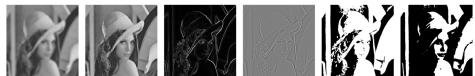




## CPSC 425: Computer Vision



### Lecture 3: Image Filtering

( unless otherwise stated slides are taken or adopted from **Bob Woodham**, **Jim Little** and **Fred Tung** )

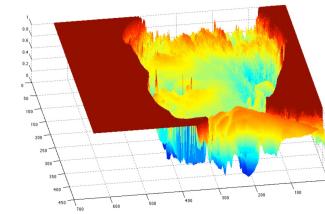
## Image as a 2D Function

A (grayscale) image is a 2D function



grayscale image

$I(X, Y)$



Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Adding two Images

Since images are functions, we can perform operations on them, e.g., **average**



$I(X, Y)$



$G(X, Y)$



$$\frac{I(X, Y)}{2} + \frac{G(X, Y)}{2}$$

## What types of **filtering** can we do?

### Point Operation



point processing

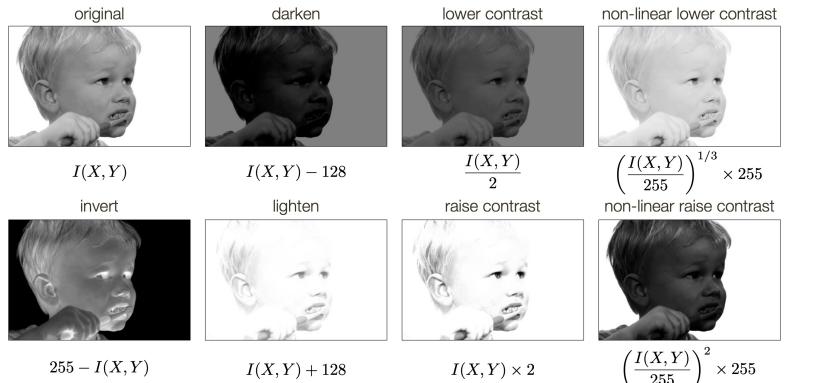
### Neighborhood Operation



“filtering”

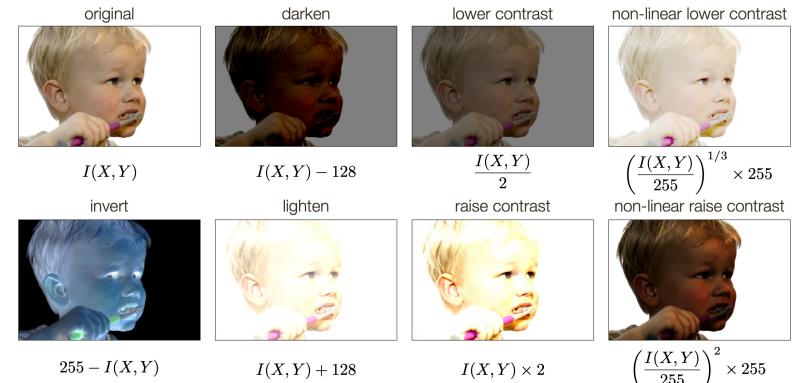
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Examples of Point Processing



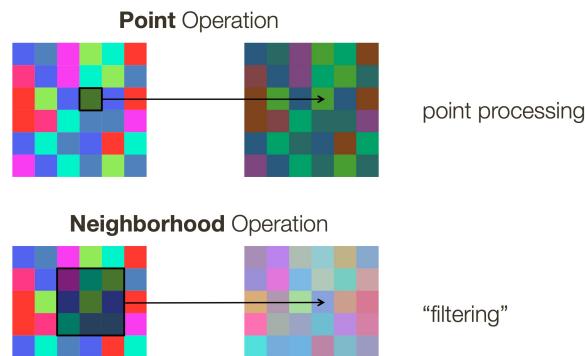
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Examples of Point Processing



Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## What types of **filtering** can we do?

