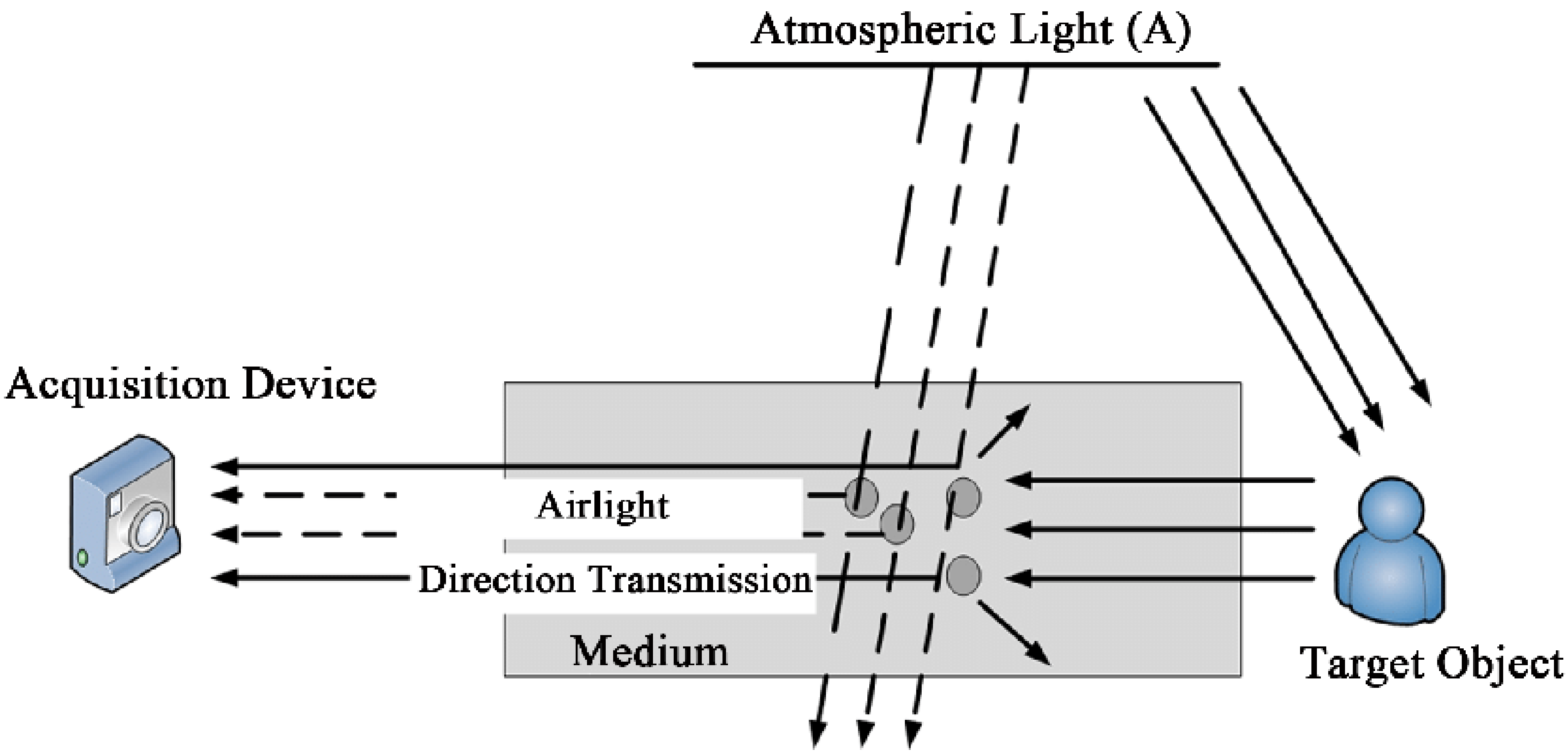
Image Dehazing

Application of Image Enhancement: Image Dehazing

Article: K. He, J. Sun, and X. Tang, “Single image haze removal using dark channel prior,” *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 33, no. 12, pp. 2341–2353, Dec. 2011

Hazy Image: The capturing process



Application of Image Enhancement: Image Dehazing (by Dark Channel Prior)

(a) (b)

$0 \leq t(x) \leq 1$

Transmission coeff

$$\mathbf{I}(\mathbf{x}) = \mathbf{J}(\mathbf{x})t(\mathbf{x}) + \mathbf{A}(1 - t(\mathbf{x})).$$

Original scene

Direct Component

Airlight Component

$t(x) = e^{-\beta d(x)}$

$d(x)$ = Distance of the object from the camera

$d(x) = 0 \Rightarrow t(x) = 1$

$d(x) = \infty \Rightarrow t(x) = 0$

$$\Rightarrow I(x) = \underline{\underline{J(x)}}\, t(x) + A\left(1 - t(x)\right)$$

Far away object: $d(x) = \infty \longrightarrow t(x) = 0 \Rightarrow I(x) = A$

Very close object: $d(x) = 0 \longrightarrow t(x) = 1 \Rightarrow I(x) = J(x)$

Homogeneous haze is dependent on the depth of the scene.

