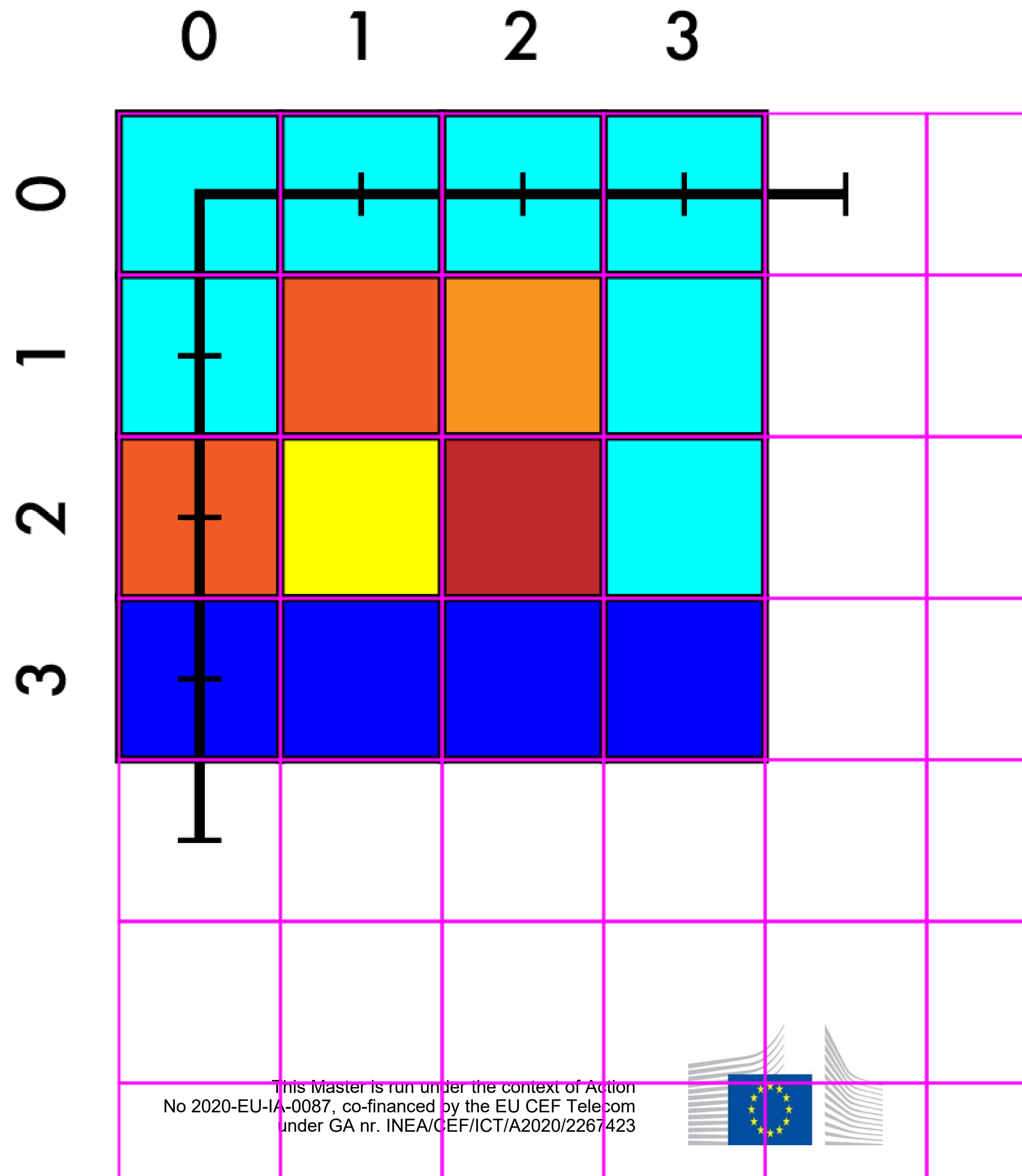
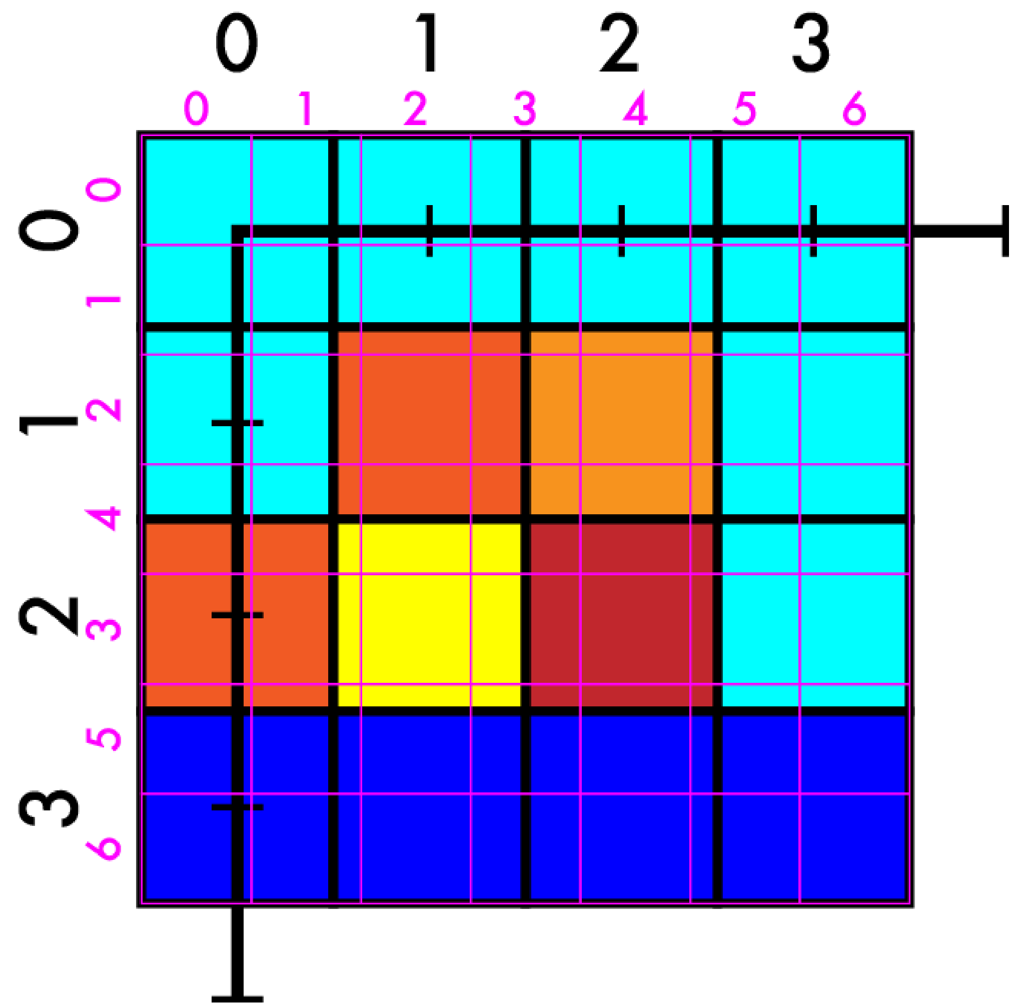
Resize 4x4 -> 7x7

- Create our new image



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates



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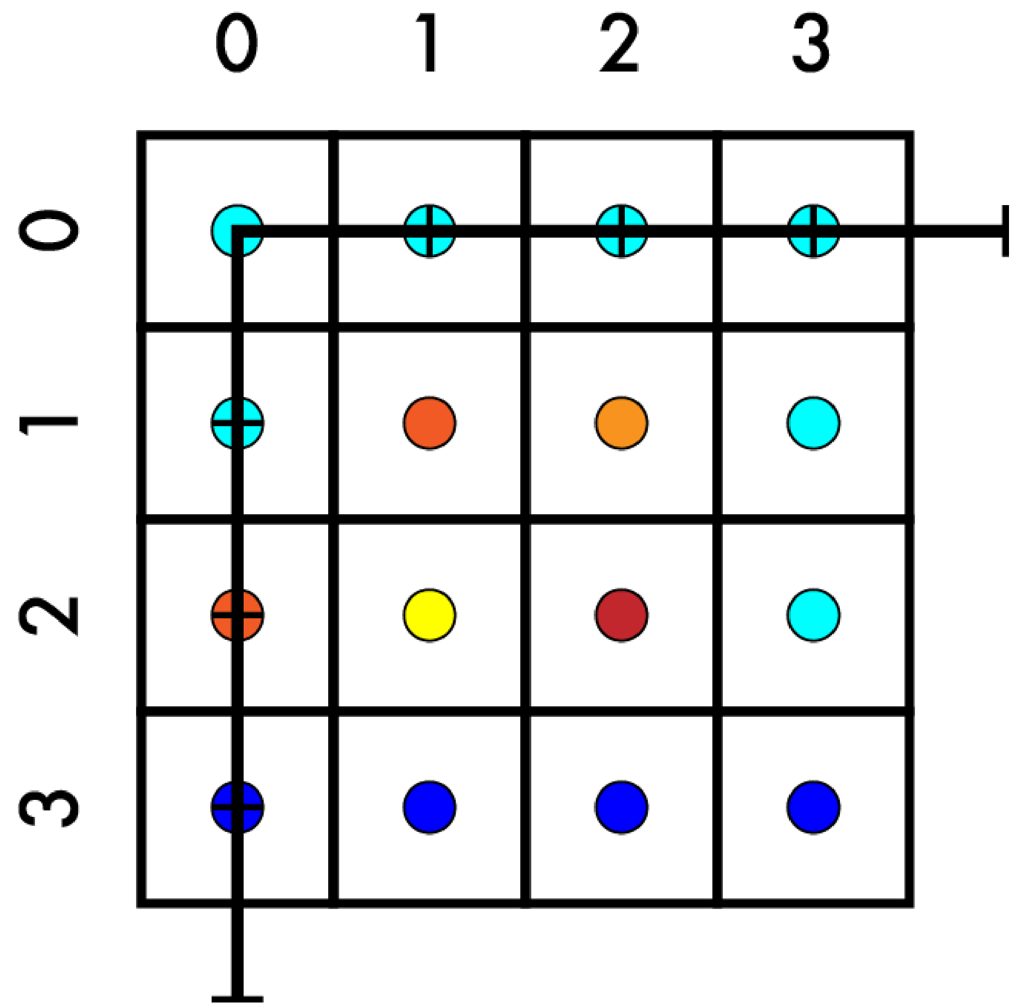
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates



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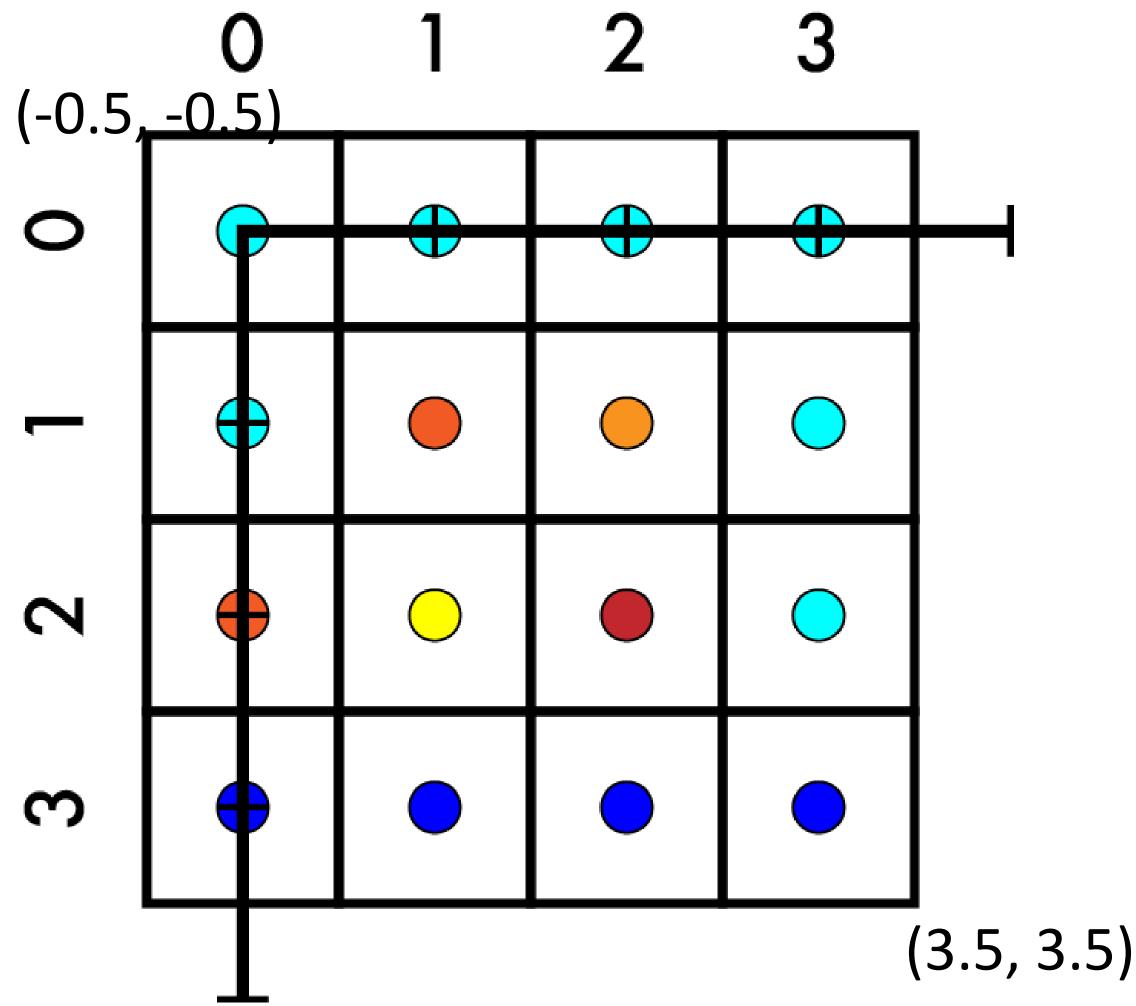
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates



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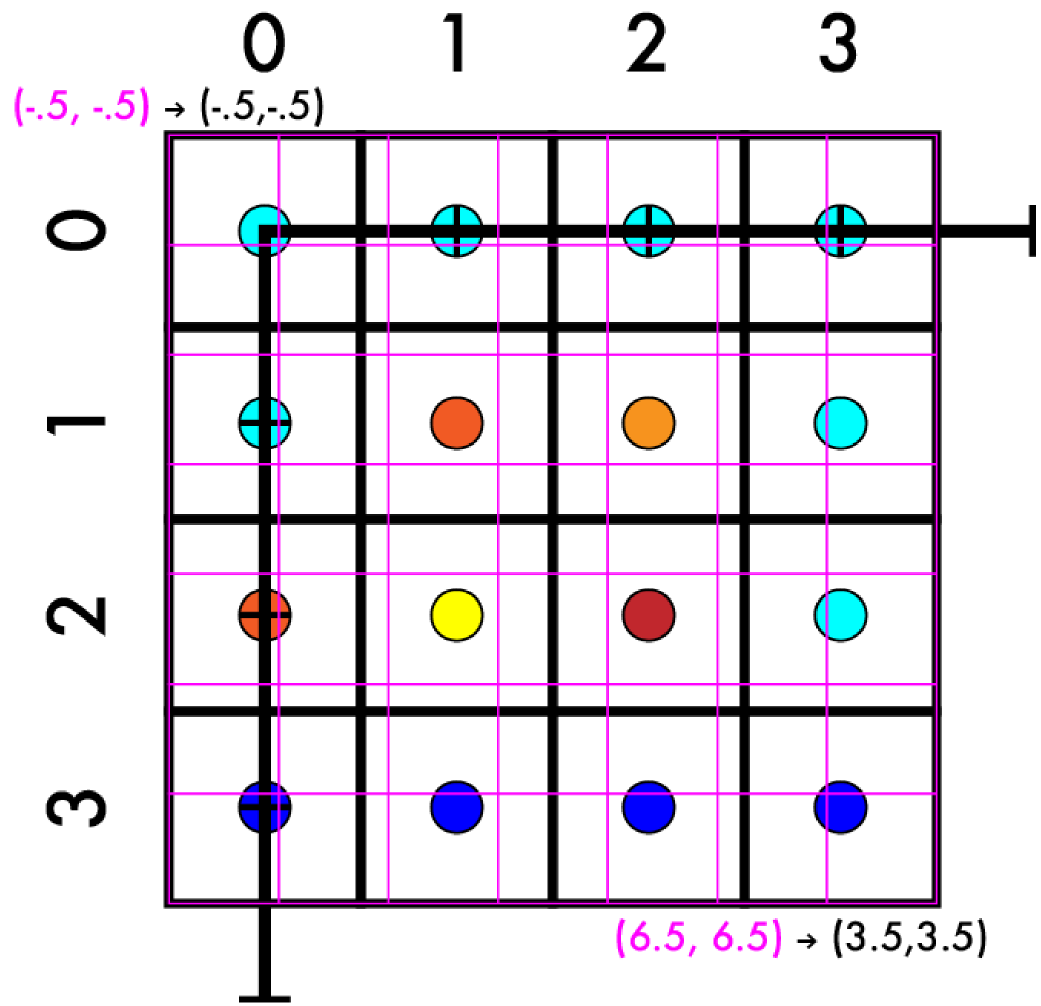
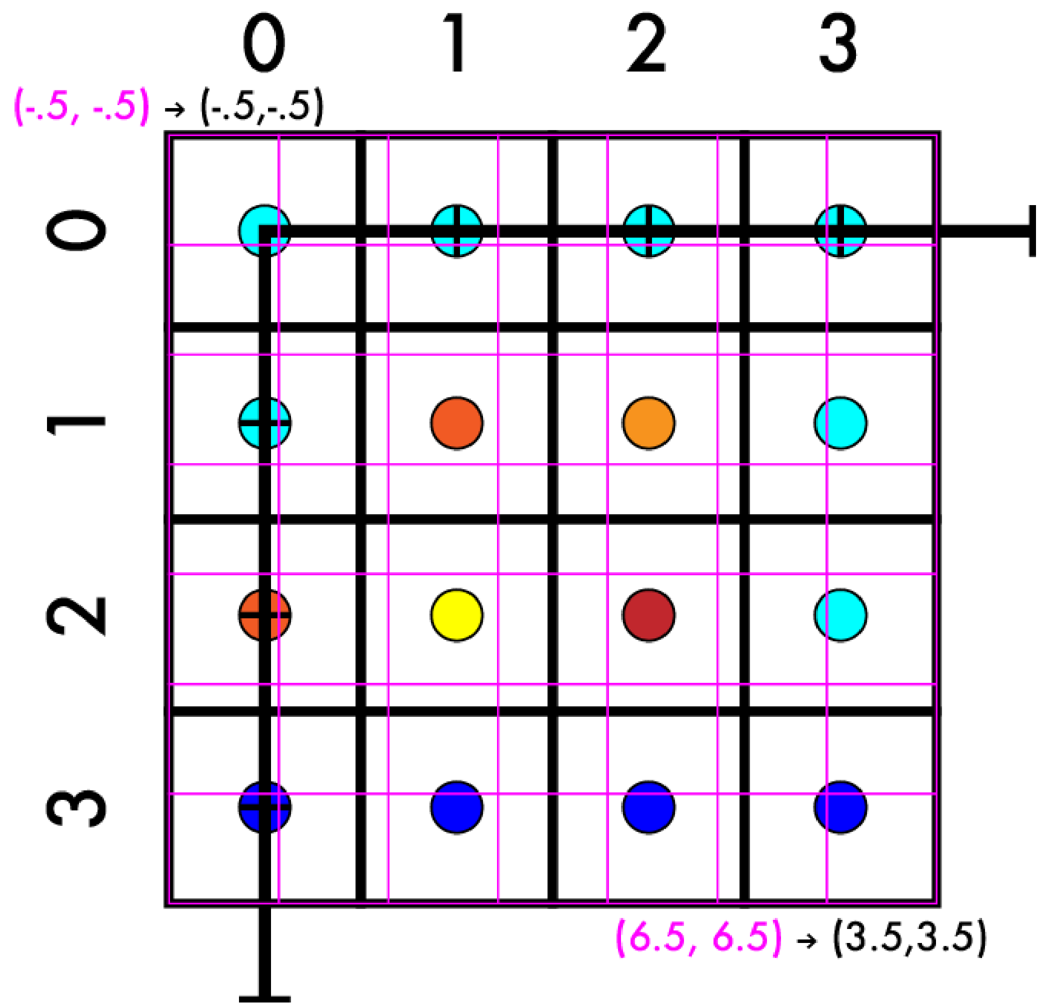
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5



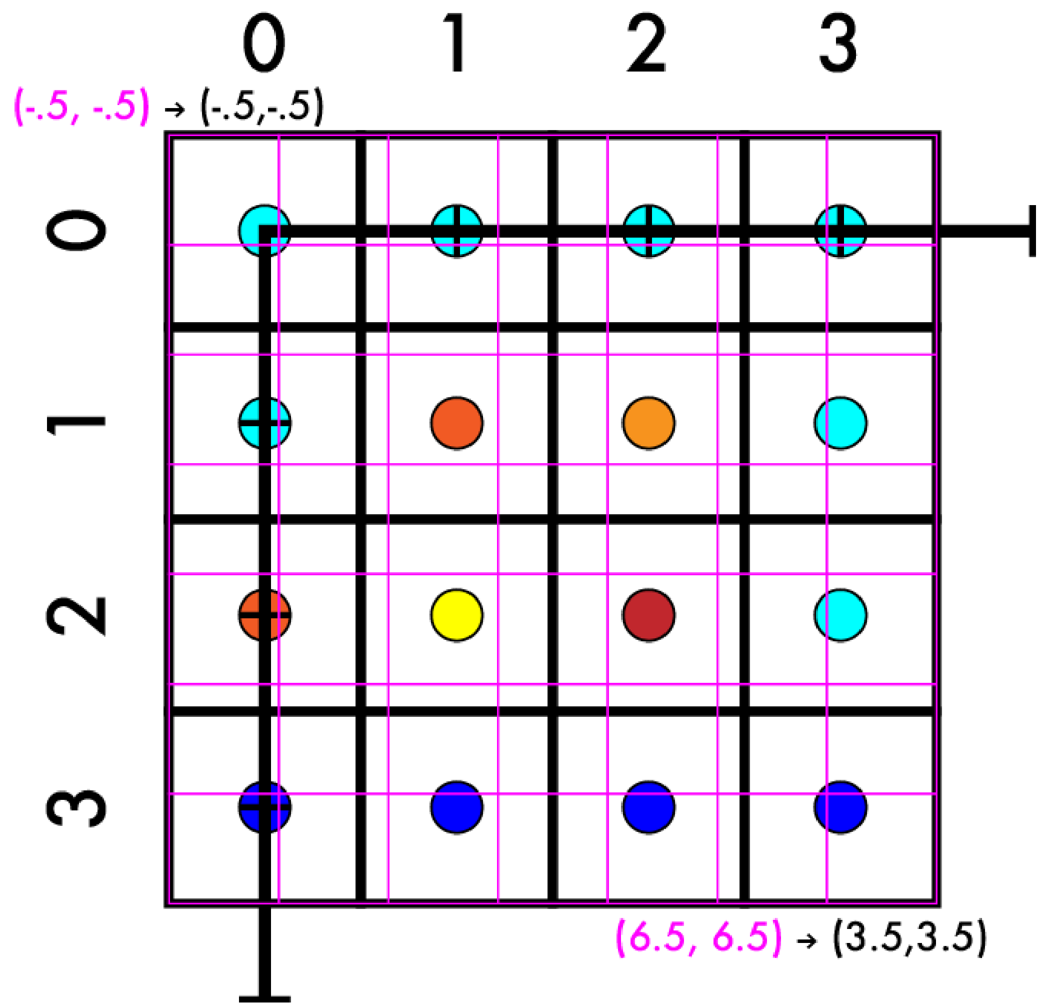
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
    - a*7 = 4



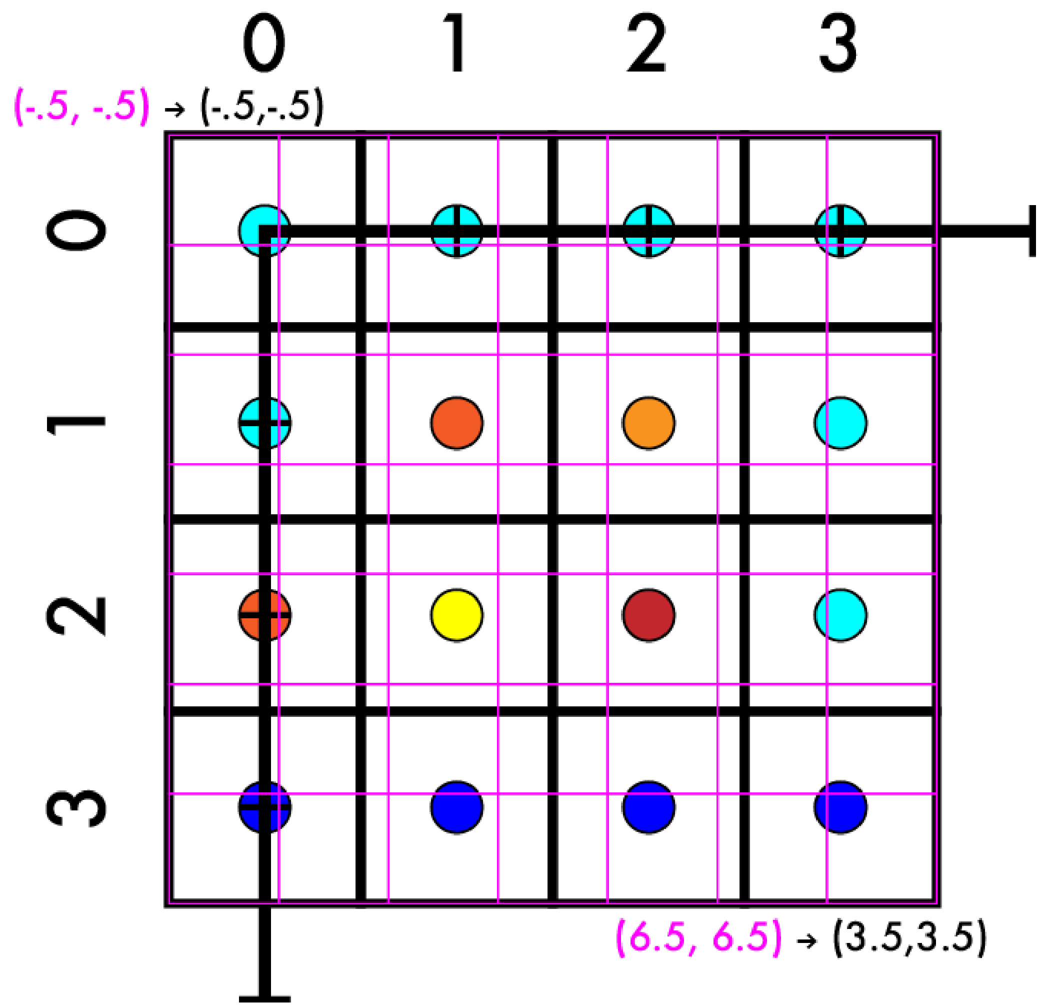
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
    - a*7 = 4
    - a = 4/7



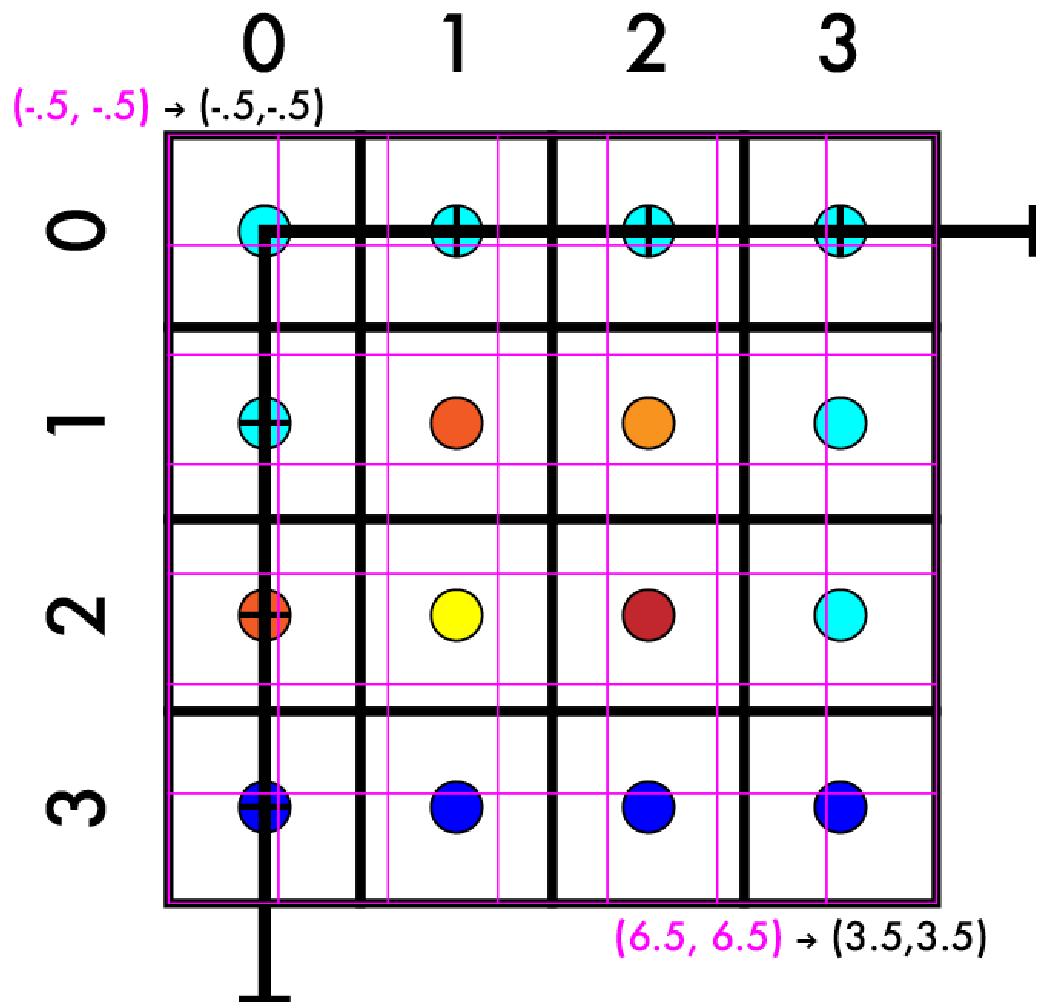
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
  - a = 4/7



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - $aX + b = Y$
  - $a*-.5 + b = -.5$
  - $a*6.5 + b = 3.5$
  - $a = 4/7$
    - $a*-.5 + b = -.5$



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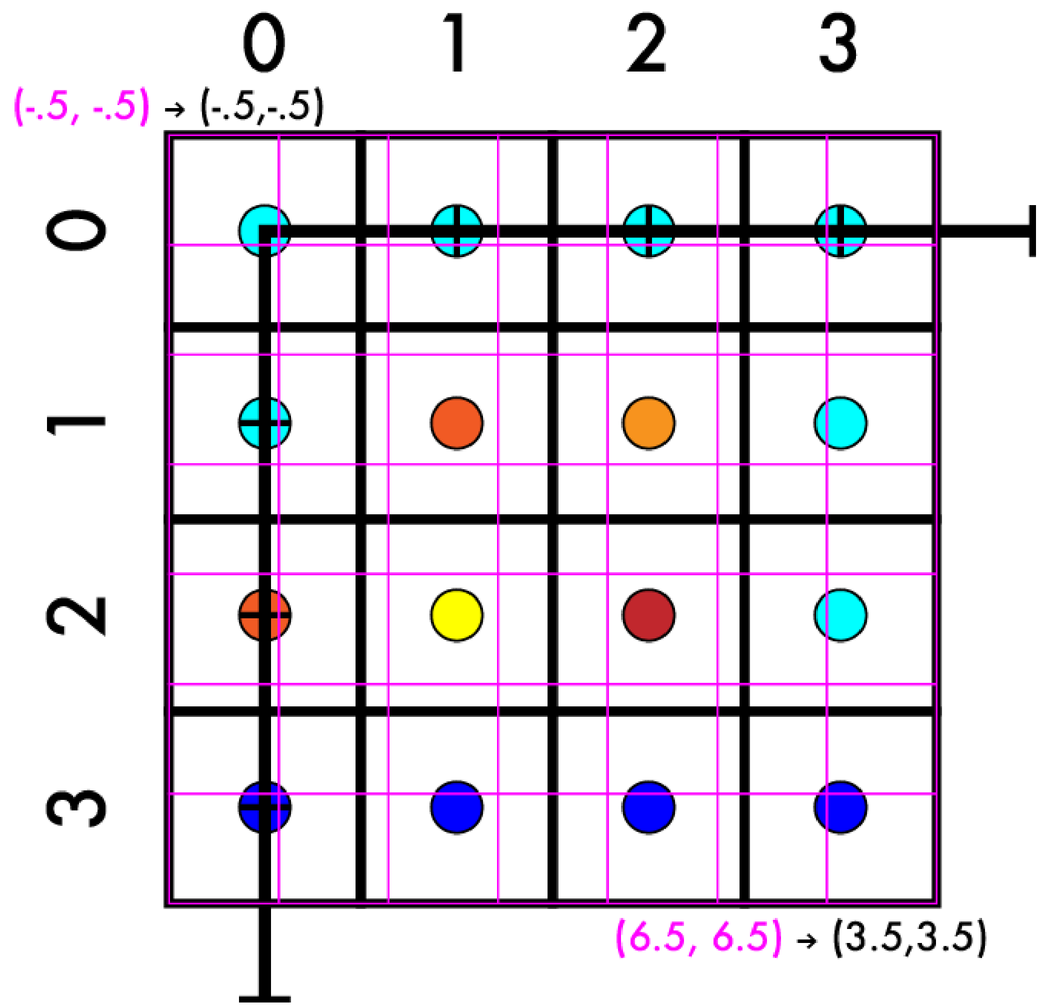
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
  - a = 4/7
    - a*-.5 + b = -.5
    - 4/7*-1/2 + b = -1/2



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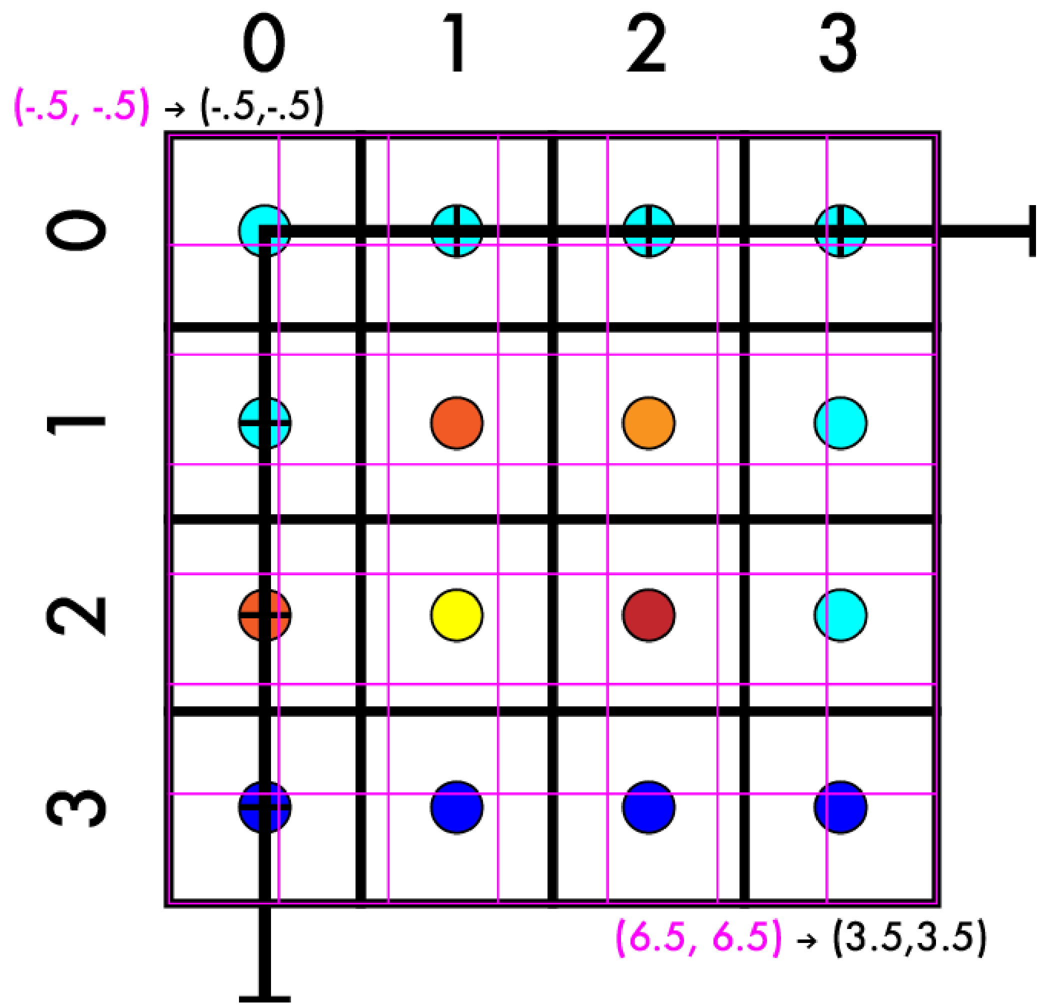
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
  - a = 4/7
    - a*-.5 + b = -.5
    - 4/7*-1/2 + b = -1/2
    - -4/14 + b = -7/14



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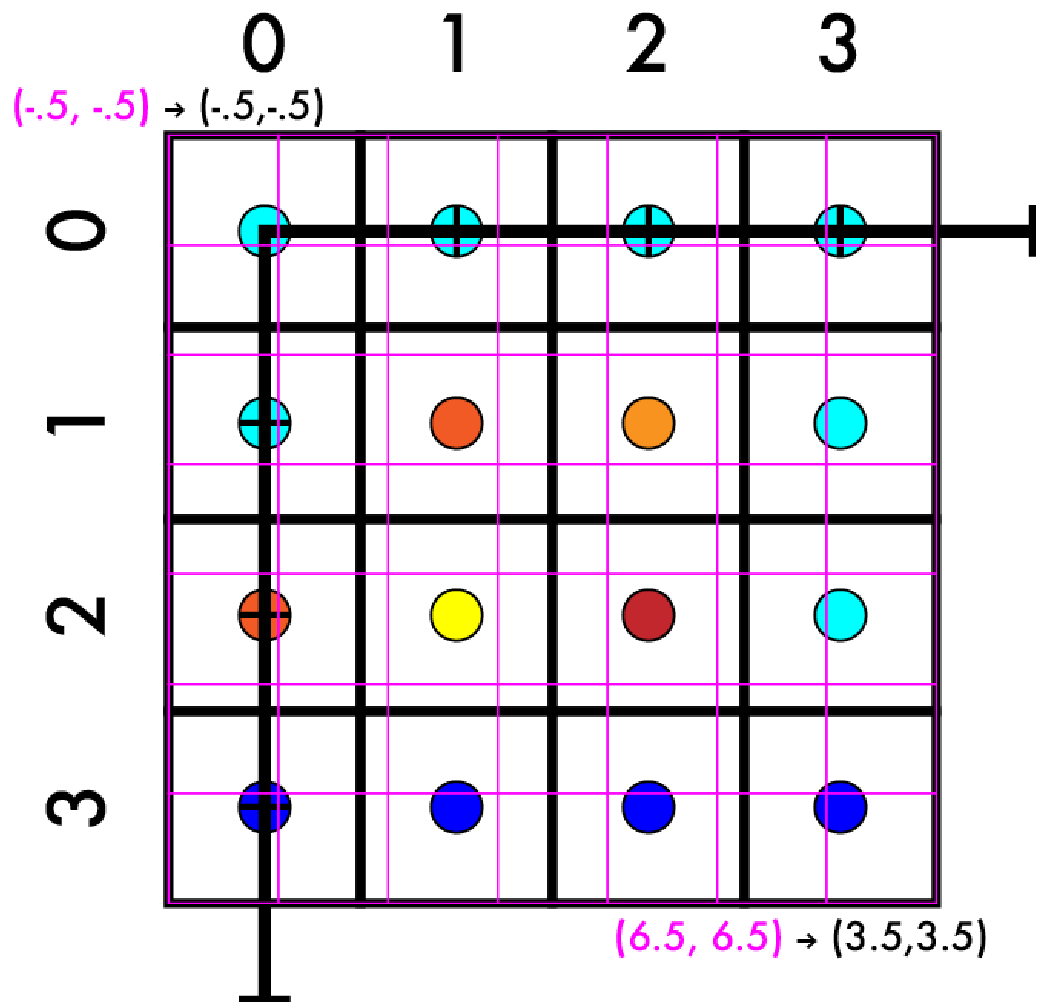
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
  - a = 4/7
    - a*-.5 + b = -.5
    - 4/7*-1/2 + b = -1/2
    - -4/14 + b = -7/14
    - b = -3/14



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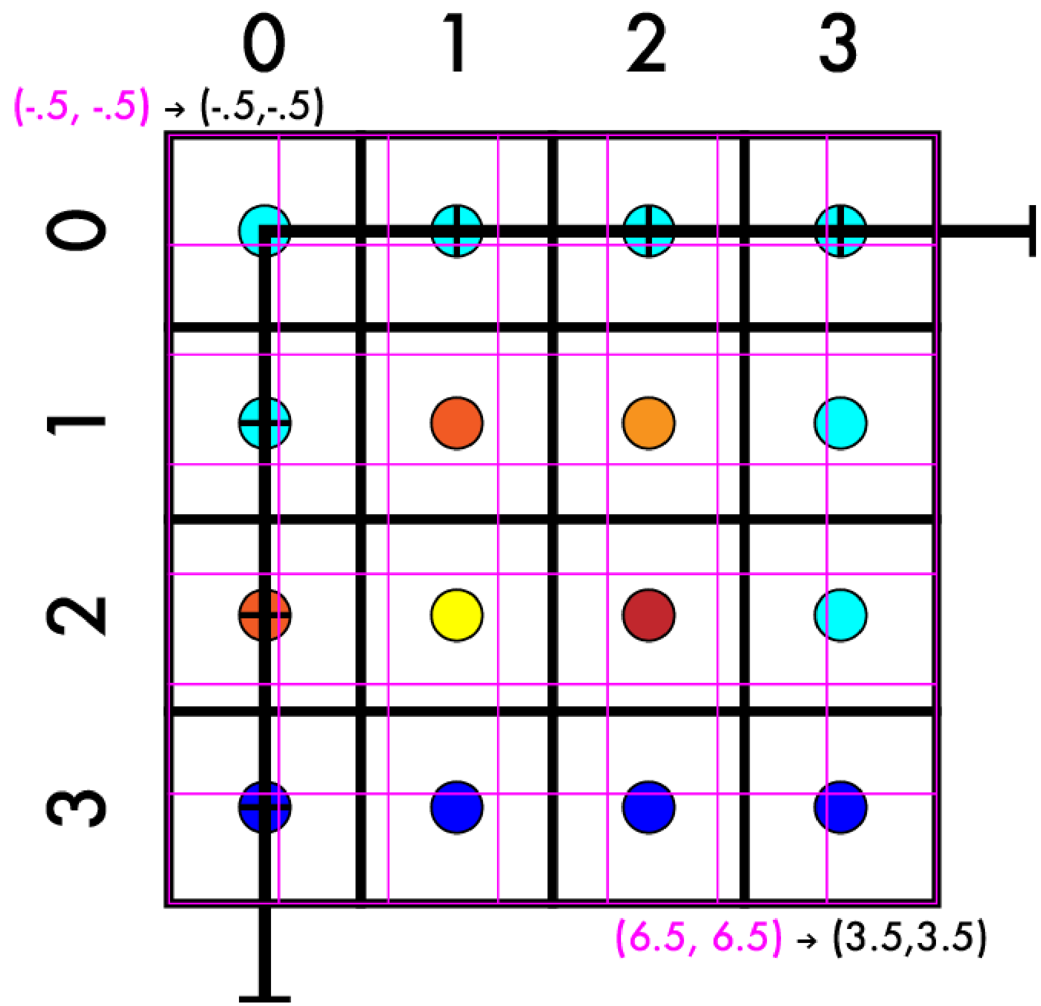
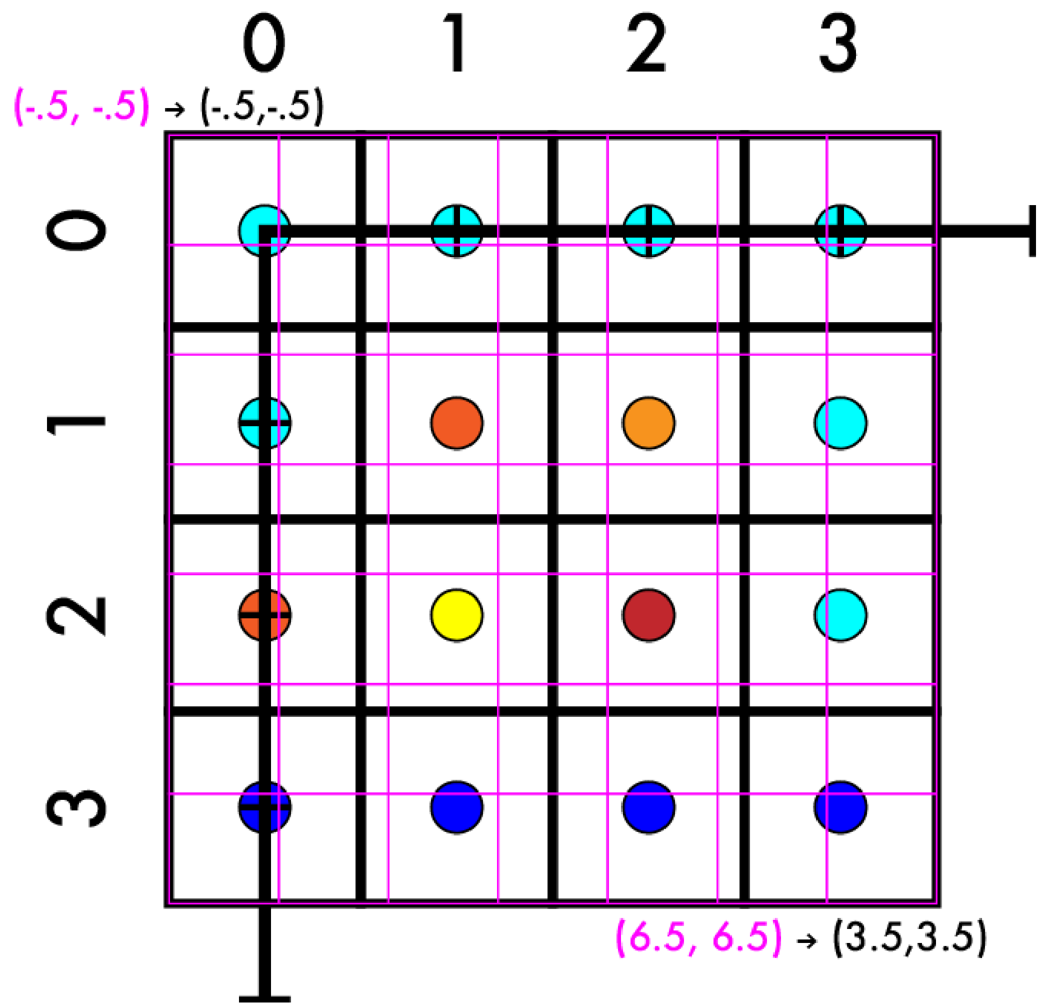
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - System of equations
  - aX + b = Y
  - a*-.5 + b = -.5
  - a*6.5 + b = 3.5
  - a = 4/7
  - b = -3/14



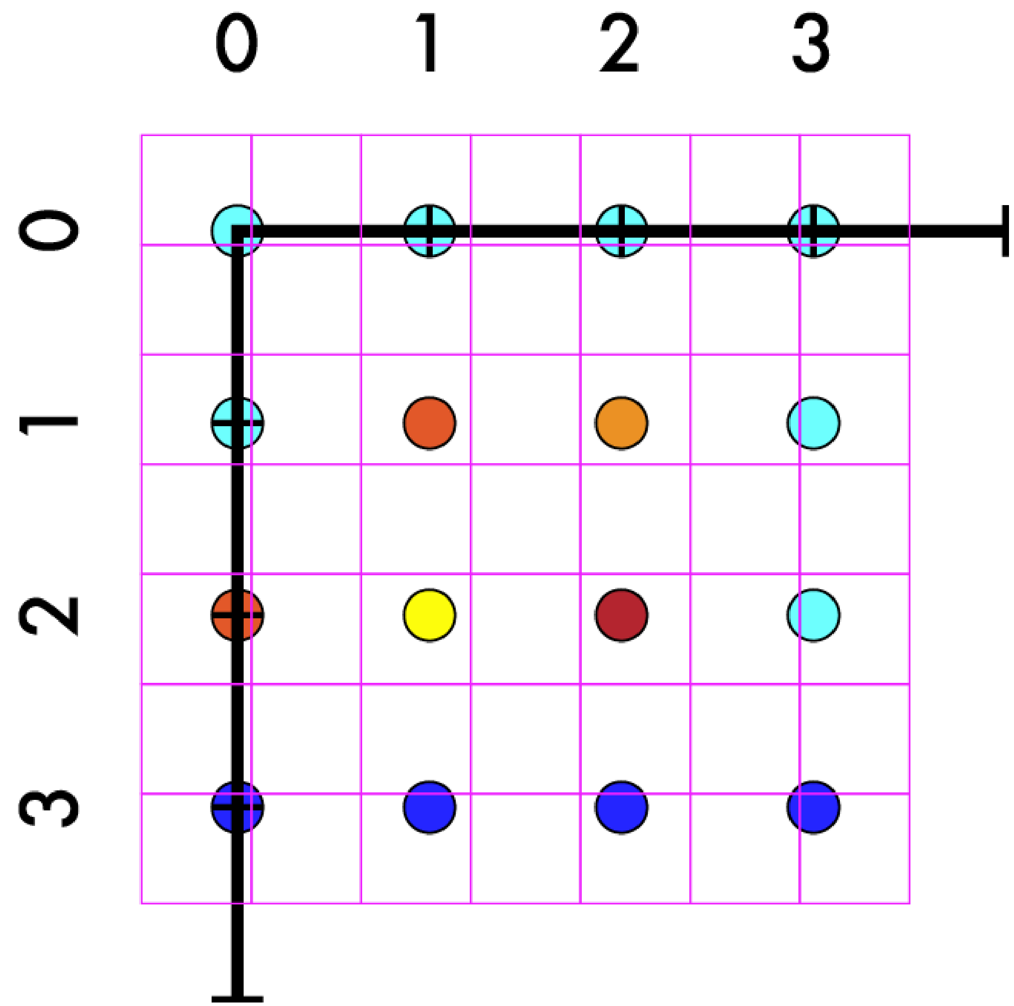
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y