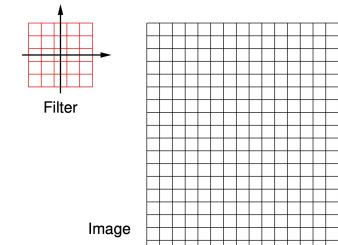


Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filters

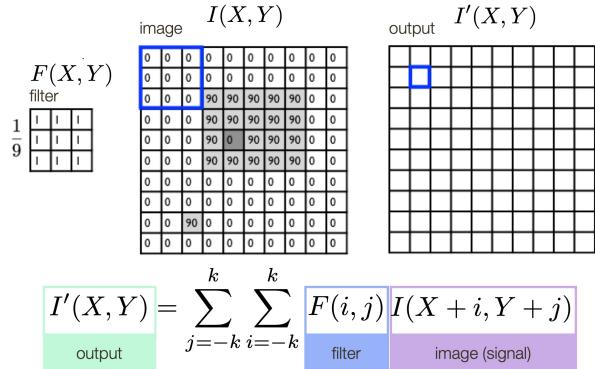
Let  $I(X, Y)$  be an  $n \times n$  digital image (for convenience we let width = height)

Let  $F(X, Y)$  be another  $m \times m$  digital image (our "**filter**" or "**kernel**")



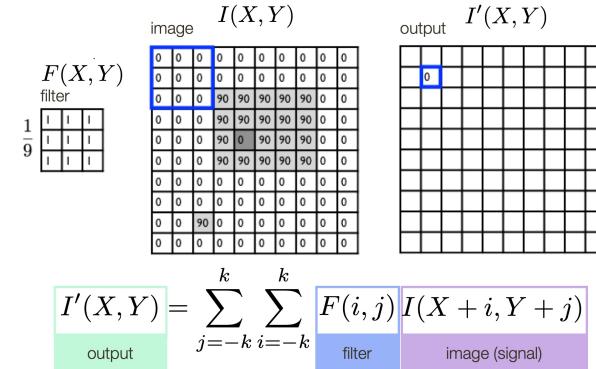
For convenience we will assume  $m$  is odd. (Here,  $m = 5$ )

## Linear Filter Example



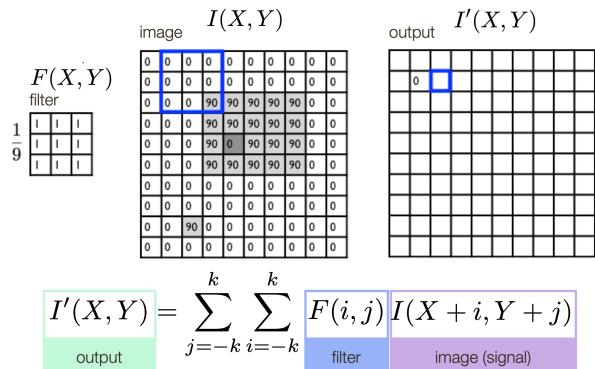
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



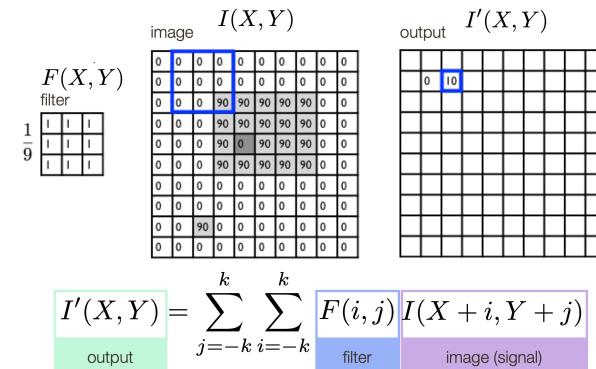
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



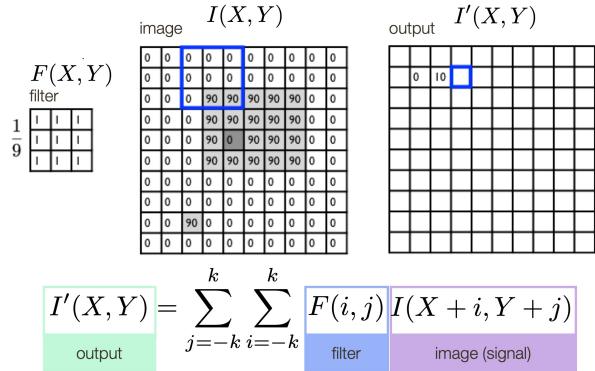
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