Dark Channel Prior (DCP)

R

$$\begin{matrix} 1 & 5 & 6 \\ 8 & 10 & 9 \\ 7 & 4 & 3 \end{matrix}$$

G

$$\begin{matrix} 5 & 10 & 7 \\ 4 & 3 & 2 \\ 0 & 6 & 8 \end{matrix}$$

B

$$\begin{matrix} 12 & 15 & 10 \\ 9 & 7 & 6 \\ 8 & 5 & 4 \end{matrix}$$

$\xrightarrow{\min_{c\in\{r,g,b\}}}$ $J^{c}_{min}(y)$

$$\begin{matrix} 1 & 5 & 6 \\ 4 & 3 & 2 \\ 0 & 4 & 3 \end{matrix}$$

$\downarrow$

$$\begin{matrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 5 & 6 & 0 \\ 0 & 4 & 3 & 2 & 0 \\ 0 & 0 & 4 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{matrix}$$

$\downarrow$

$$\begin{matrix} 0 & 0 & 0 \\ 0 & 4 & 2 \\ 0 & 2 & 0 \end{matrix}$$

- Outdoor haze-free images: In most of the non-sky patches, at least one color channel has some pixels whose intensity are very low and close to zero.

$$J^{\text{dark}}(\mathbf{x}) = \min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_{c\in\{r,g,b\}} J^{c}(\mathbf{y})\right) \qquad J^{\text{dark}} \rightarrow 0.$$

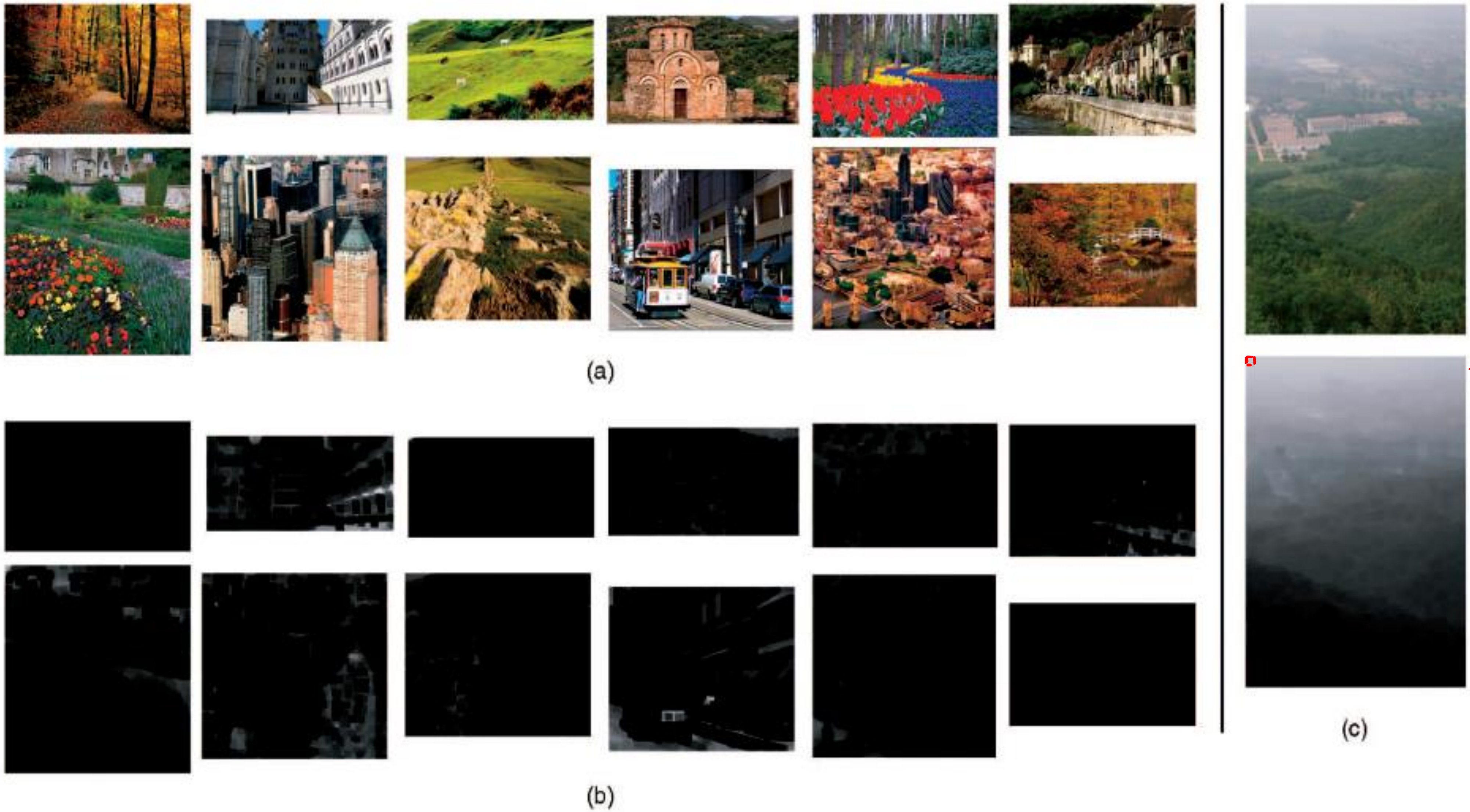
(a) (b) (c)

Fig. Calculation of a dark channel. (a) An arbitrary image $\mathbf{J}$. (b) For each pixel, we calculate the minimum of its (r, g, b) values. (c) A minimum filter is performed on (b). This is the dark channel of $\mathbf{J}$. The image size is 800×551, and the patch size of Ω is 15×15.