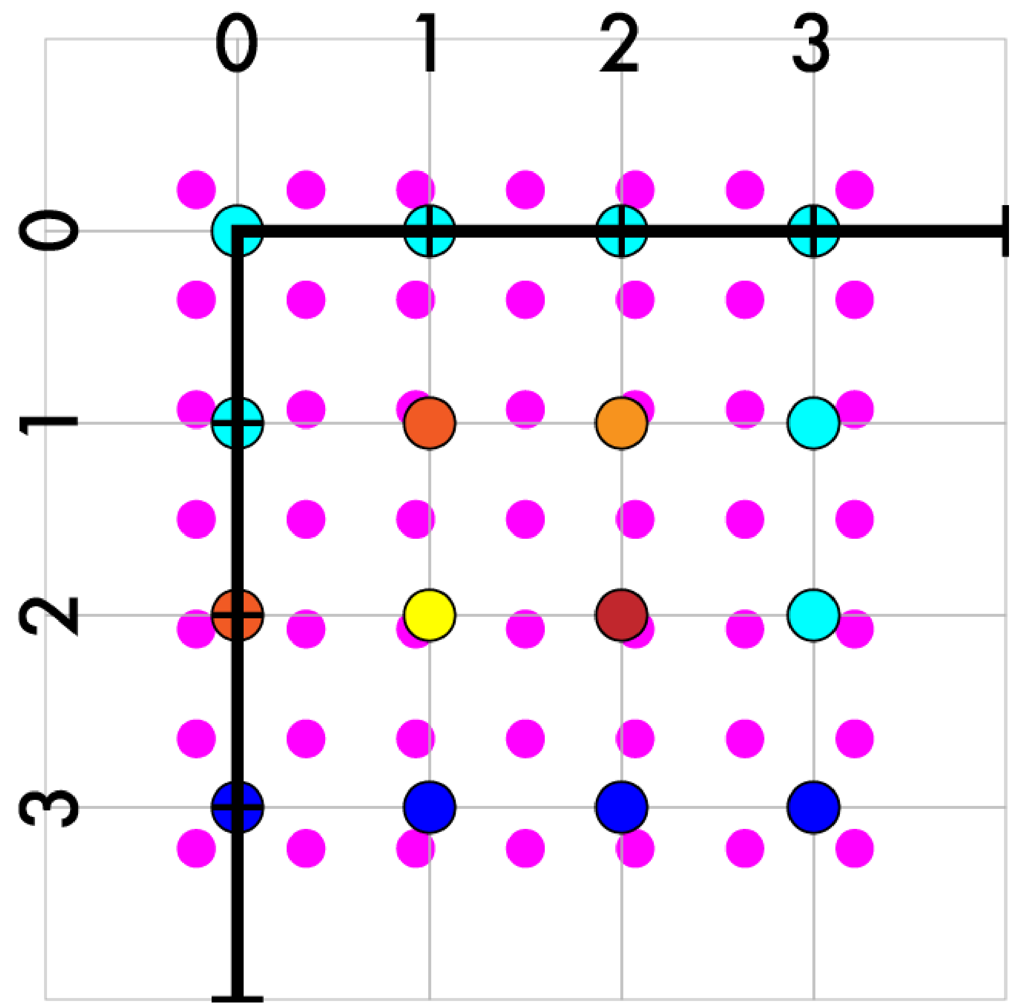
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - $4/7\ X - 3/14 = Y$



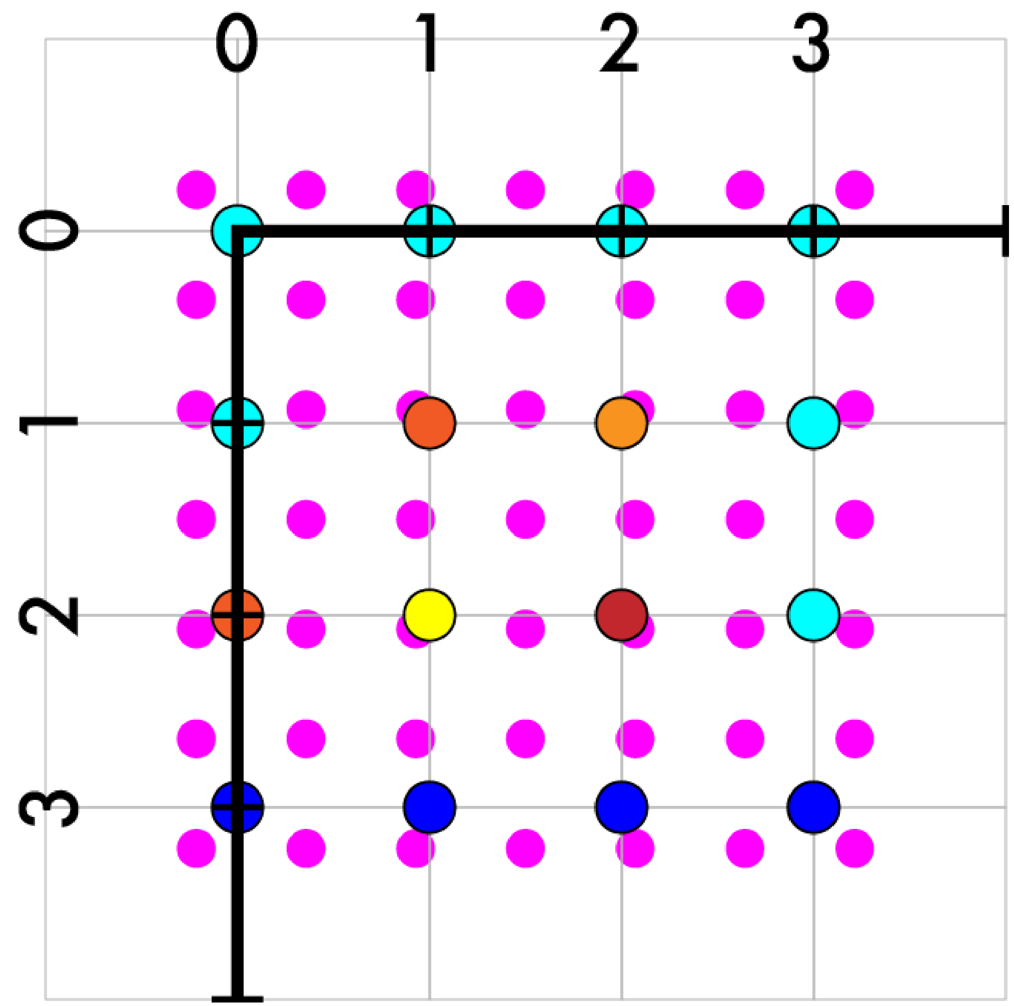
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts



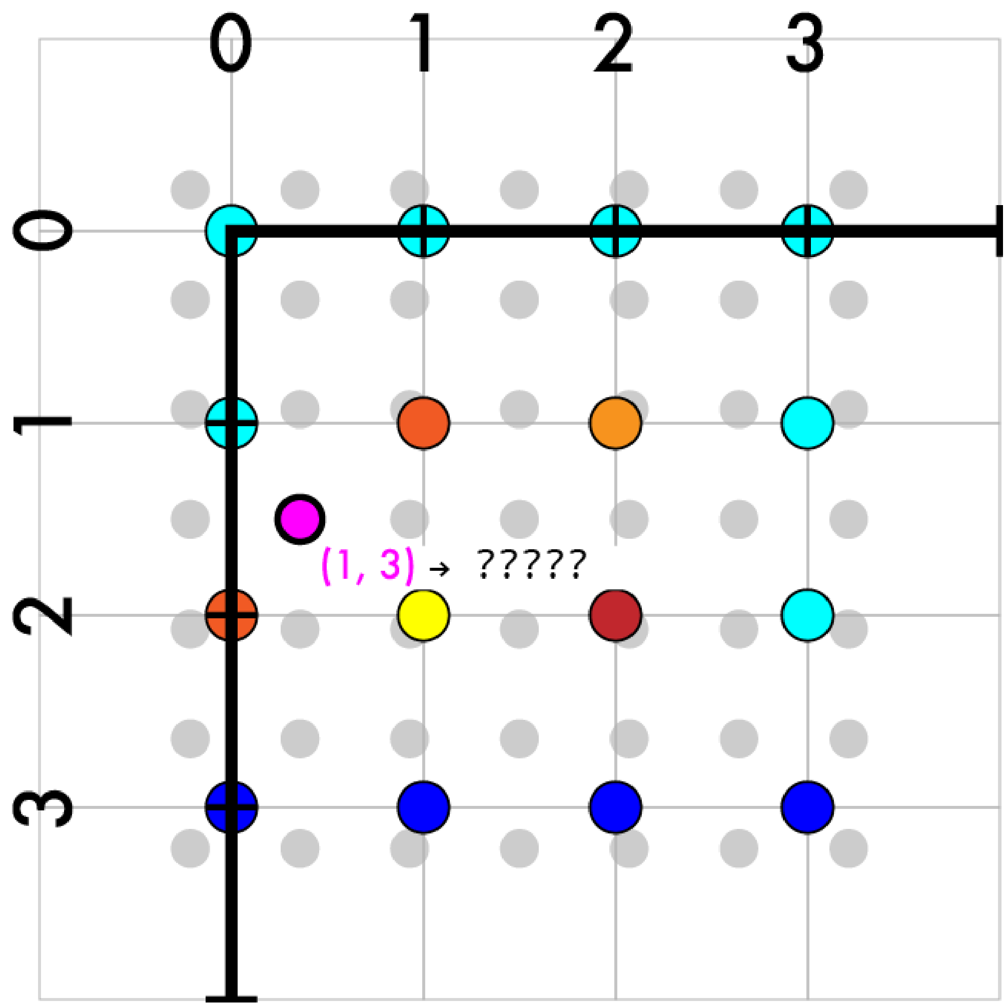
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3)



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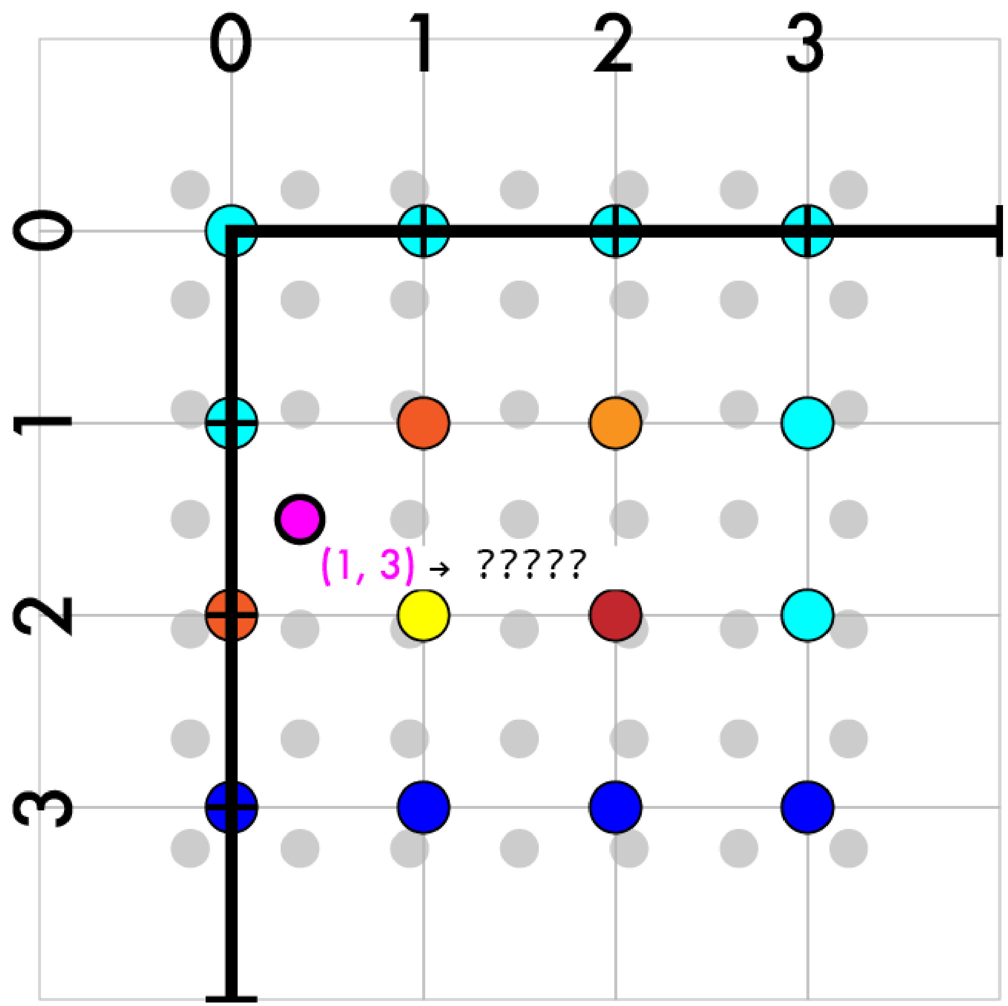
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3)
  - 4/7*1 - 3/14
  - 4/7*3 - 3/14



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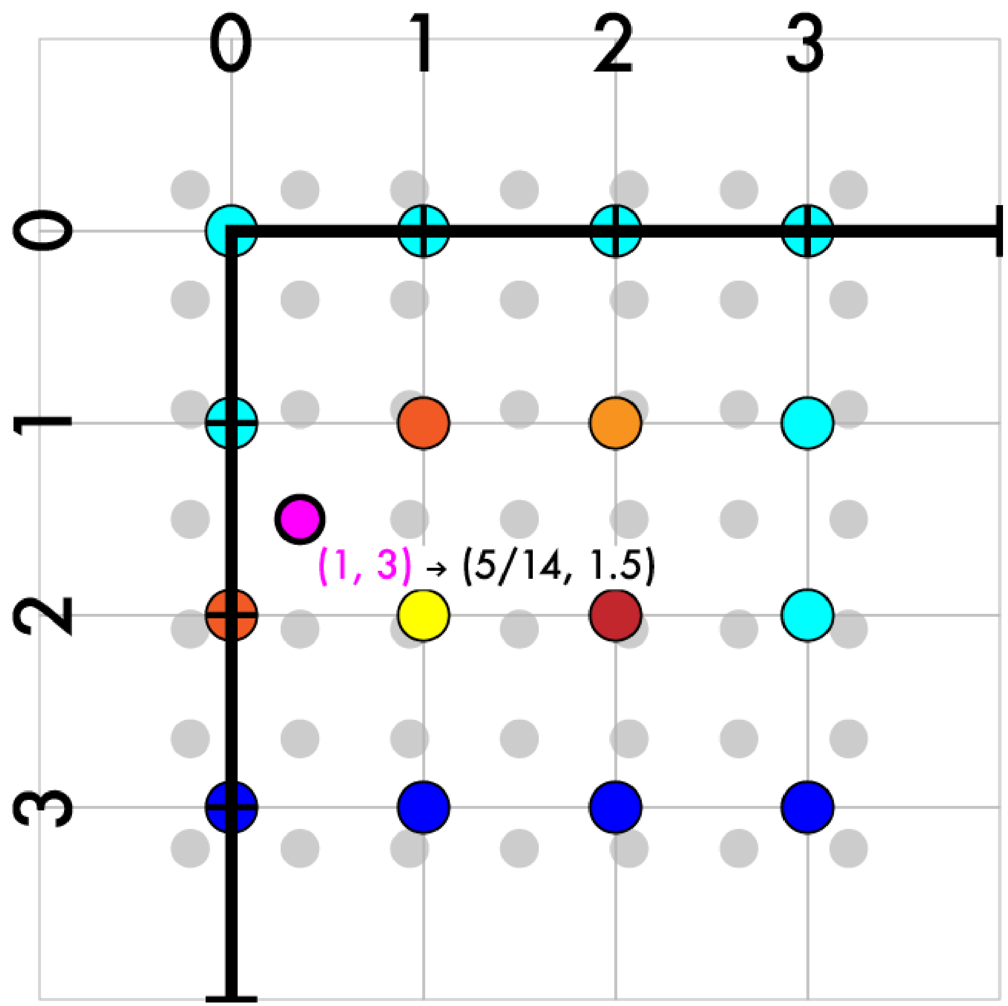
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
    - 4/7 X - 3/14 = Y
- Iterate over new pts
    - Map to old coords
    - (1, 3)
    - 4/7*1 - 3/14
    - 4/7*3 - 3/14
    - (5/14, 21/14)



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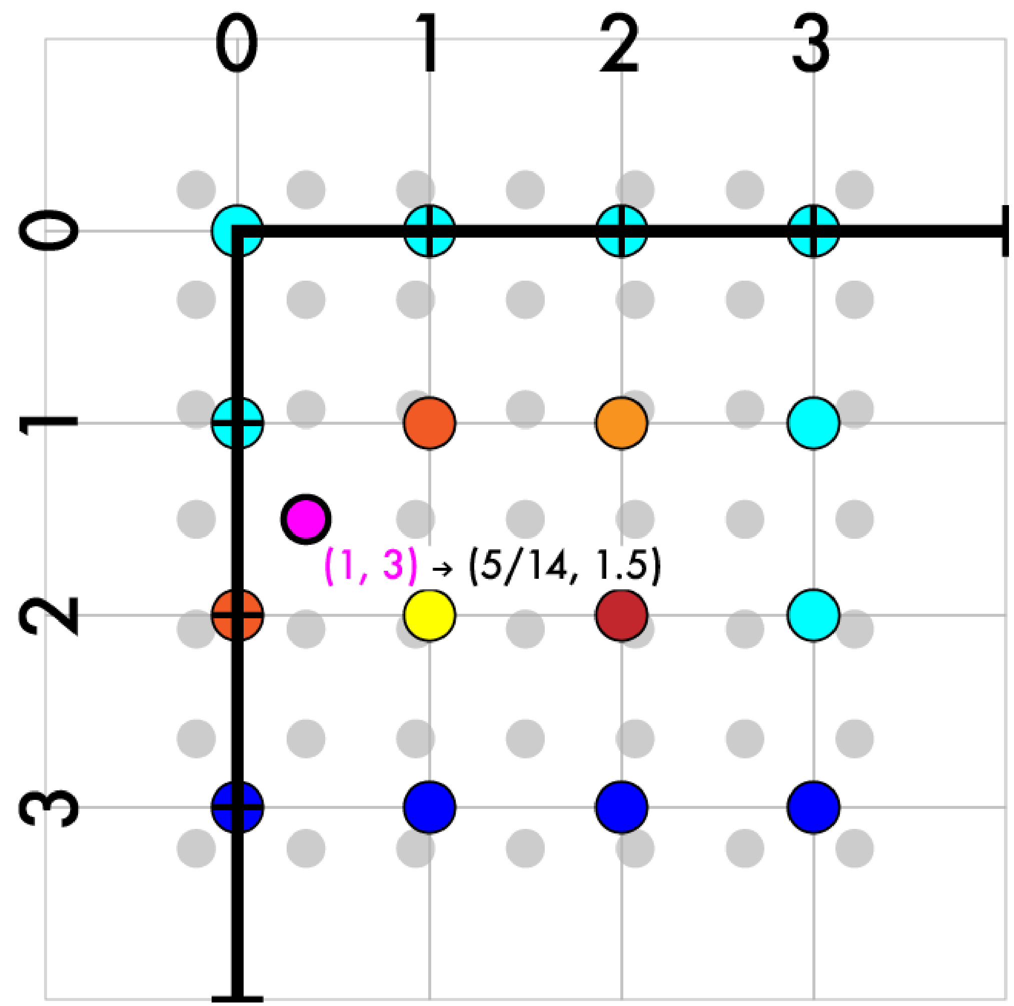
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
    - 4/7 X - 3/14 = Y
- Iterate over new pts
    - Map to old coords
    - (1, 3) -> (5/14, 21/14)



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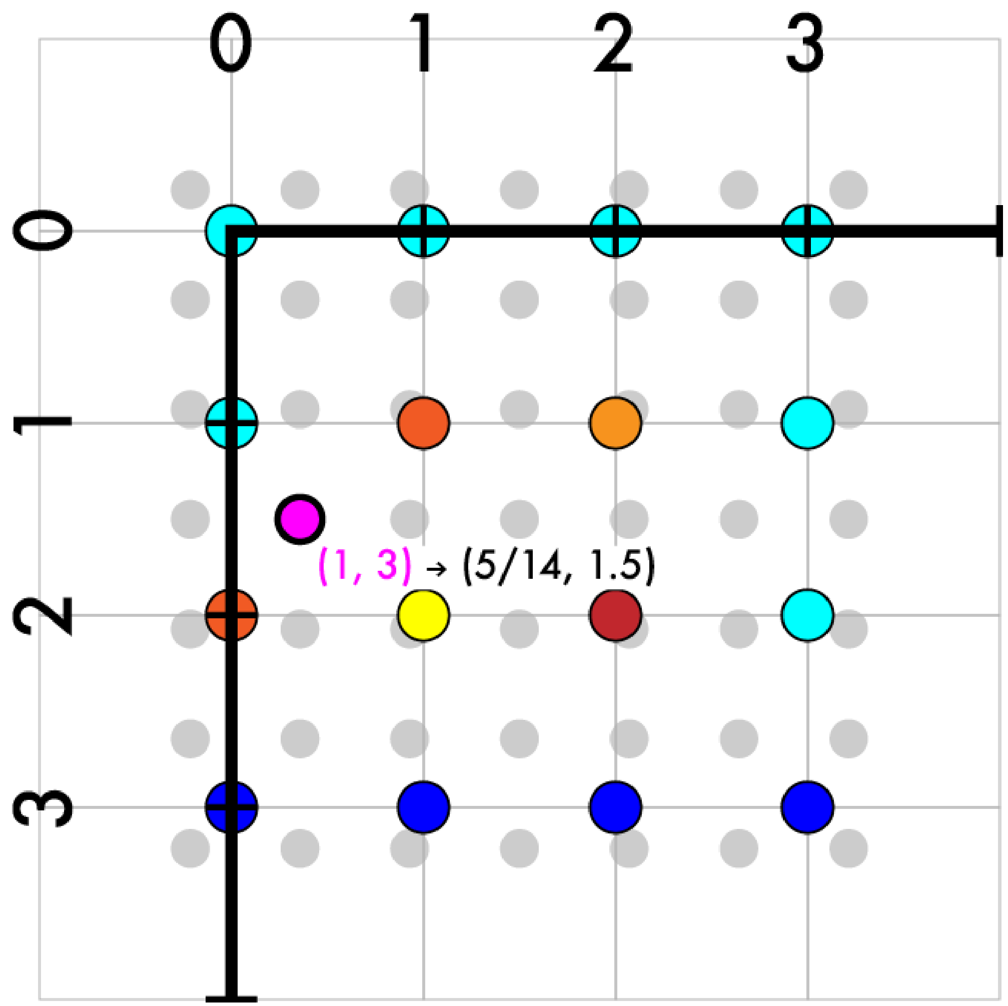
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values



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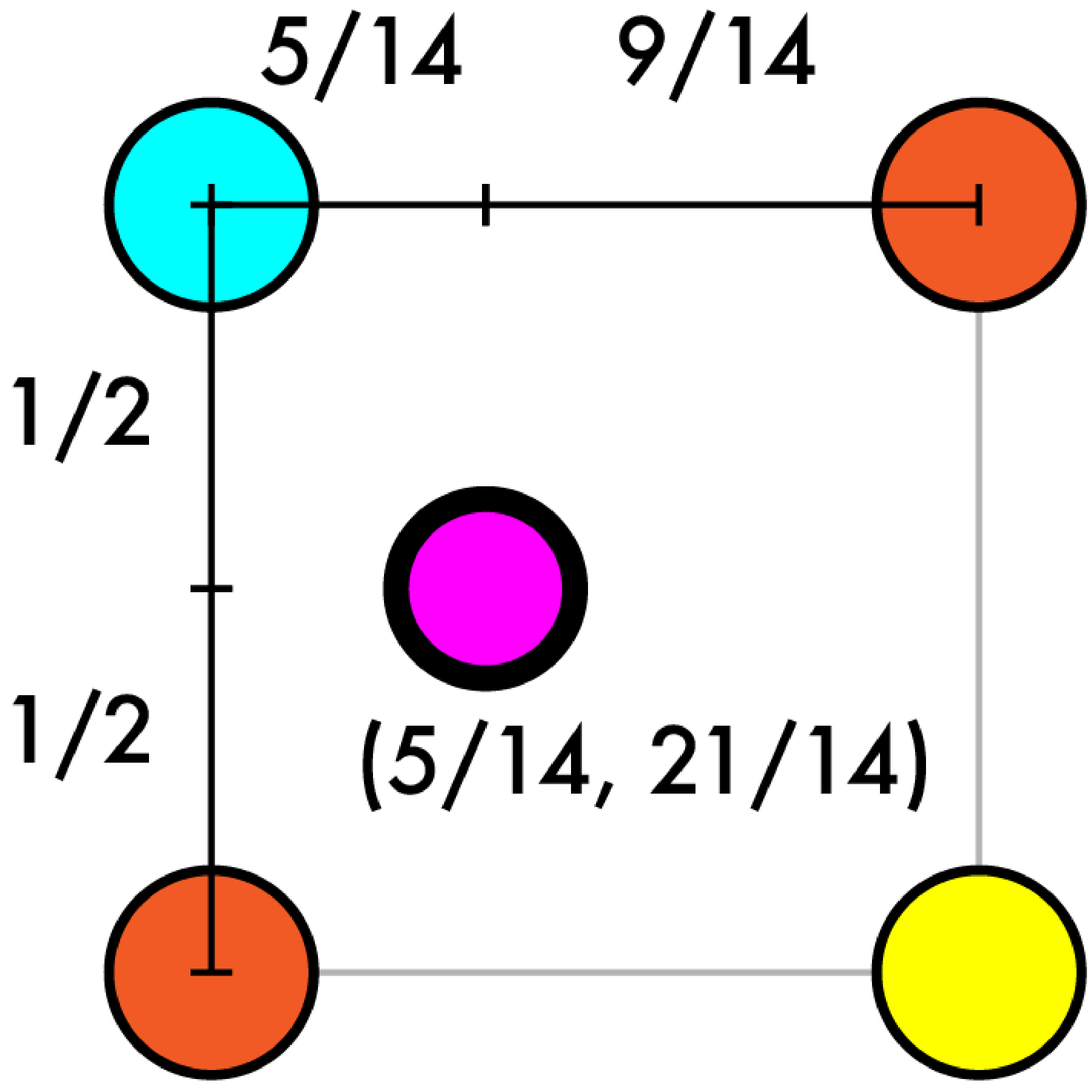
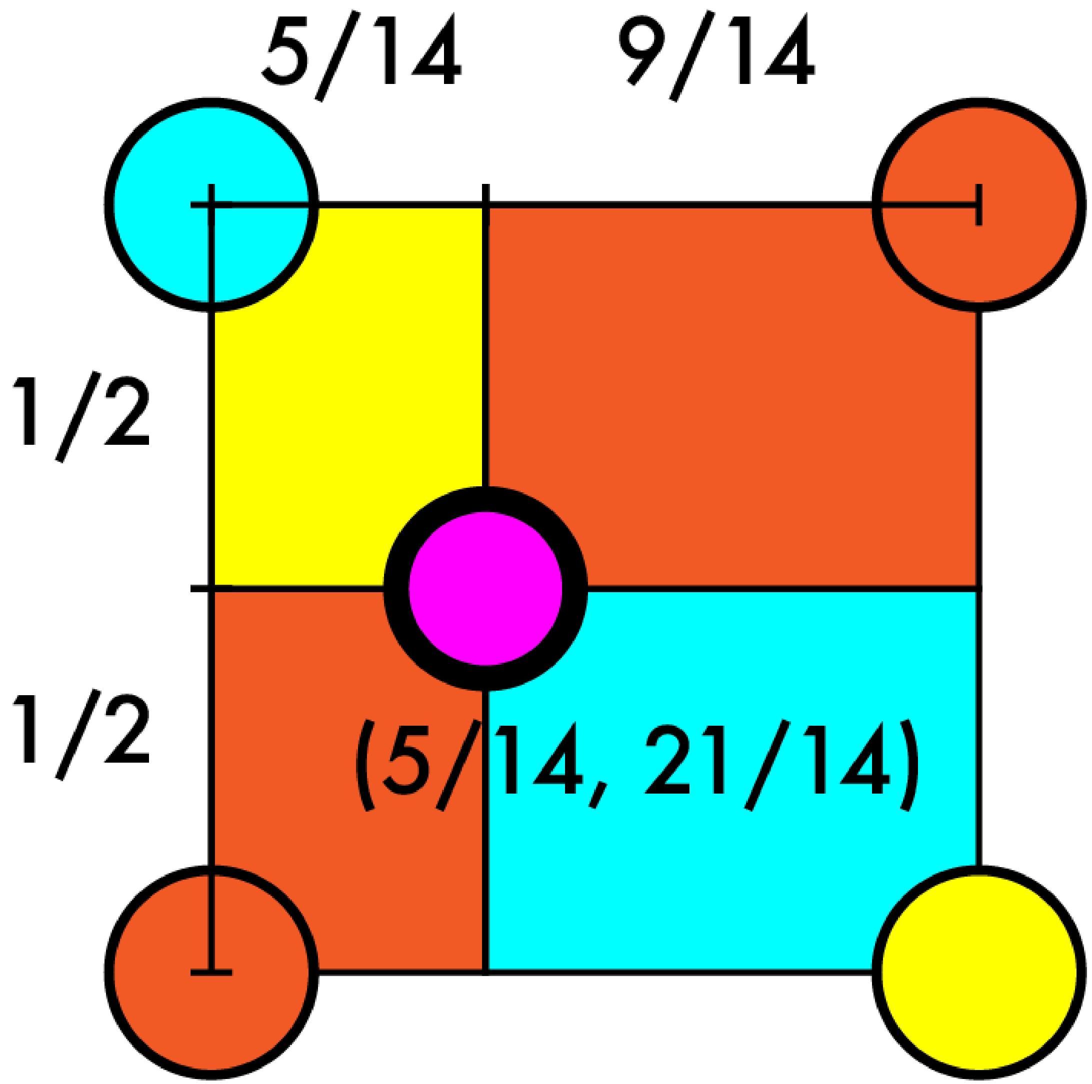
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values



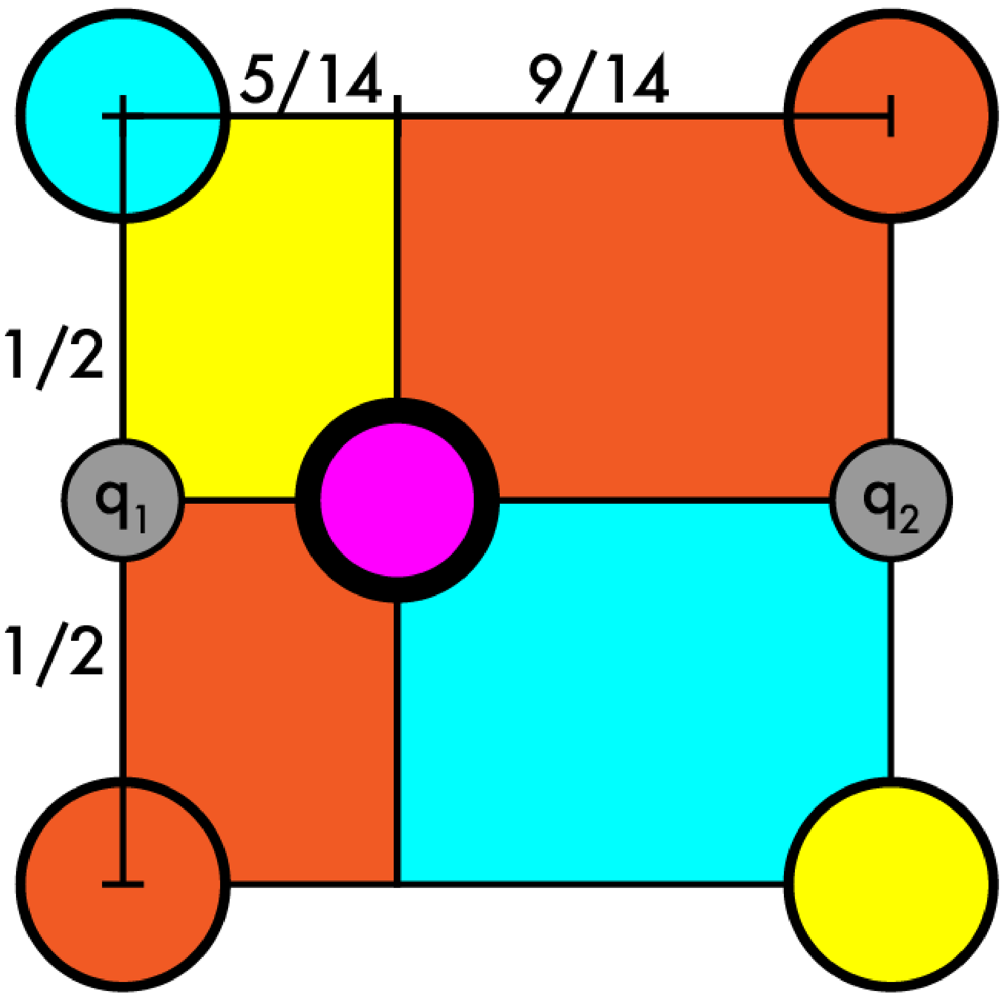
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - Size of opposite rects



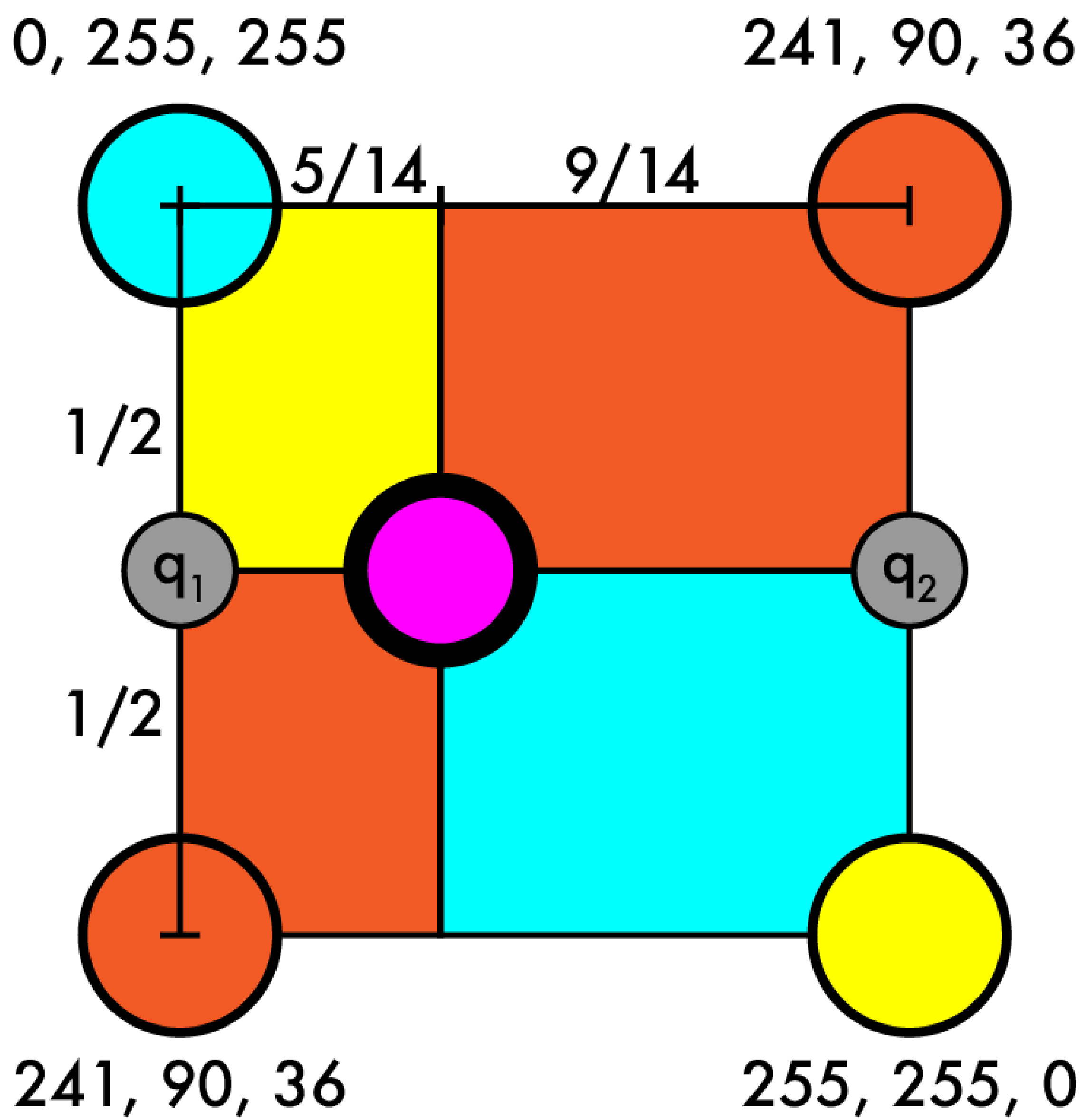
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - Size of opposite rects
    - OR find q1 and q2, then interpolate between them



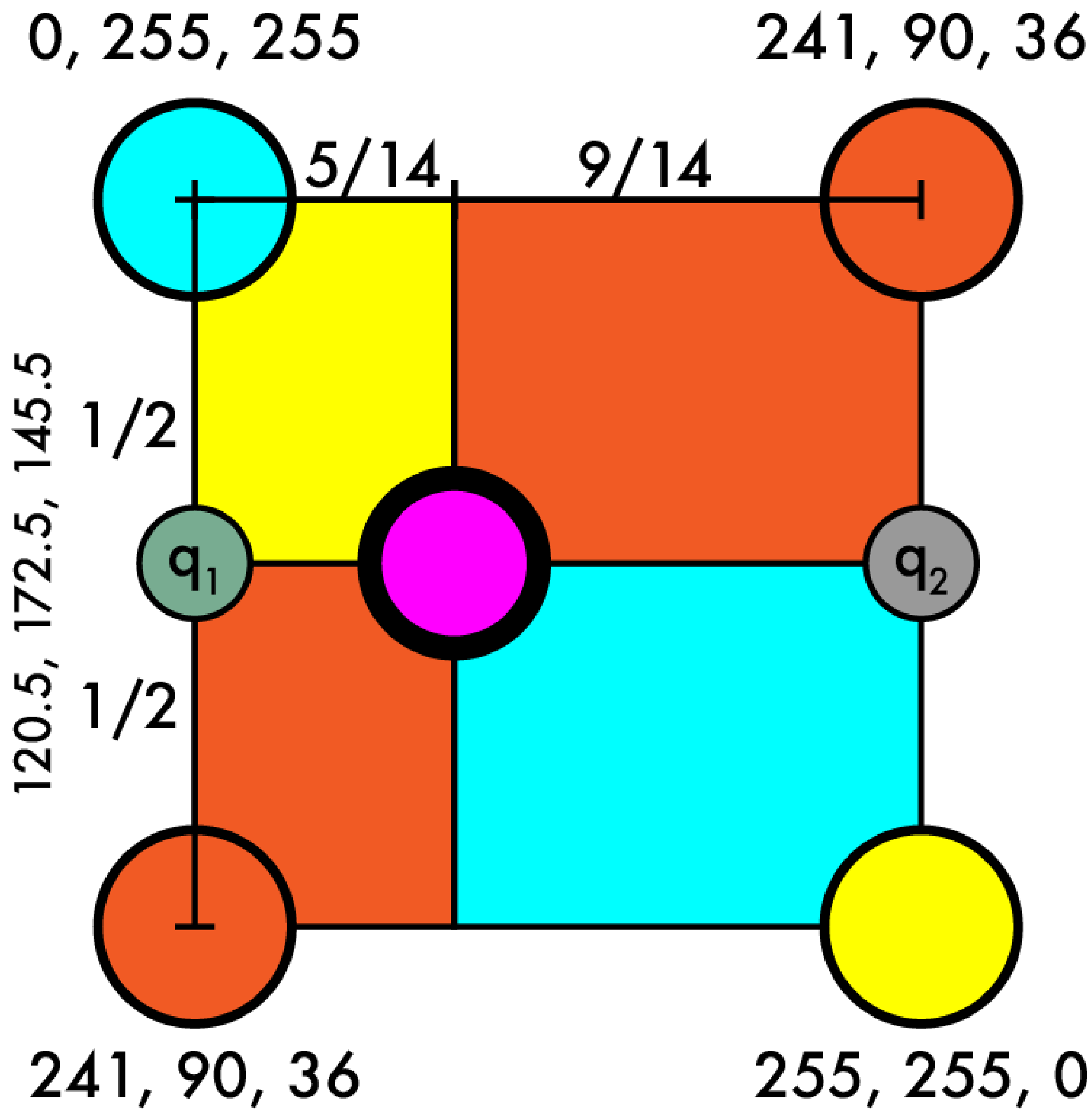
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = r1, g1, b1
    - r1 = .5*0 + .5*241
    - g1 = .5*255 + .5*90
    - b1 = .5*255 + .5*36



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = (120.5, 172.5, 145.5)
    - q2 = r2, g2, b2



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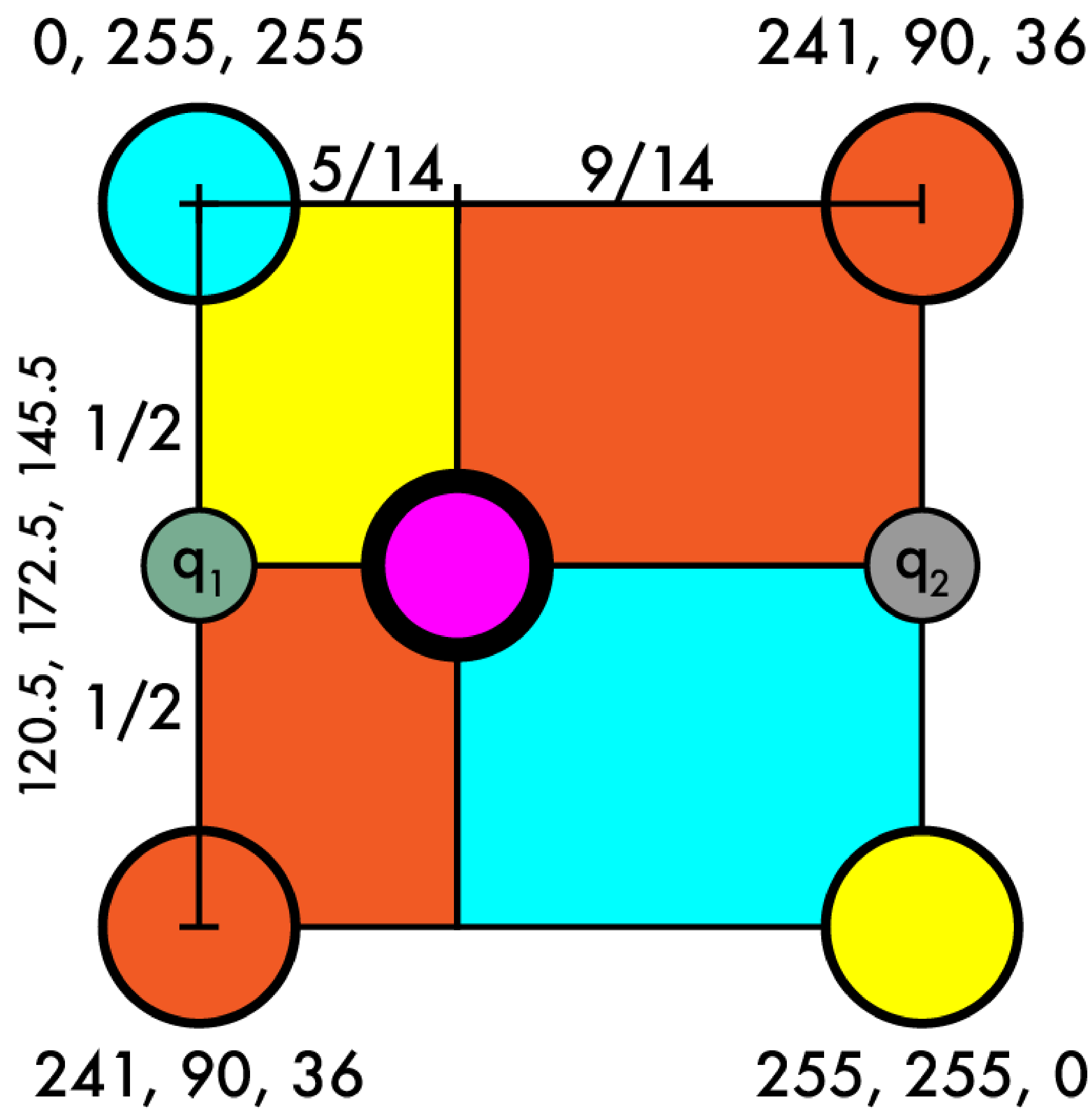
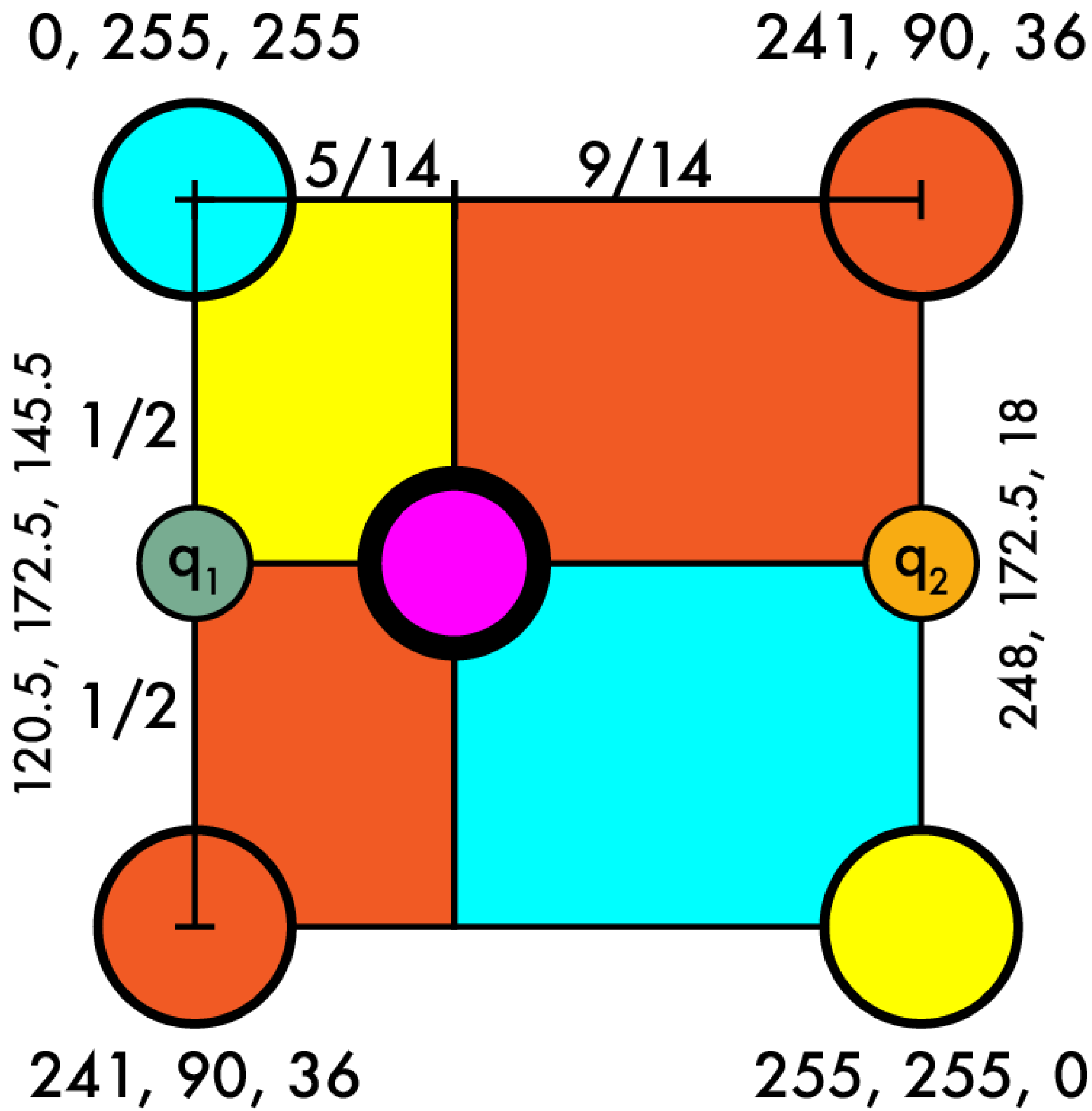
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = (120.5, 172.5, 145.5)
    - q2 = r2, g2, b2
    - r2 = .5*241 + .5*255
    - g2 = .5*90 + .5*255
    - b2 = .5*36 + .5*0