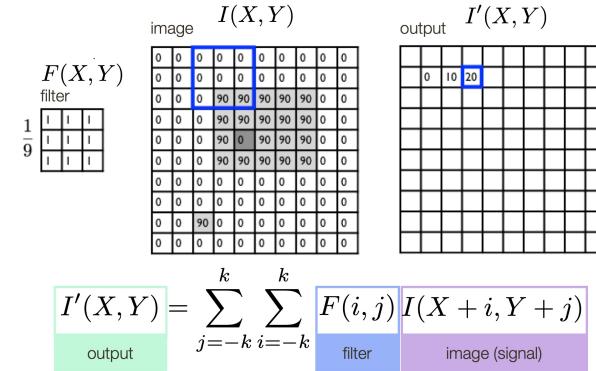
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



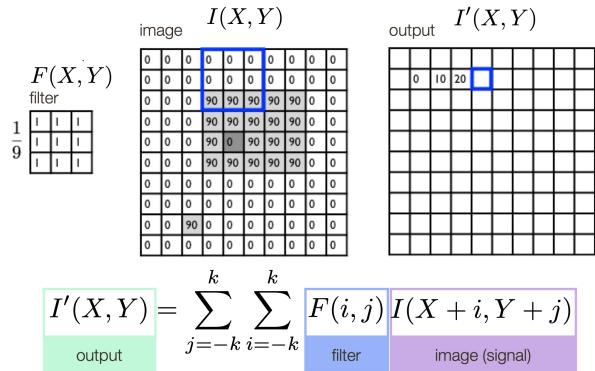
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

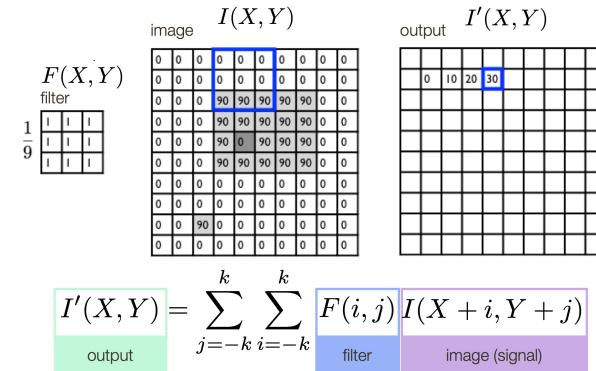
## Linear Filter Example



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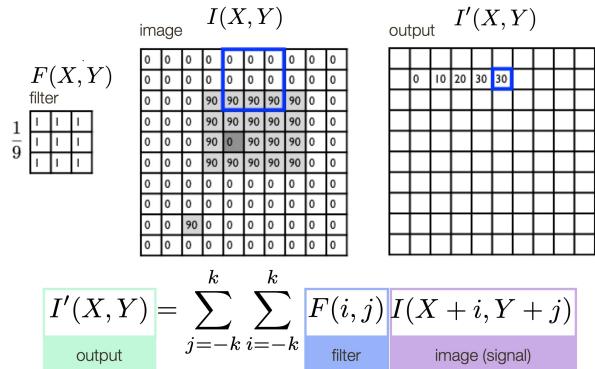
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



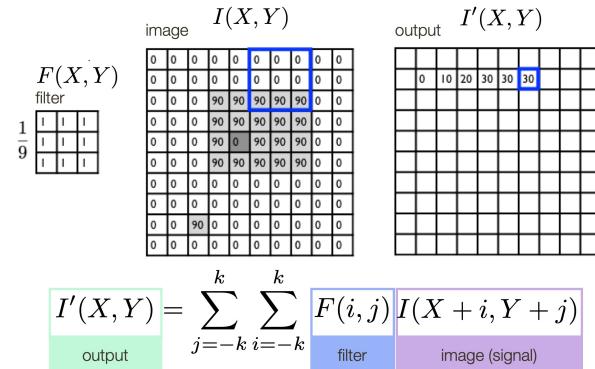
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



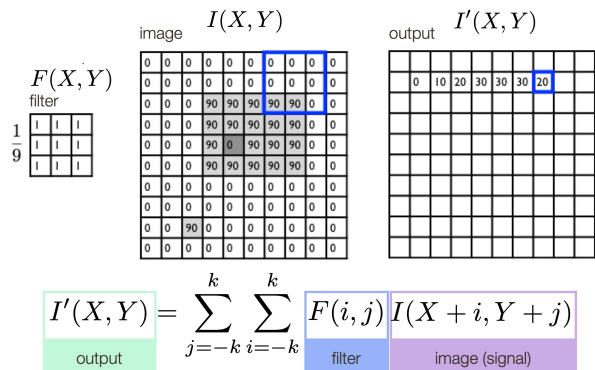
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