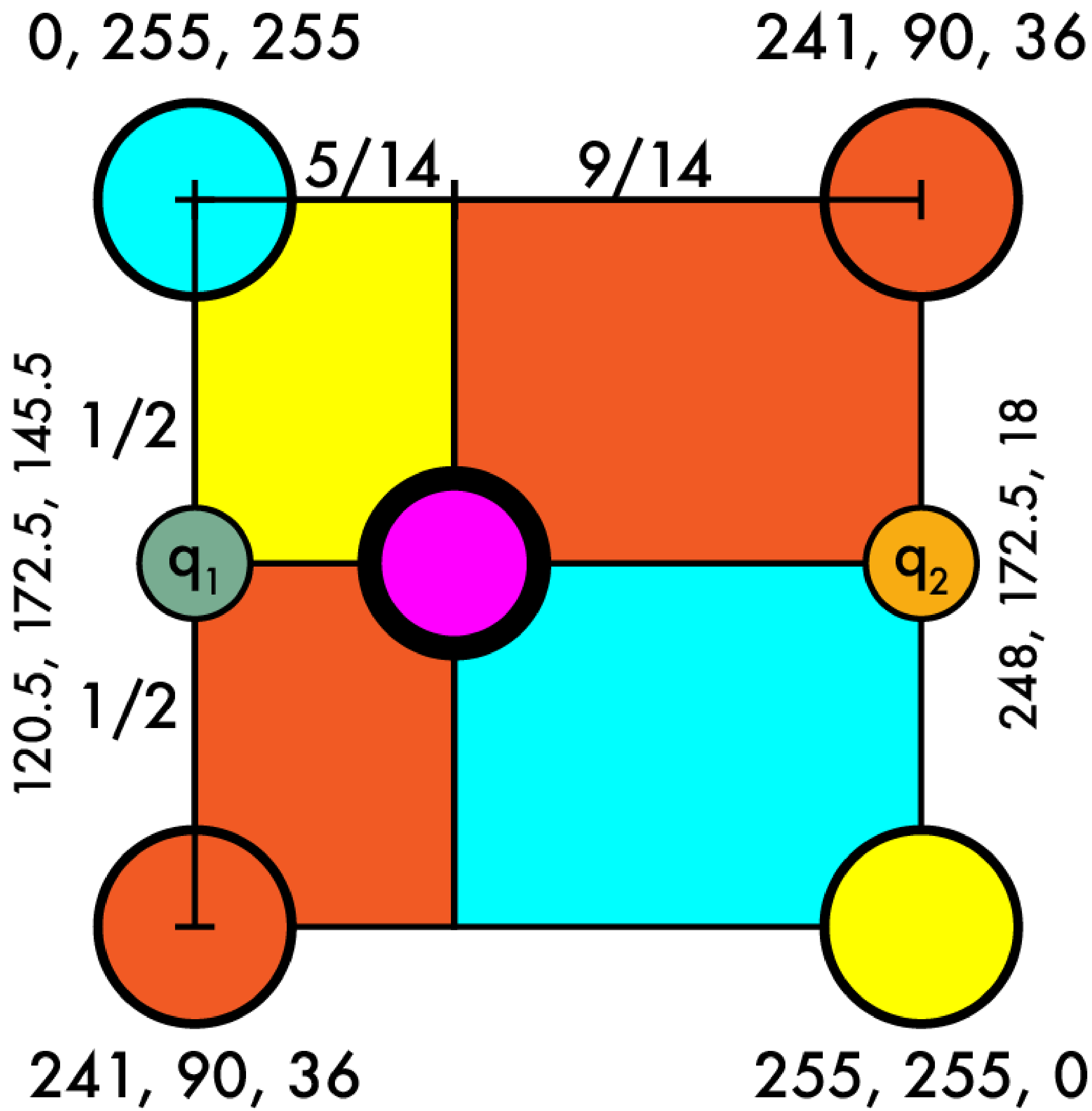
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
    - 4/7 X - 3/14 = Y
- Iterate over new pts
    - Map to old coords
    - (1, 3) -> (5/14, 21/14)
    - Interpolate old values
        - q1 = (120.5, 172.5, 145.5)
        - q2 = (248, 172.5, 18)



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = (120.5, 172.5, 145.5)
    - q2 = (248, 172.5, 18)
    - q = r, g, b
    - q = 9/14*q1 + 5/14*q2



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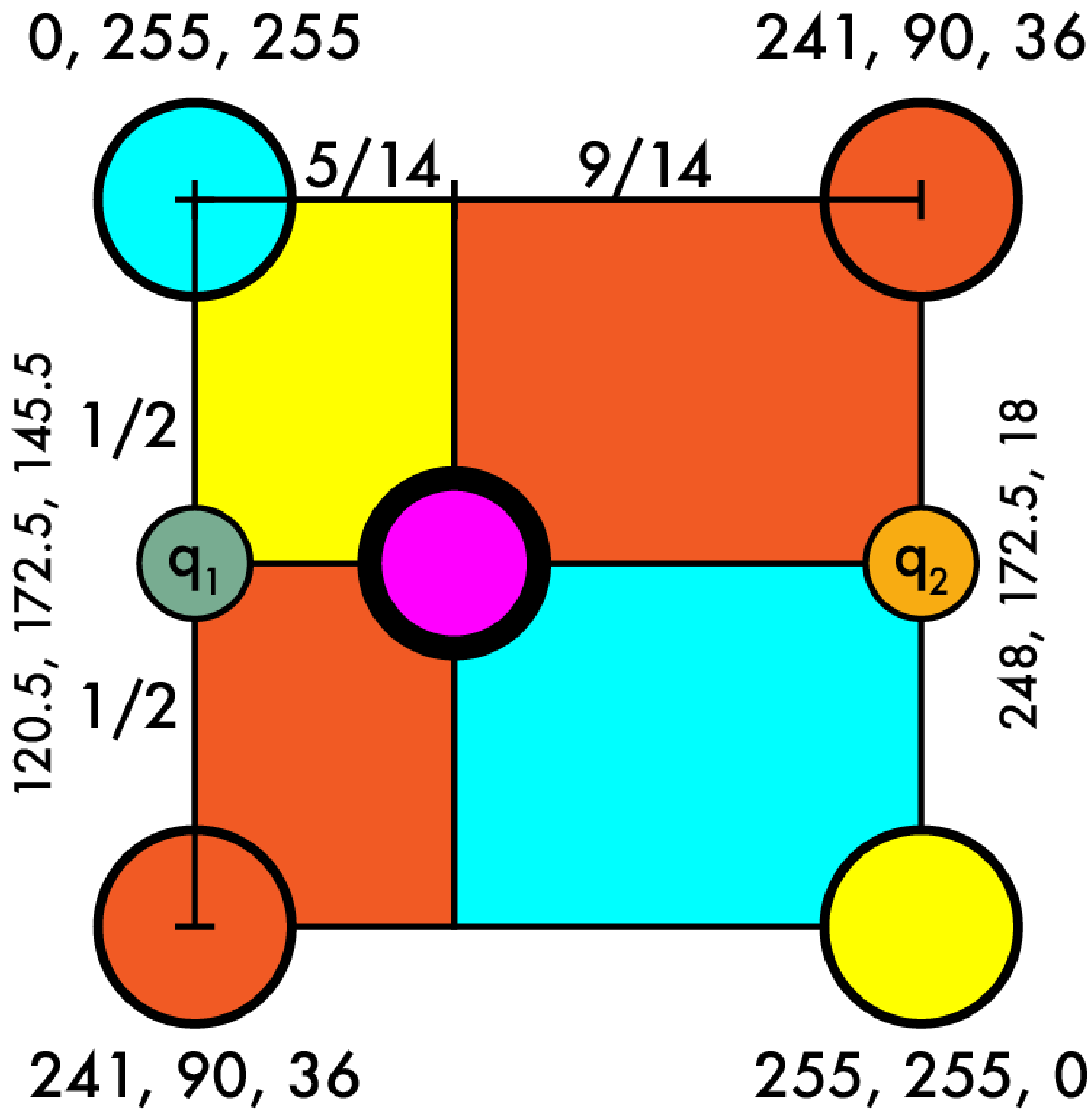
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = (120.5, 172.5, 145.5)
    - q2 = (248, 172.5, 18)
    - q = r, g, b
    - q = 9/14*q1 + 5/14*q2
    - r = 9/14*120.5 + 5/14*248
    - g = 9/14*172.5 + 5/14*172.5
    - b = 9/14*145.5 + 5/14*18



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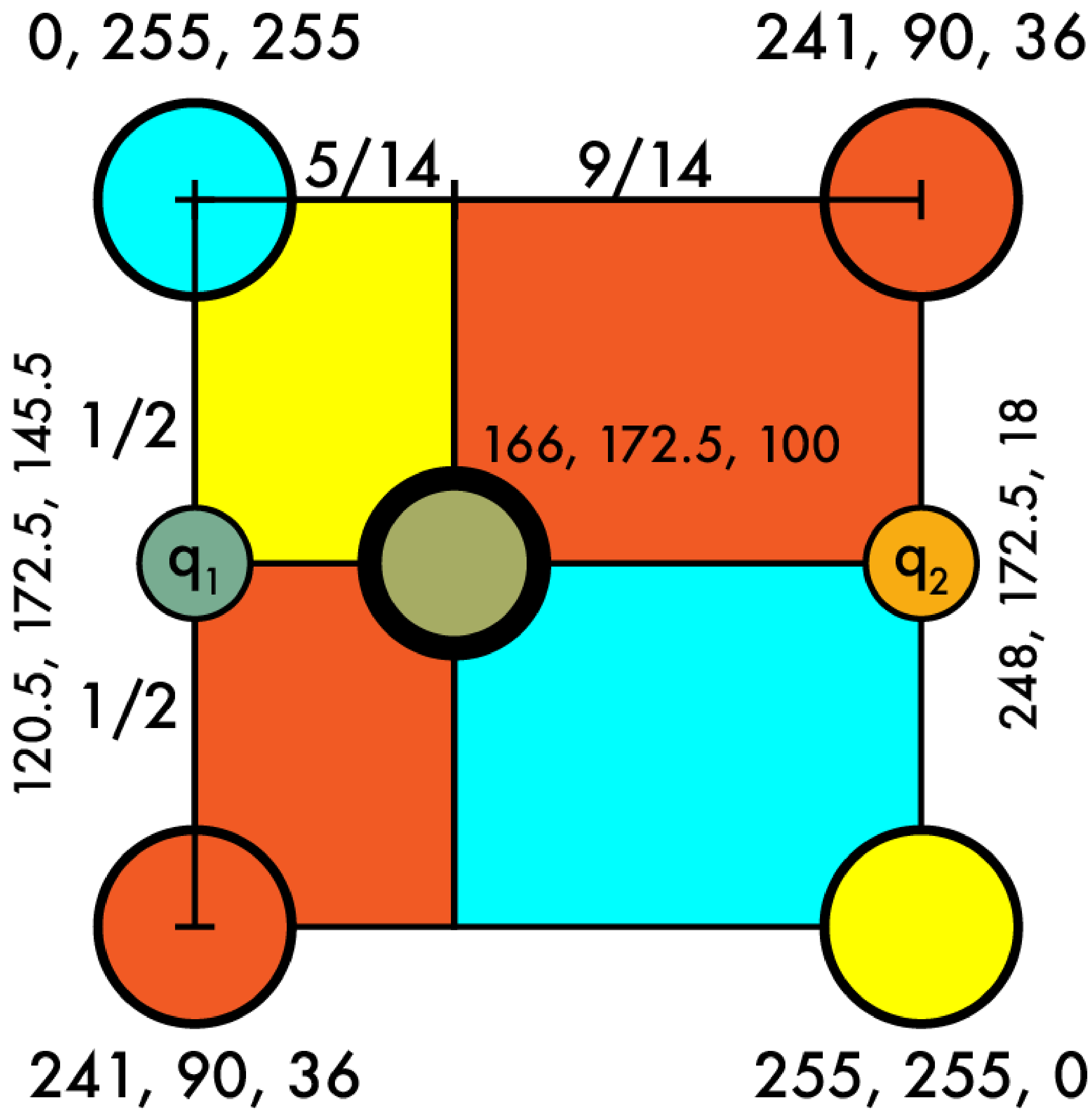
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q1 = (120.5, 172.5, 145.5)
    - q2 = (248, 172.5, 18)
    - q = (166, 172.5, 100)



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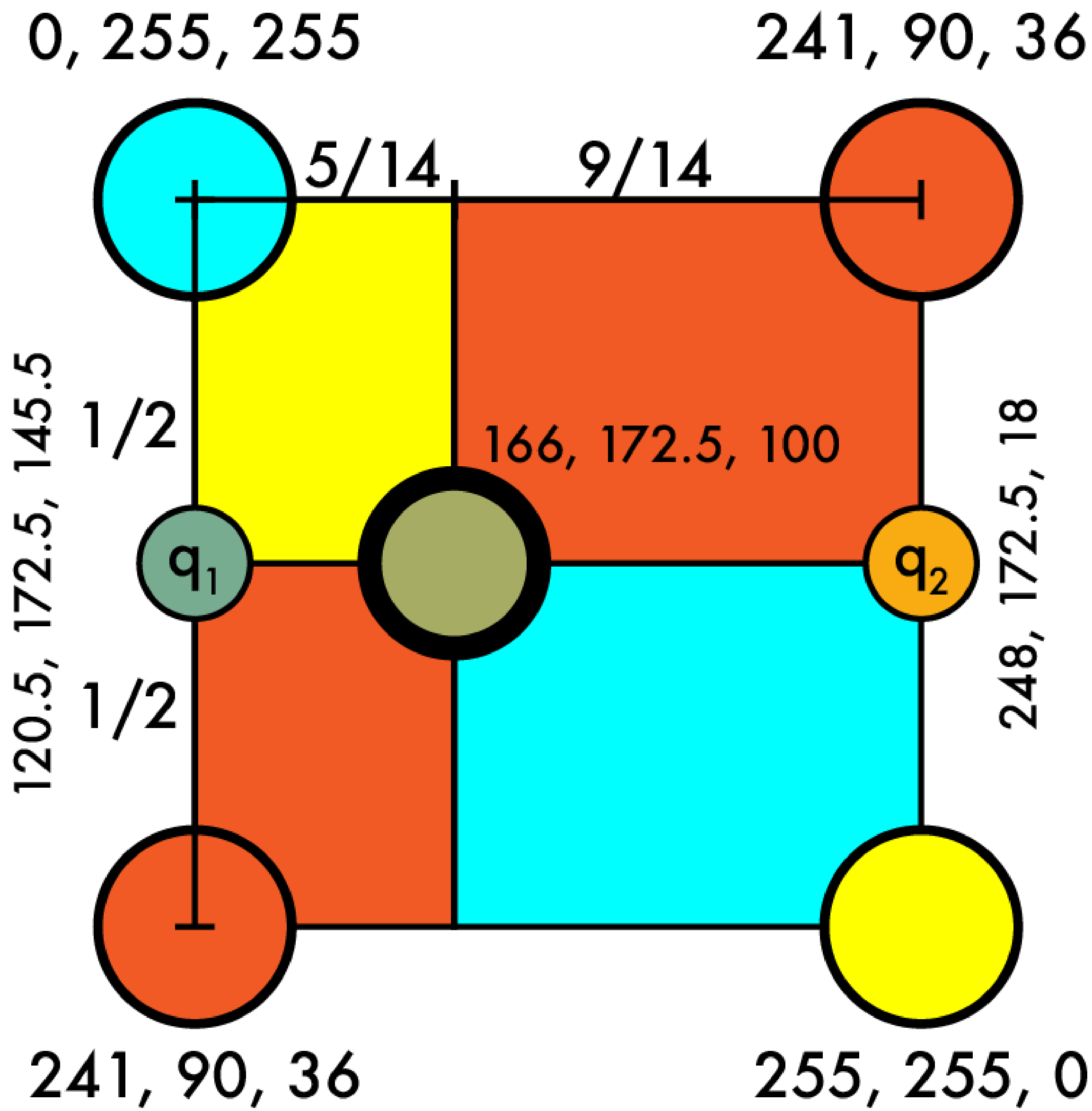
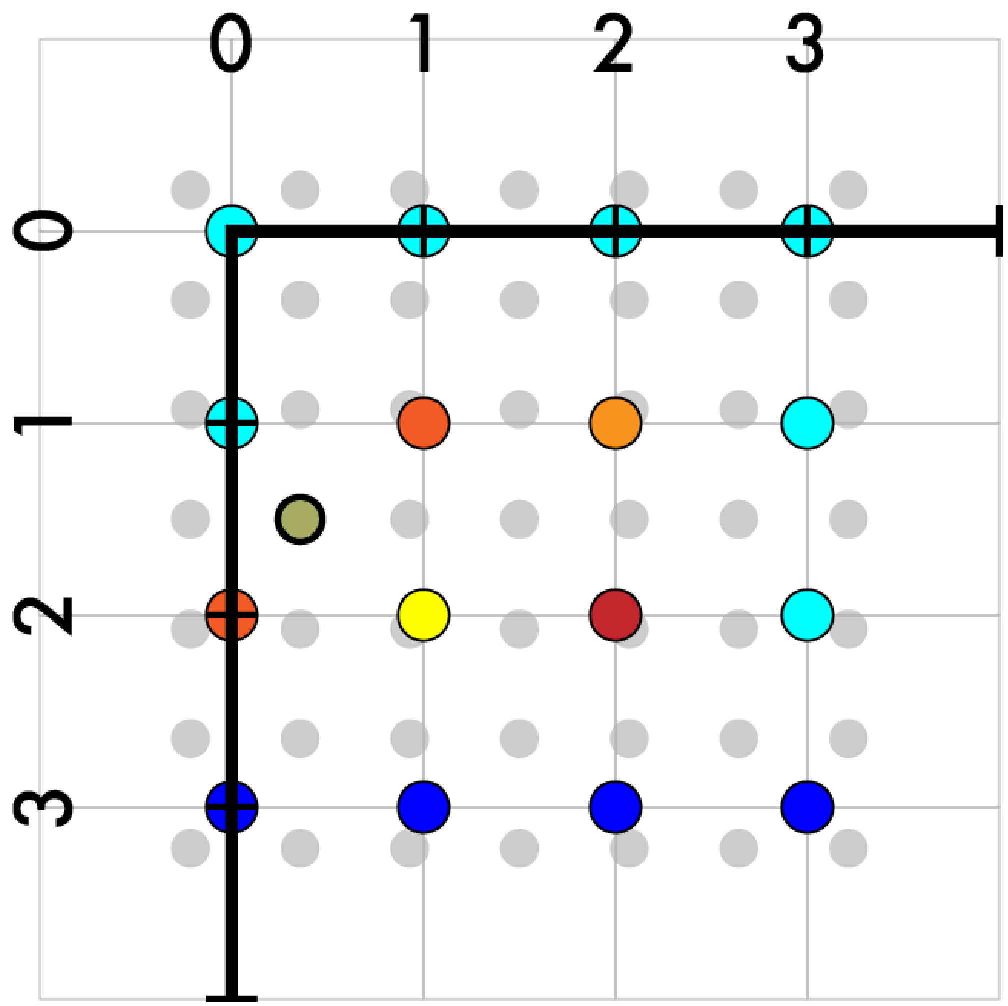
Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q = (166, 172.5, 100)



Resize 4x4 -> 7x7

- Create our new image
- Match up coordinates
  - 4/7 X - 3/14 = Y
- Iterate over new pts
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q = (166, 172.5, 100)



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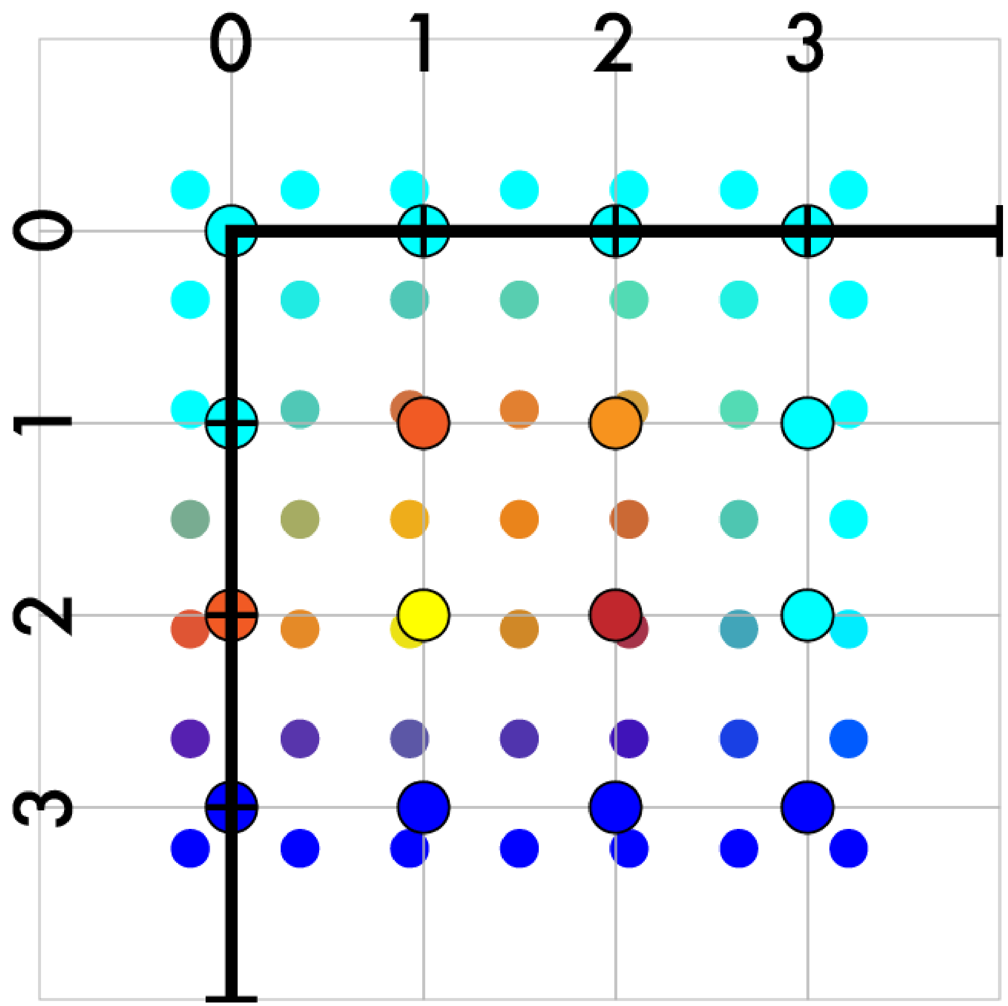
    - q = (166, 172.5, 100)
- Fill in the rest



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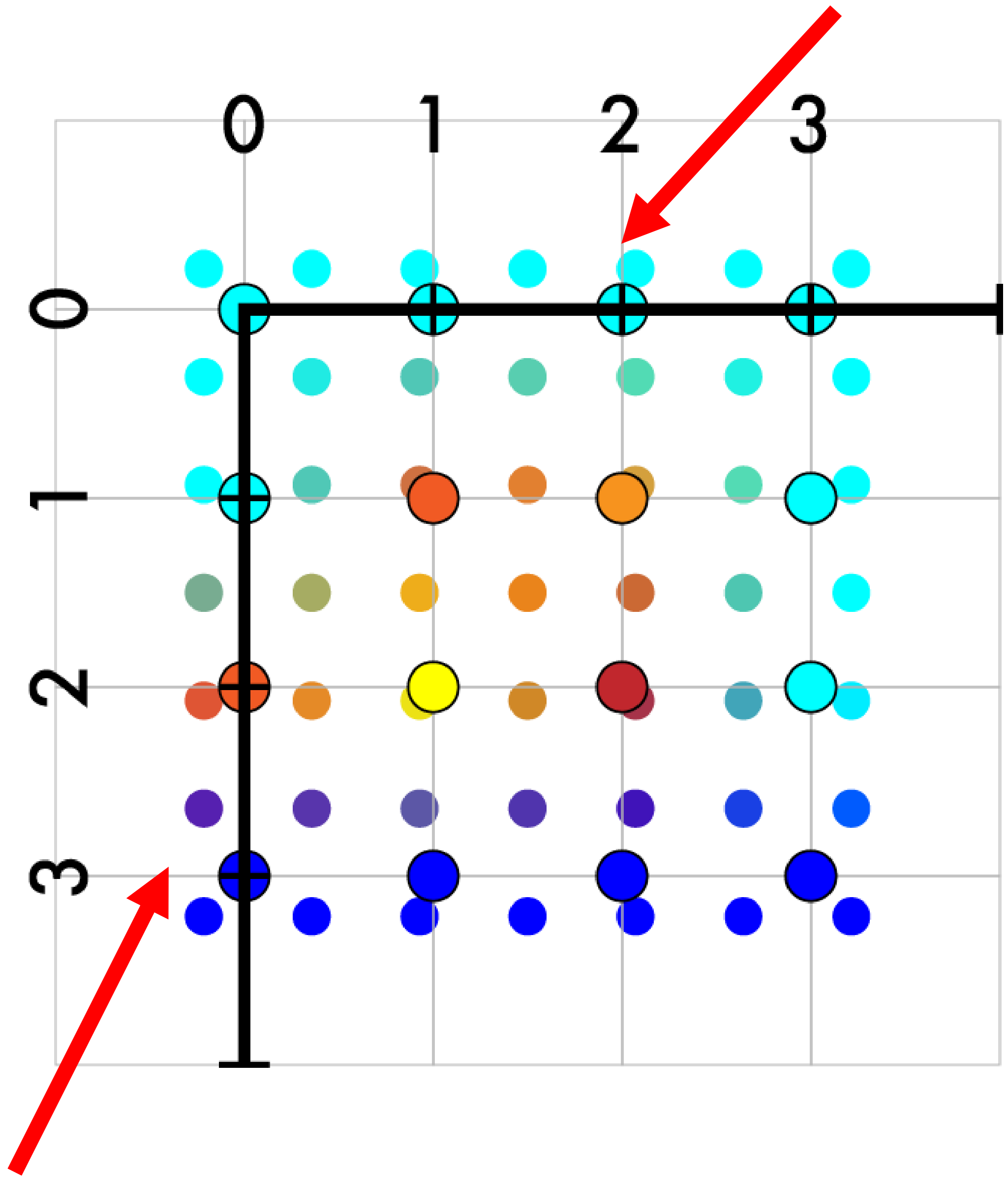
  - Map to old coords
  - (1, 3) -> (5/14, 21/14)
  - Interpolate old values
    - q = (166, 172.5, 100)
- Fill in the rest
  - On outer edges use padding!



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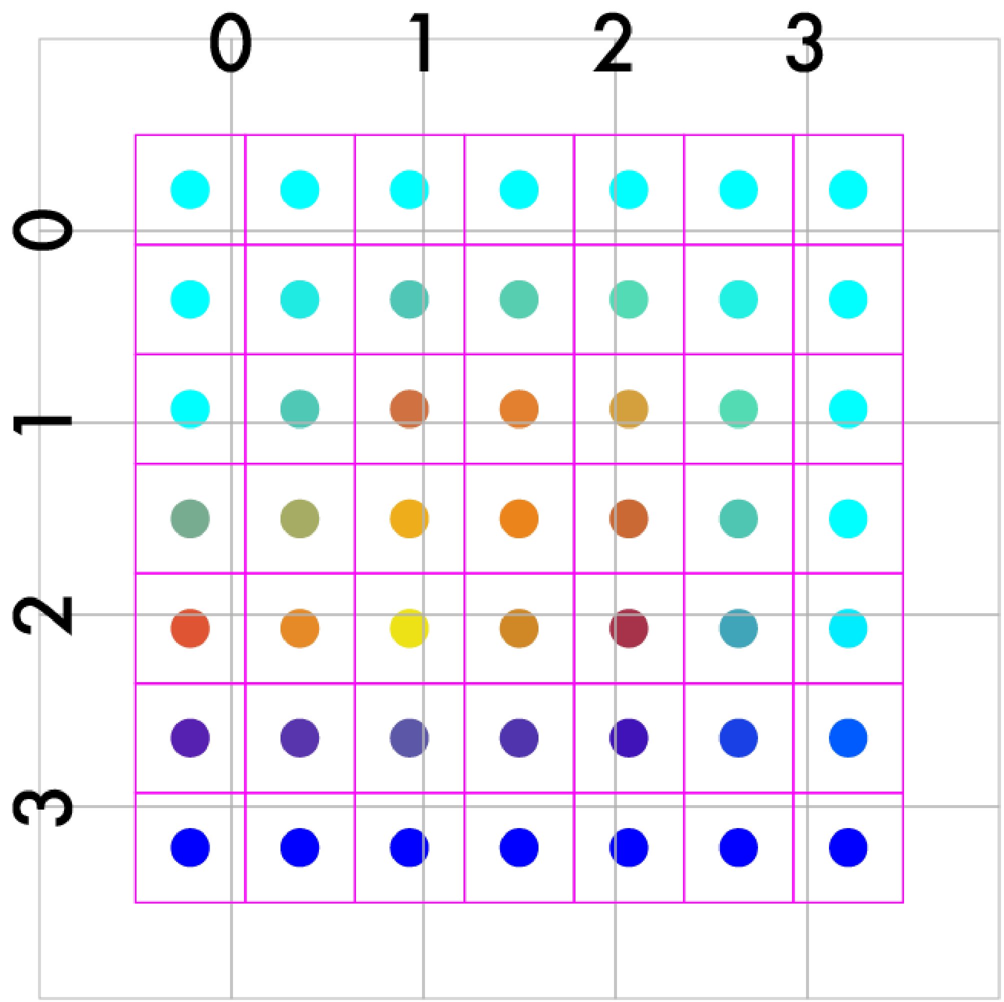
- Fill in the rest



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Resize 4x4 -> 7x7

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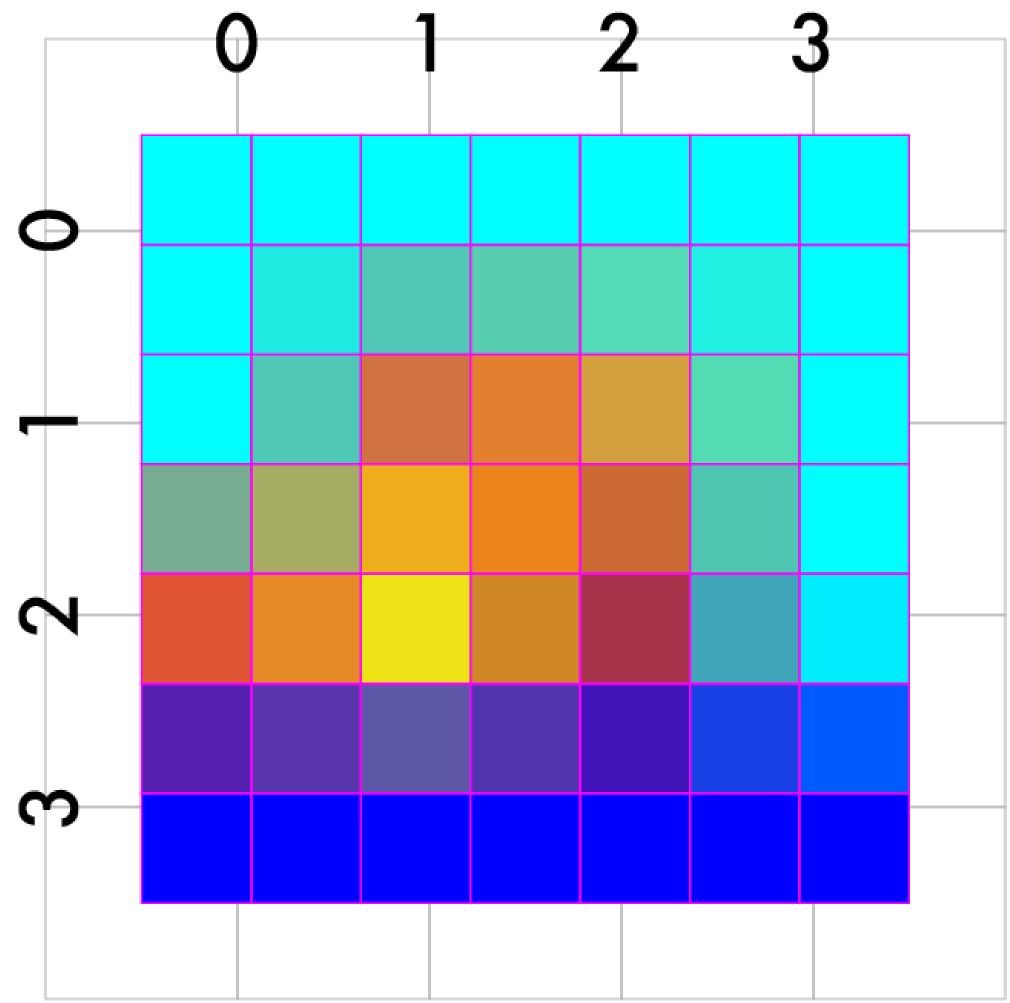
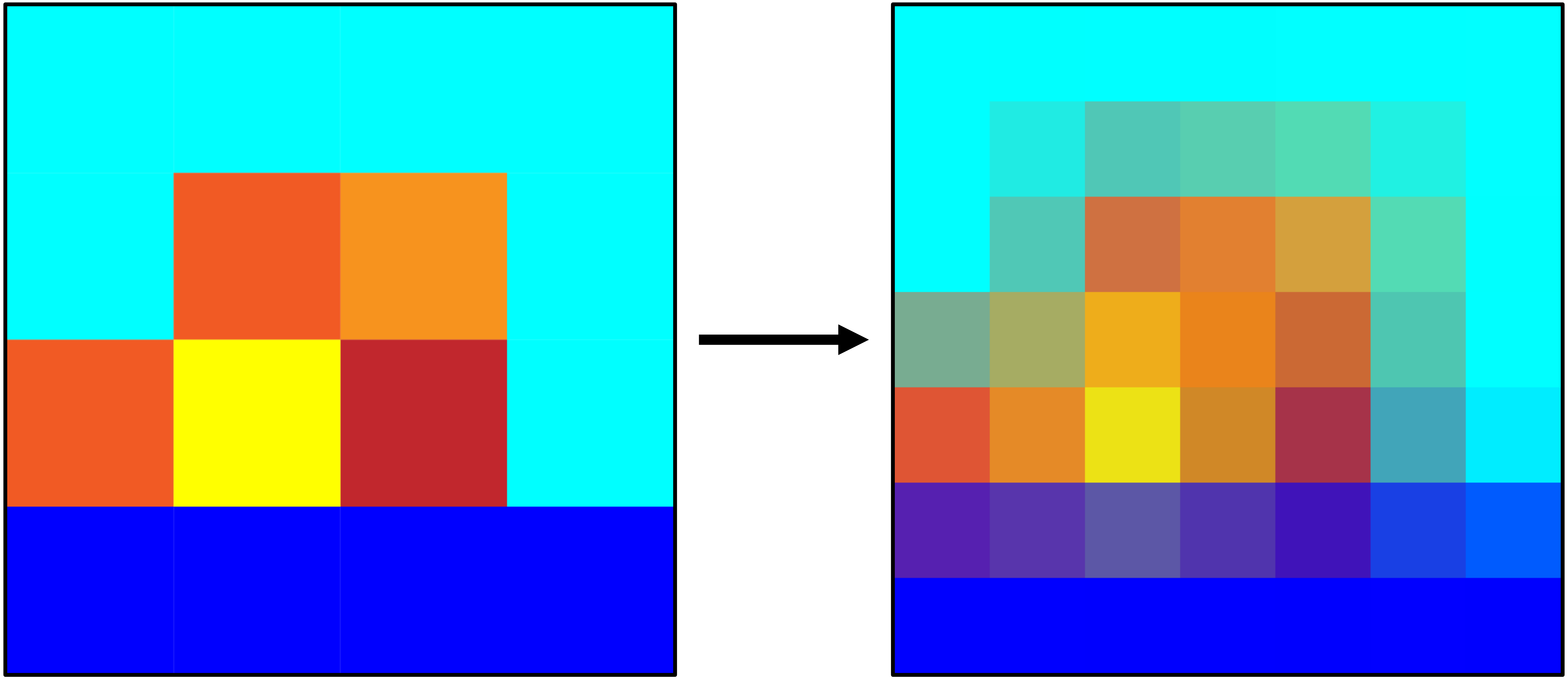
  - Interpolate old values
    - q = (166, 172.5, 100)
- Fill in the rest



We did it!



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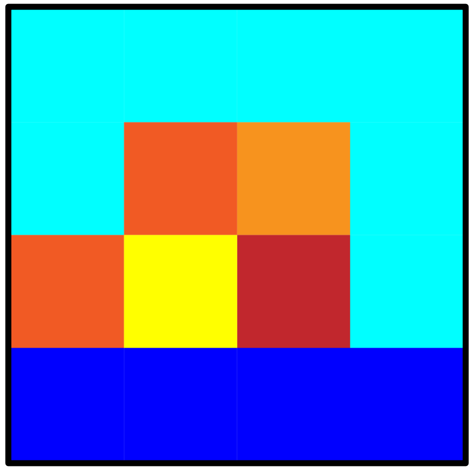
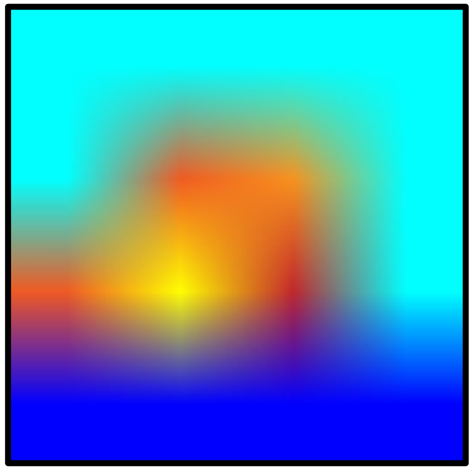
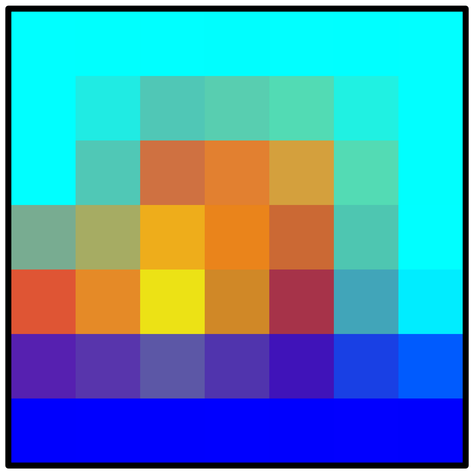
Different scales

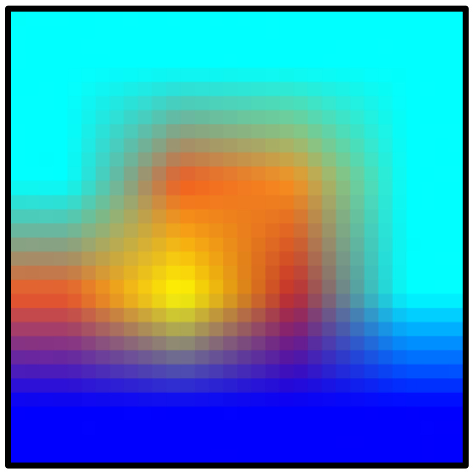




256x256



7x7



32x32

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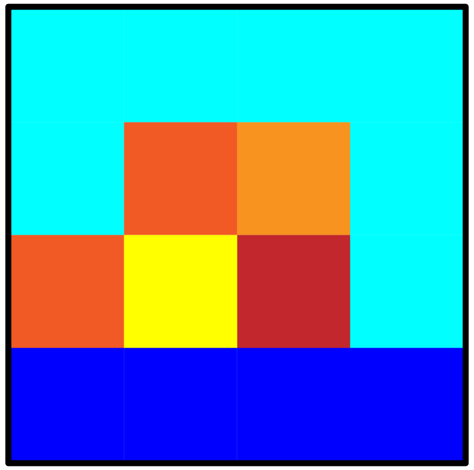
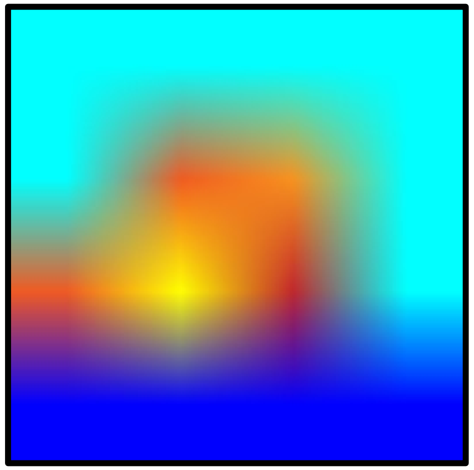
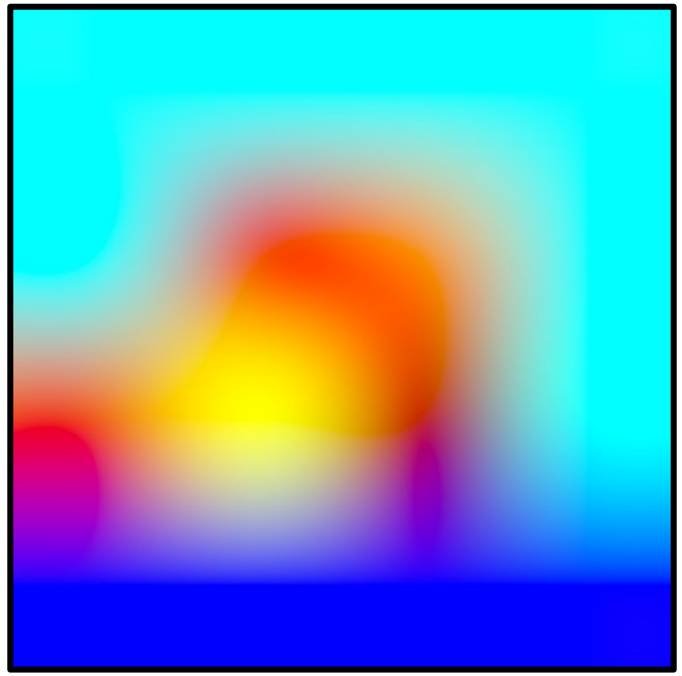
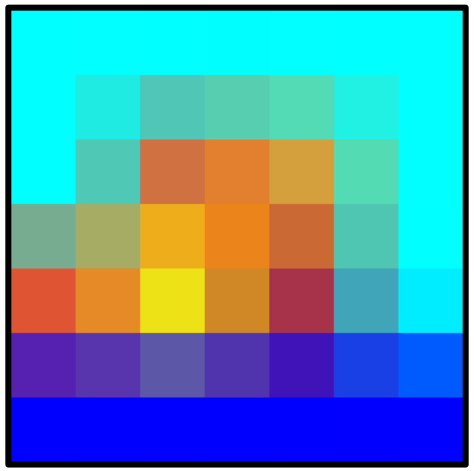
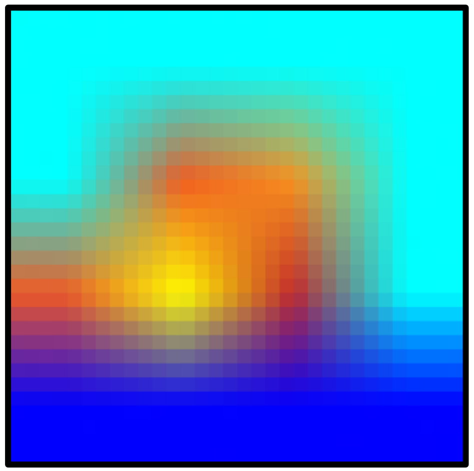
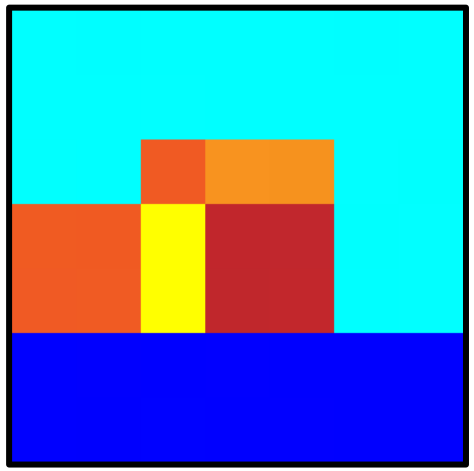
Different methods

Bicubic

7x7
NN

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Today's Agenda

- Image basics
  - What is an image – addressing pixels
  - Image as a function – image coordinates
- Image interpolation
  - Nearest neighbor
  - Bilinear
  - Bicubic
- Image resizing
  - Enlarge
  - Shrink

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Want to make image smaller

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448x448 -> 64x64

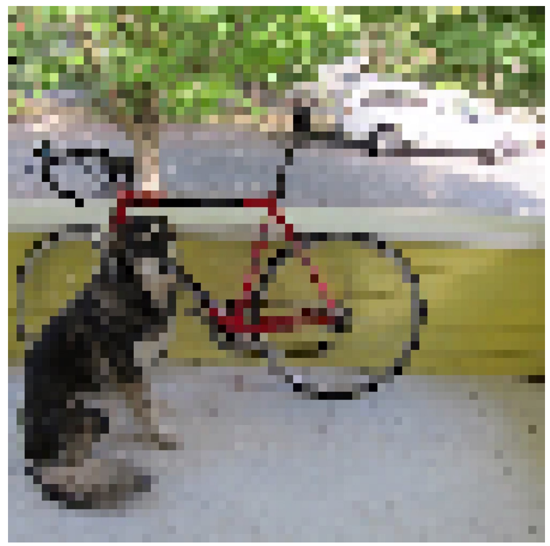
448x448 -> 64x64

NN

Bilinear

448x448 -> 64x64

448x448 -> 64x64



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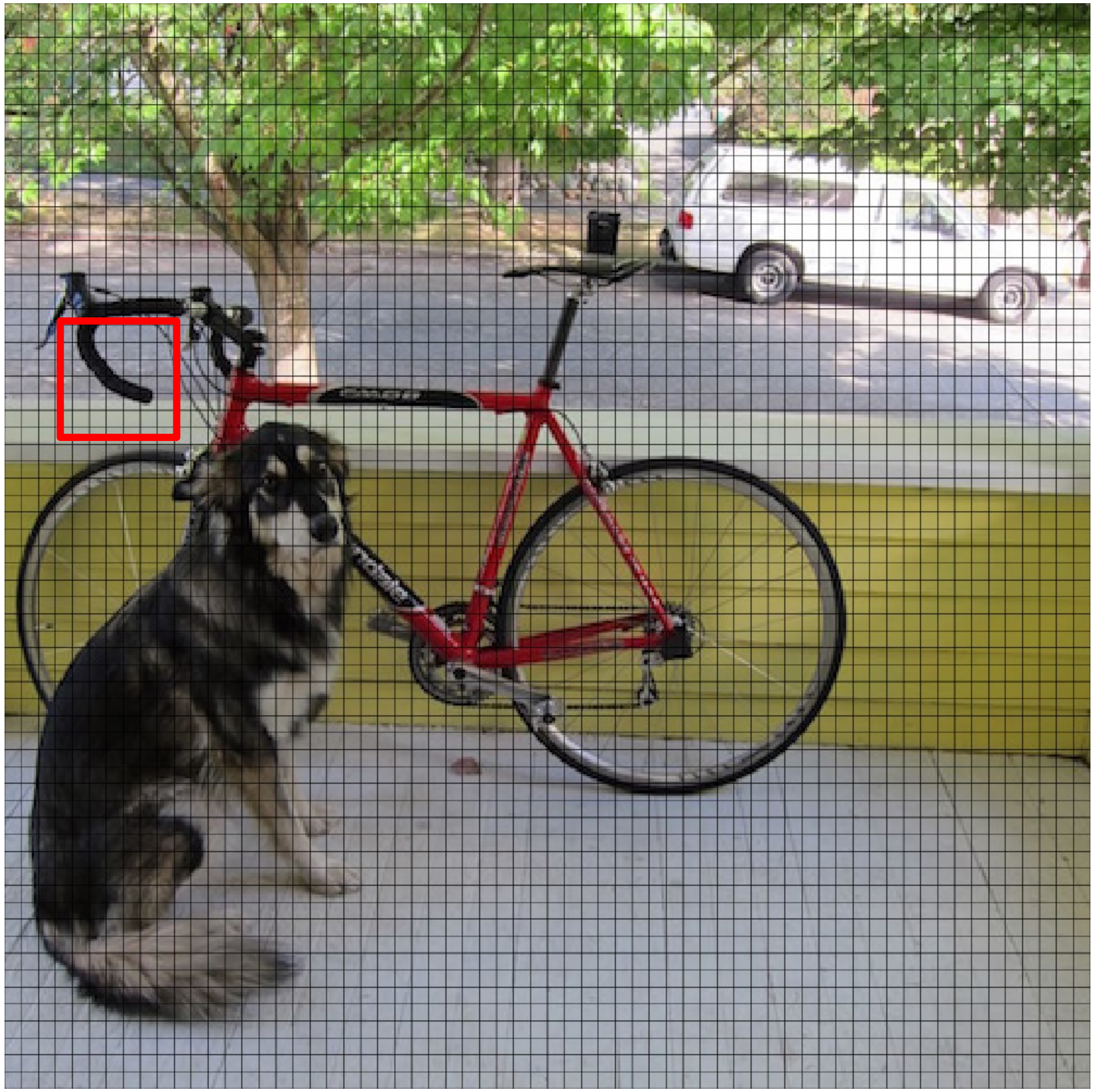

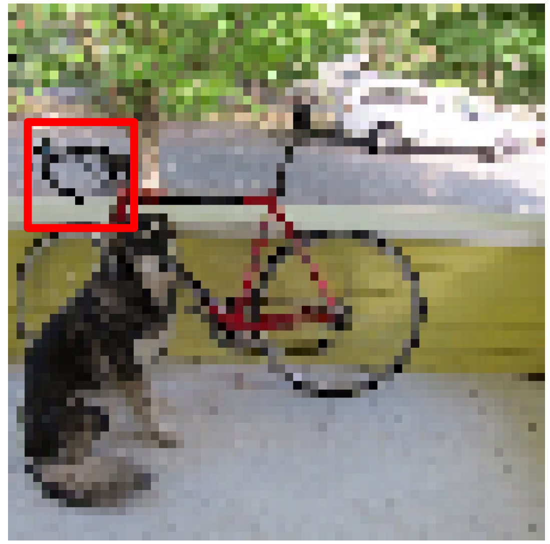

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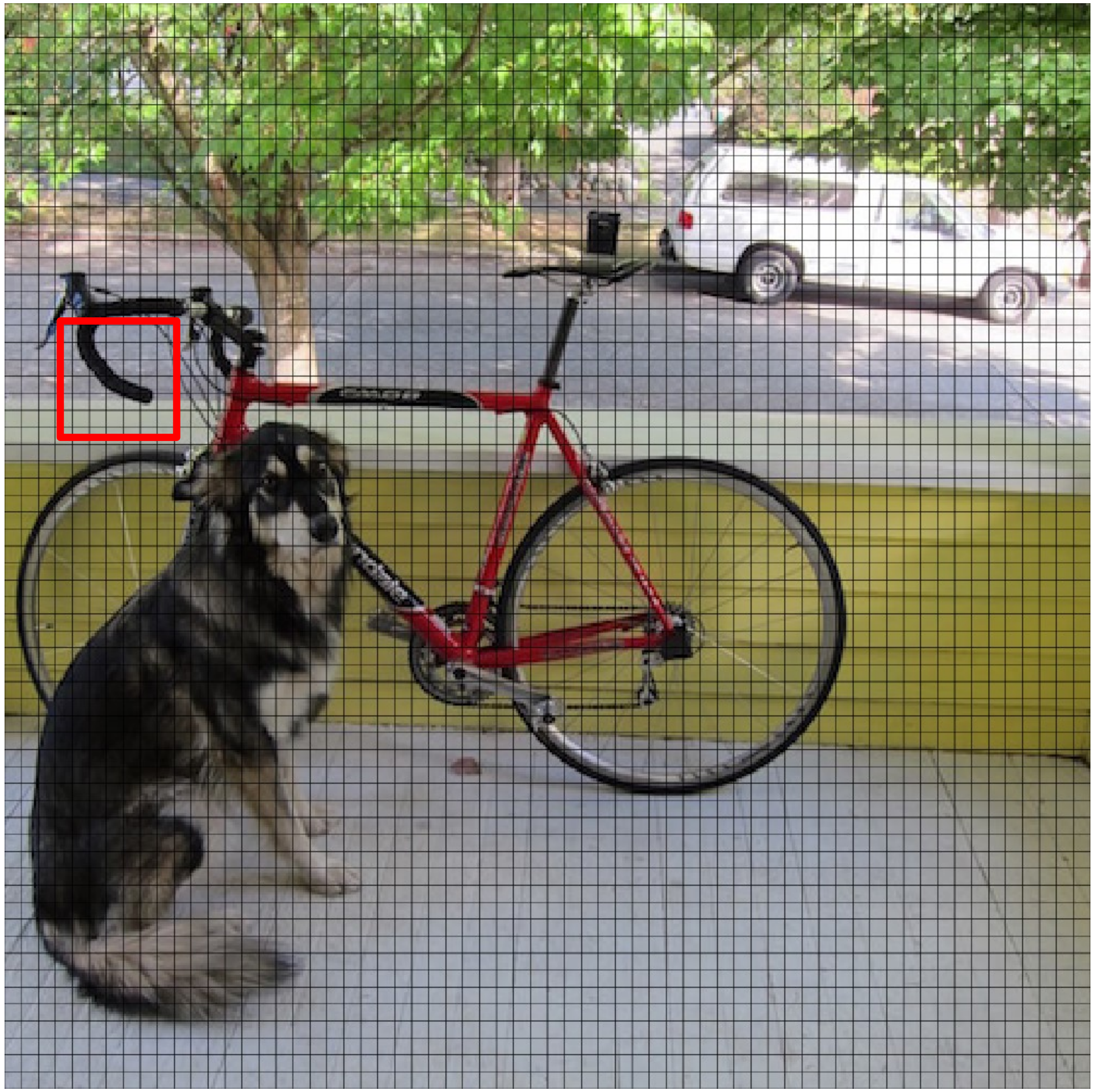

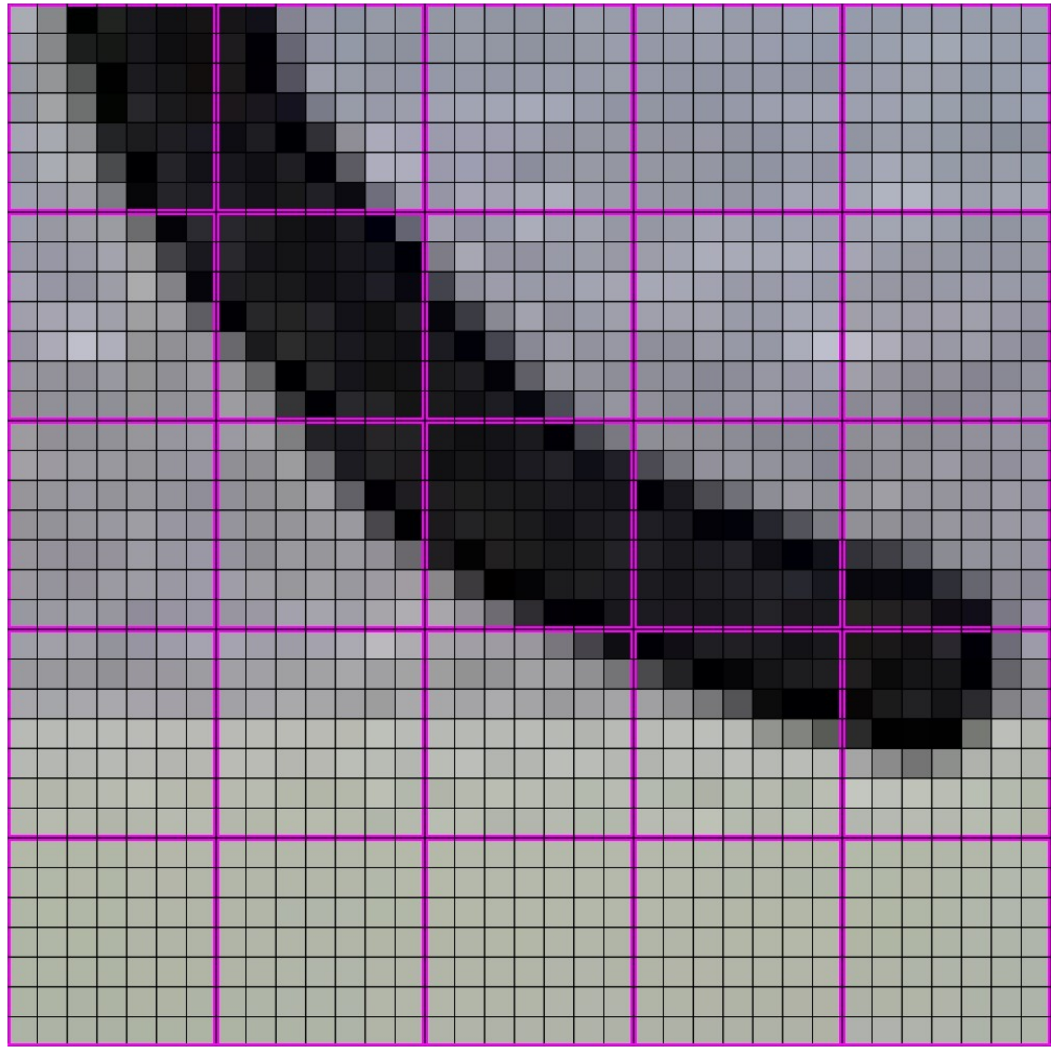

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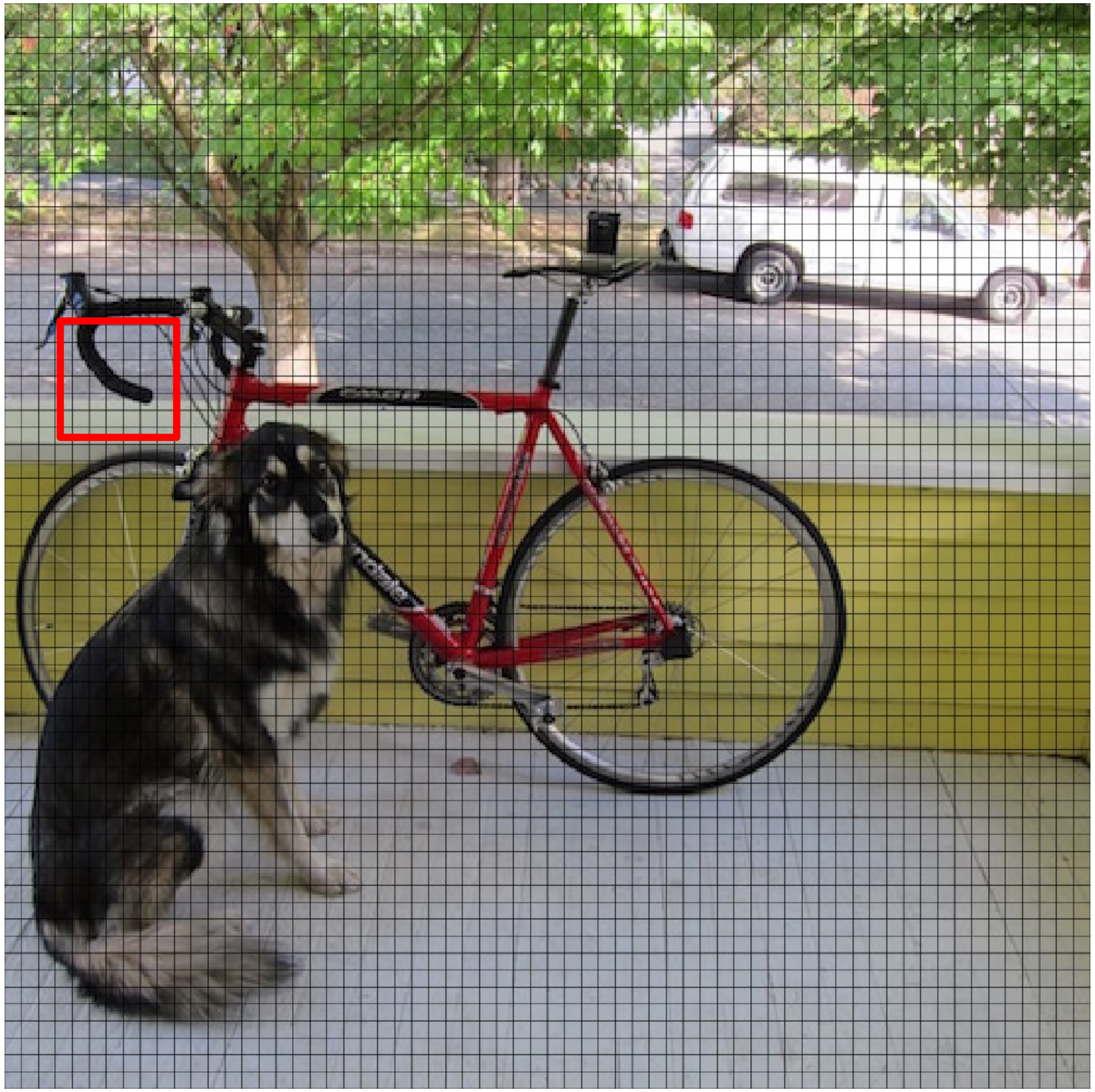

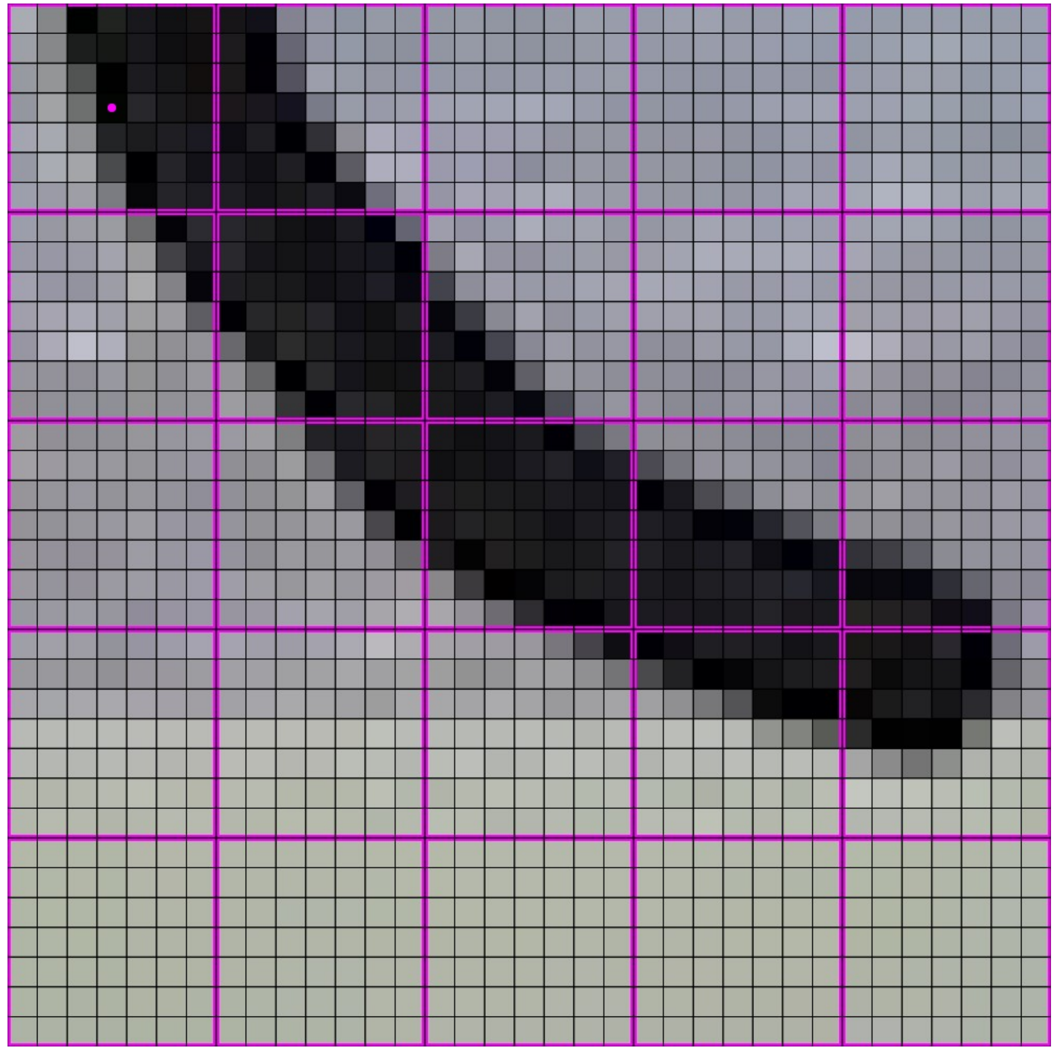

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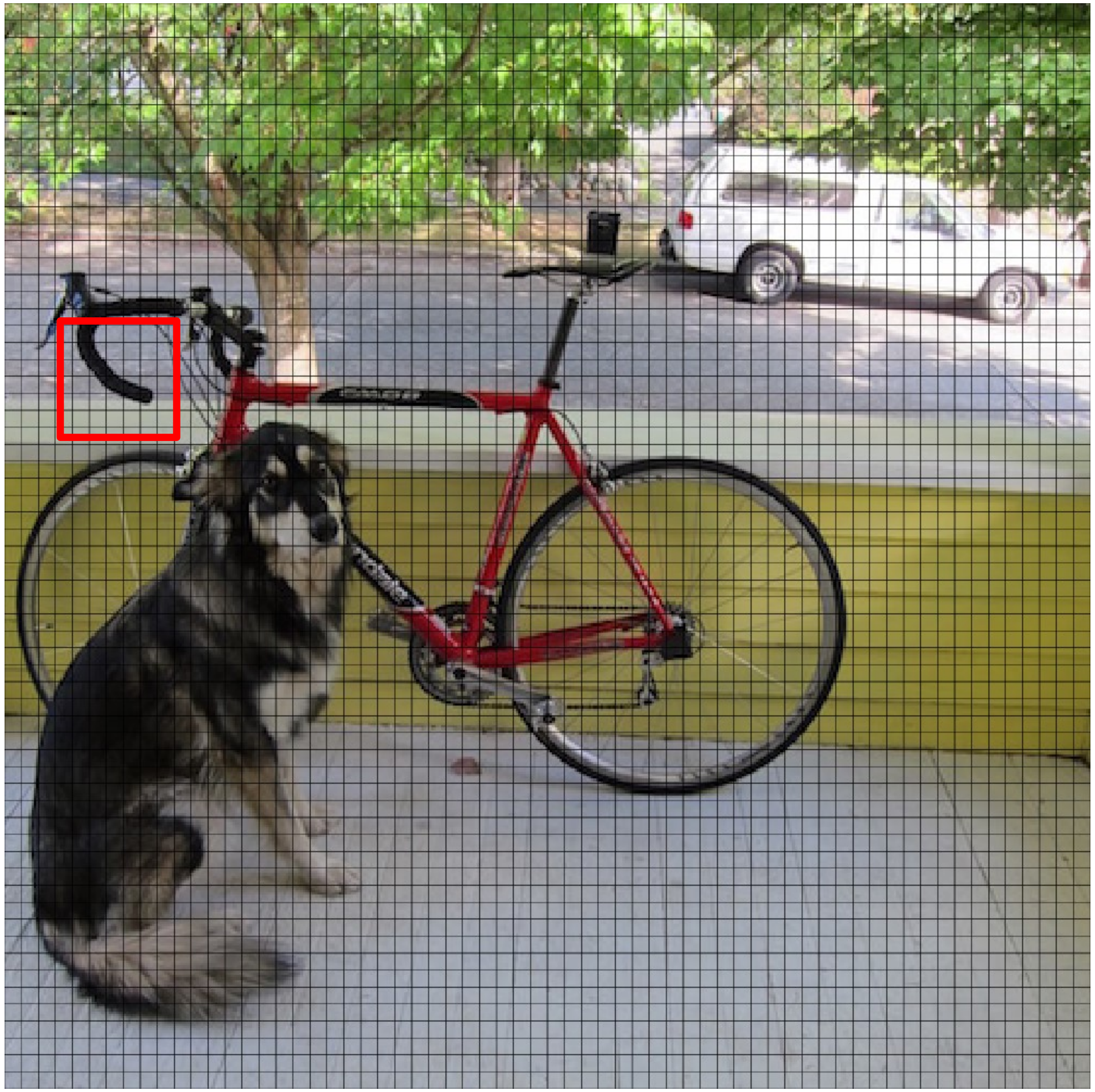

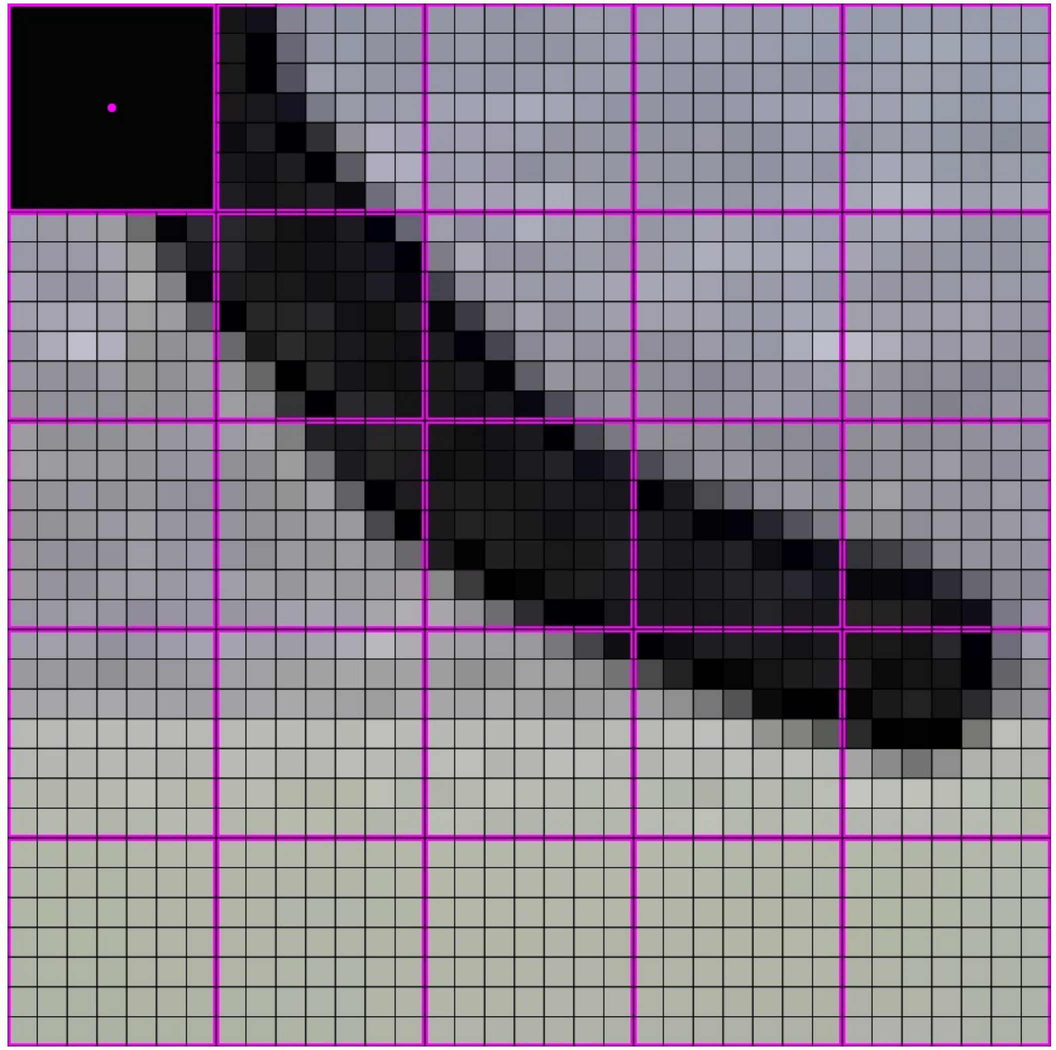

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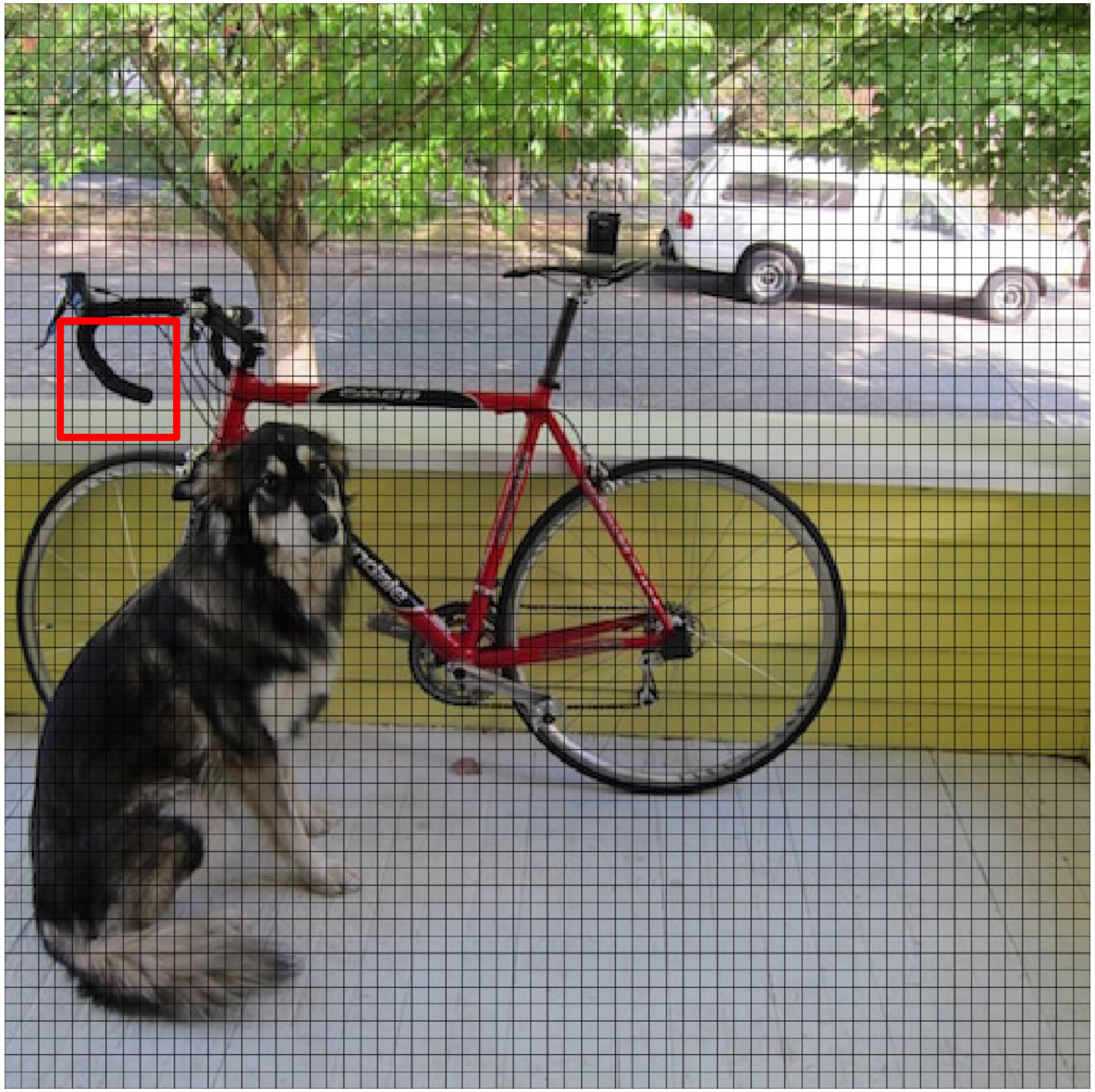

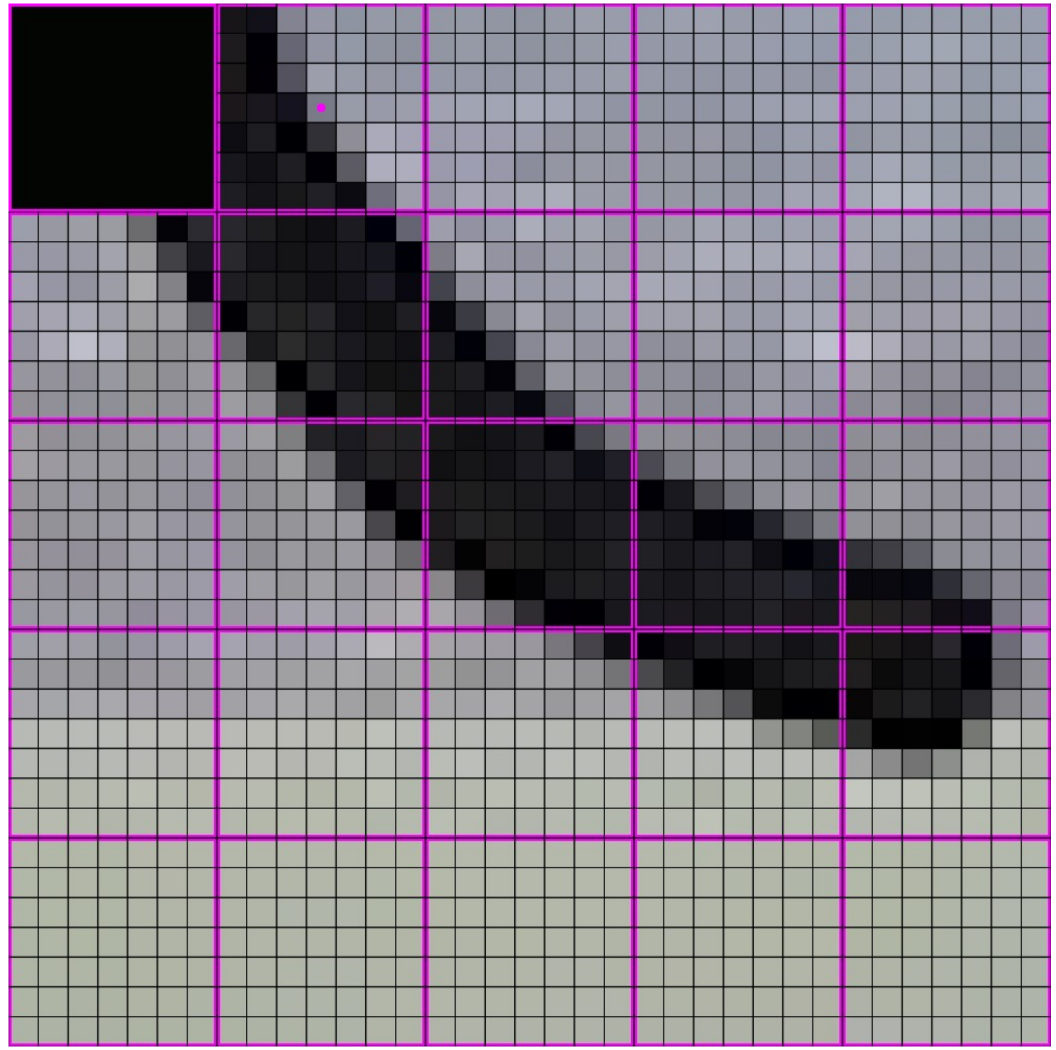

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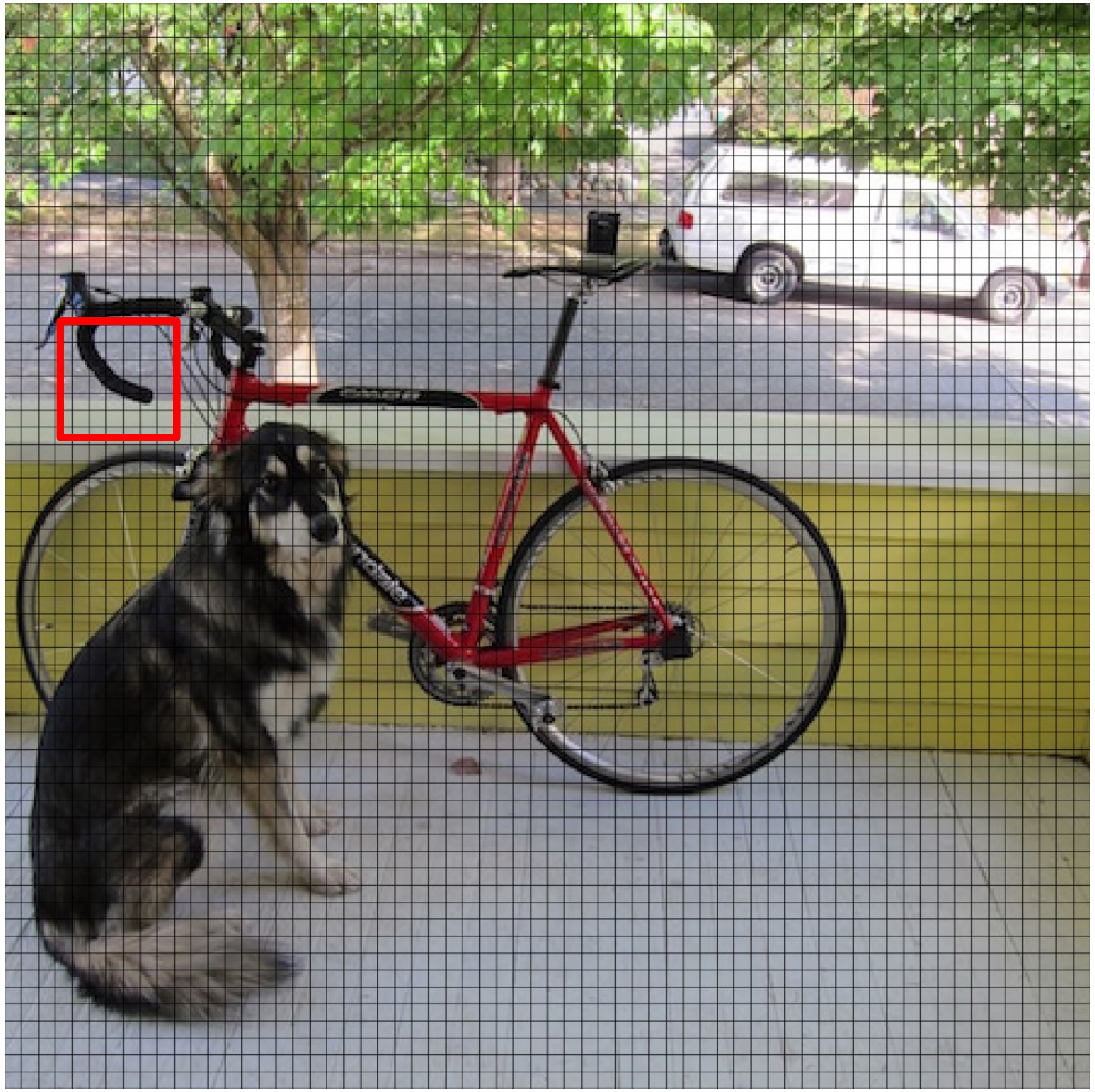

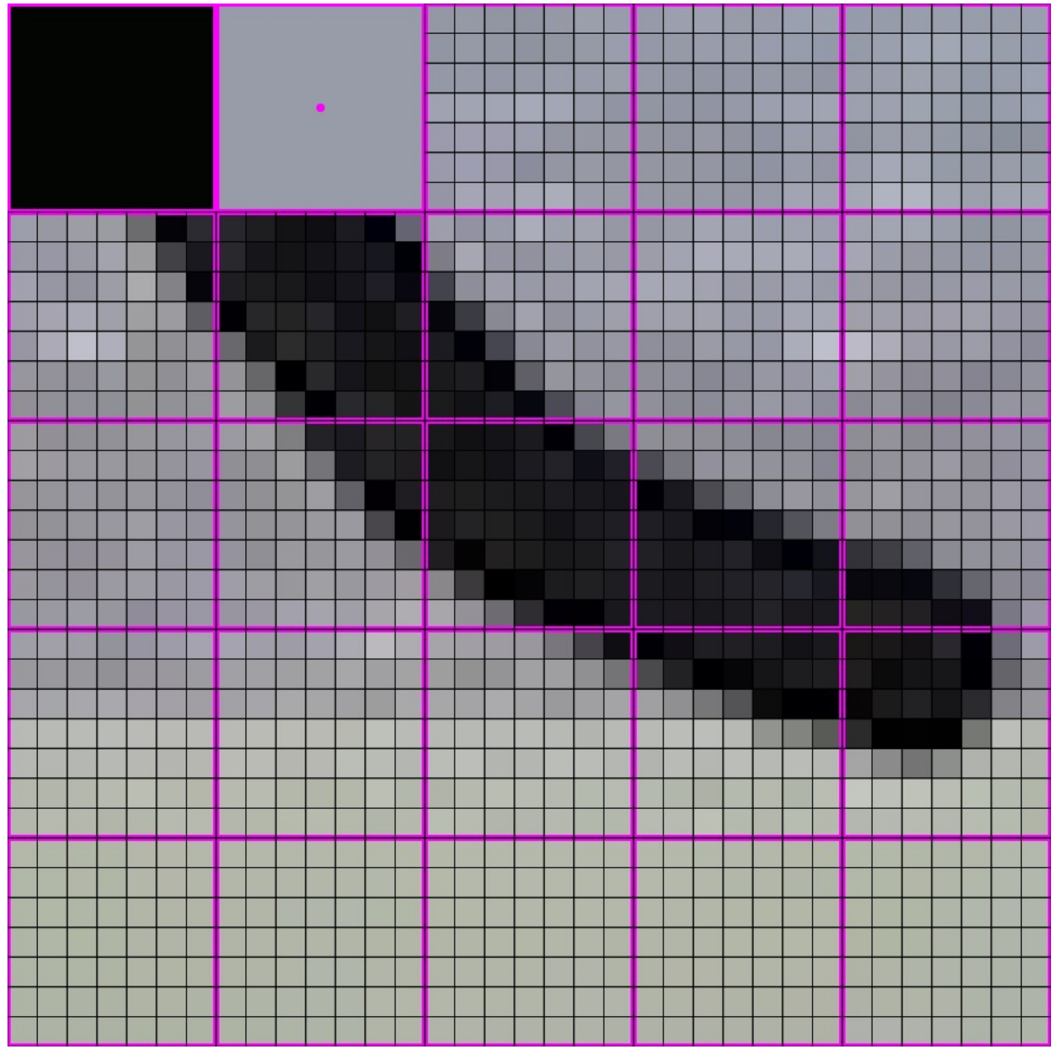

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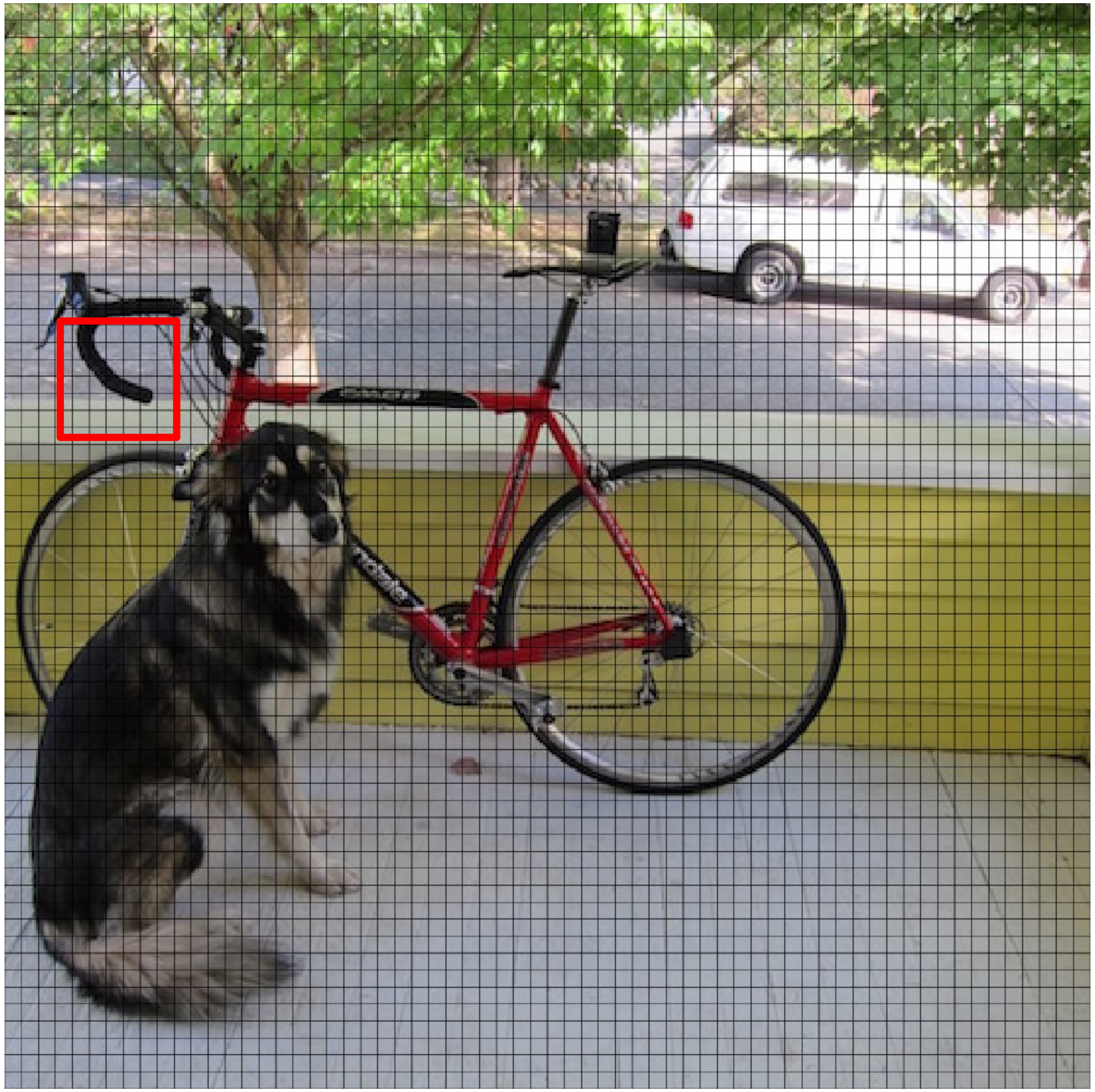

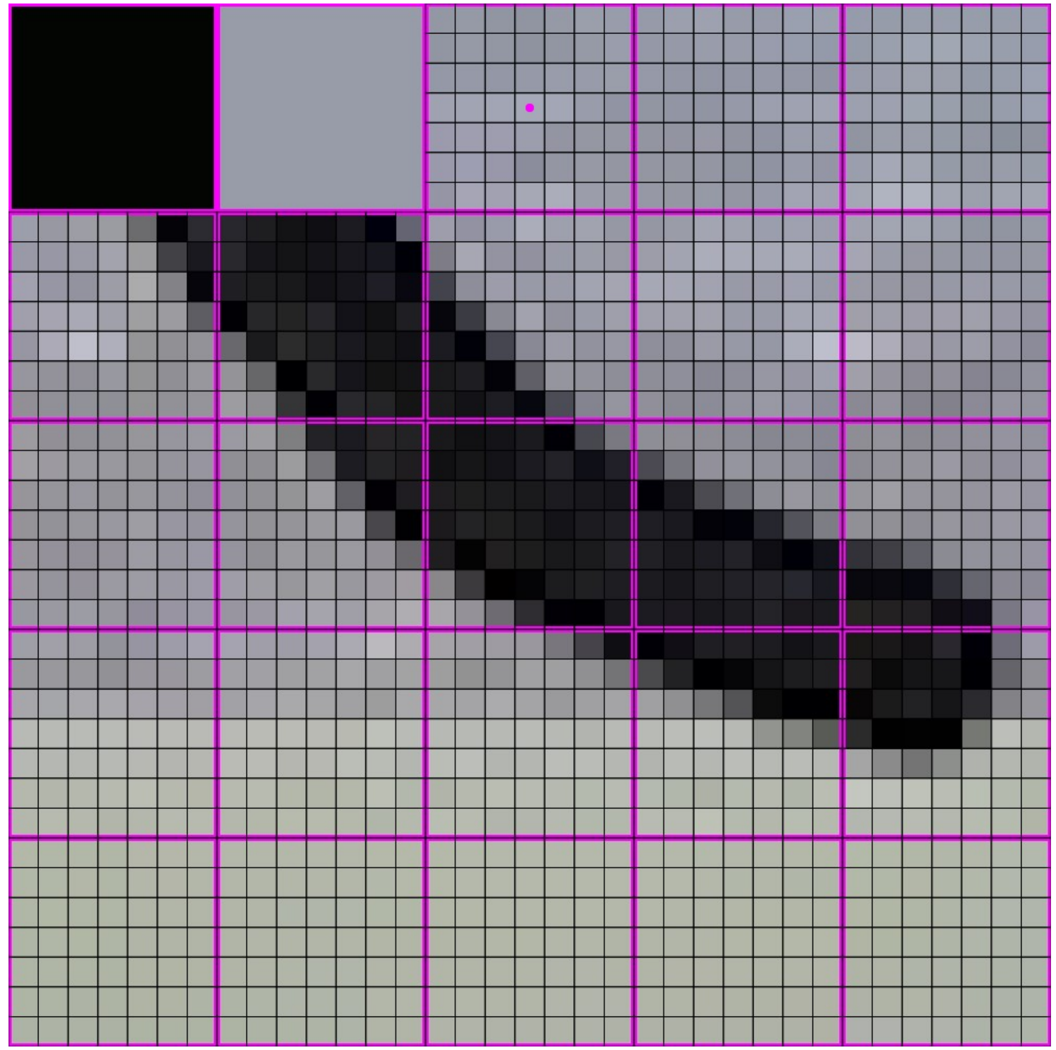

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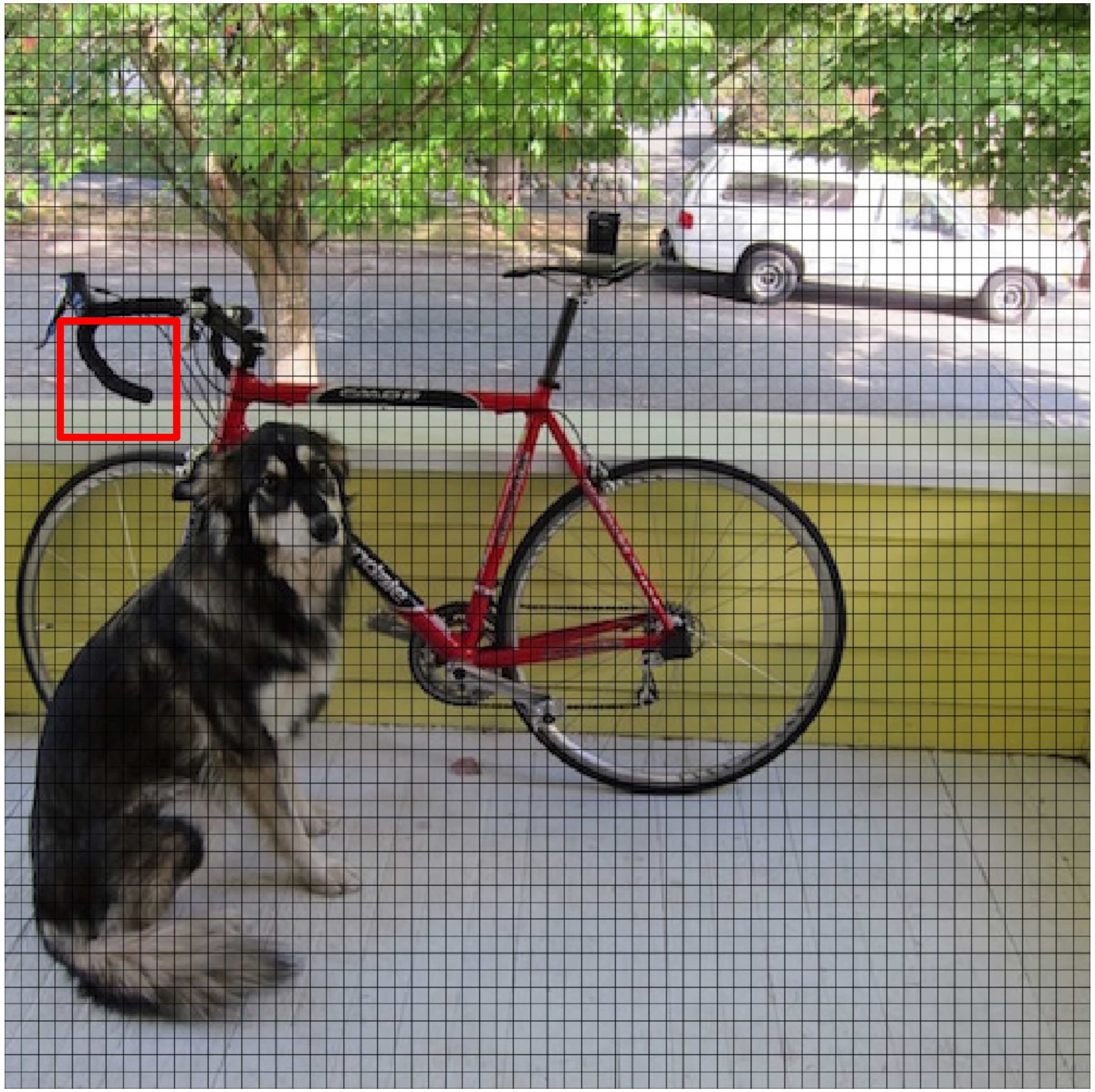

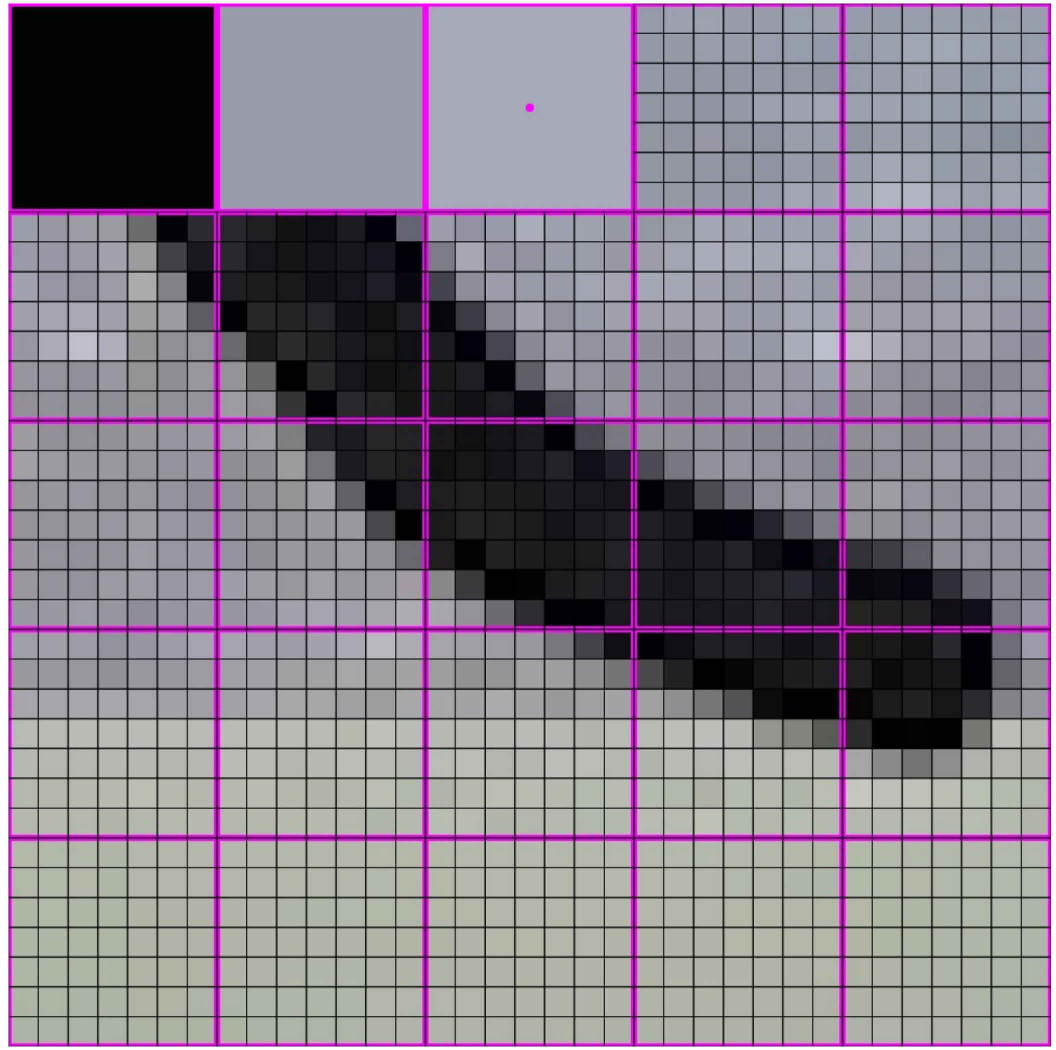

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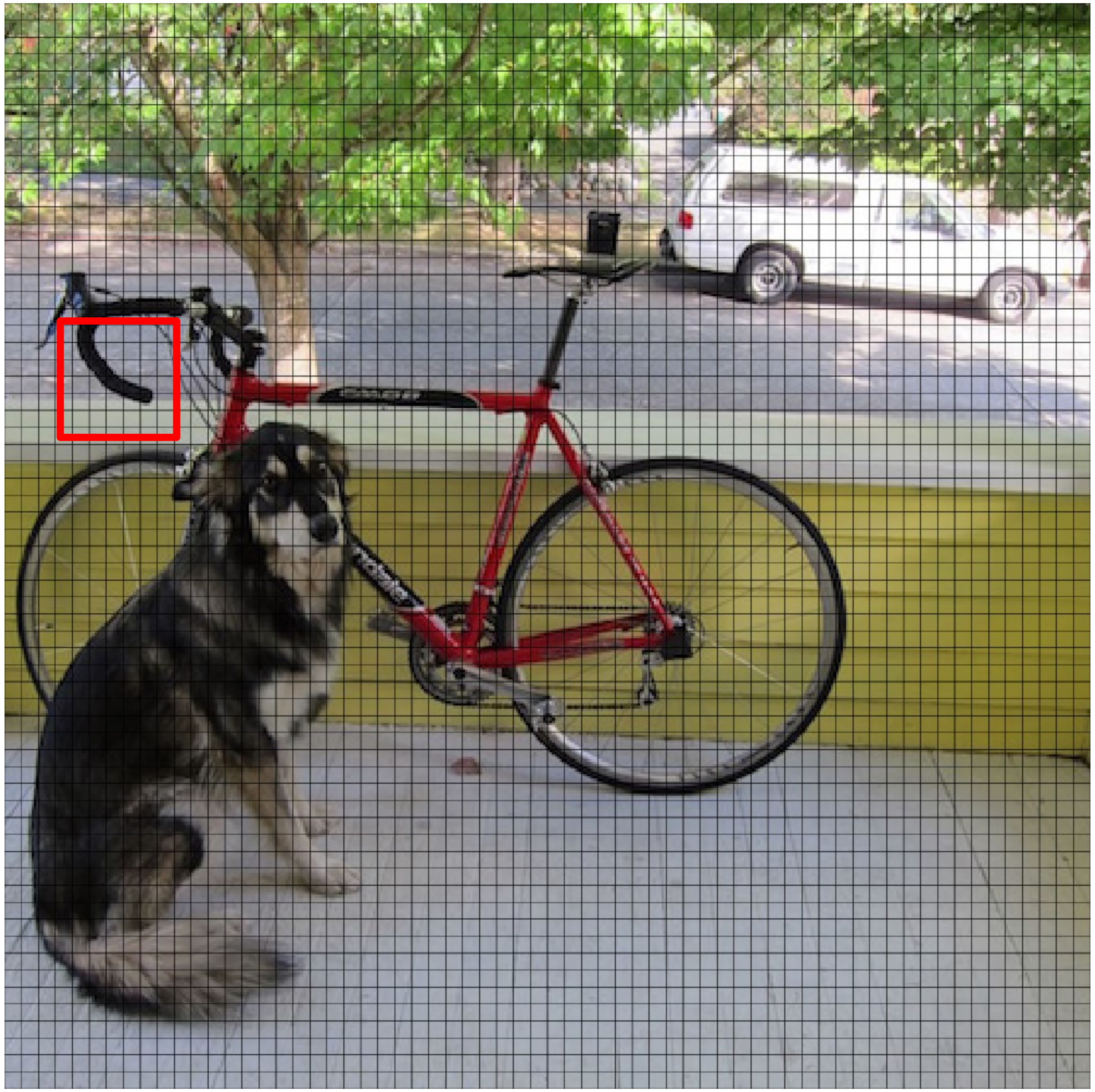