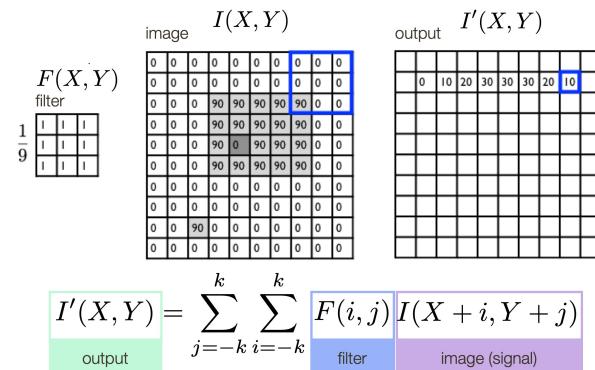
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



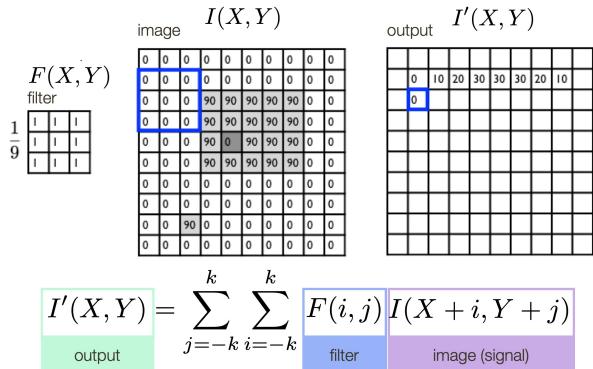
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



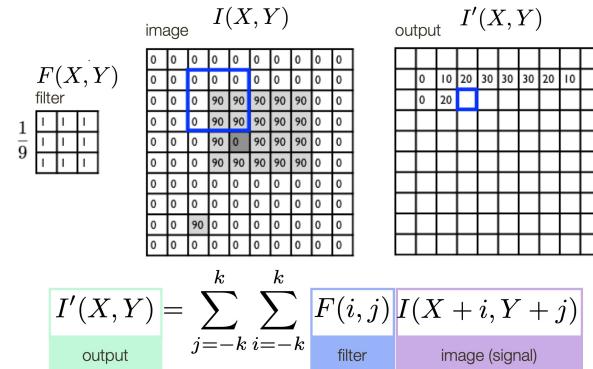
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



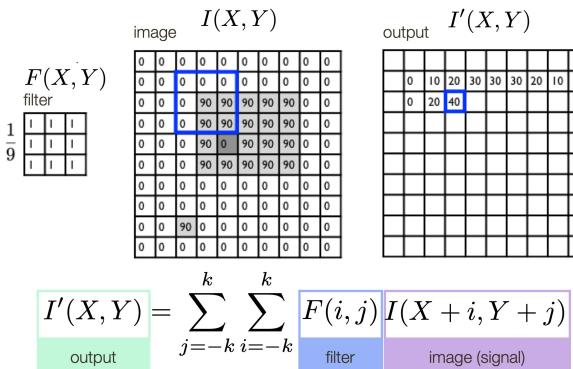
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter **Example**



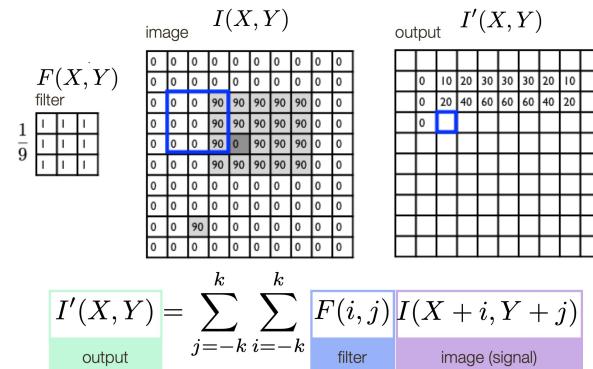
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



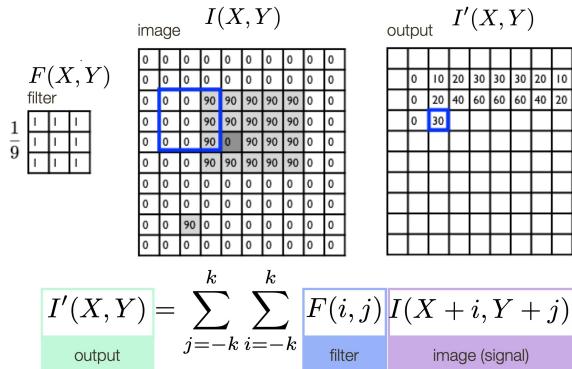
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