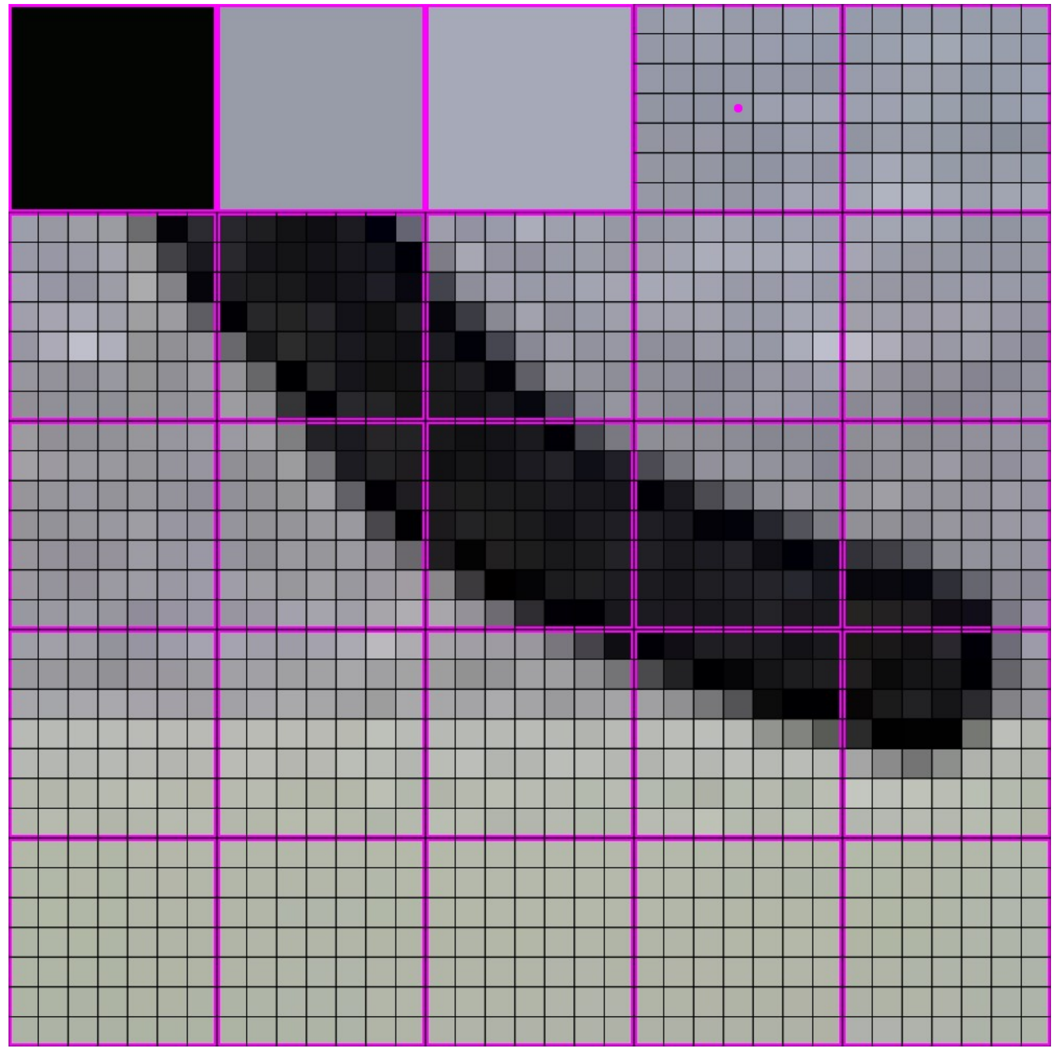

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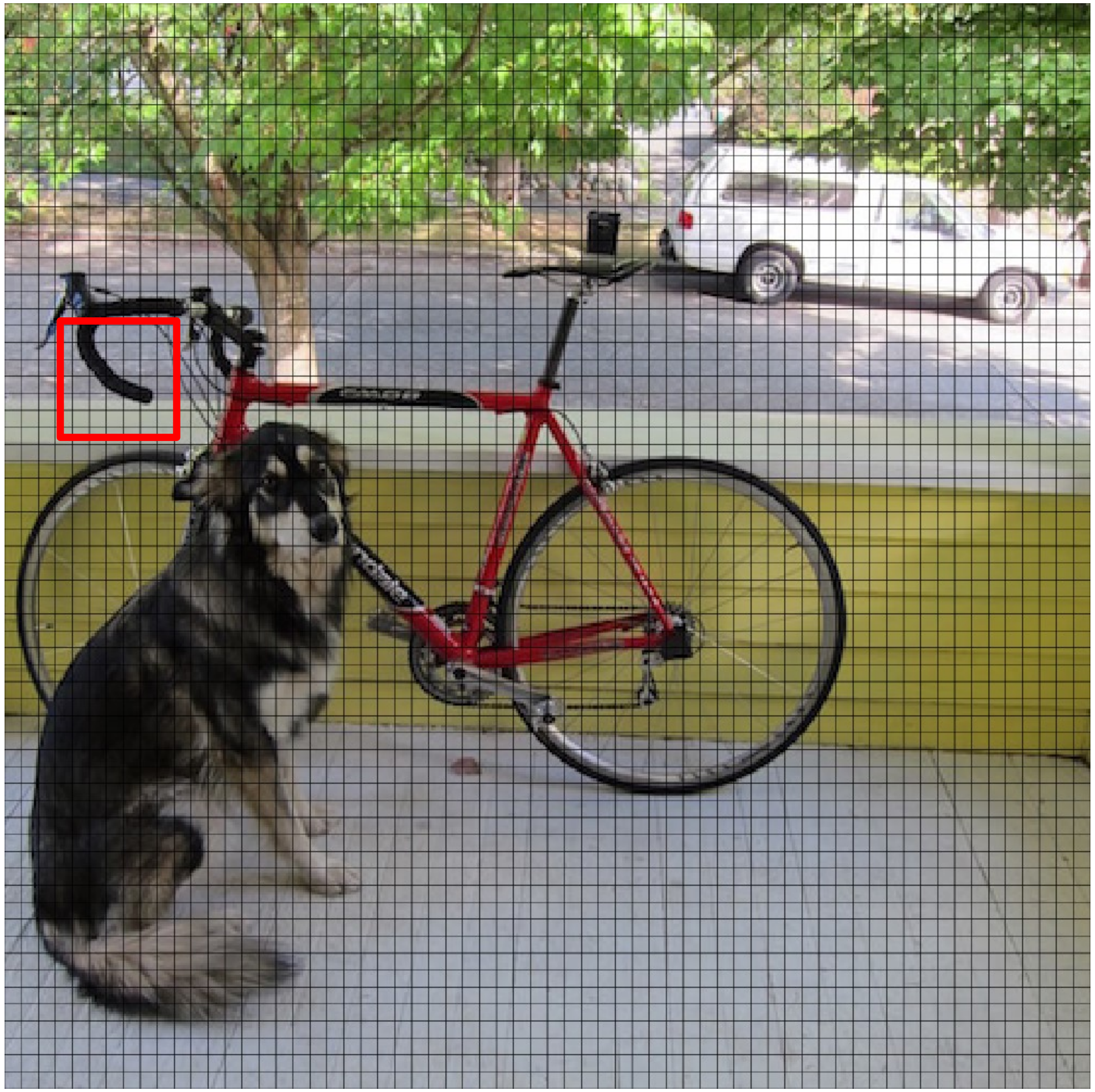

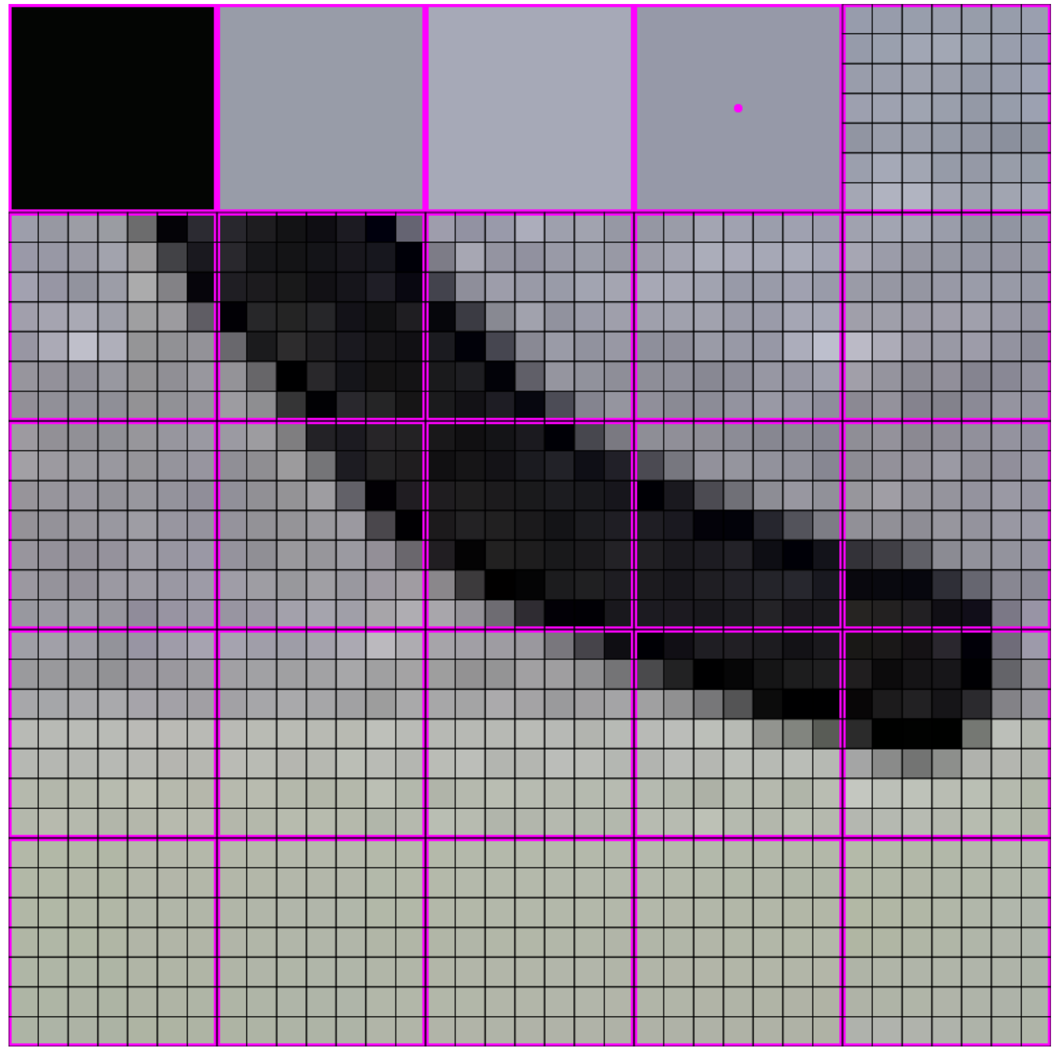

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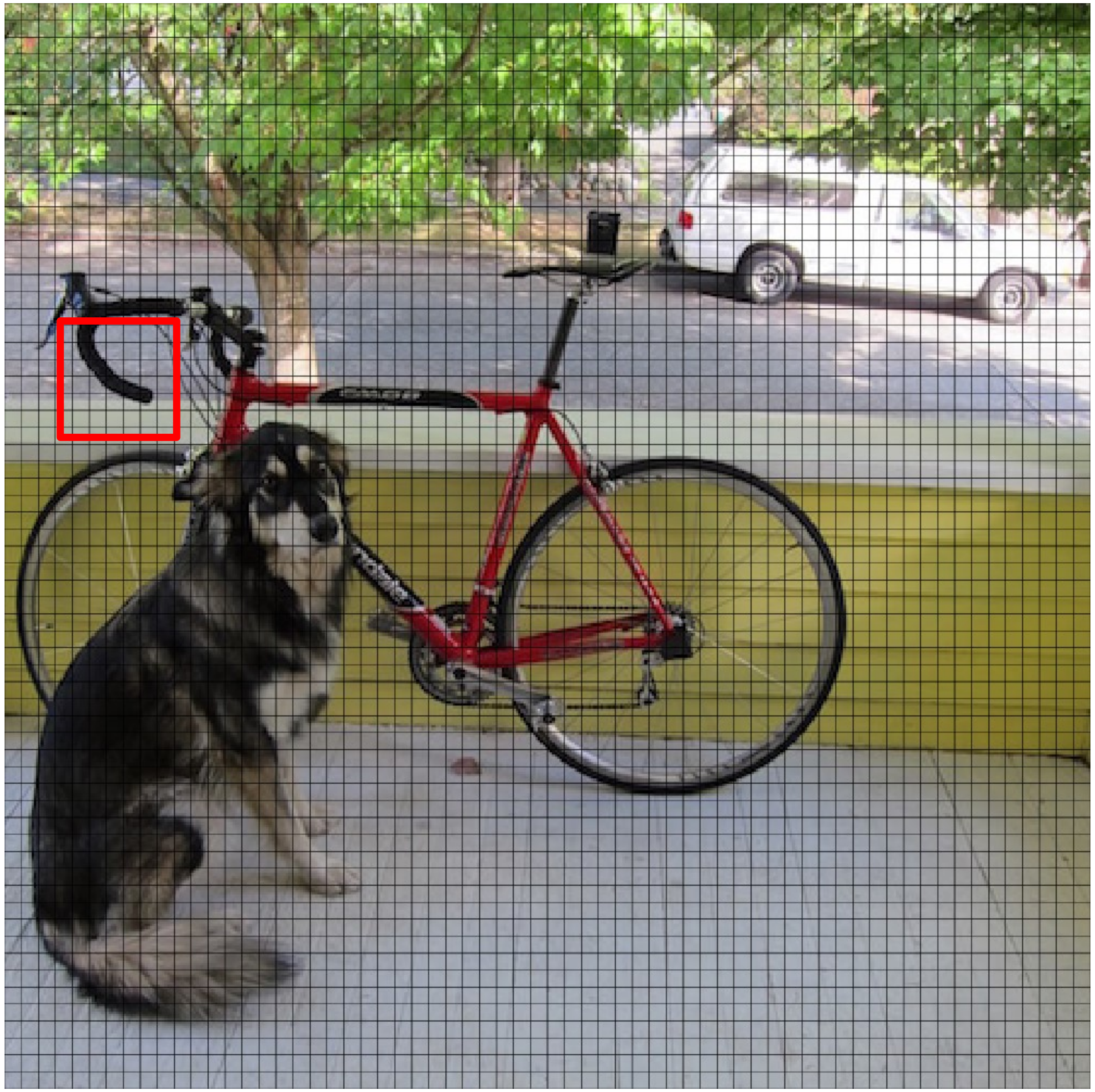

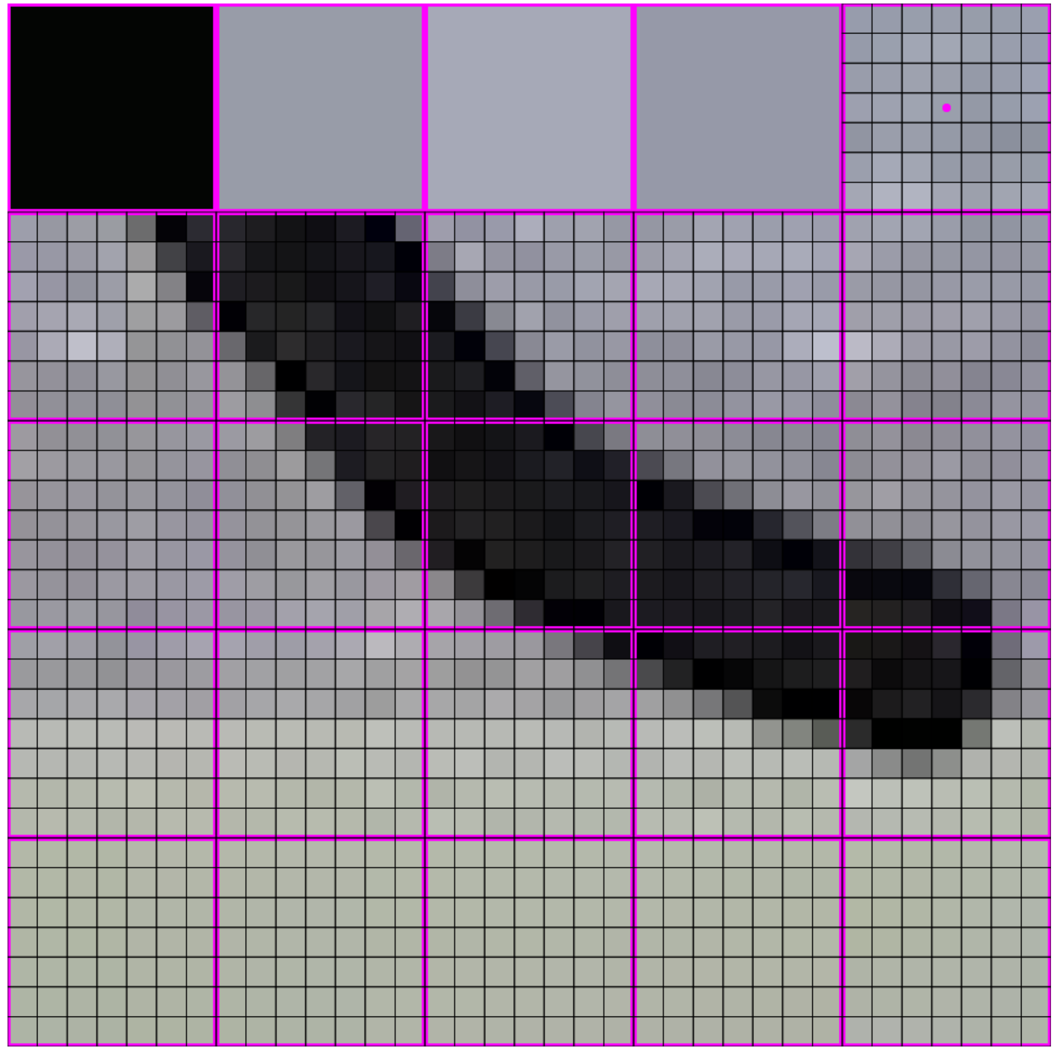

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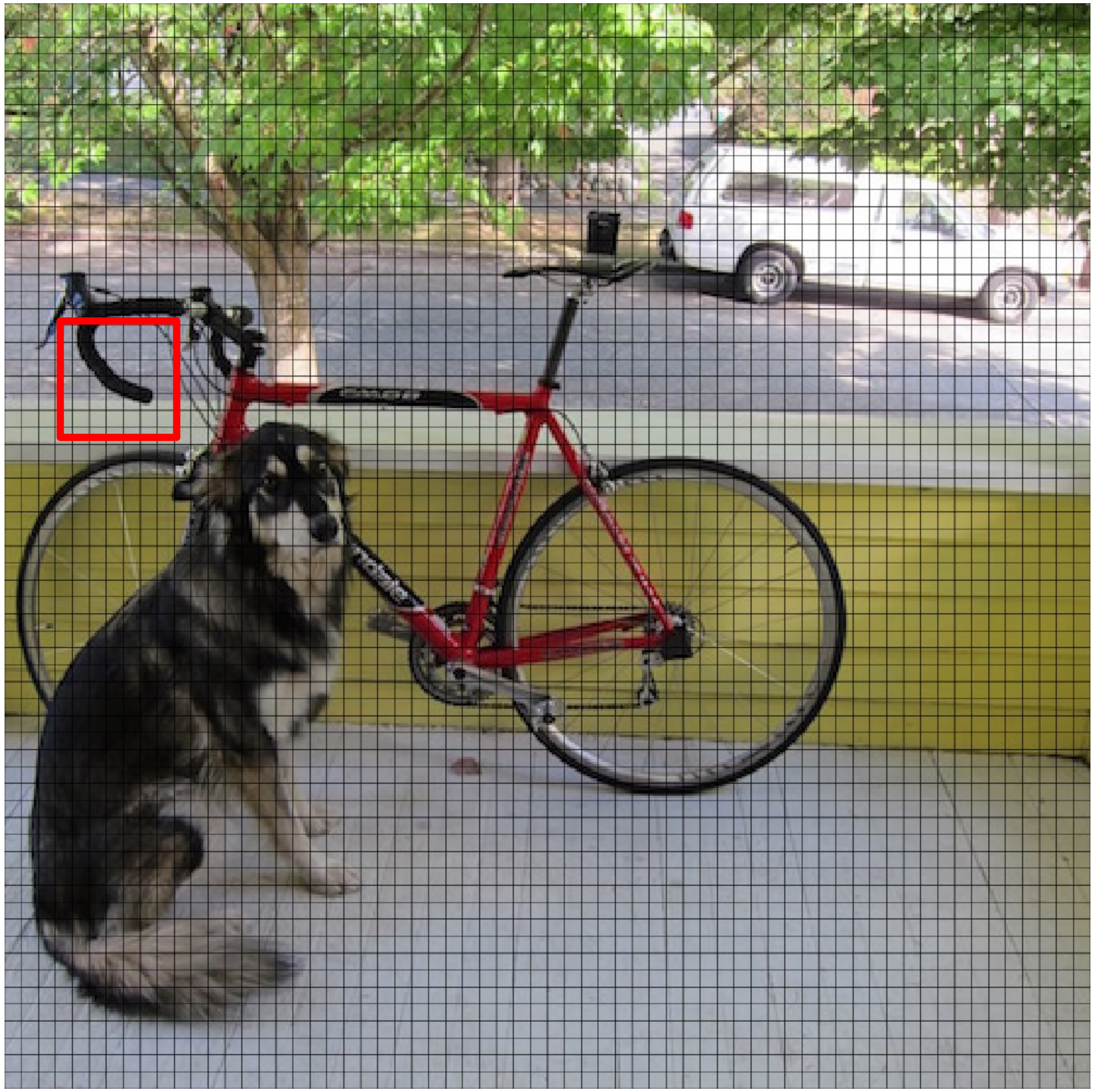

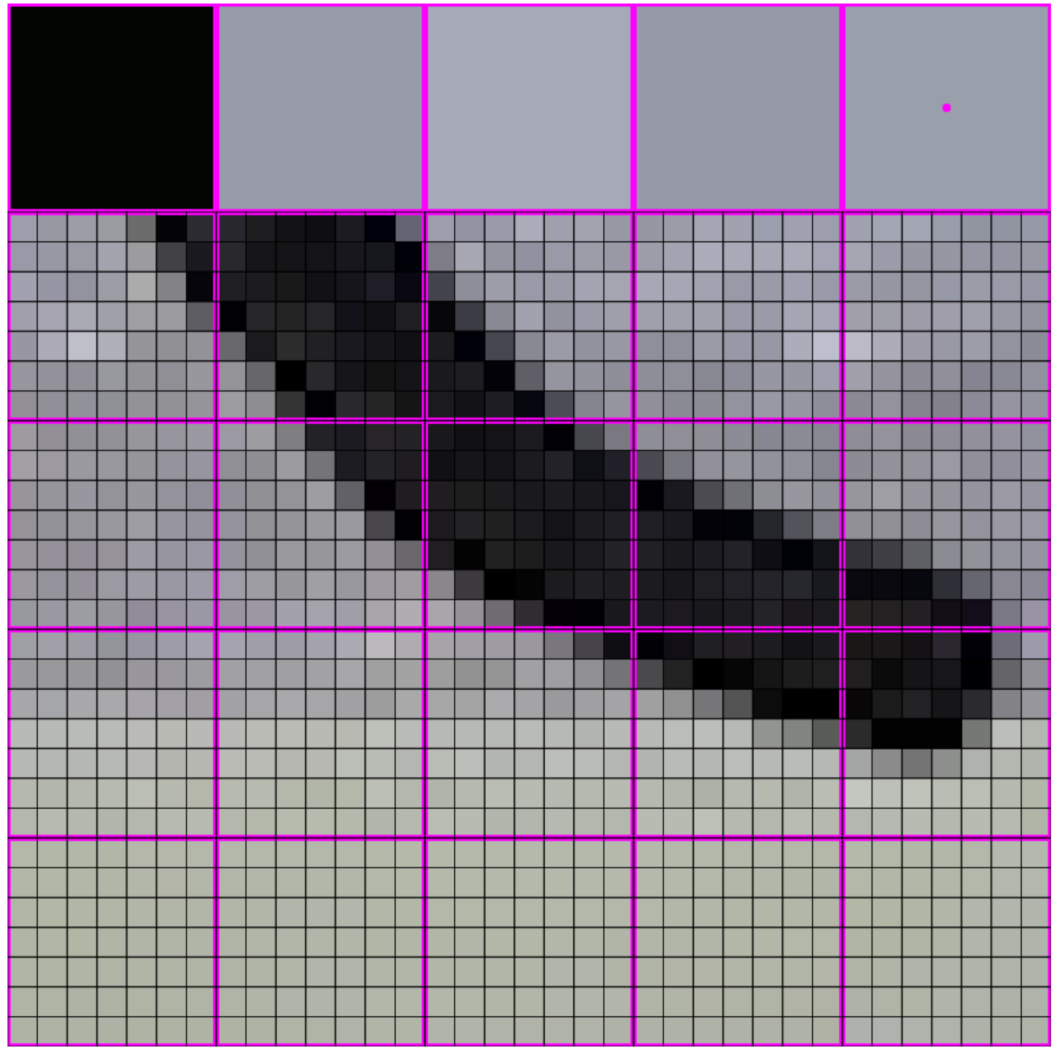

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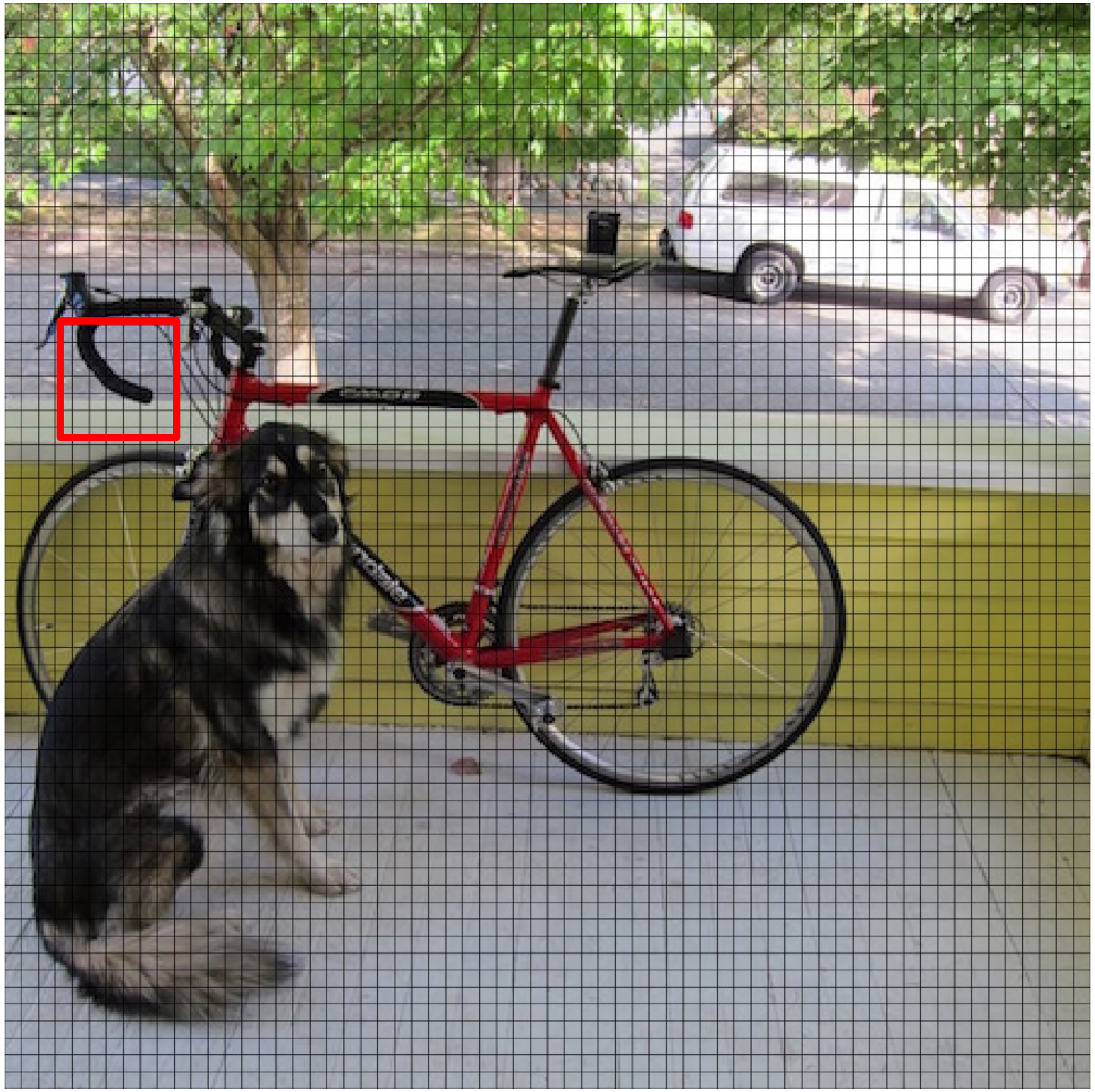

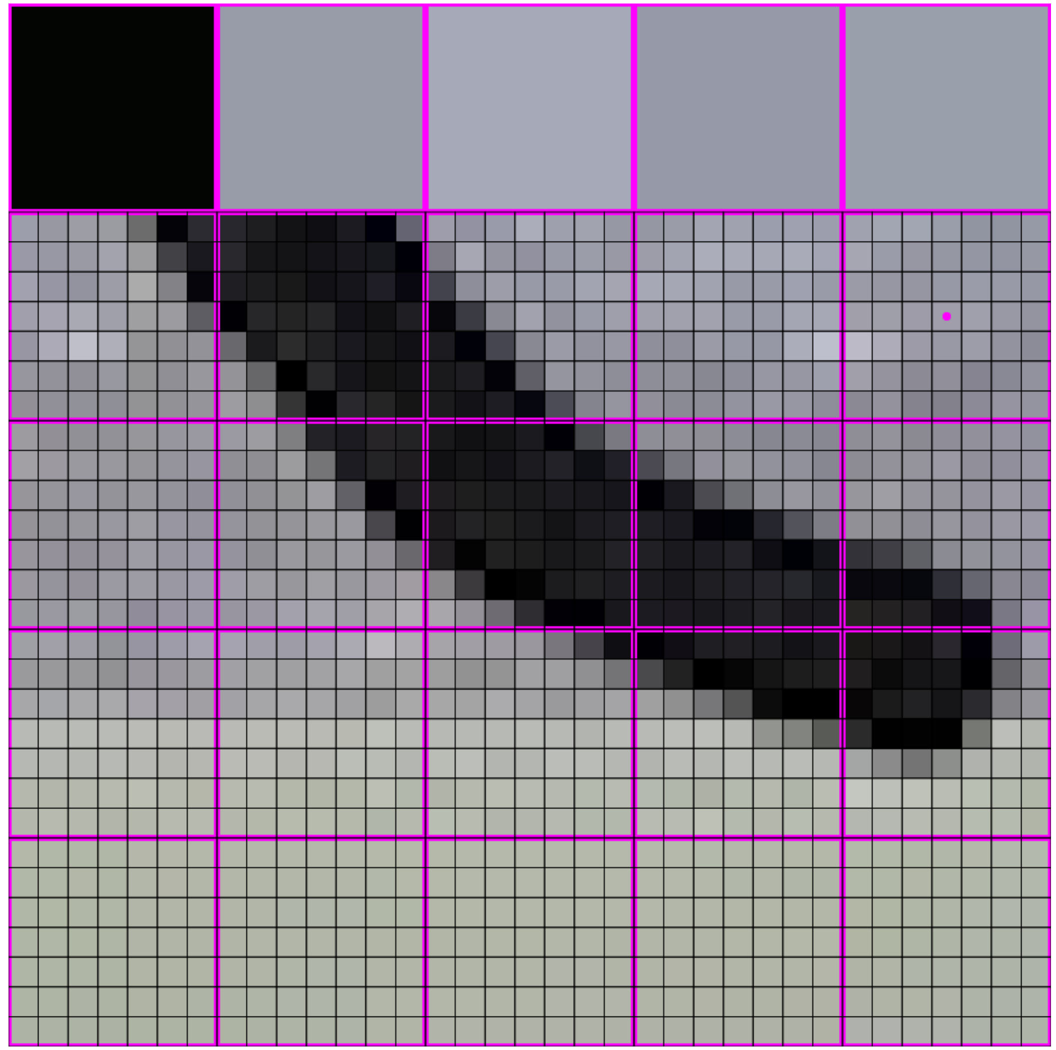

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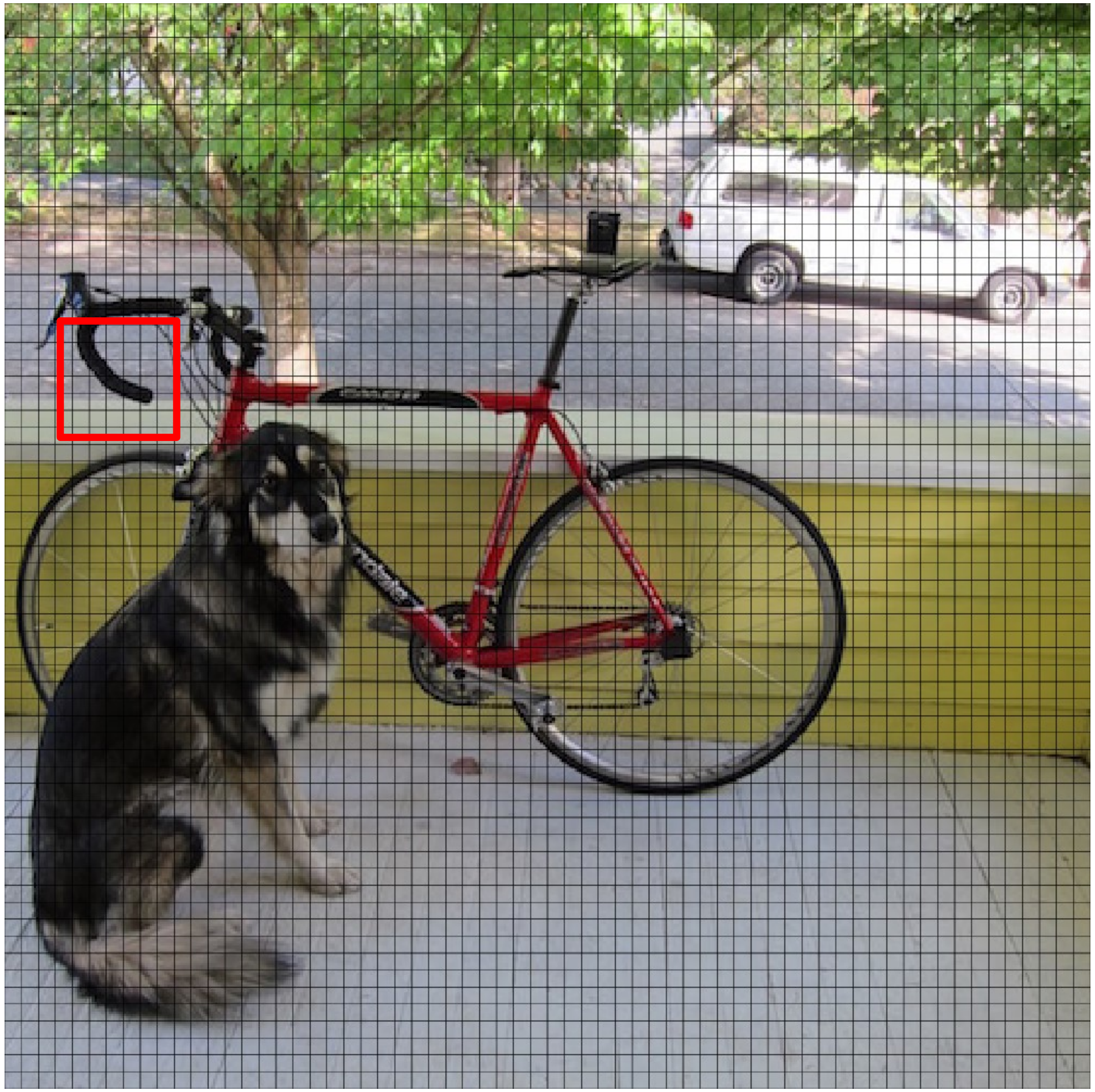

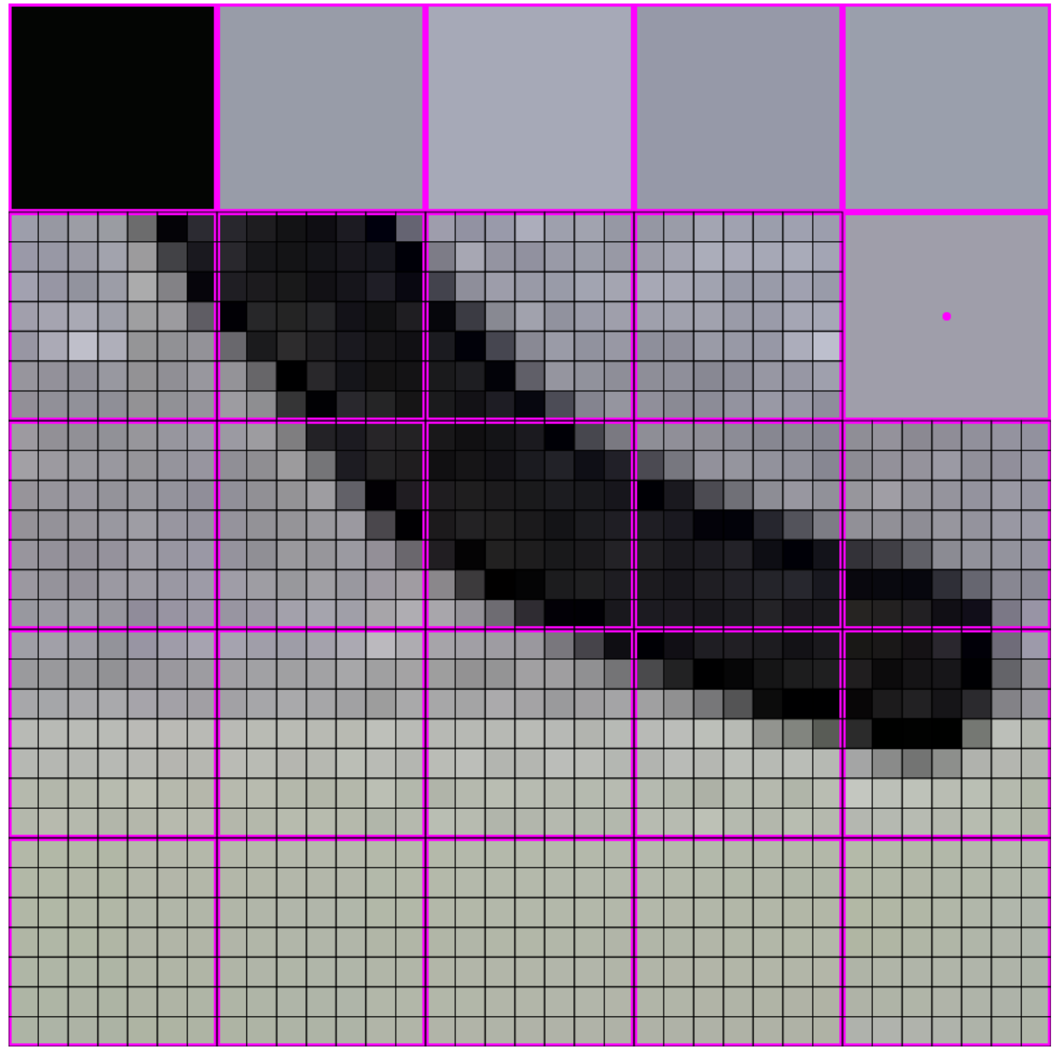

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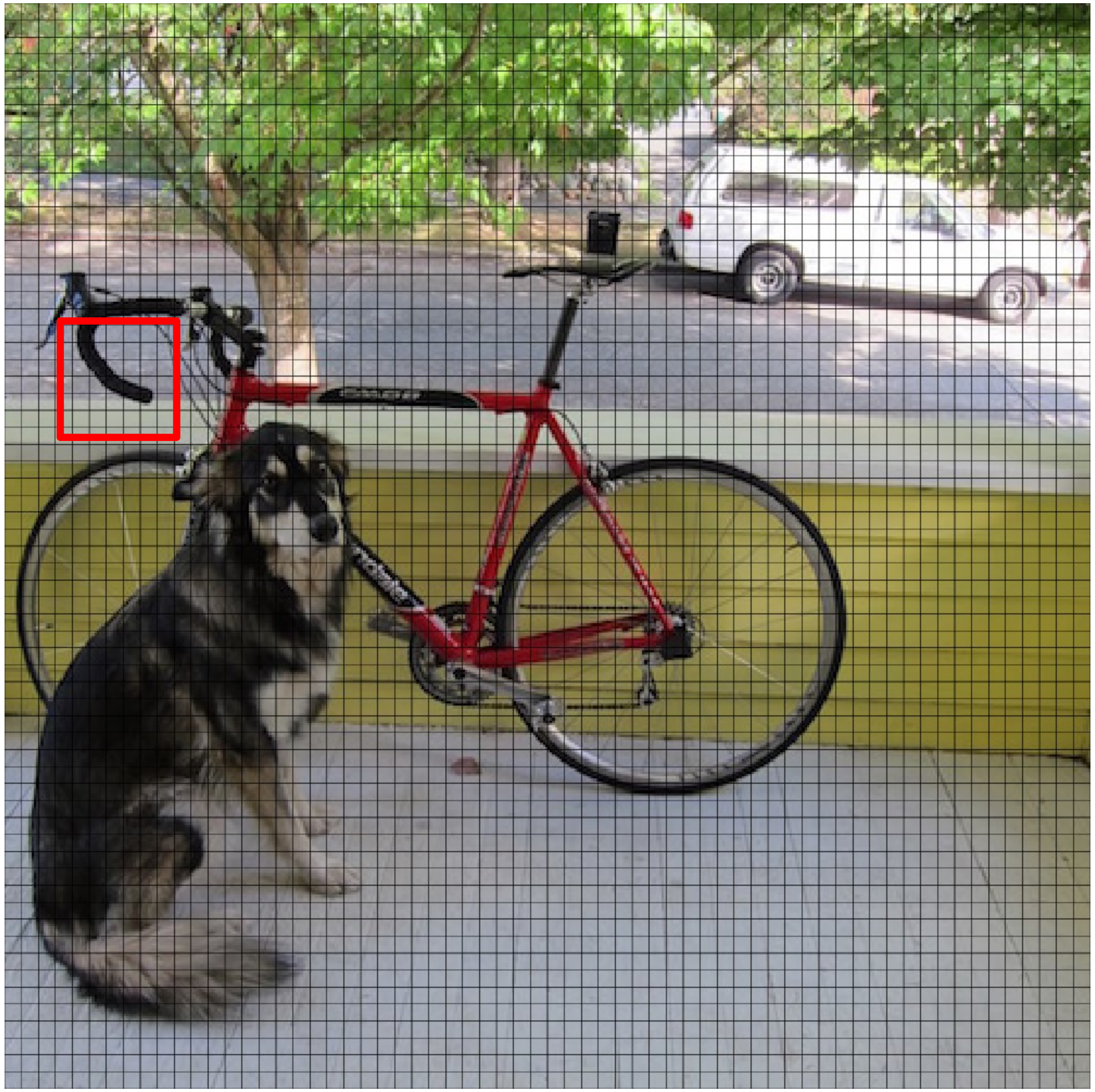

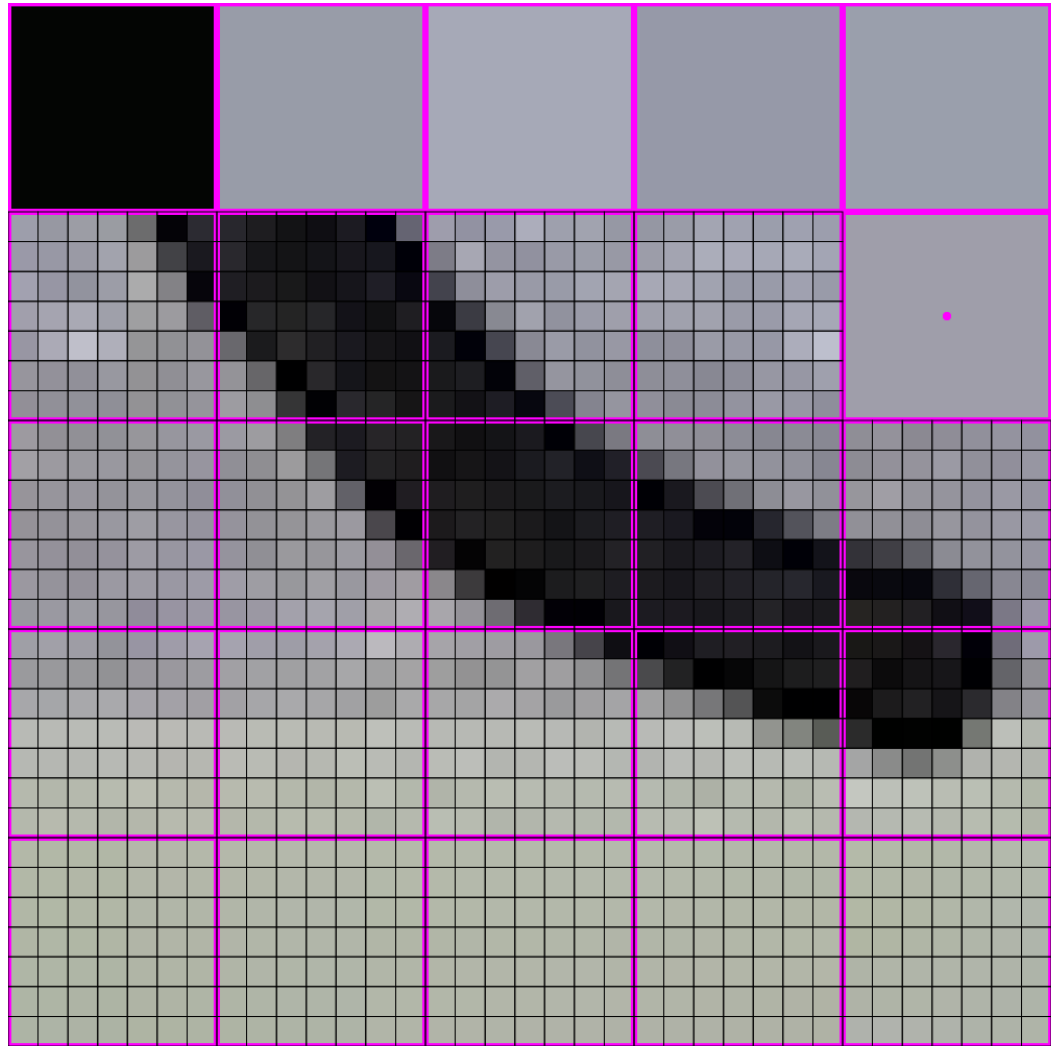

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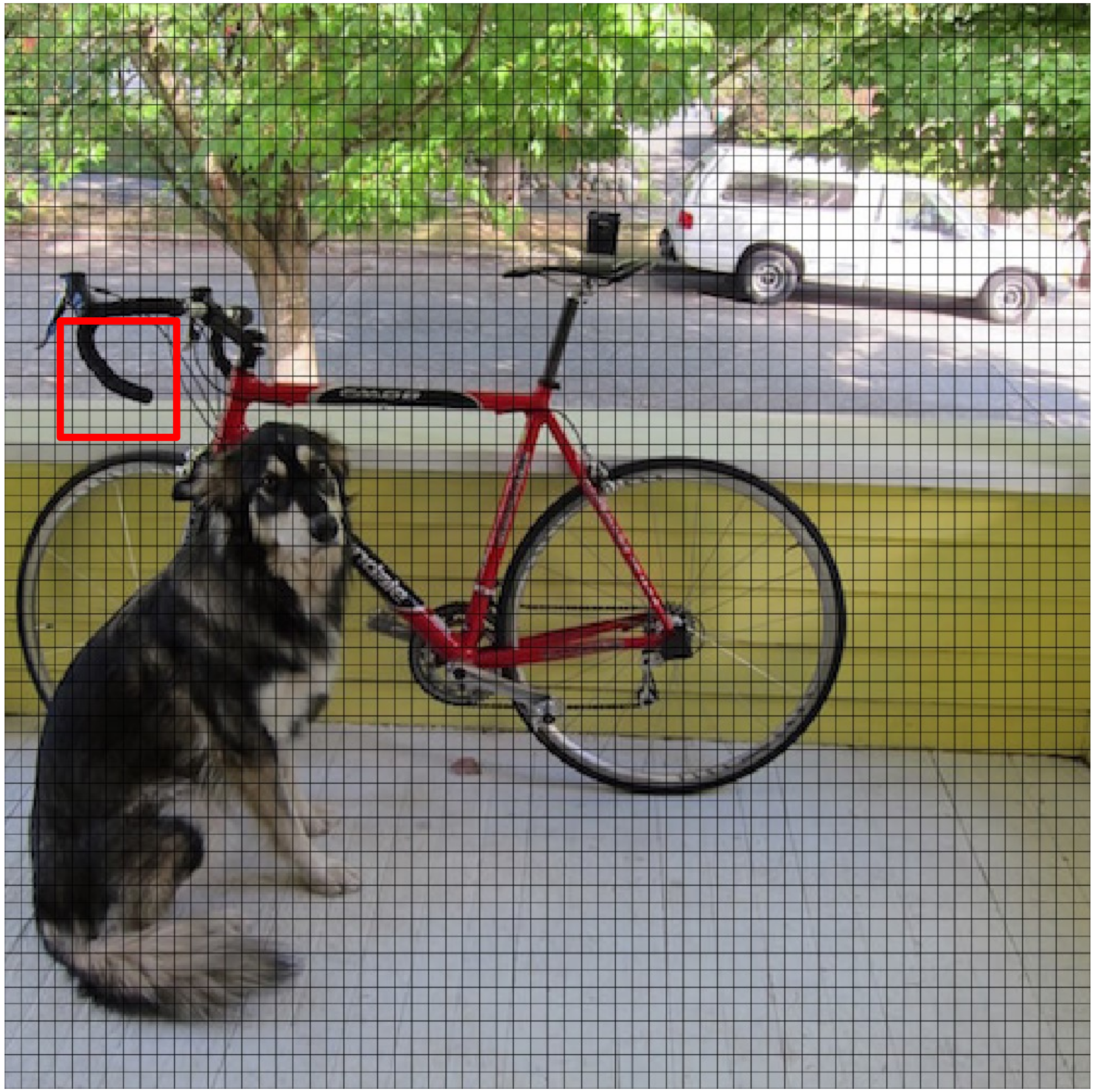

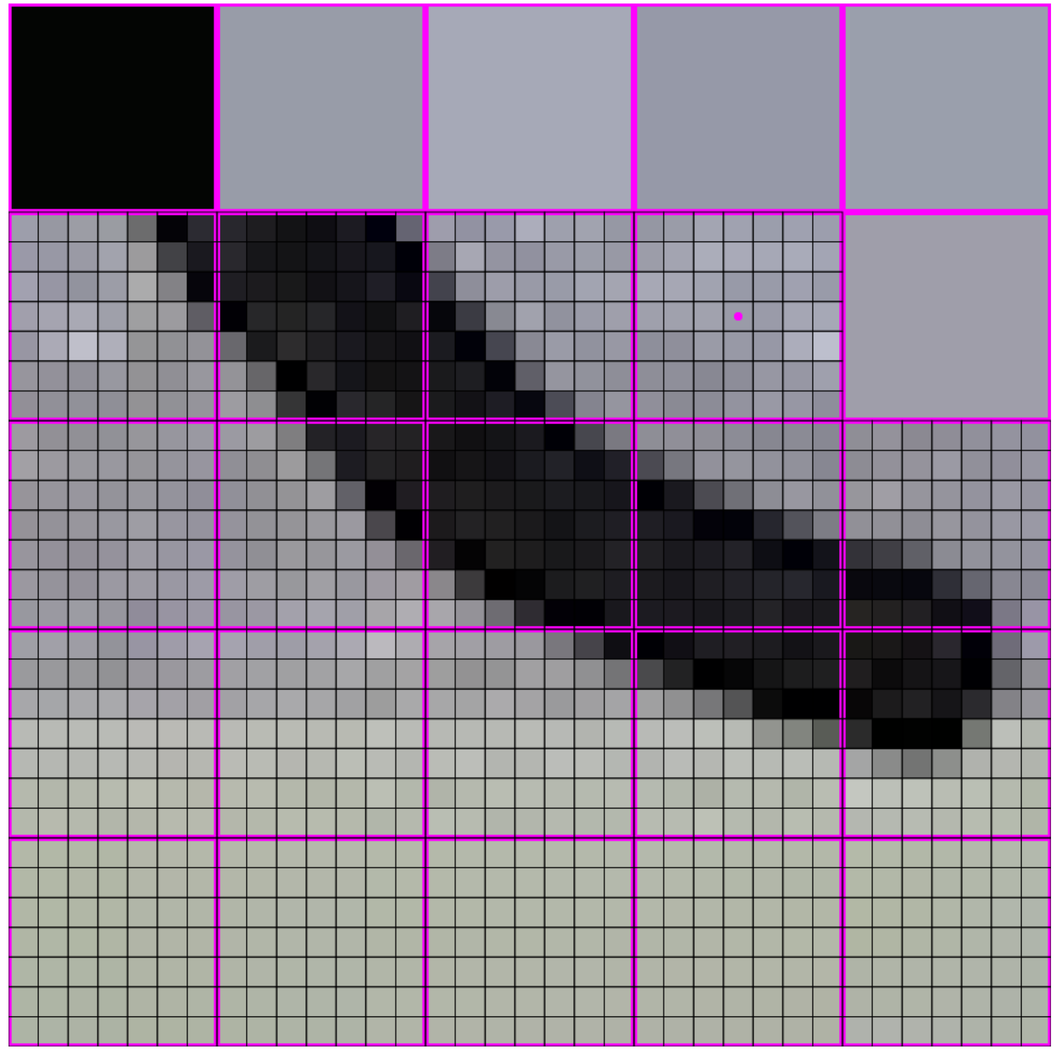

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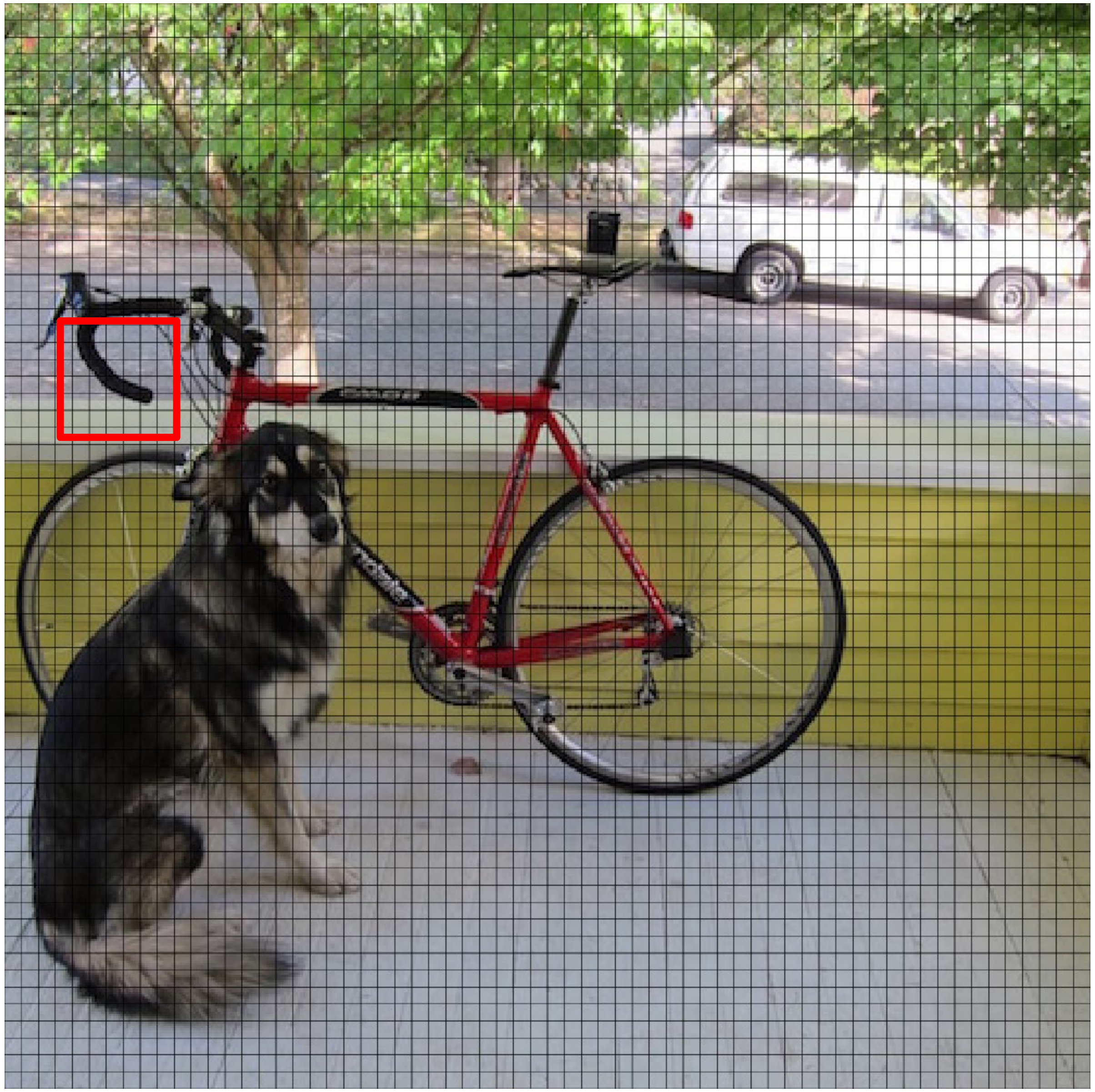

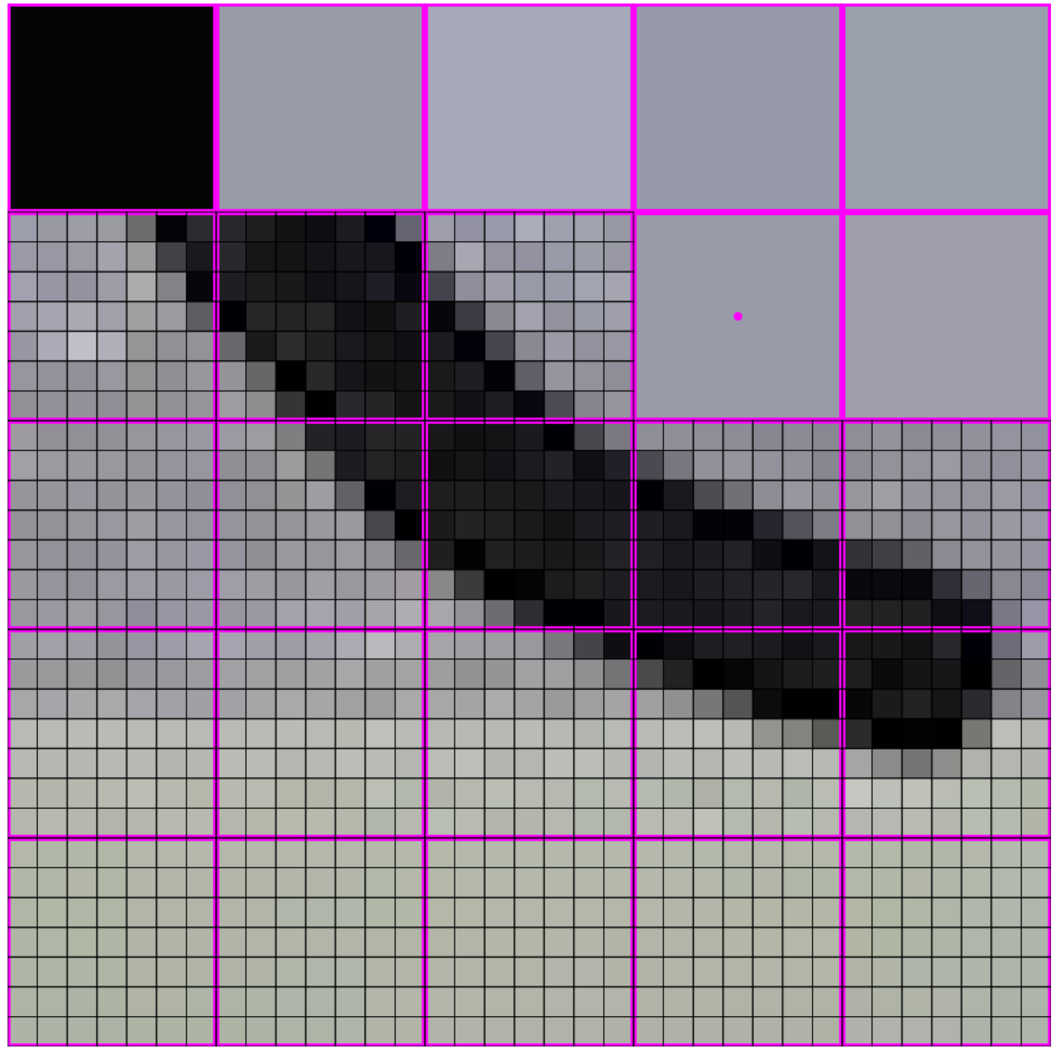

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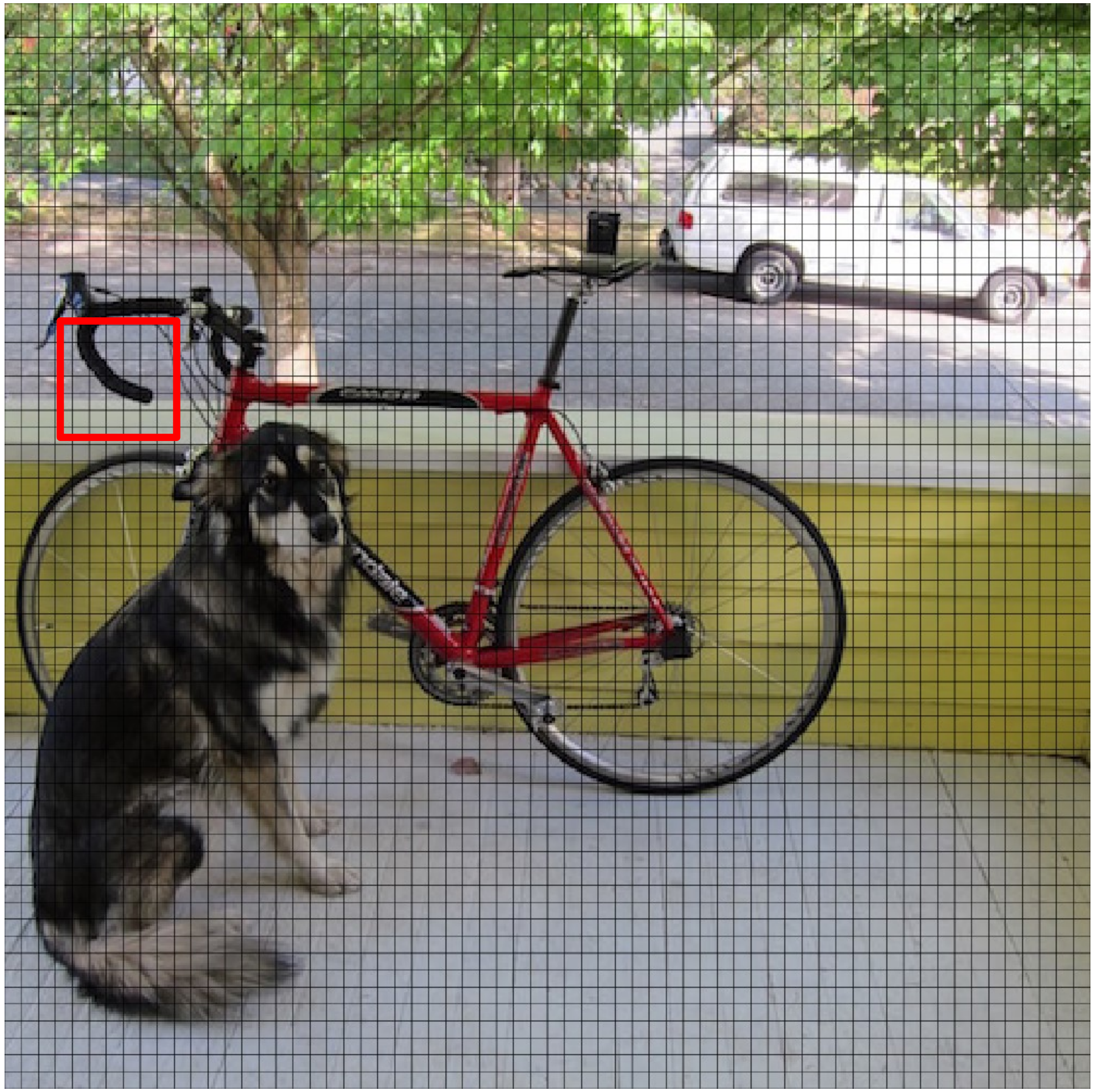

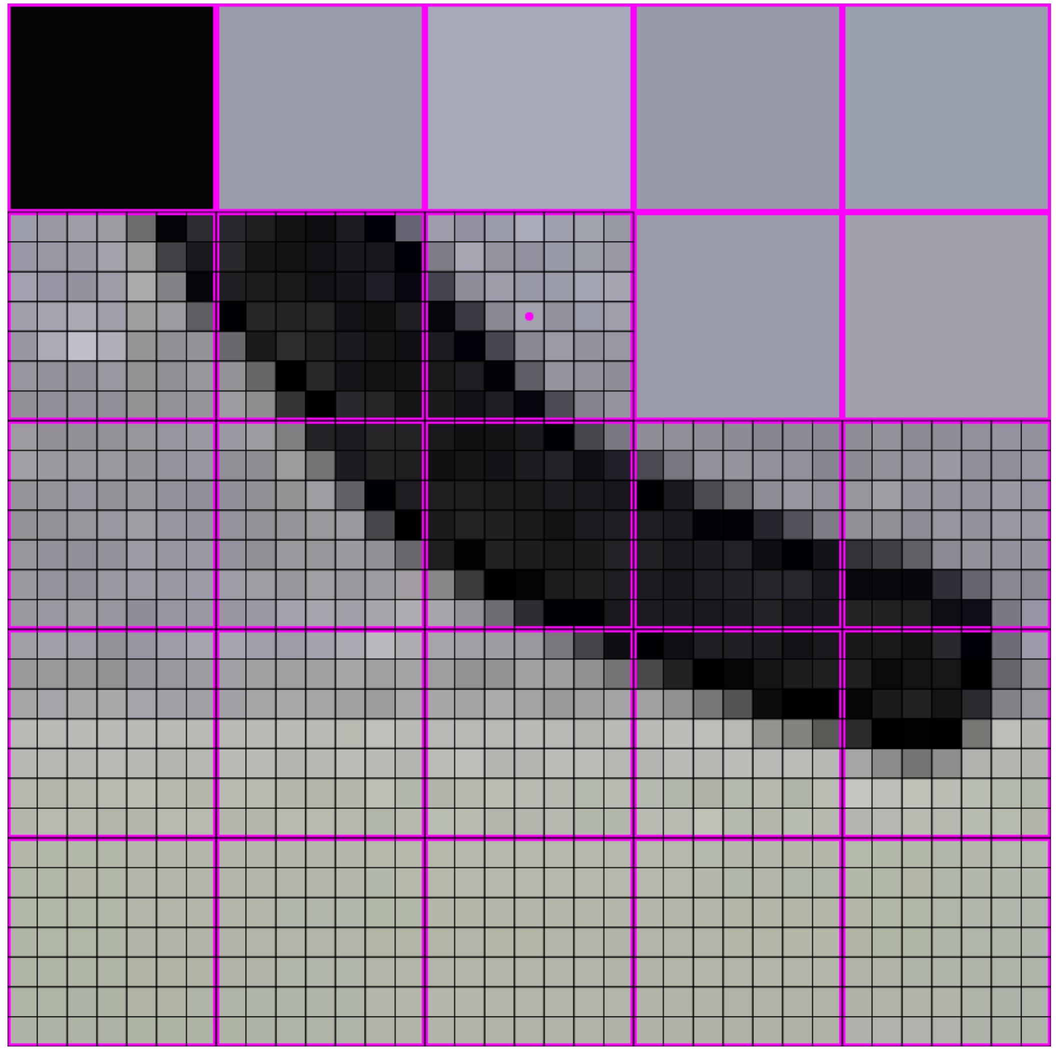

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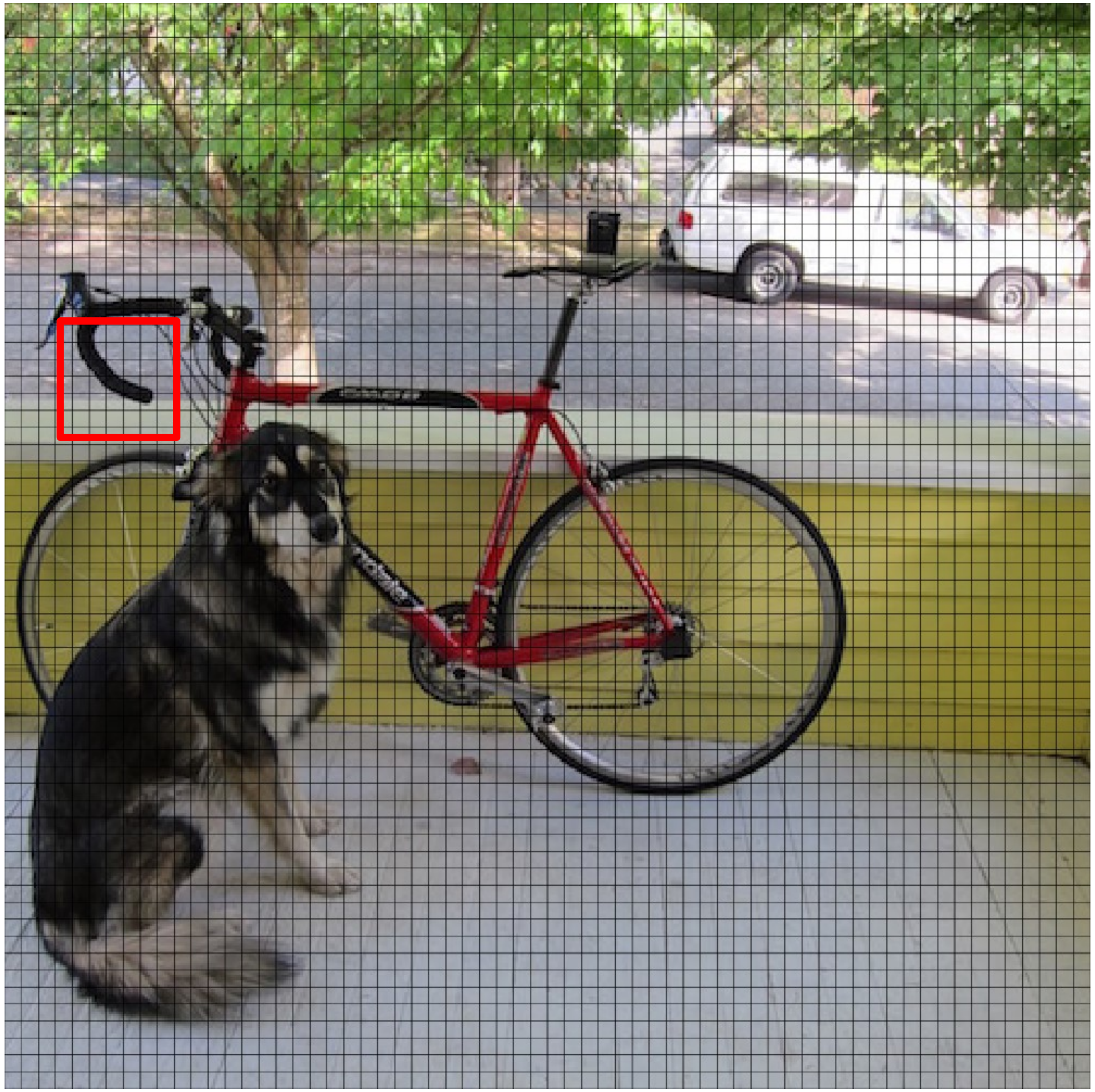

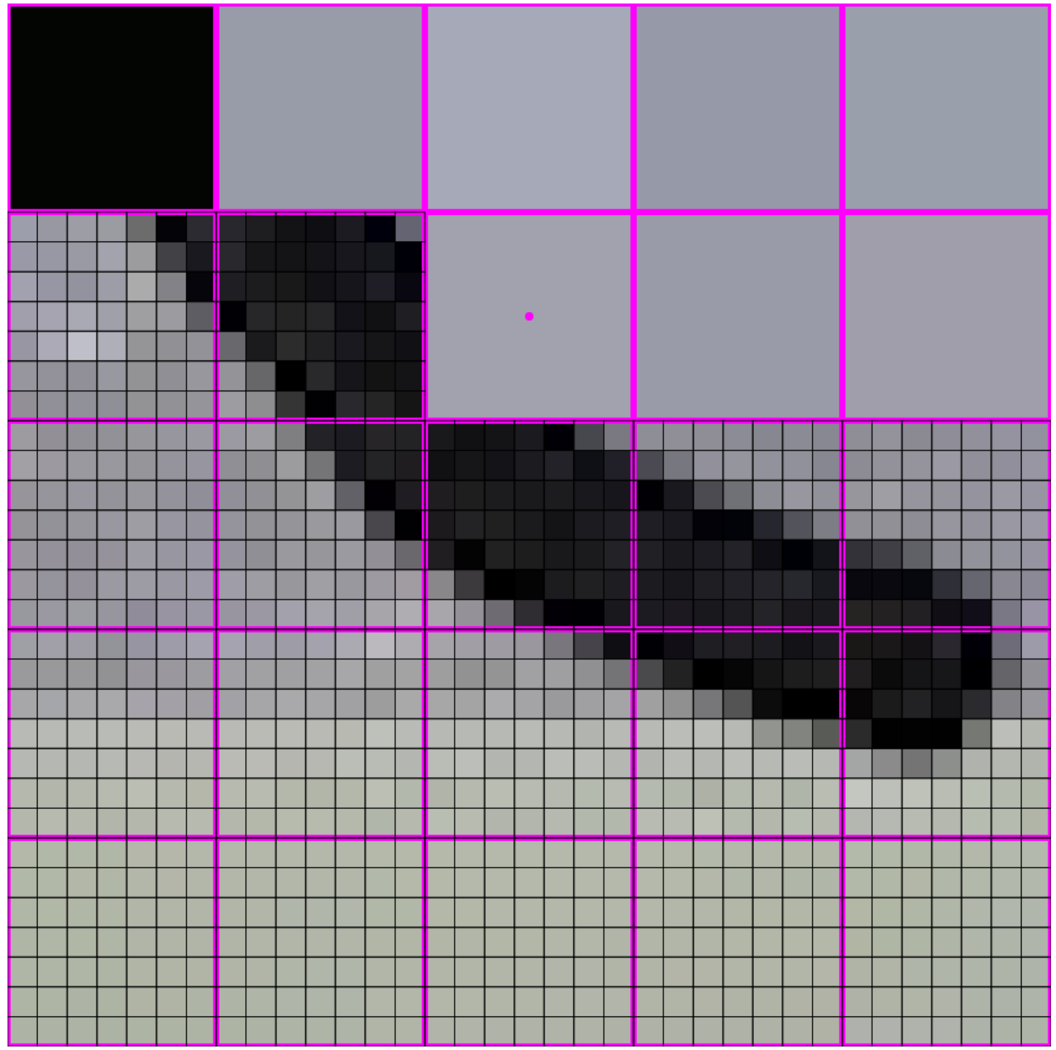

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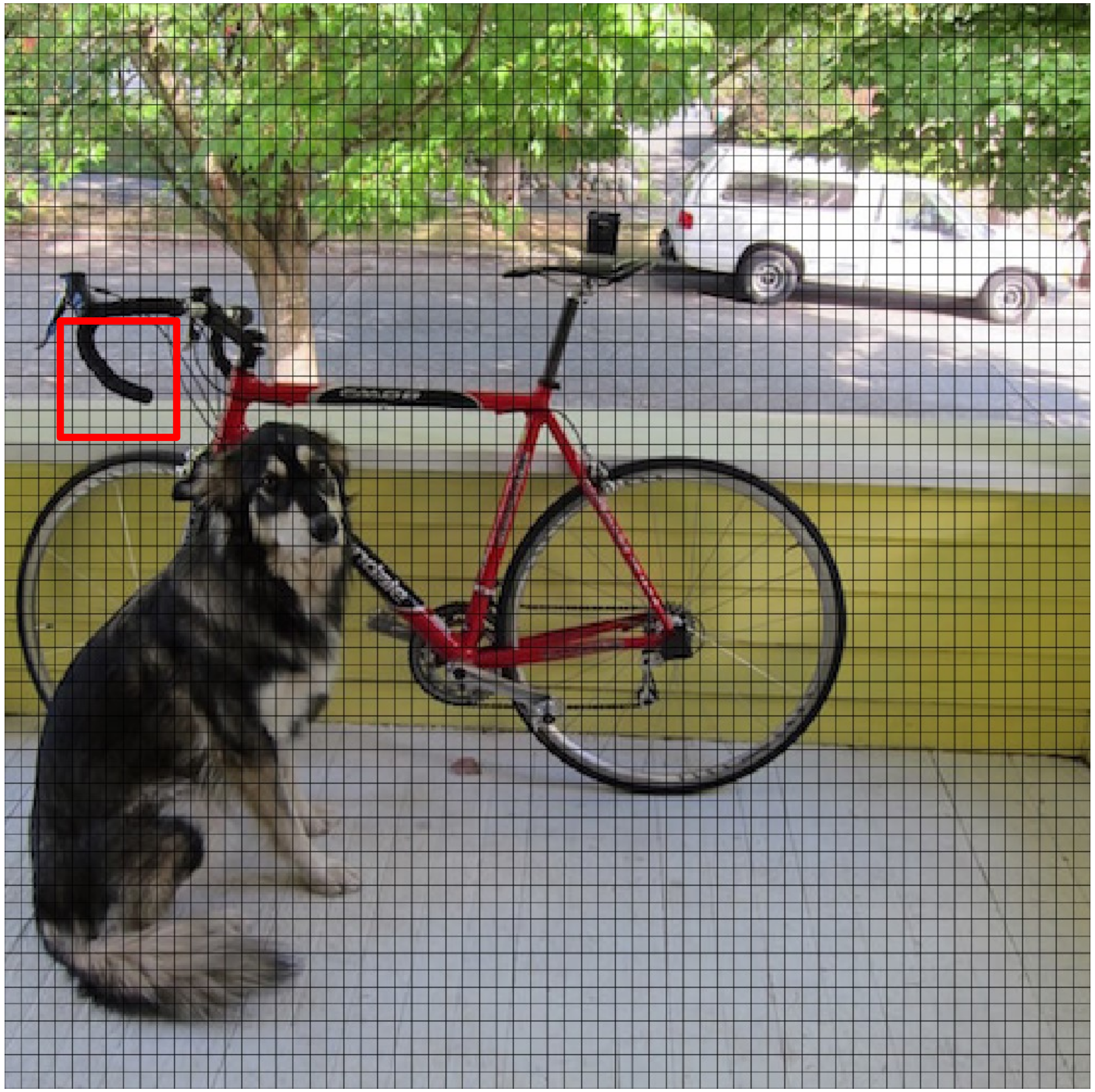

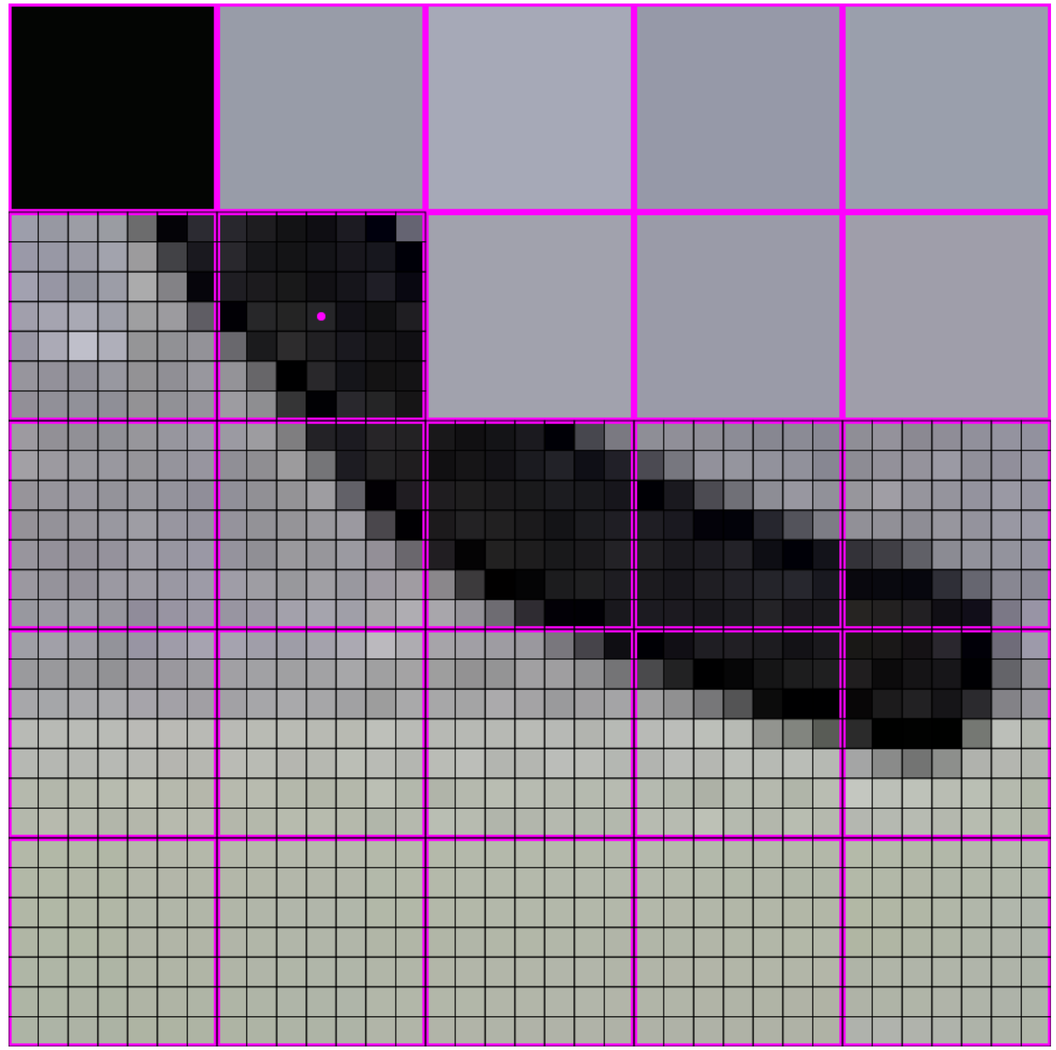

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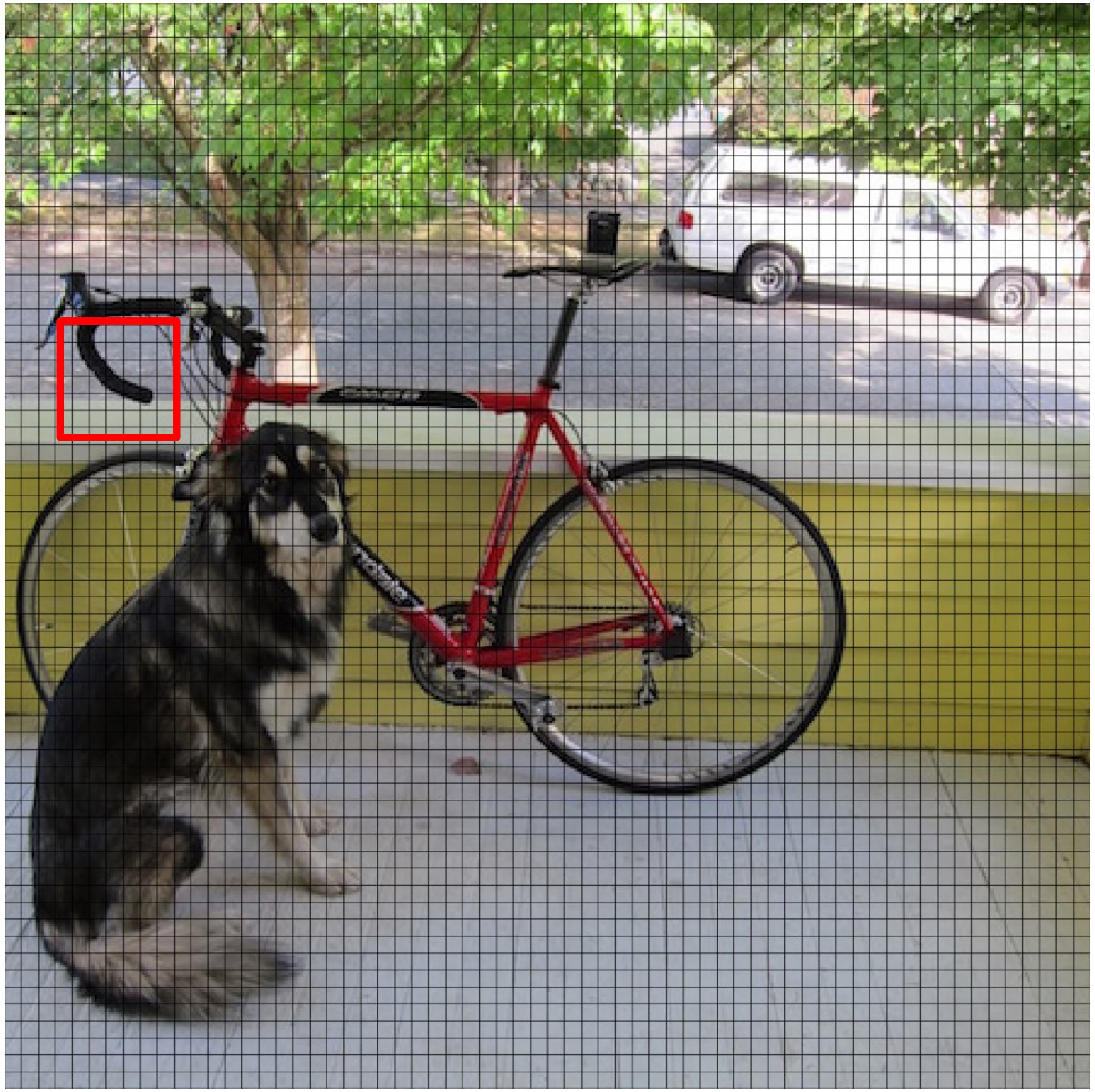

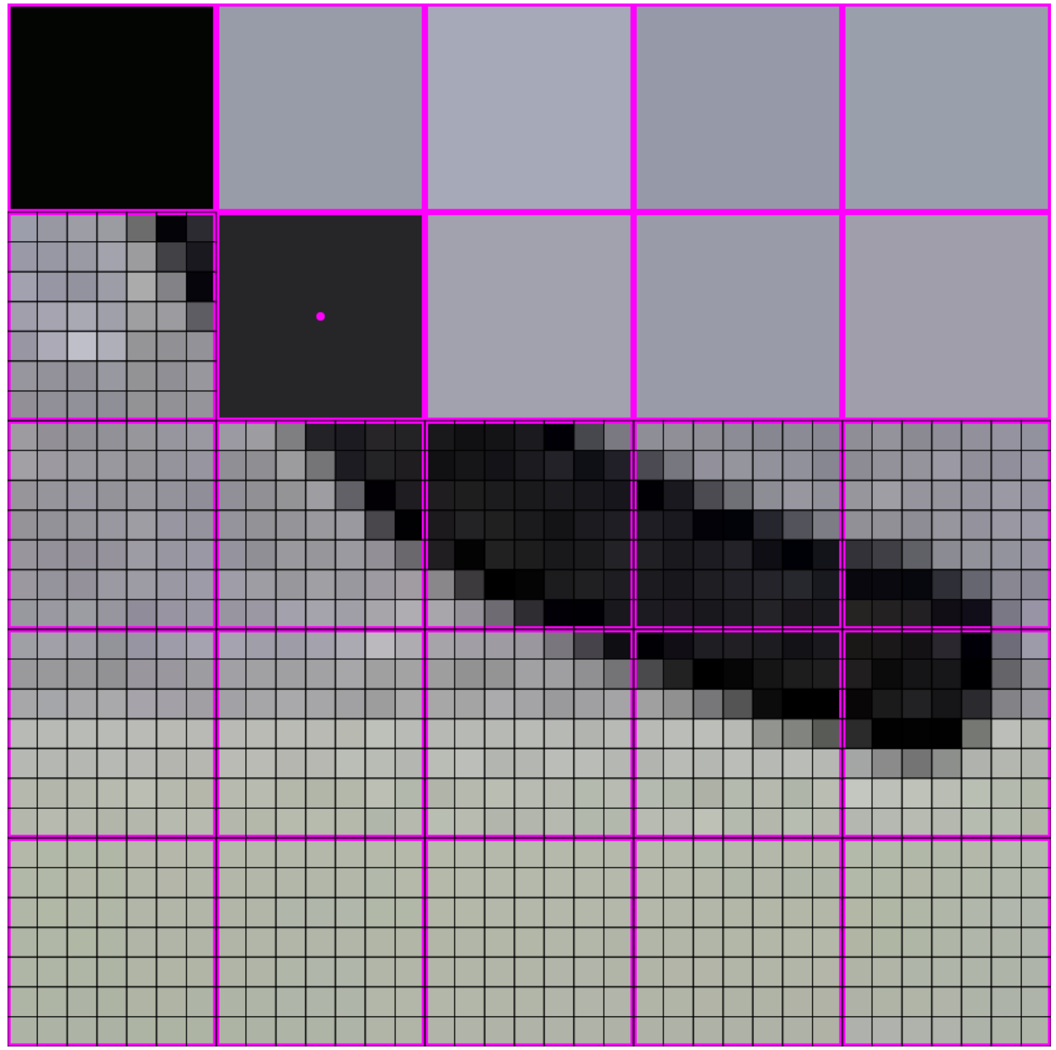

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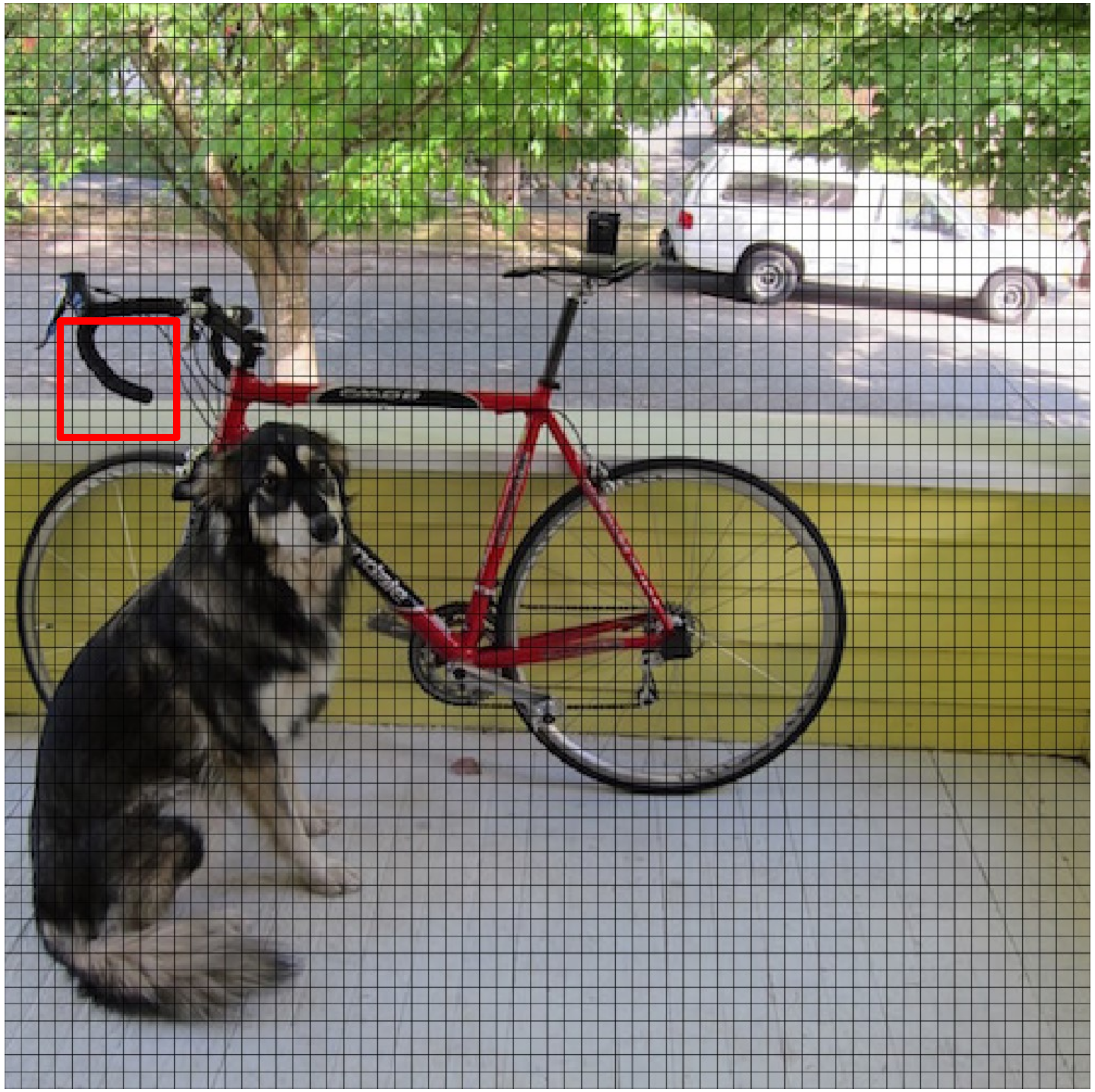

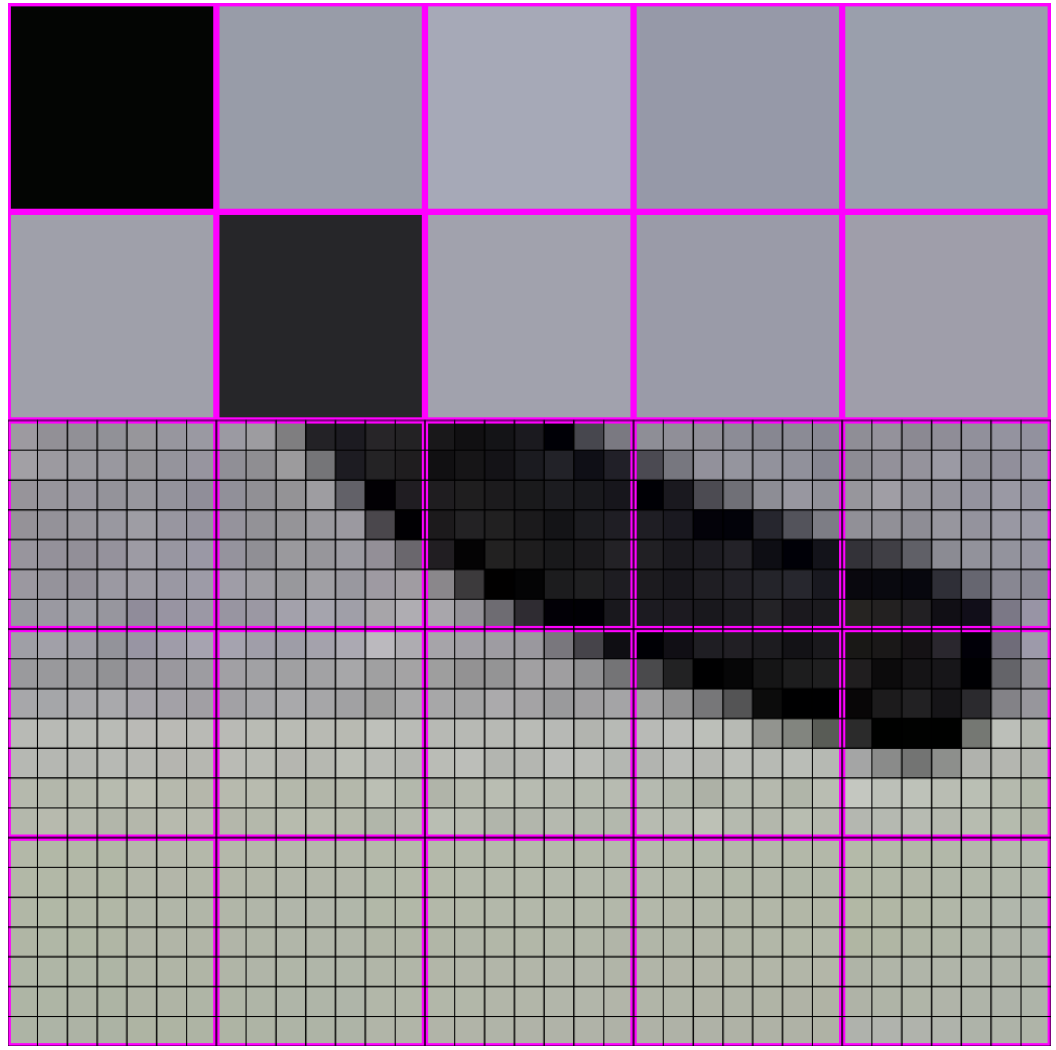

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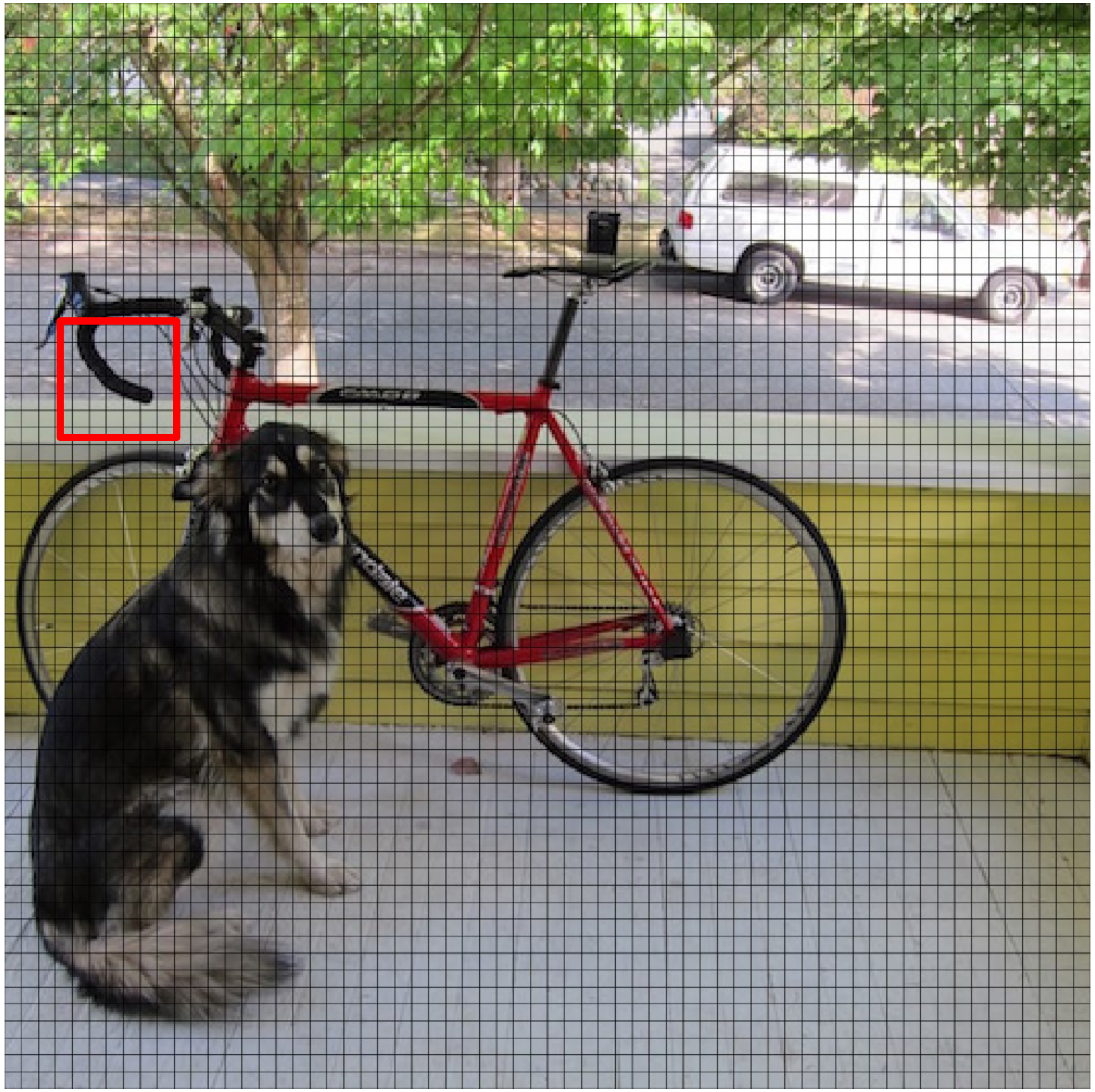