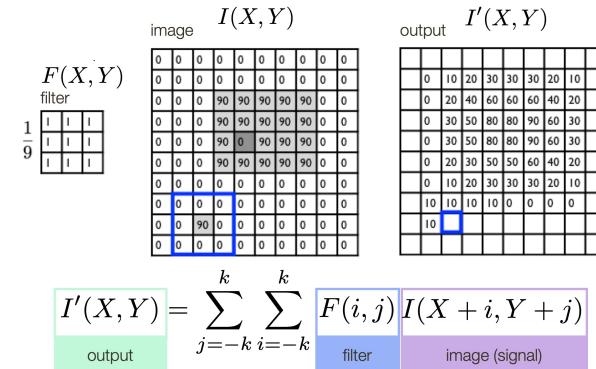
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



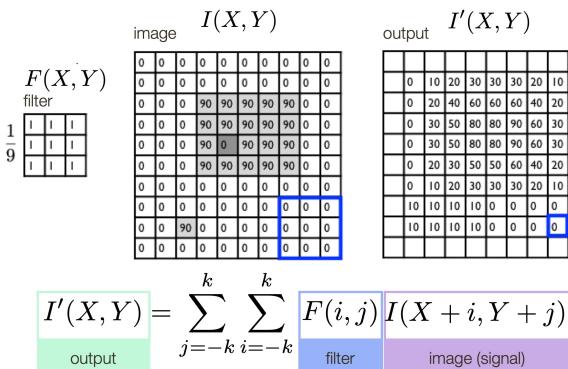
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



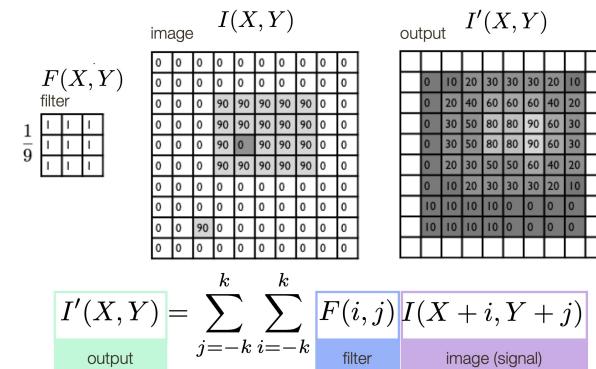
**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filter Example



Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

## Linear Filters: Correlation vs. Convolution

Definition: **Correlation**

$$I'(X, Y) = \sum_{j=-k}^k \sum_{i=-k}^k F(i, j)I(X + i, Y + j)$$

a   b   c	1   2   3
d   e   f	4   5   6
g   h   i	7   8   9

Filter

1   2   3
4   5   6
7   8   9

Image


Output

$$= 1a + 2b + 3c + 4d + 5e + 6f + 7g + 8h + 9i$$

## Linear Filters: Correlation vs. Convolution

Definition: **Correlation**

$$I'(X, Y) = \sum_{j=-k}^k \sum_{i=-k}^k F(i, j)I(X + i, Y + j)$$

Definition: **Convolution**

$$I'(X, Y) = \sum_{j=-k}^k \sum_{i=-k}^k F(i, j)I(X - i, Y - j)$$

a   b   c
d   e   f
g   h   i

Filter

1   2   3
4   5   6
7   8   9

Image


Output

$$= 9a + 8b + 7c + 6d + 5e + 4f + 3g + 2h + 1i$$

## Linear Filters: Correlation vs. Convolution

Definition: **Correlation**

$$I'(X, Y) = \sum_{j=-k}^k \sum_{i=-k}^k F(i, j)I(X + i, Y + j)$$

Definition: **Convolution**

$$I'(X, Y) = \sum_{j=-k}^k \sum_{i=-k}^k F(i, j)I(X - i, Y - j)$$

**Filter**  
(rotated by 180)

!   Ȣ   Ȧ
ȴ   Ȣ   Ȫ
Ȭ   Ȣ   Ȫ

a   b   c
d   e   f
g   h   i

Filter

1   2   3
4   5   6
7   8   9

Image


Output

$$= 9a + 8b + 7c + 6d + 5e + 4f + 3g + 2h + 1i$$