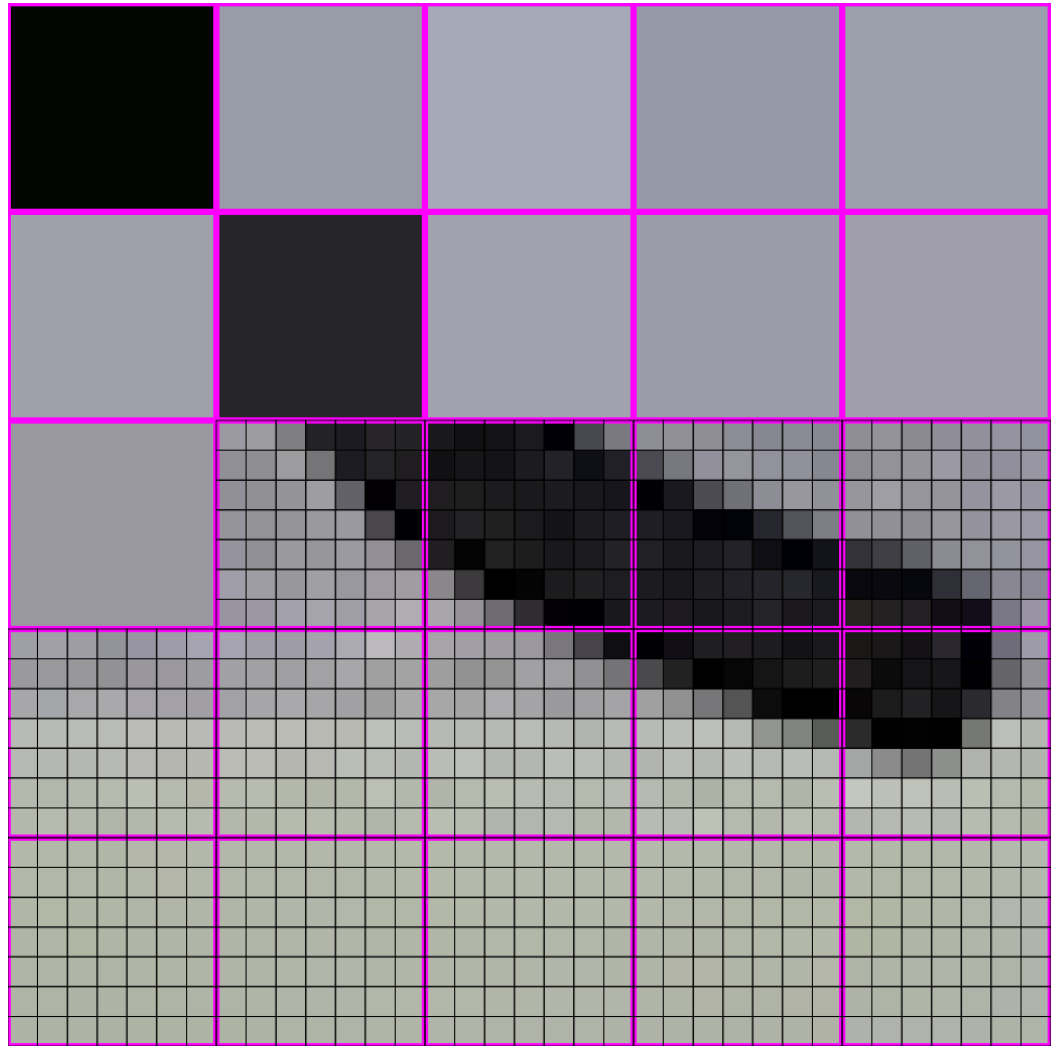

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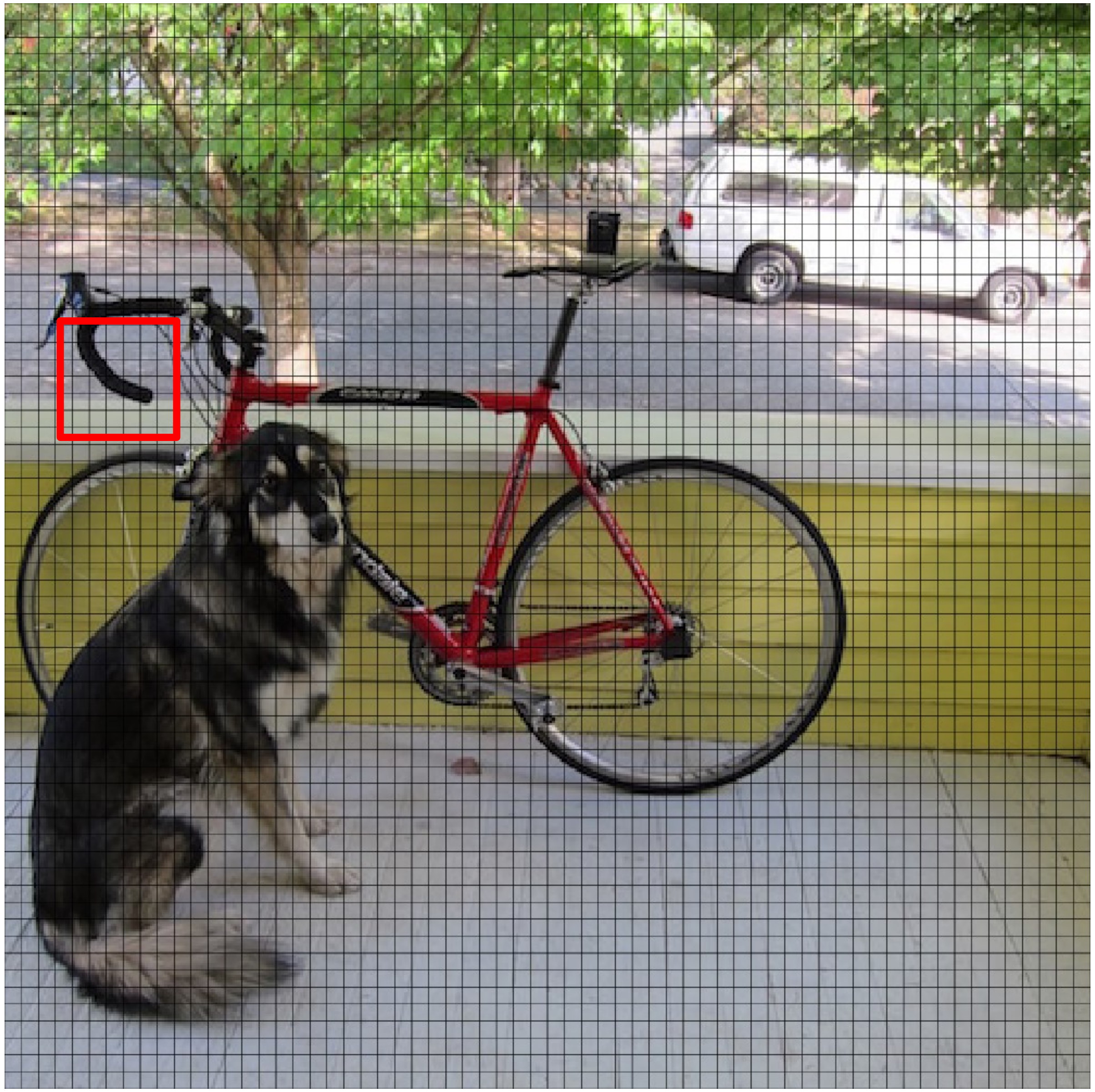

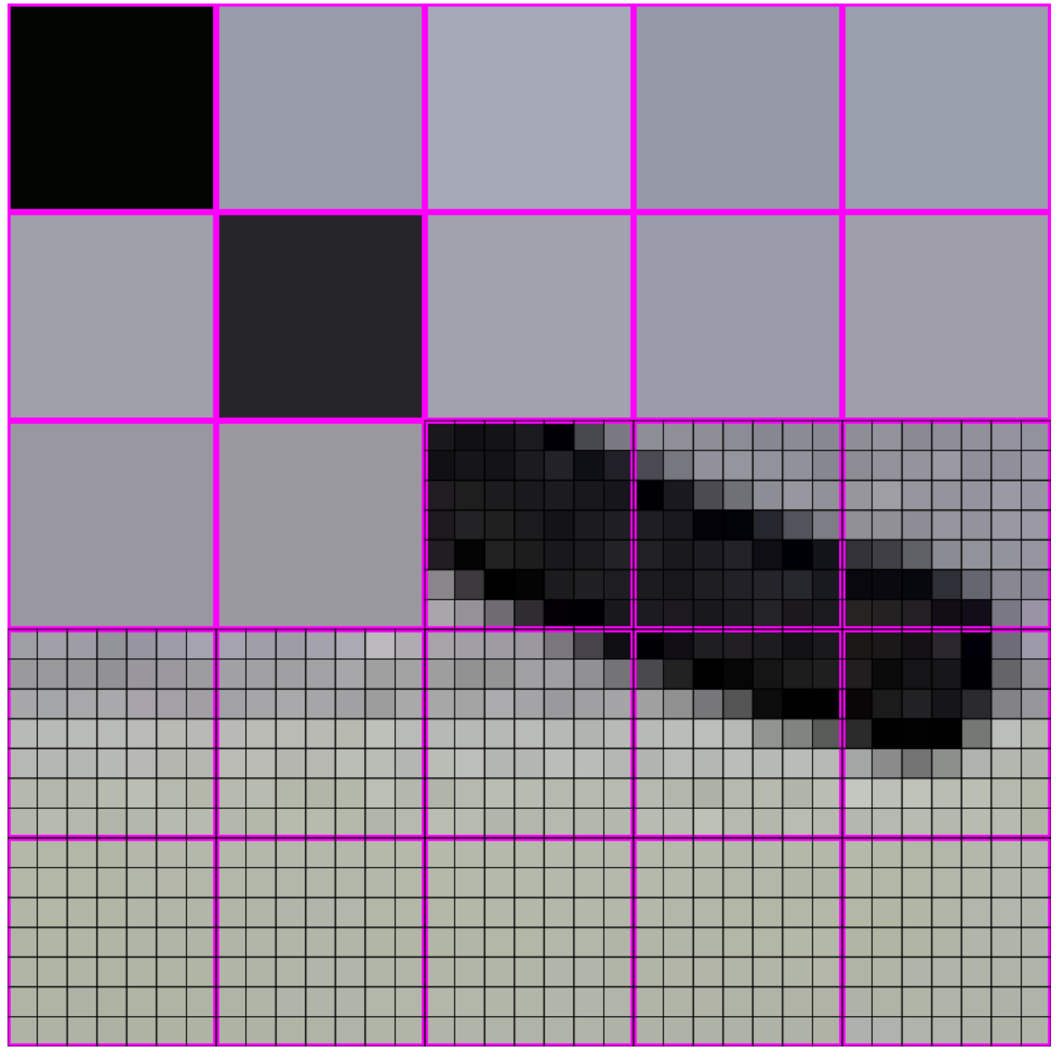

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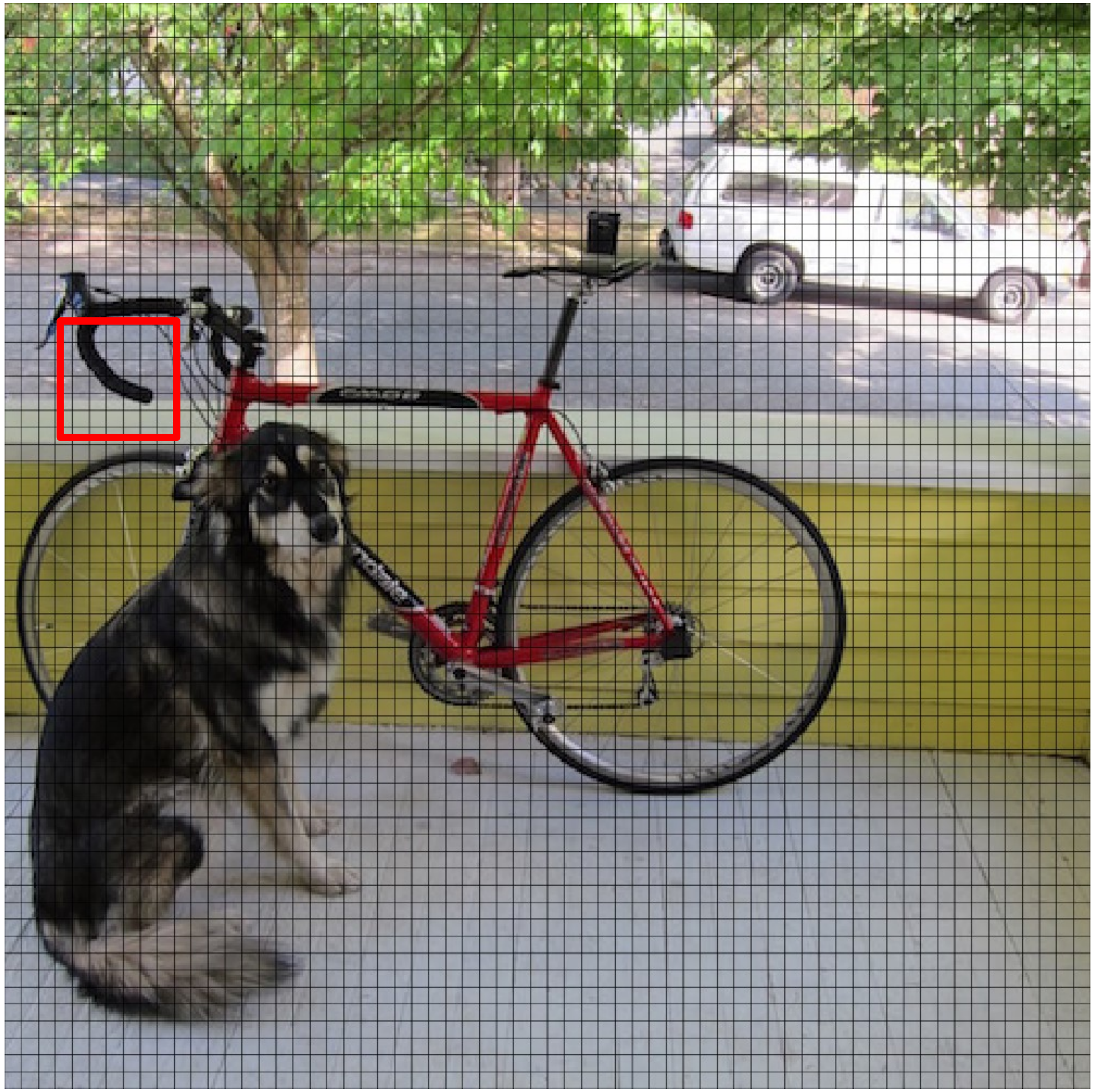

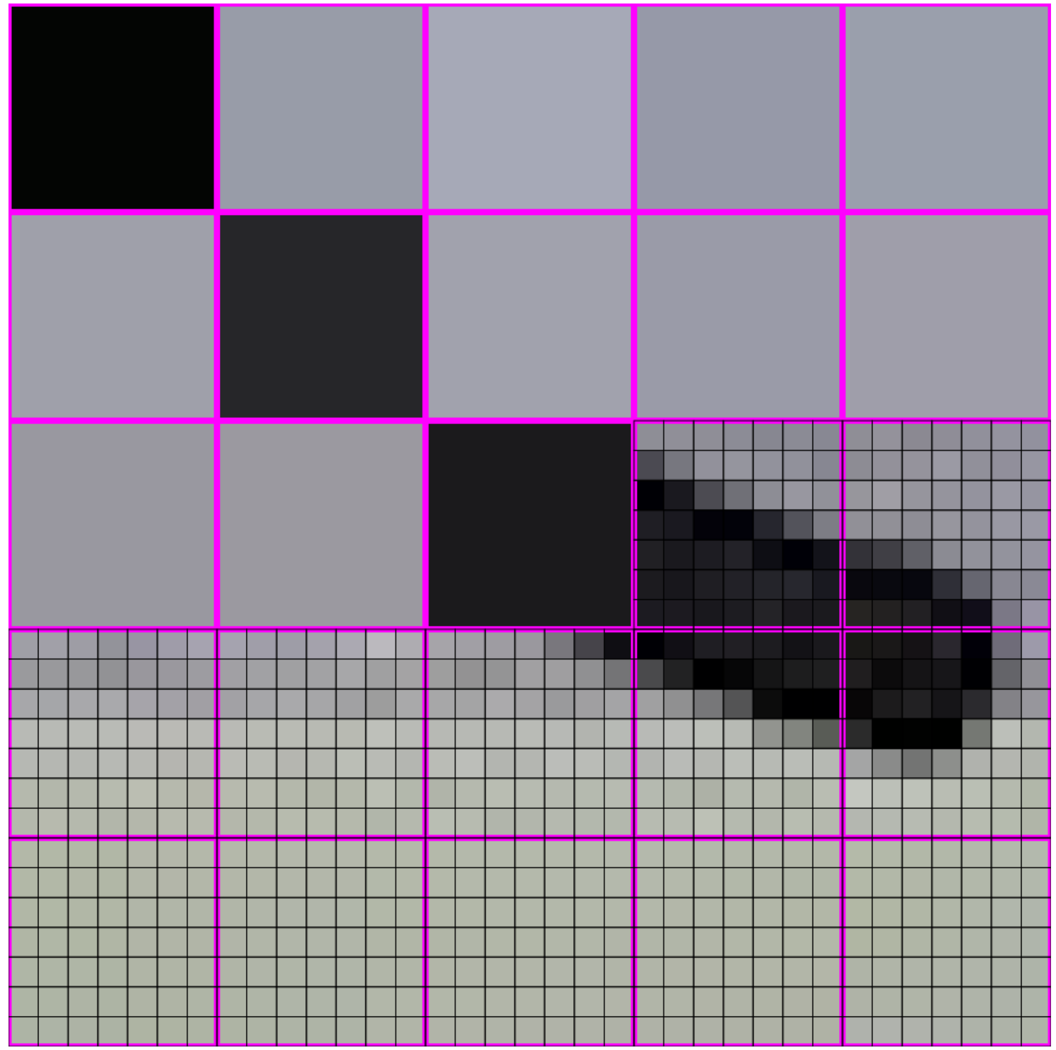

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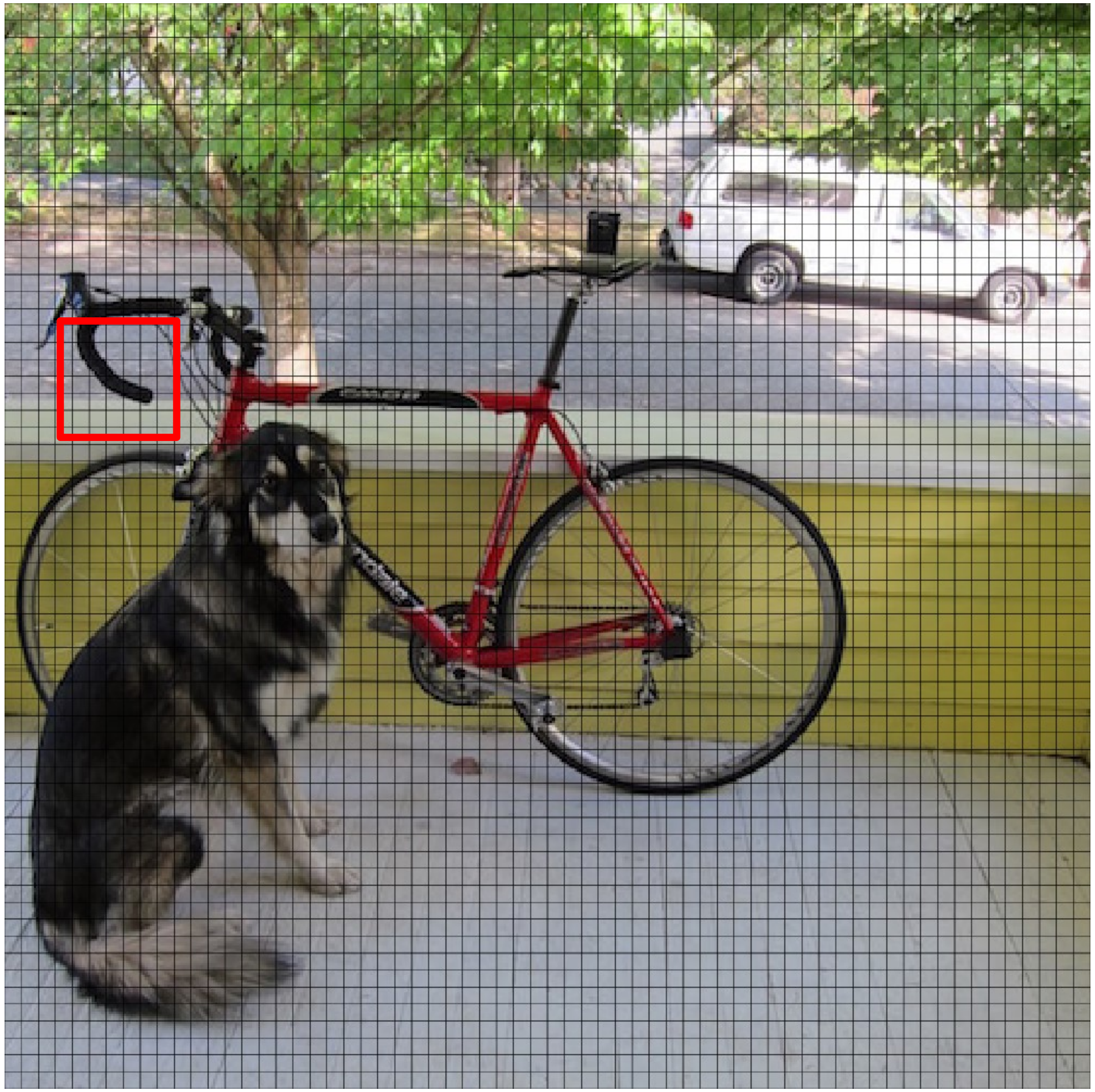

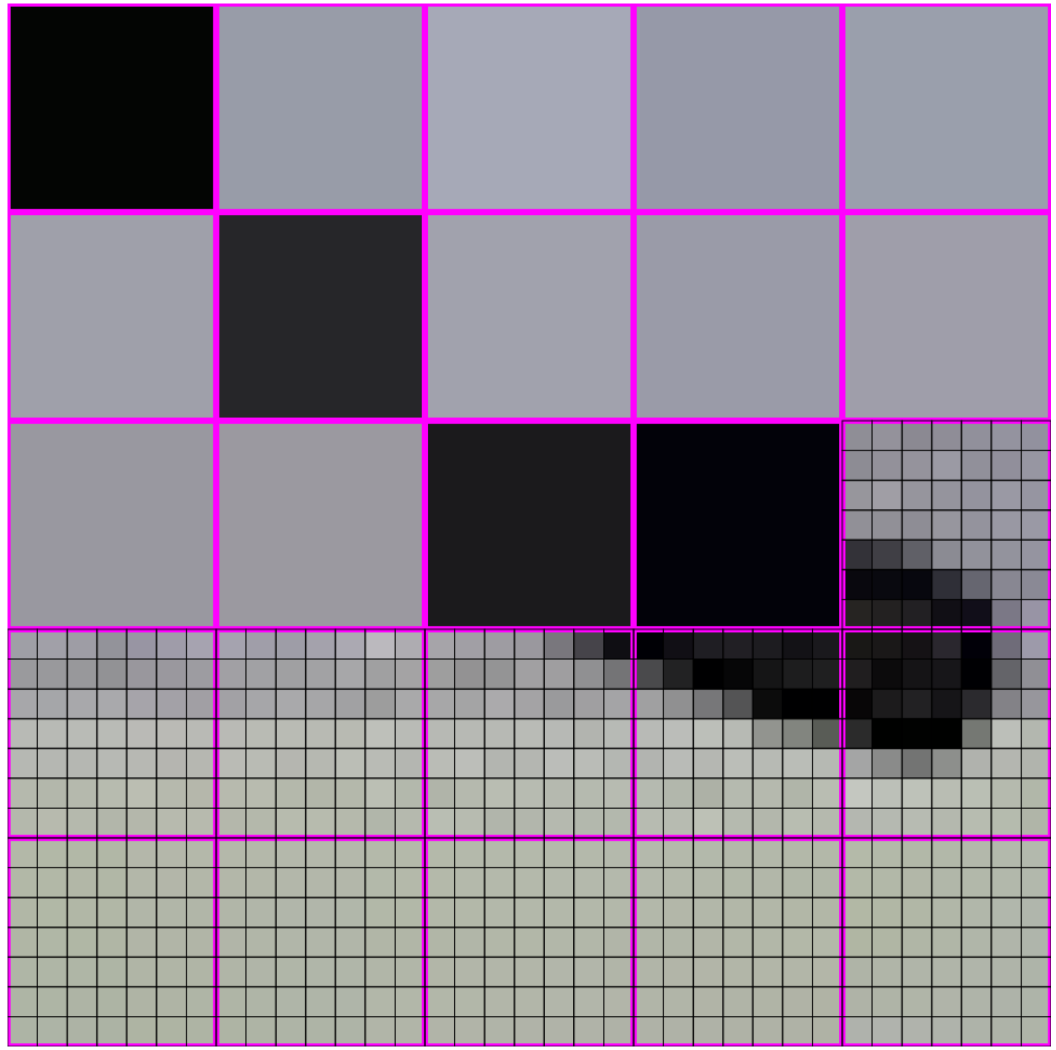

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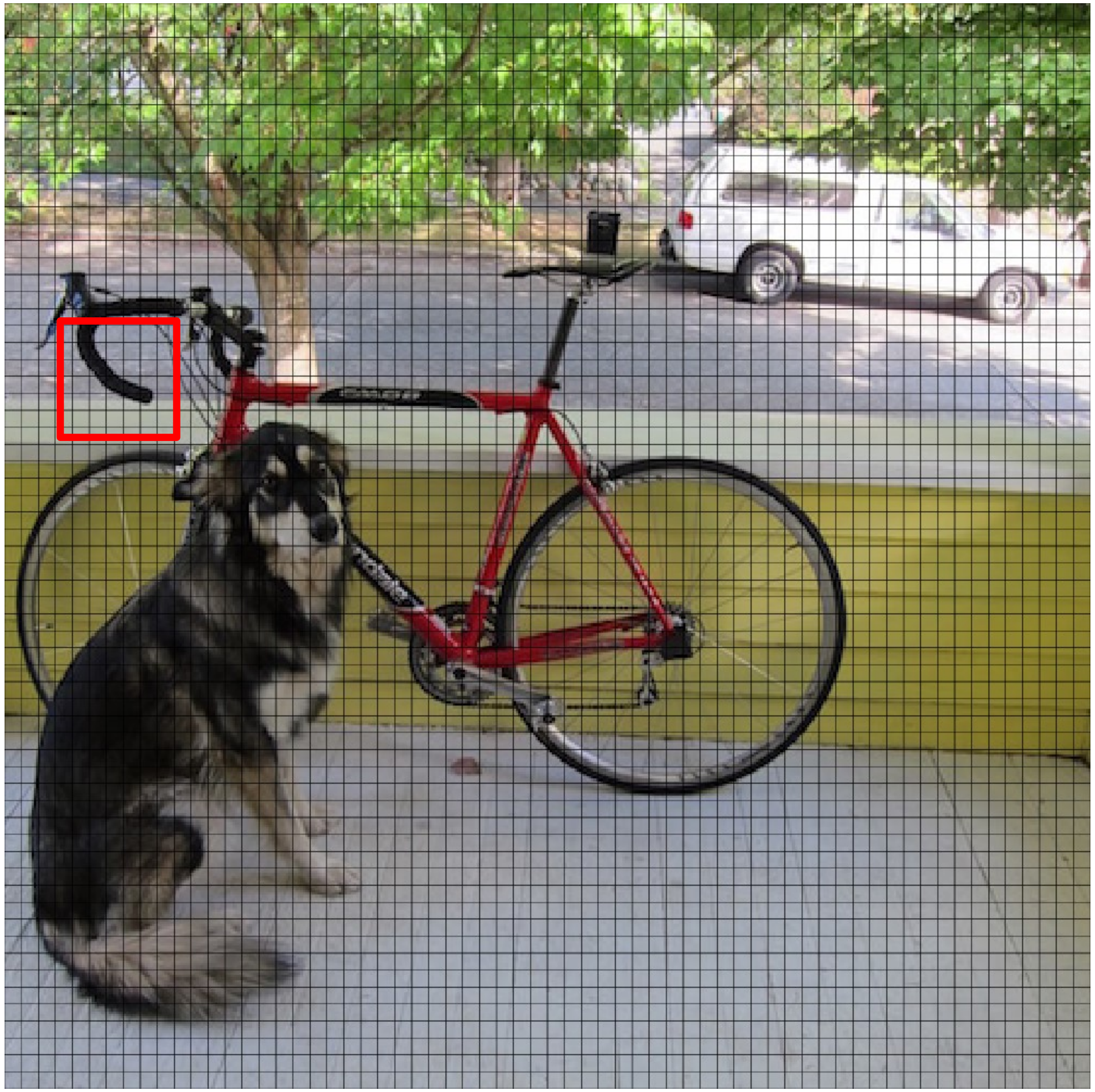

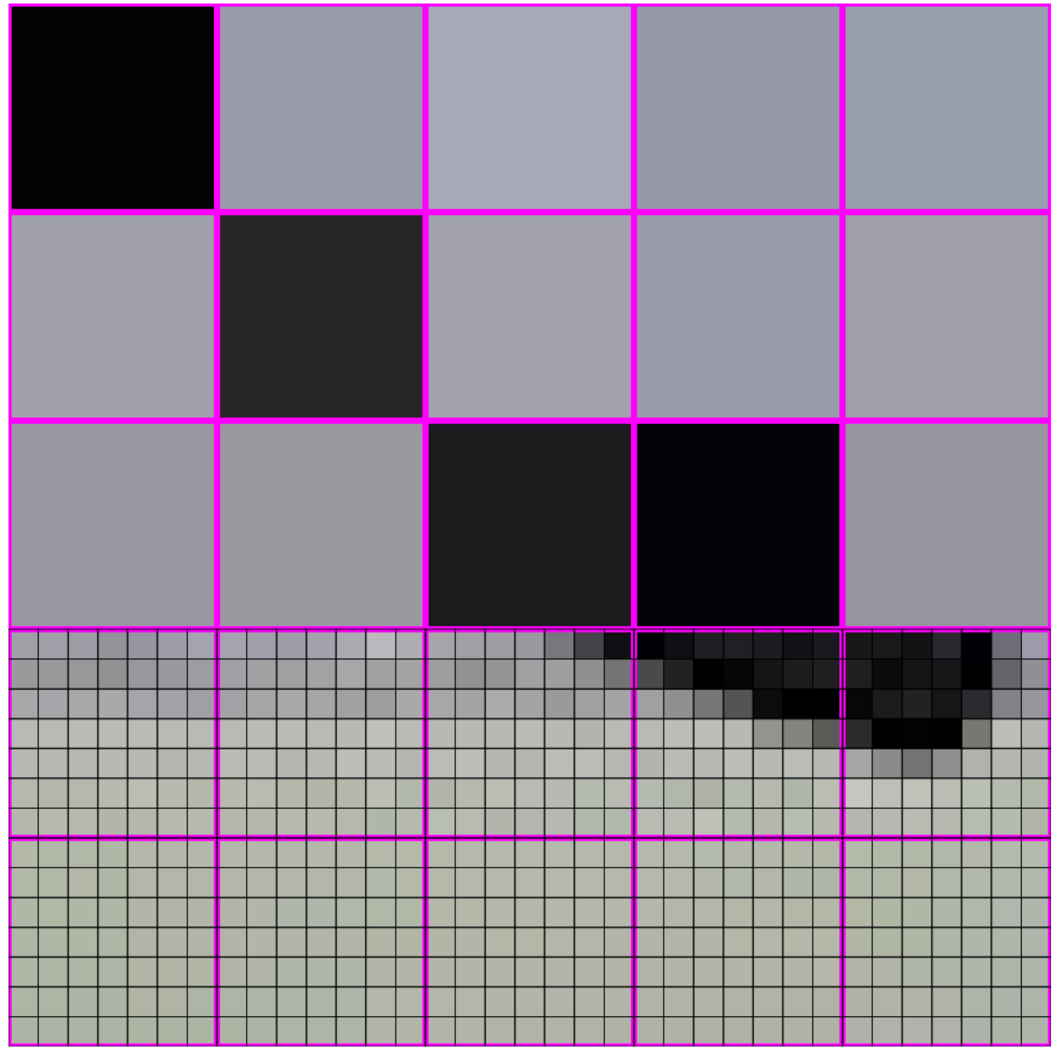

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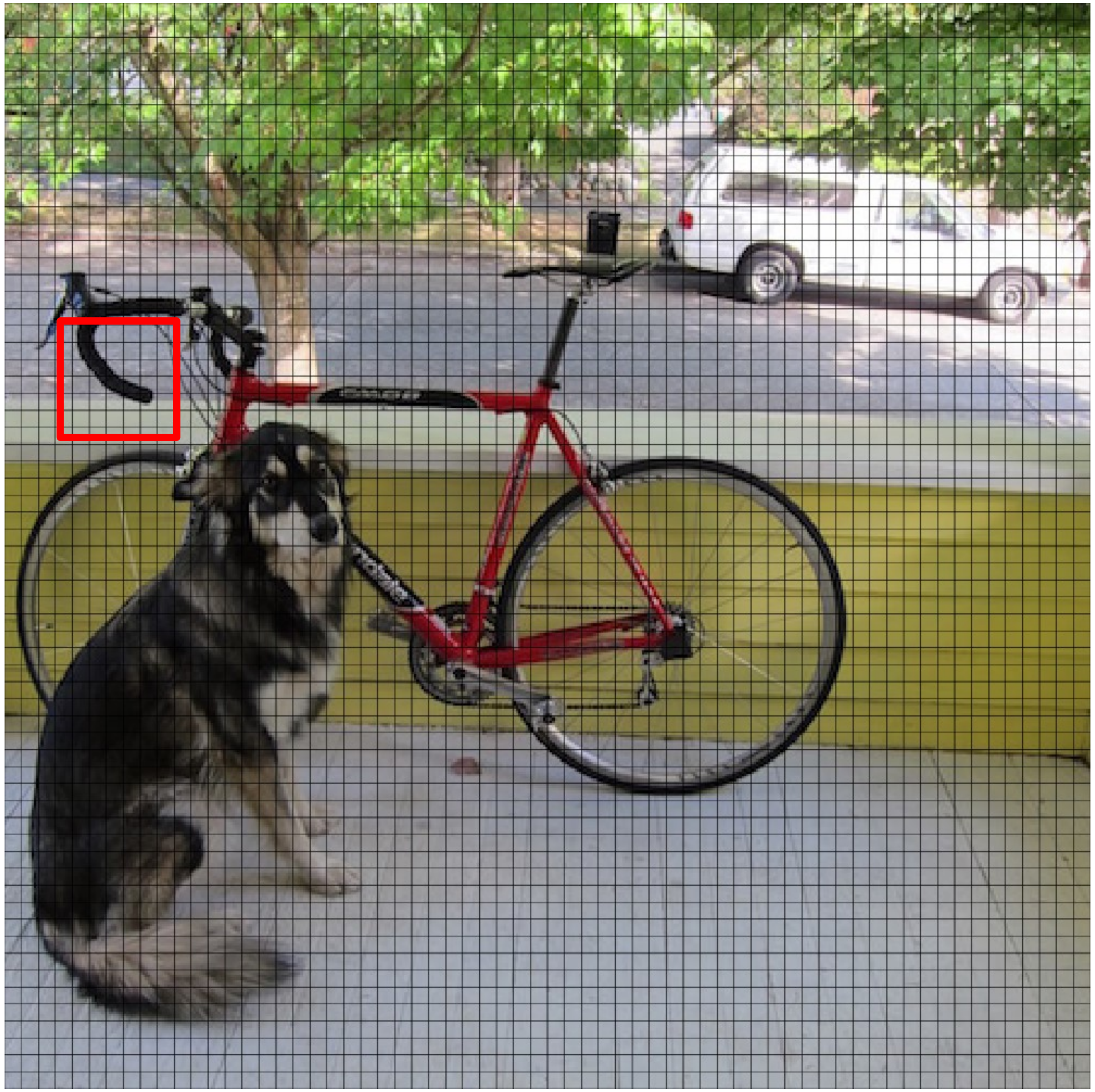

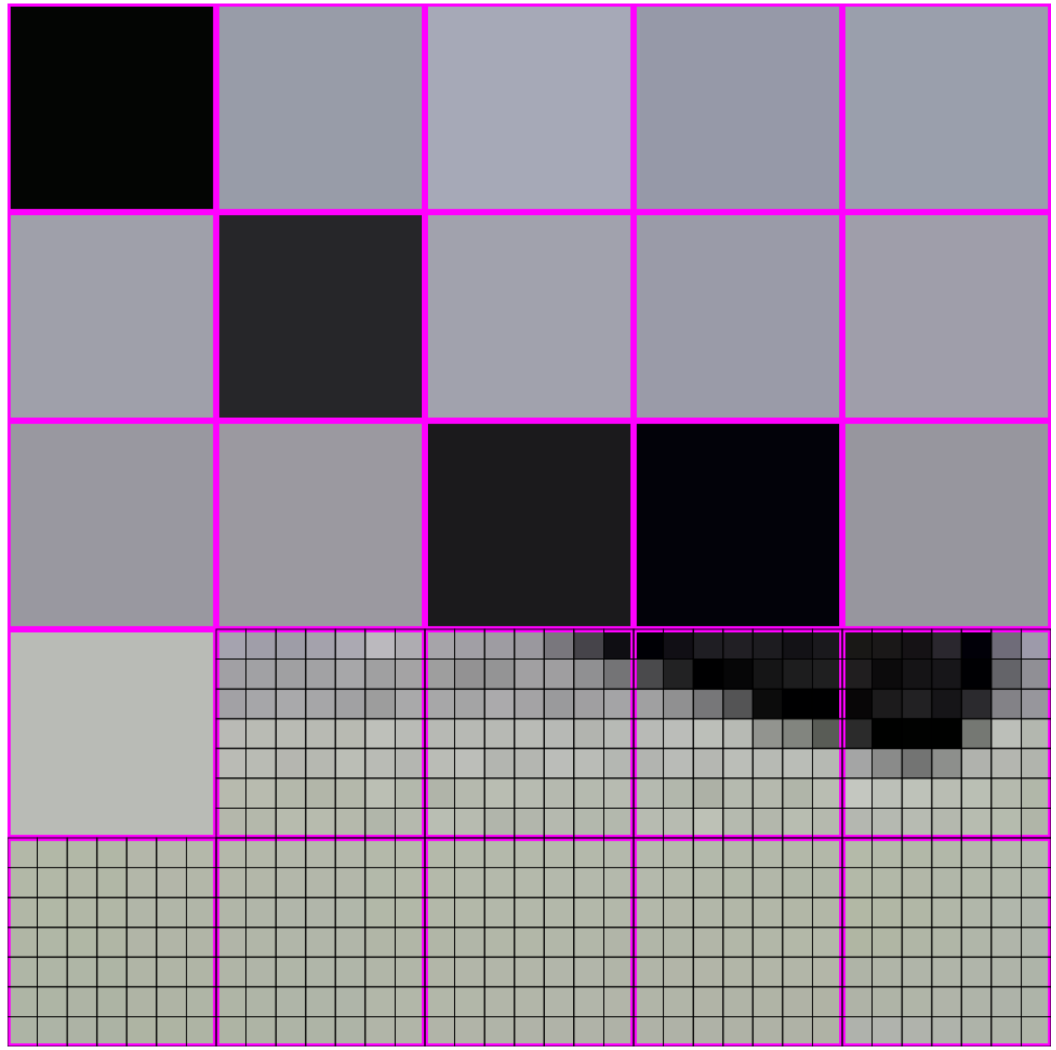

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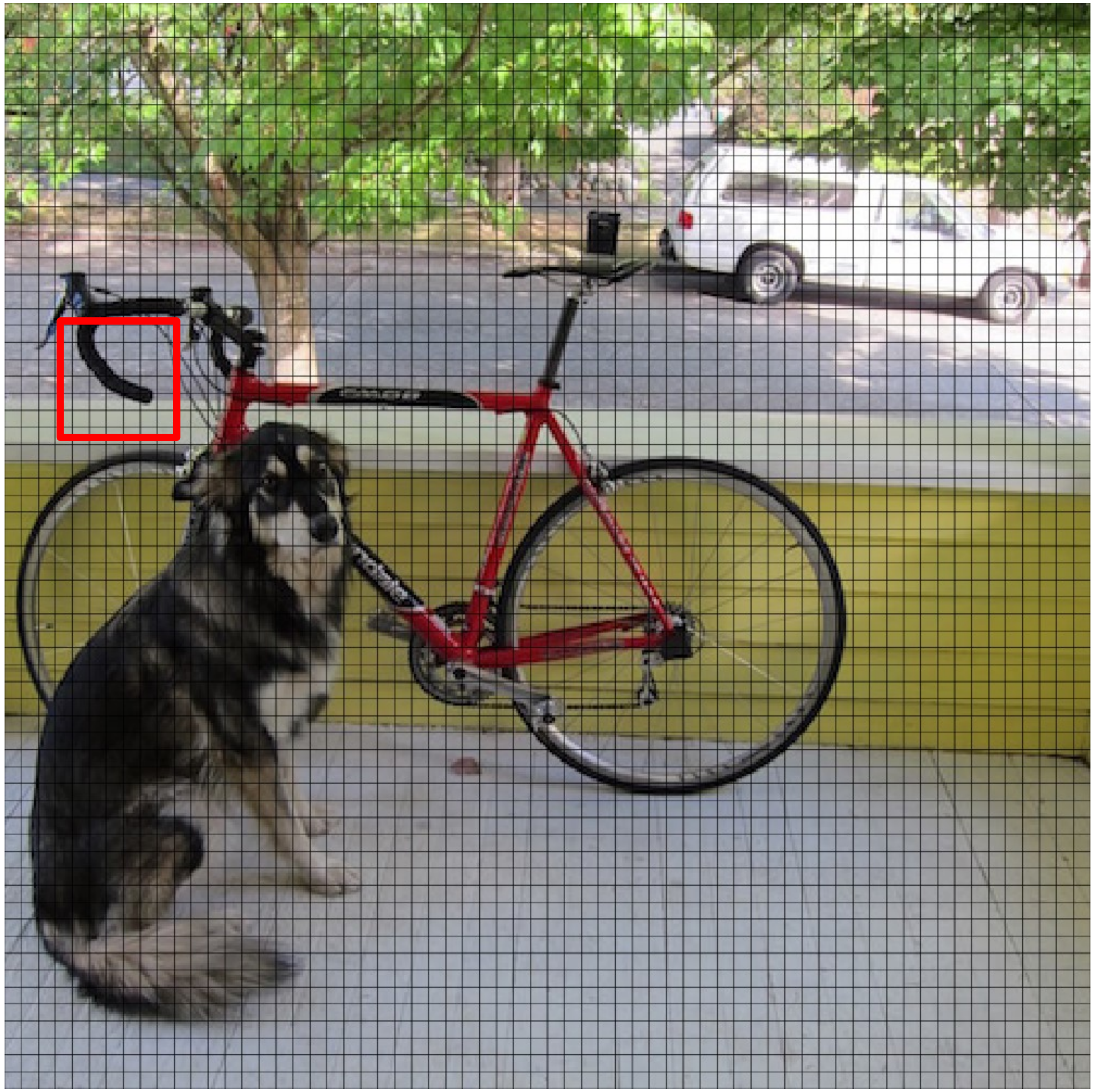

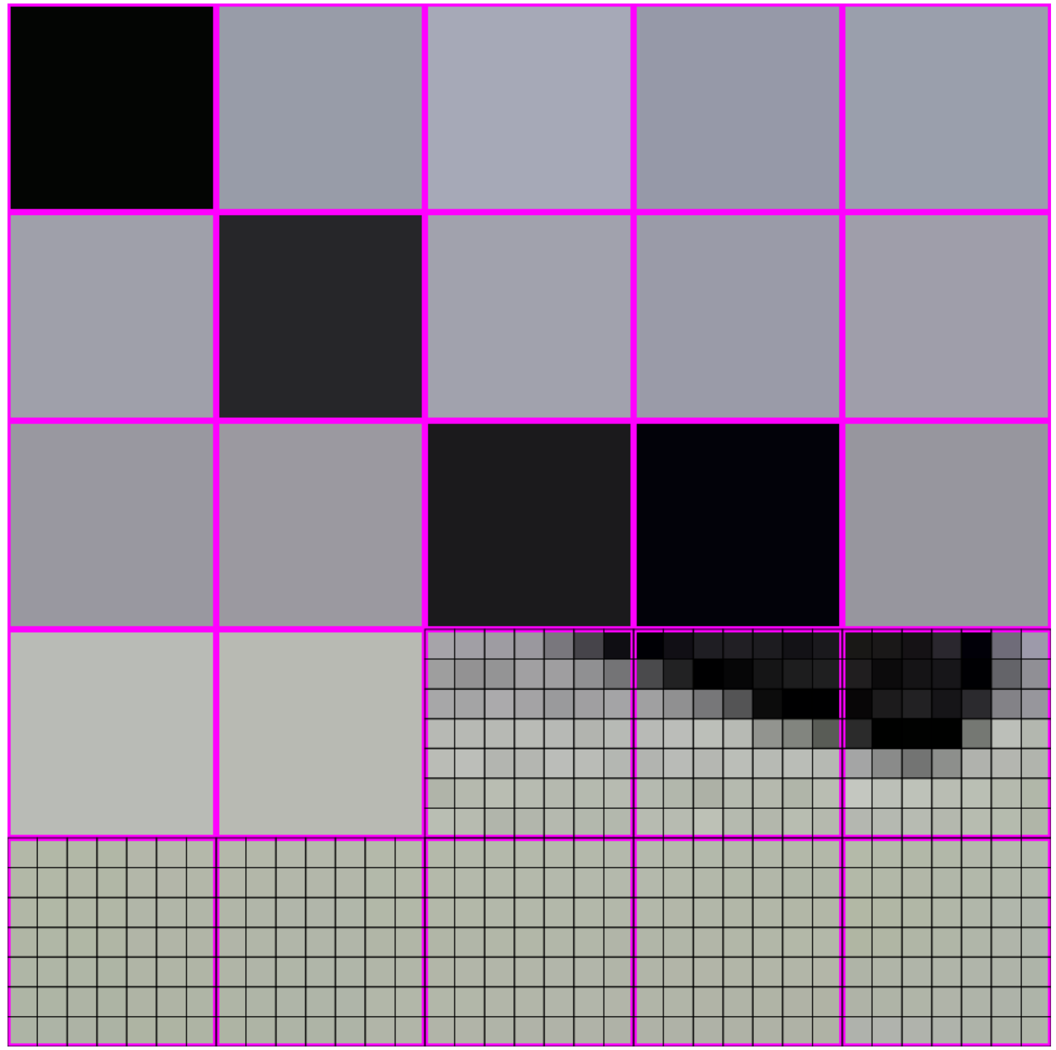

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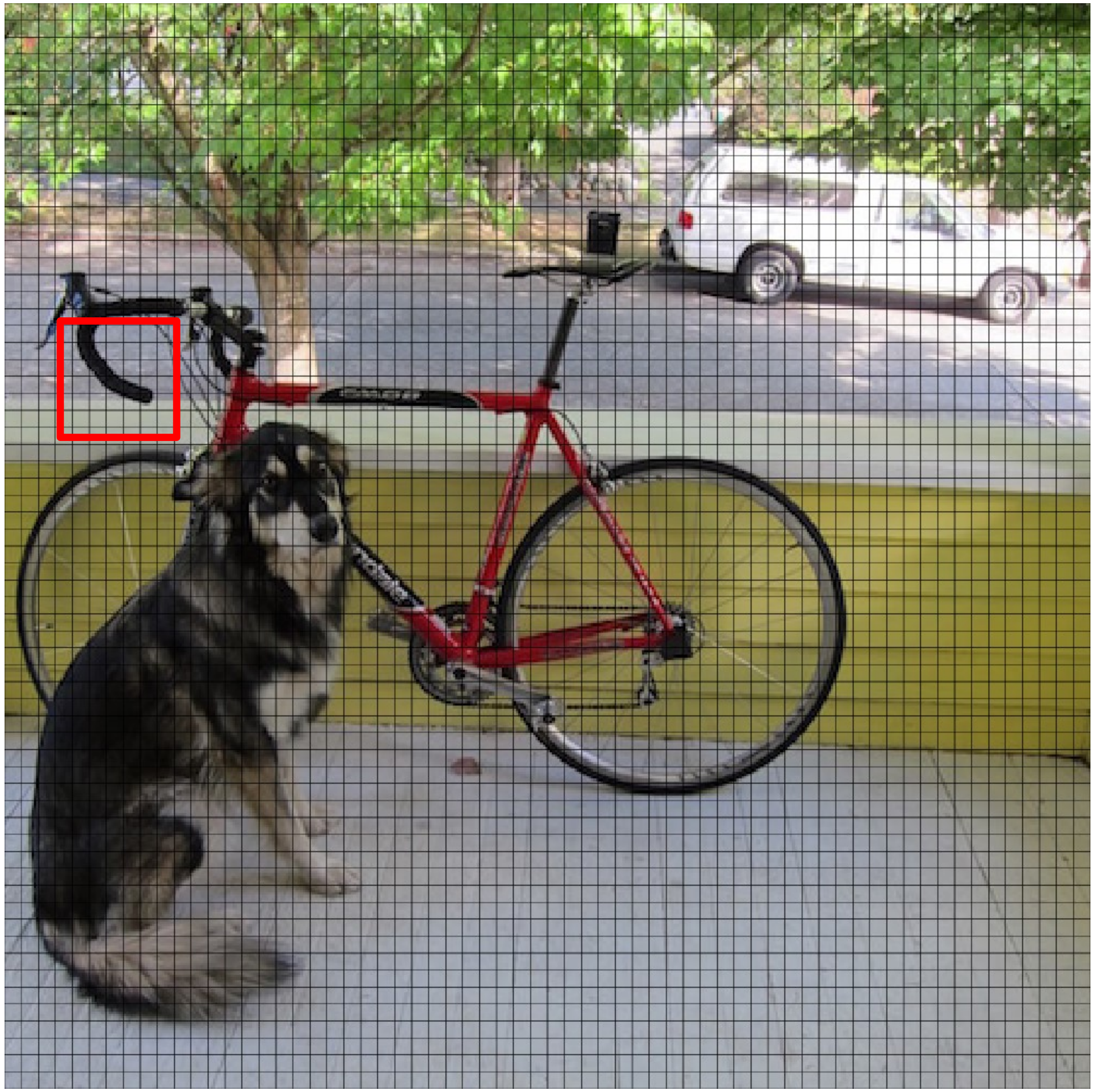

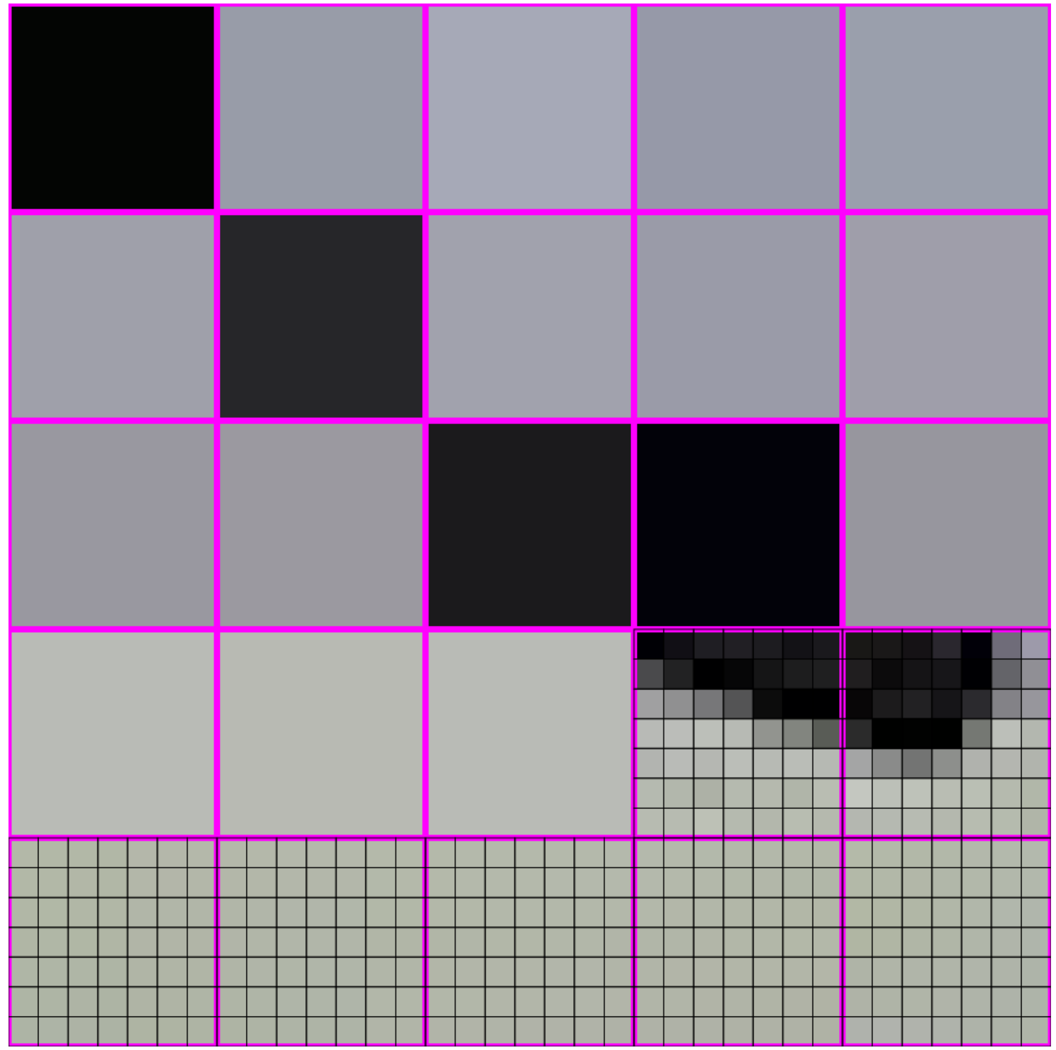

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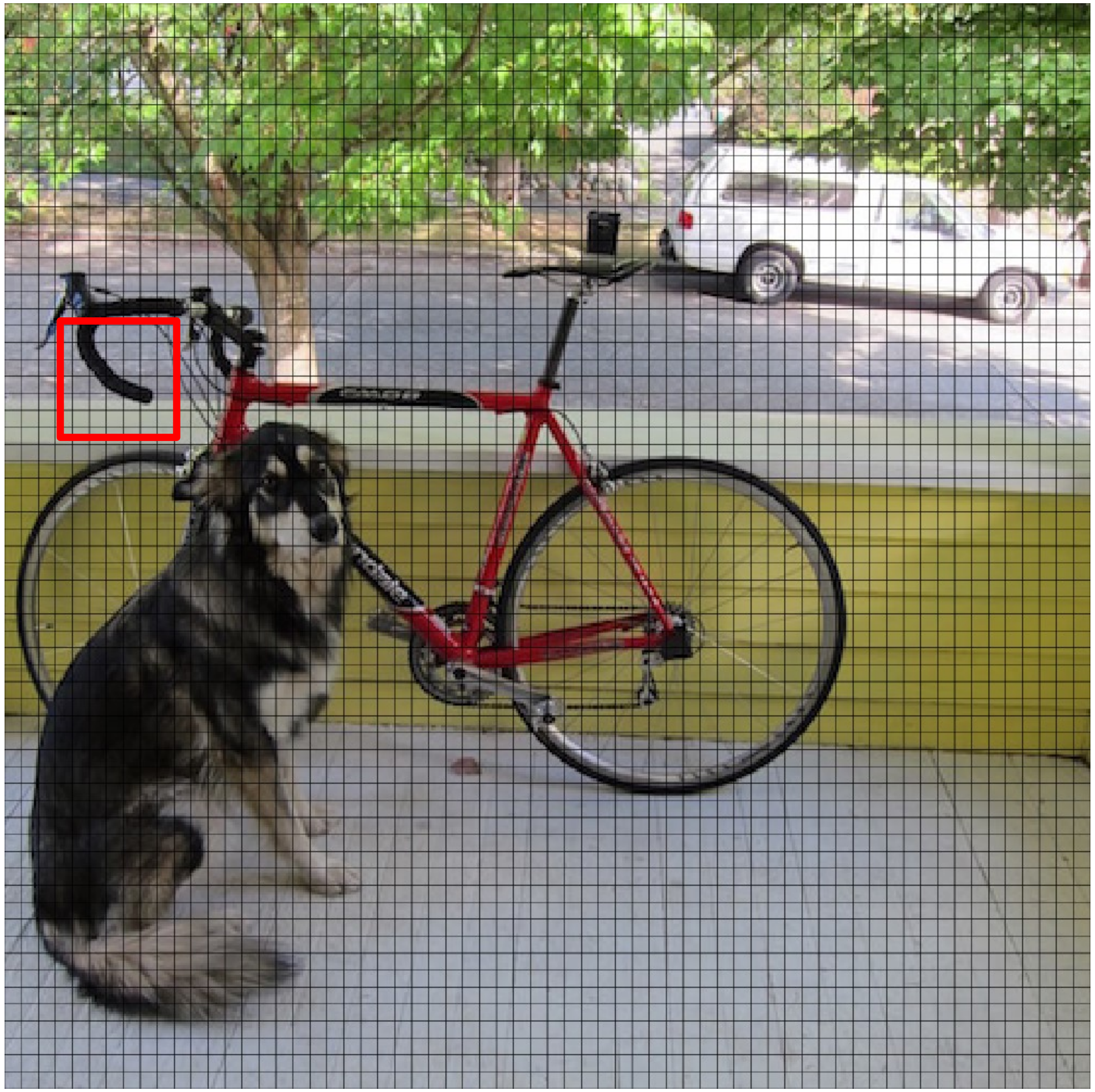

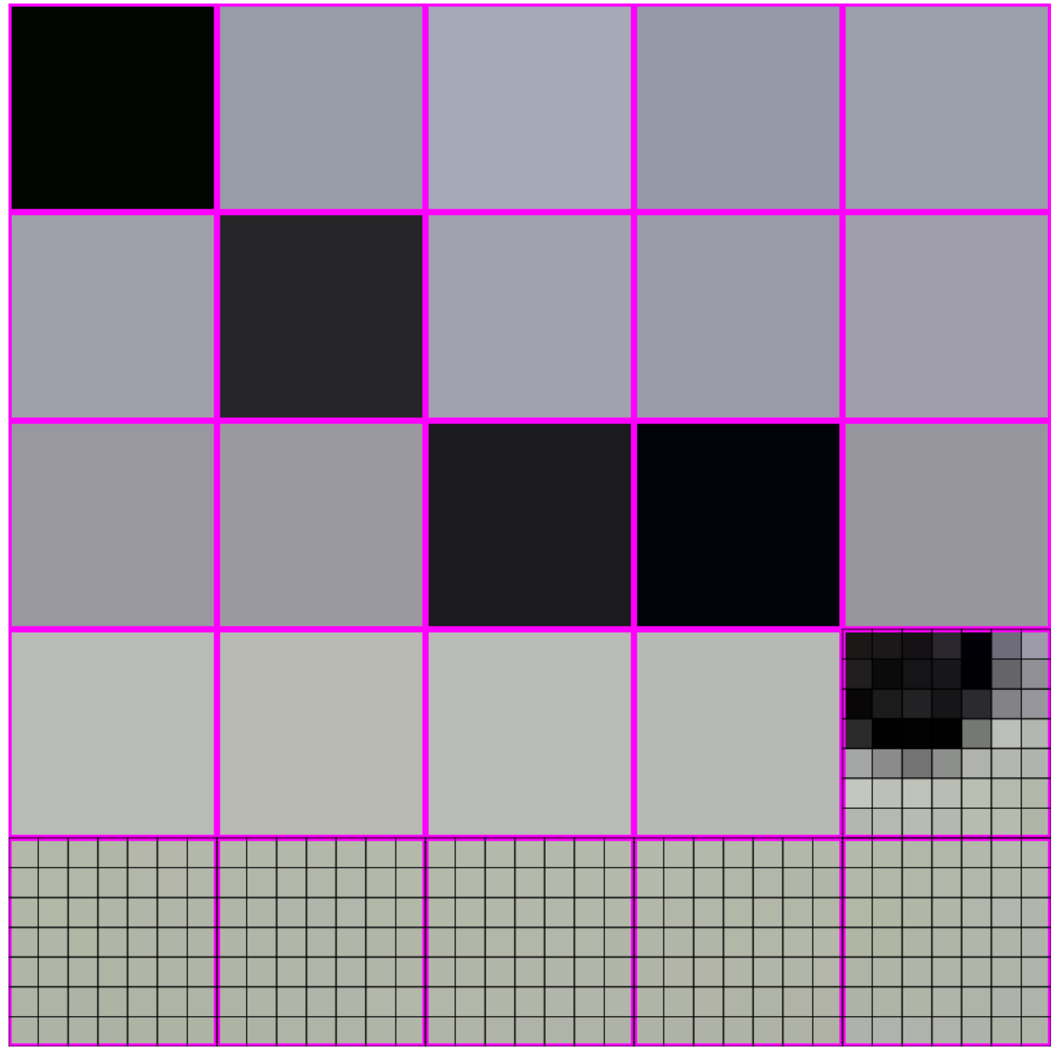

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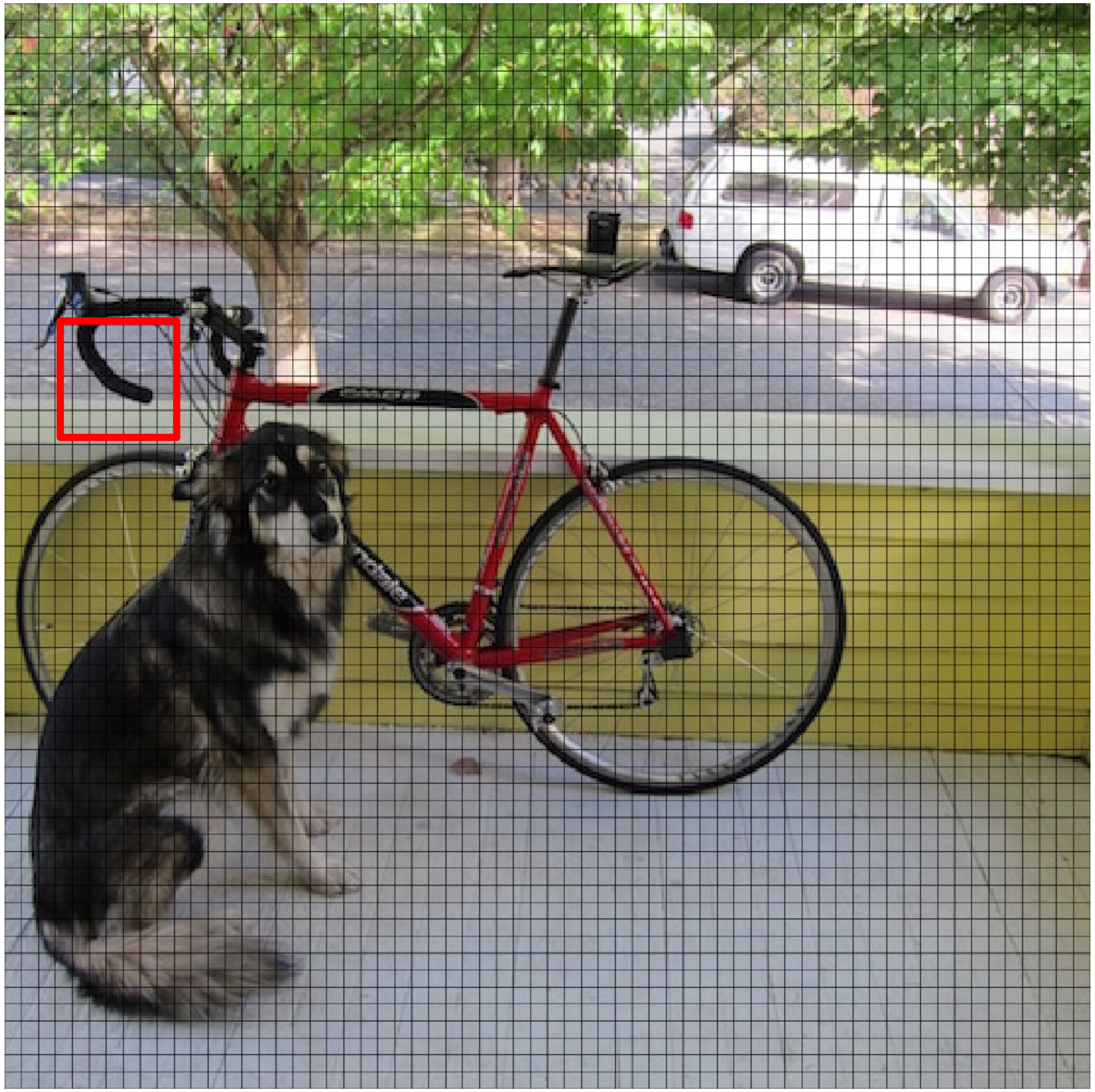

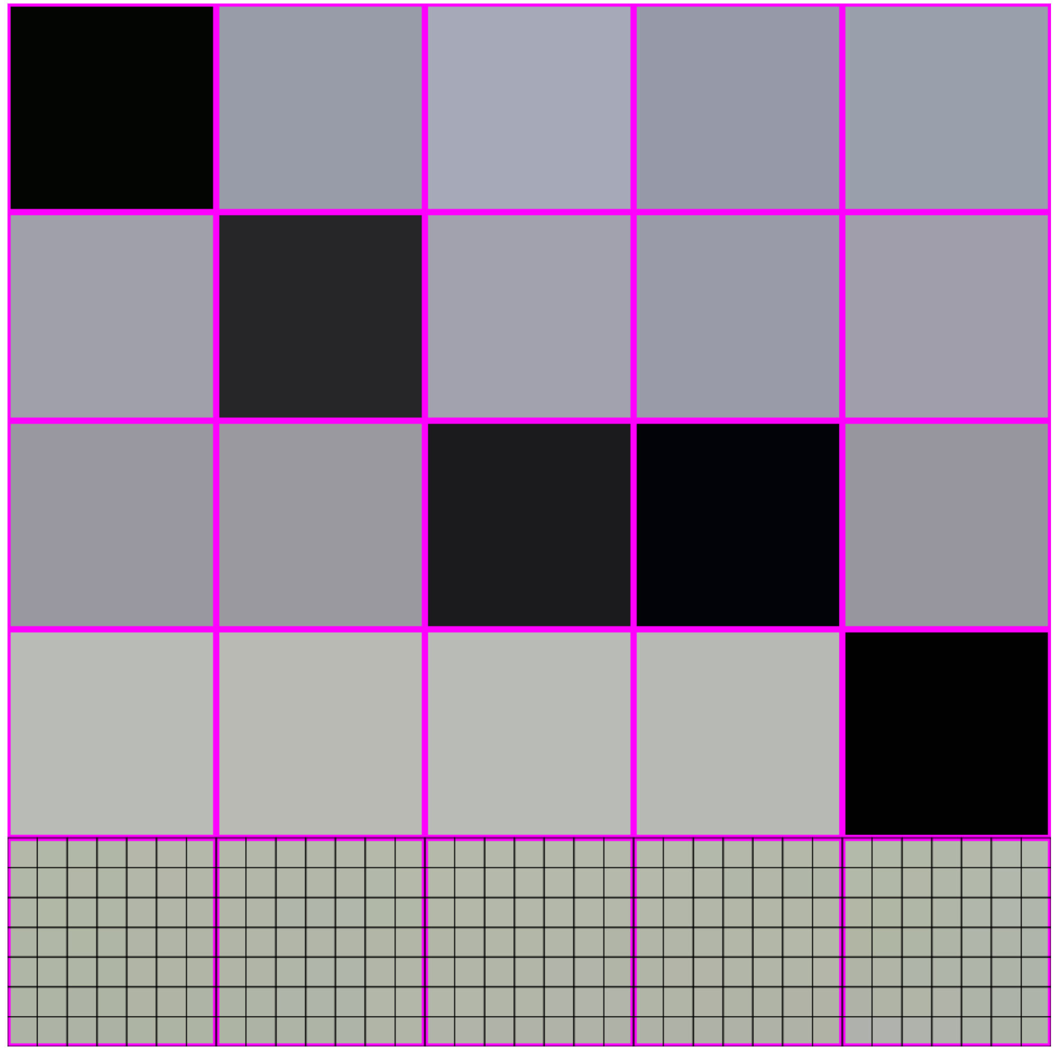

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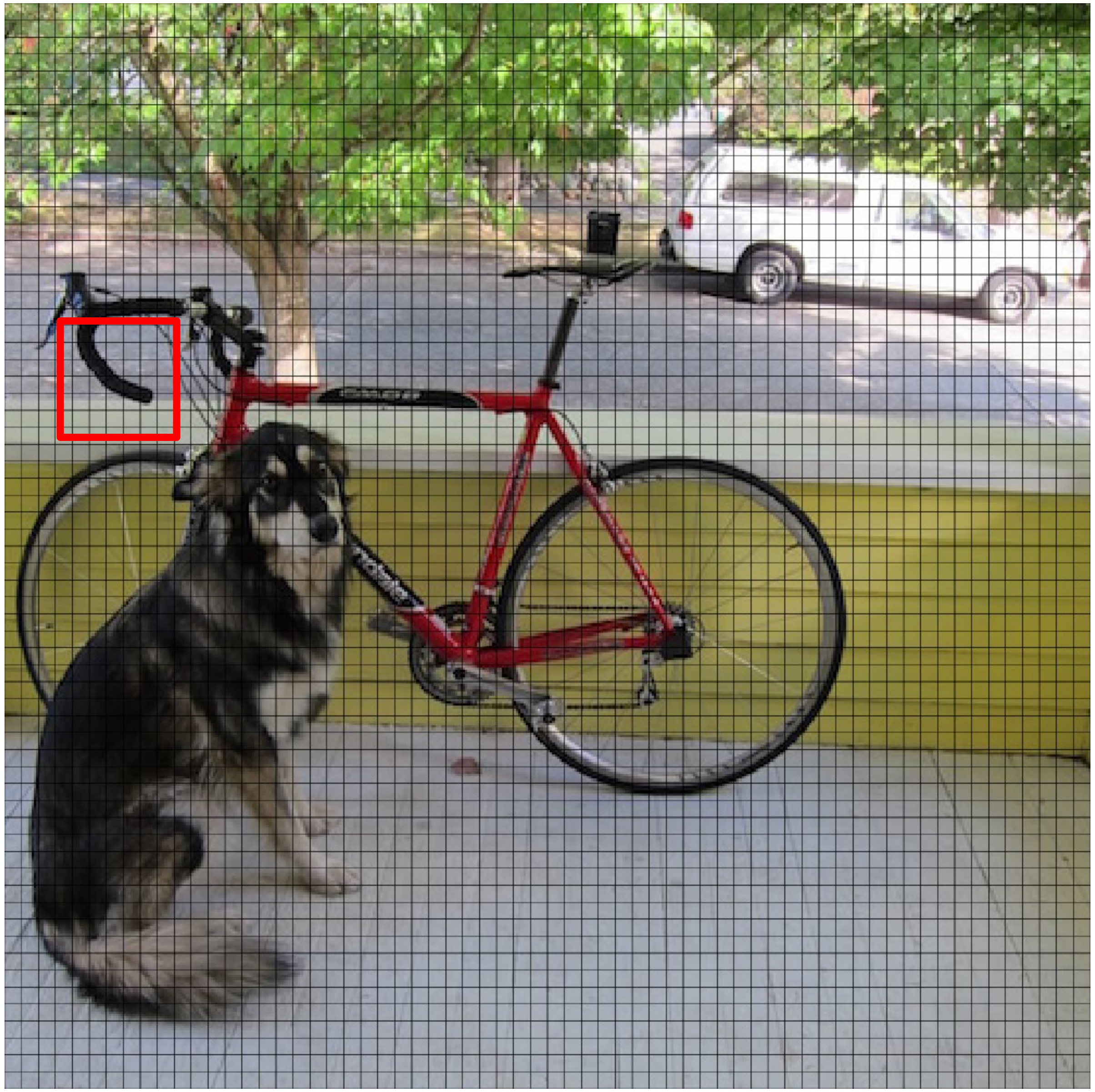

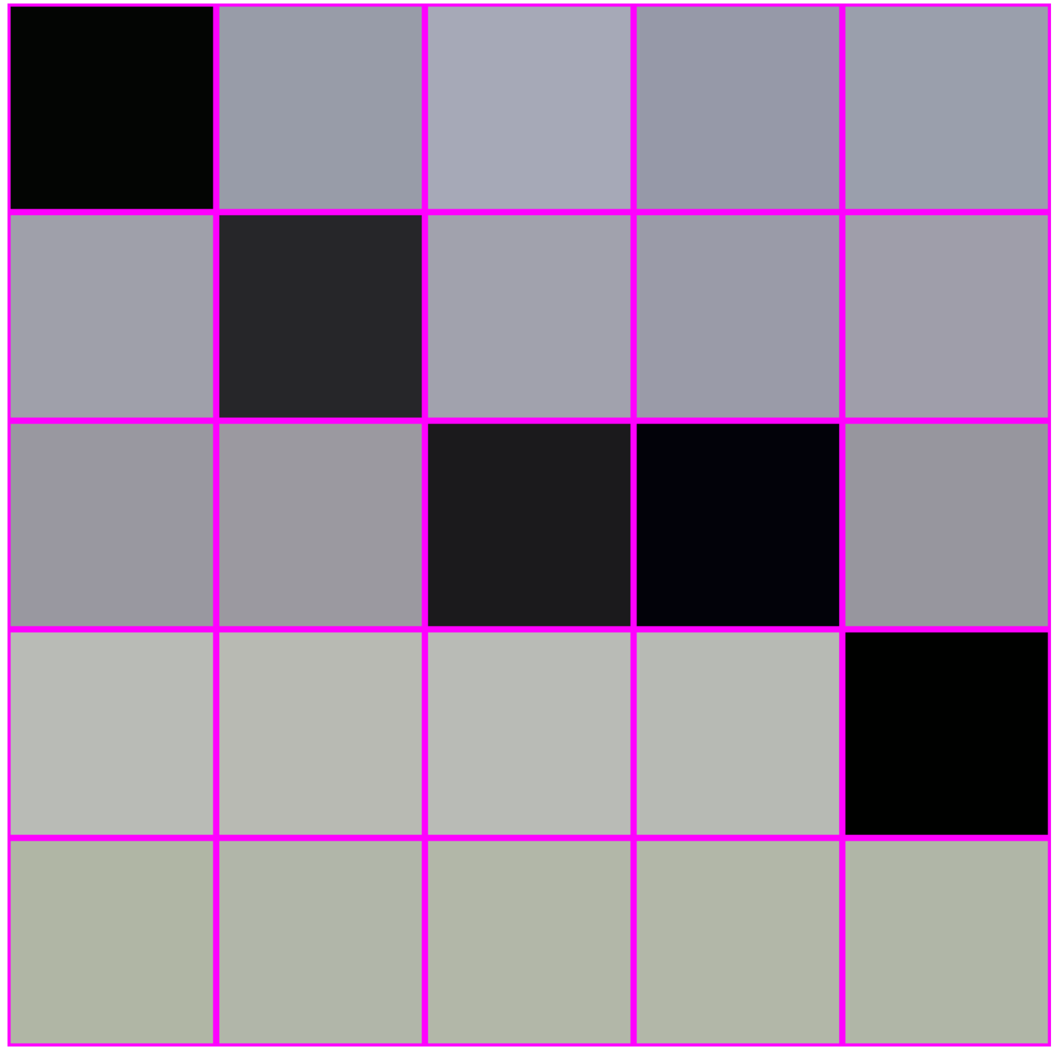

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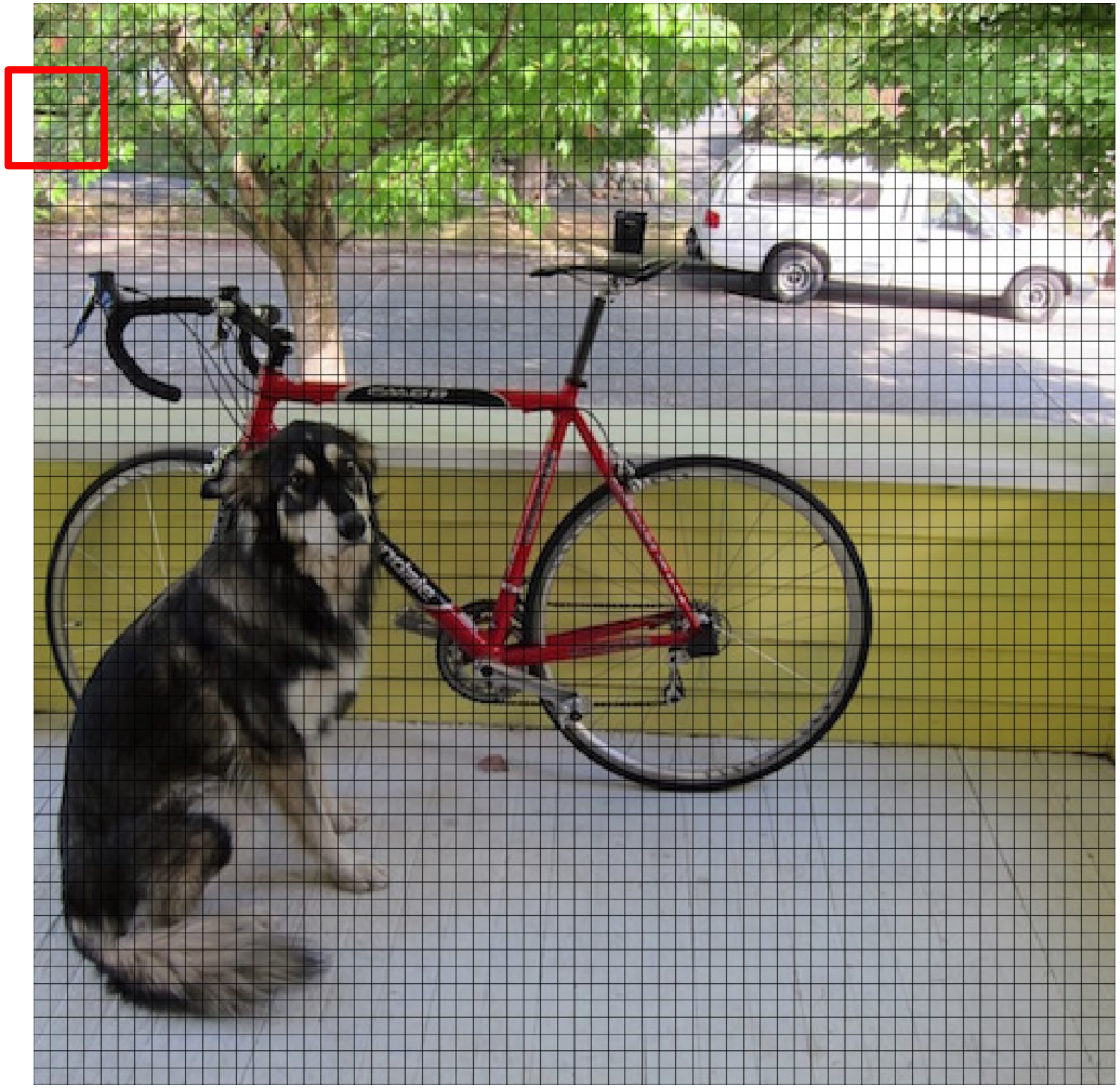

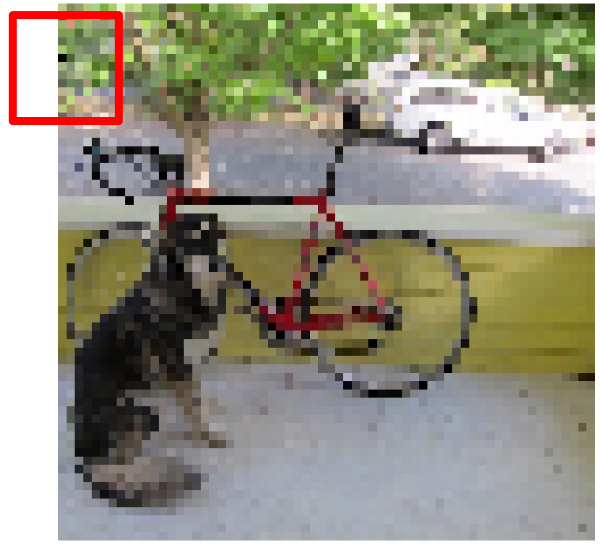

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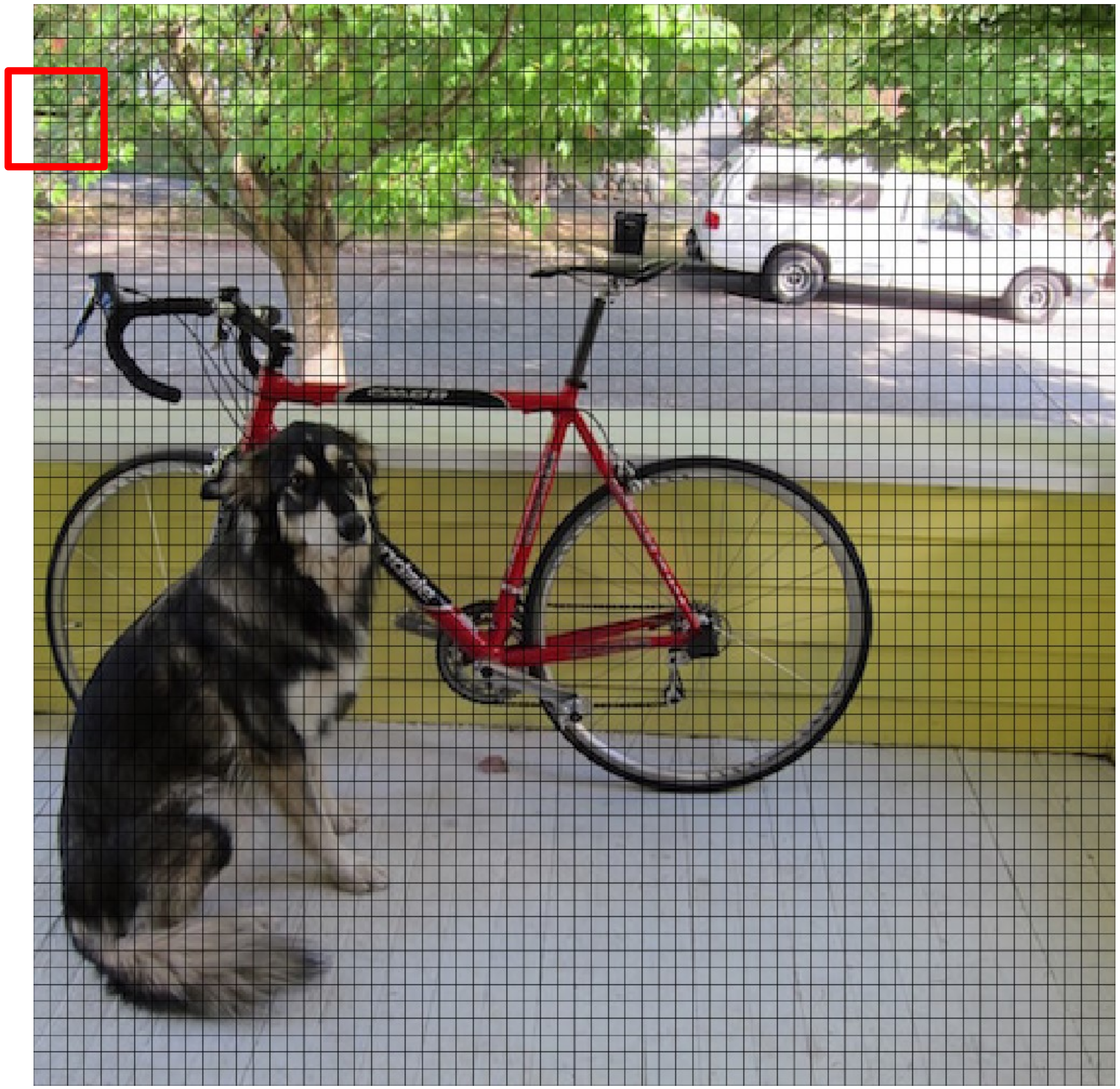

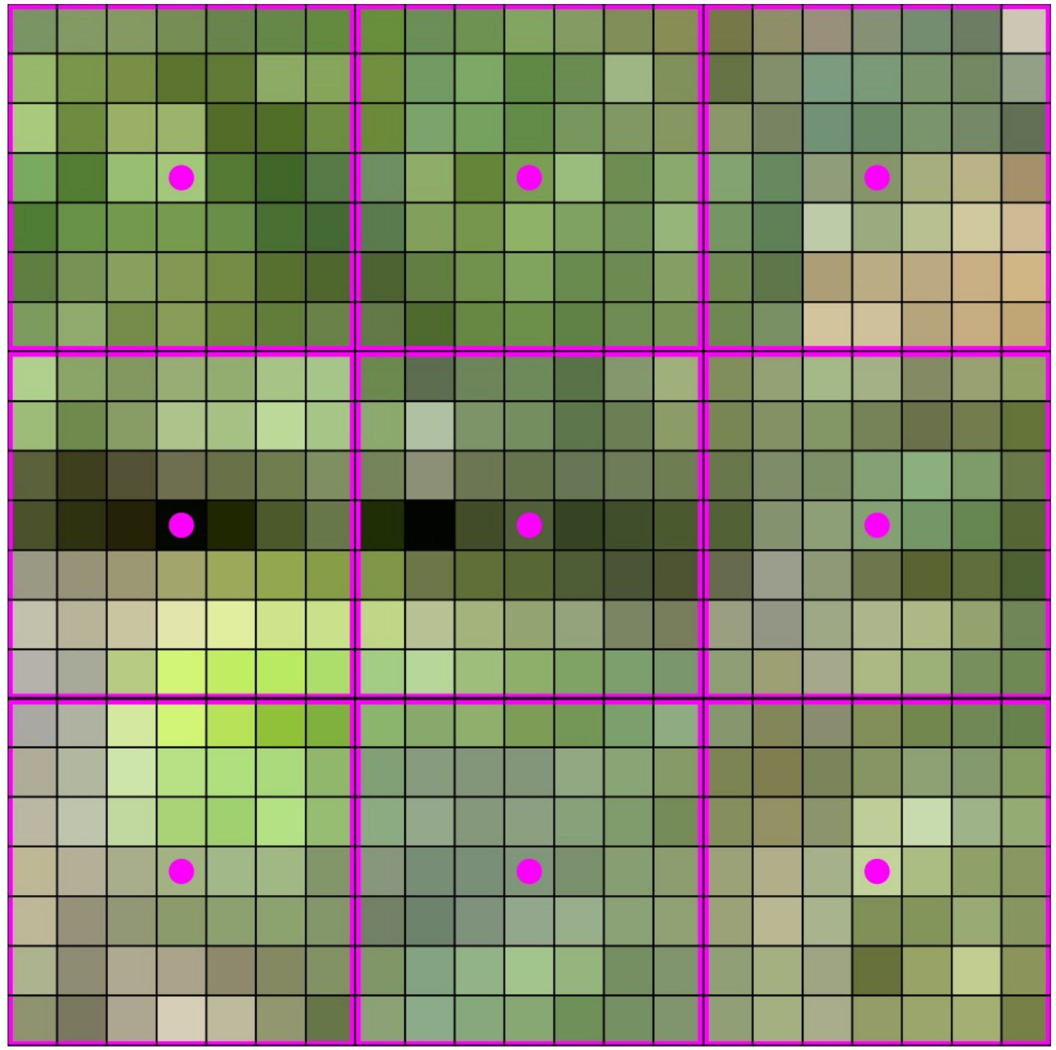

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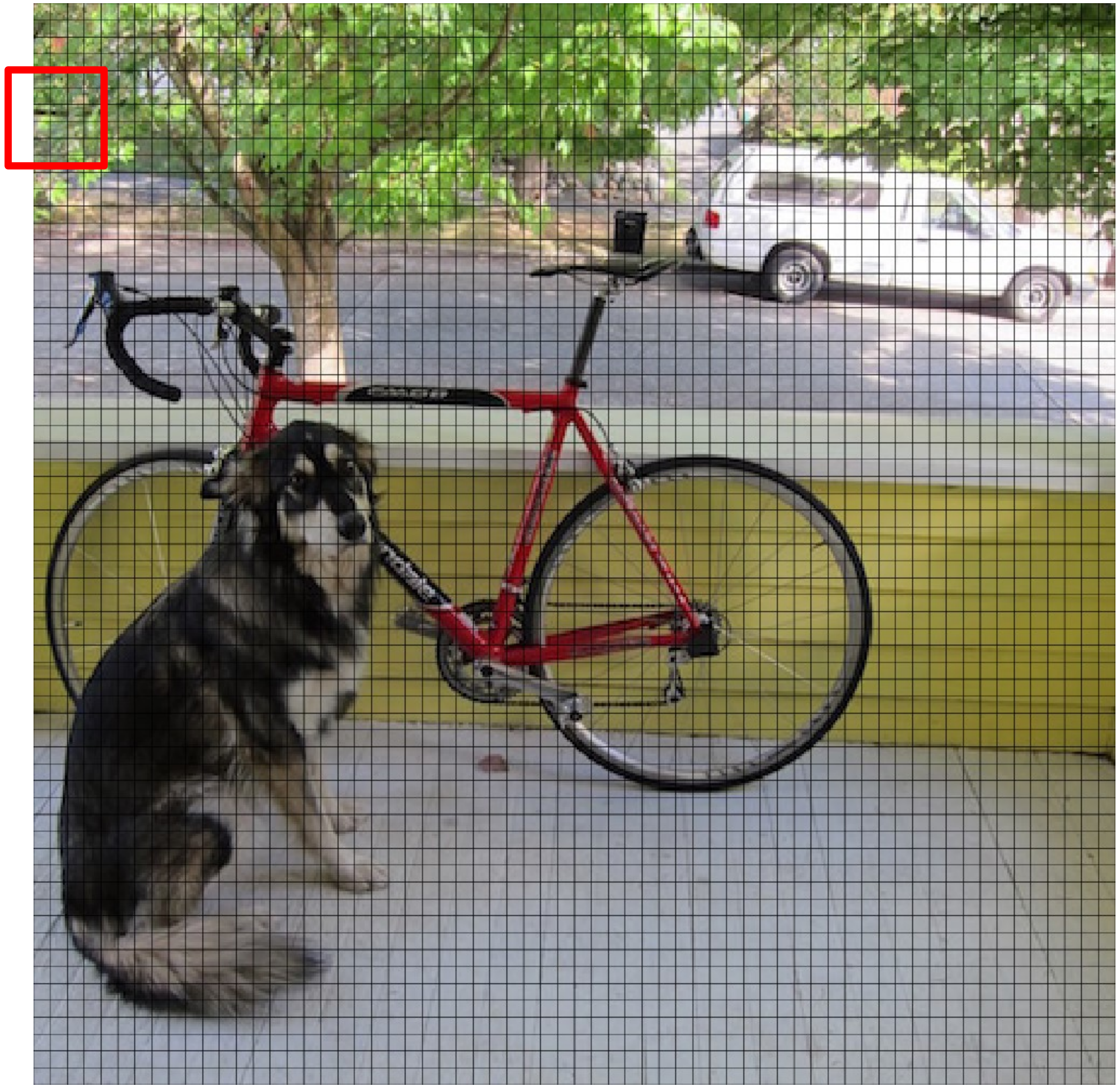

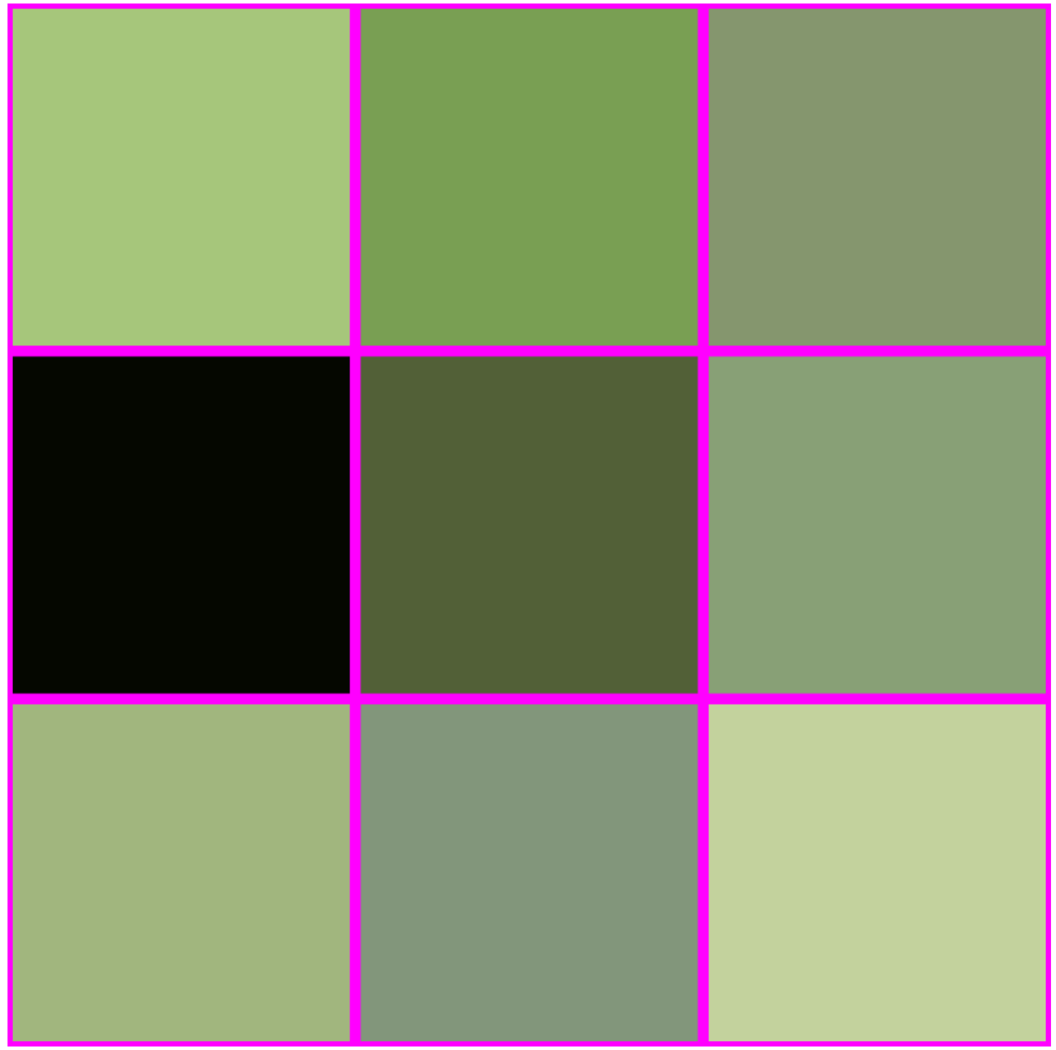

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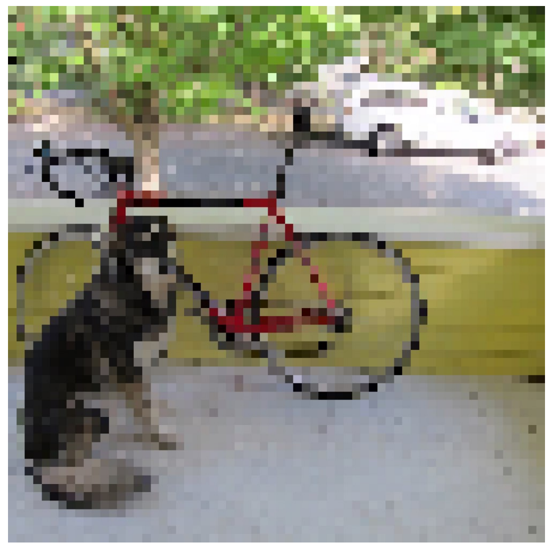
Lots of issues

- NN and Bilinear only look at small area
- Lots of artifacting
- Staircase pattern on diagonal lines
- We'll fix this with filters!

NN



Bilinear

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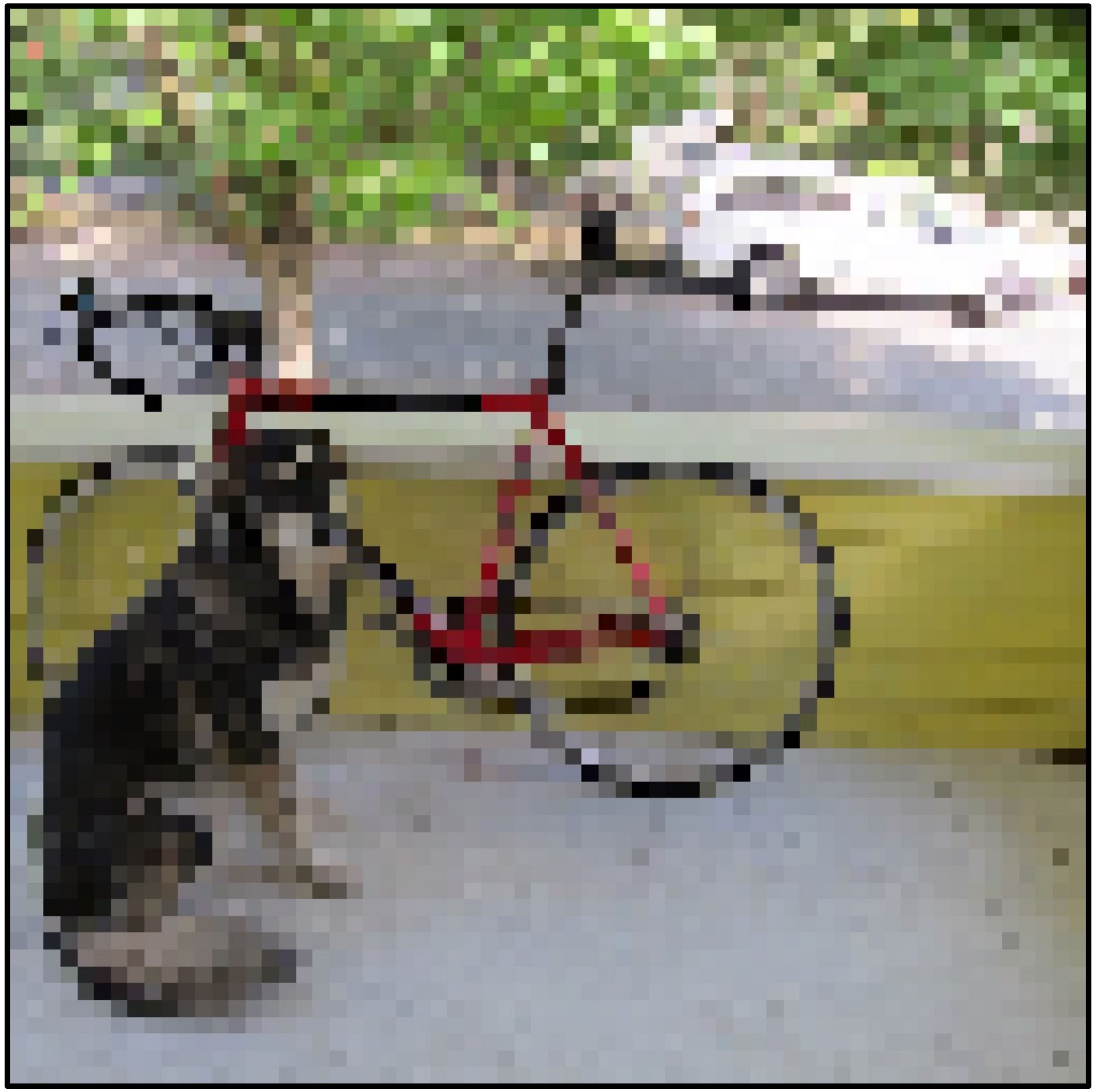
IS THIS ALL THERE IS??



THERE IS A BETTER WAY!

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Visual Computing Group

CYENS
CENTRE OF EXCELLENCE

Thank you.

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