Reasons for Dark Channel

- Shadows, e.g., the shadows of cars, buildings, and the inside of windows in cityscape images, or the shadows of leaves, trees, and rocks in landscape images.
- Colorful objects or surfaces, e.g., any object with low reflectance in any color channel (for example, green grass/tree/plant, red or yellow flower/leaf, and blue water surface) will result in low values in the dark channel.
- Dark objects or surfaces, e.g., dark tree trunks and stones.
- As the natural outdoor images are usually colorful and full of shadows, the dark channels of these images are really dark.

Examples



Distance map

$\Downarrow$

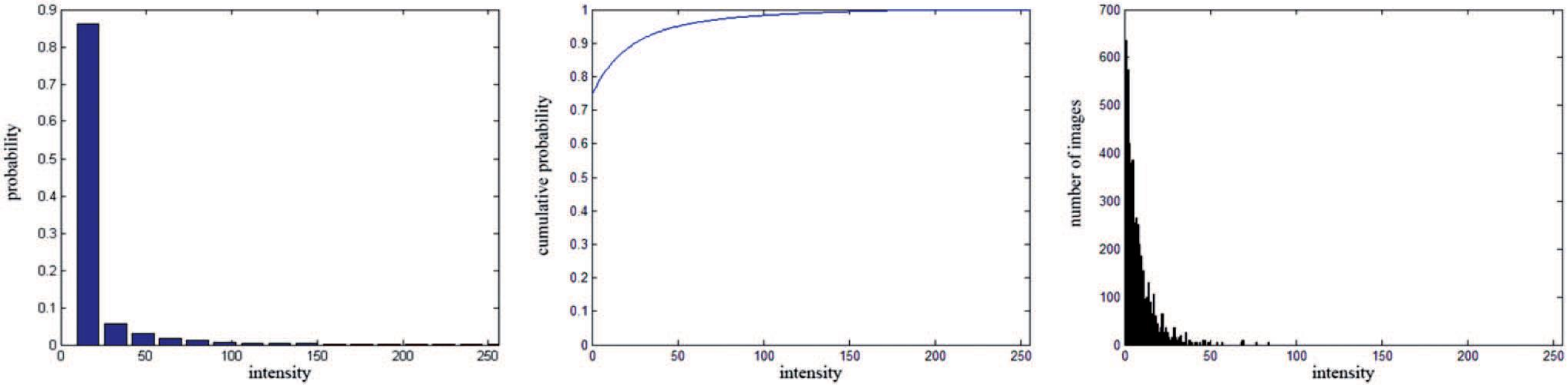
transmission map.

$0 \leq t \leq 1$

$d(x) = 0$

$t(x) = 1$

Statistics of DCP



(a) (b) (c)

Statistics of the dark channels. (a) Histogram of the intensity of the pixels in all of the 5,000 dark channels (each bin stands for 16 intensity levels). (b) Cumulative distribution. (c) Histogram of the average intensity of each dark channel.

Interpretation

$$I = Jt + A(1-t)$$

$$\Rightarrow J = \frac{I - A + At}{t}$$

Haze-free image

Hazy image

- Due to the additive airlight, a hazy image is brighter than its haze-free version where the transmission t is low. So, the dark channel of a hazy image will have higher intensity in regions with denser haze.
- The intensity of the dark channel is a rough approximation of the thickness of the haze.

Hazefree :- $J^{dark}(x) \to 0$

Hazy : $J^{dark}(x) \neq 0$

Estimating the Transmission

$I(x) = J(x)t(x) + A(1 - t(x))$

- Assuming known **A** $\quad \frac{I^c(\mathbf{x})}{A^c} = t(\mathbf{x})\frac{J^c(\mathbf{x})}{A^c} + 1 - t(\mathbf{x})$
- Transmission in a local patch is constant. $\tilde{t}(x)$
- Calculate the dark channel on both sides of the above equation.

$$\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_c \frac{I^c(\mathbf{y})}{A^c}\right) = \tilde{t}(\mathbf{x}) \min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_c \frac{J^c(\mathbf{y})}{A^c}\right) + 1 - \tilde{t}(\mathbf{x}).$$

- Since, $\quad J^{\mathrm{dark}}(\mathbf{x}) = \min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_c J^c(\mathbf{y})\right) = 0.$

$$\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_c \frac{J^c(\mathbf{y})}{A^c}\right) = 0.$$

$$\tilde{t}(\mathbf{x}) = 1 - \min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\min_c \frac{I^c(\mathbf{y})}{A^c}\right).$$

Estimating Atmospheric Light

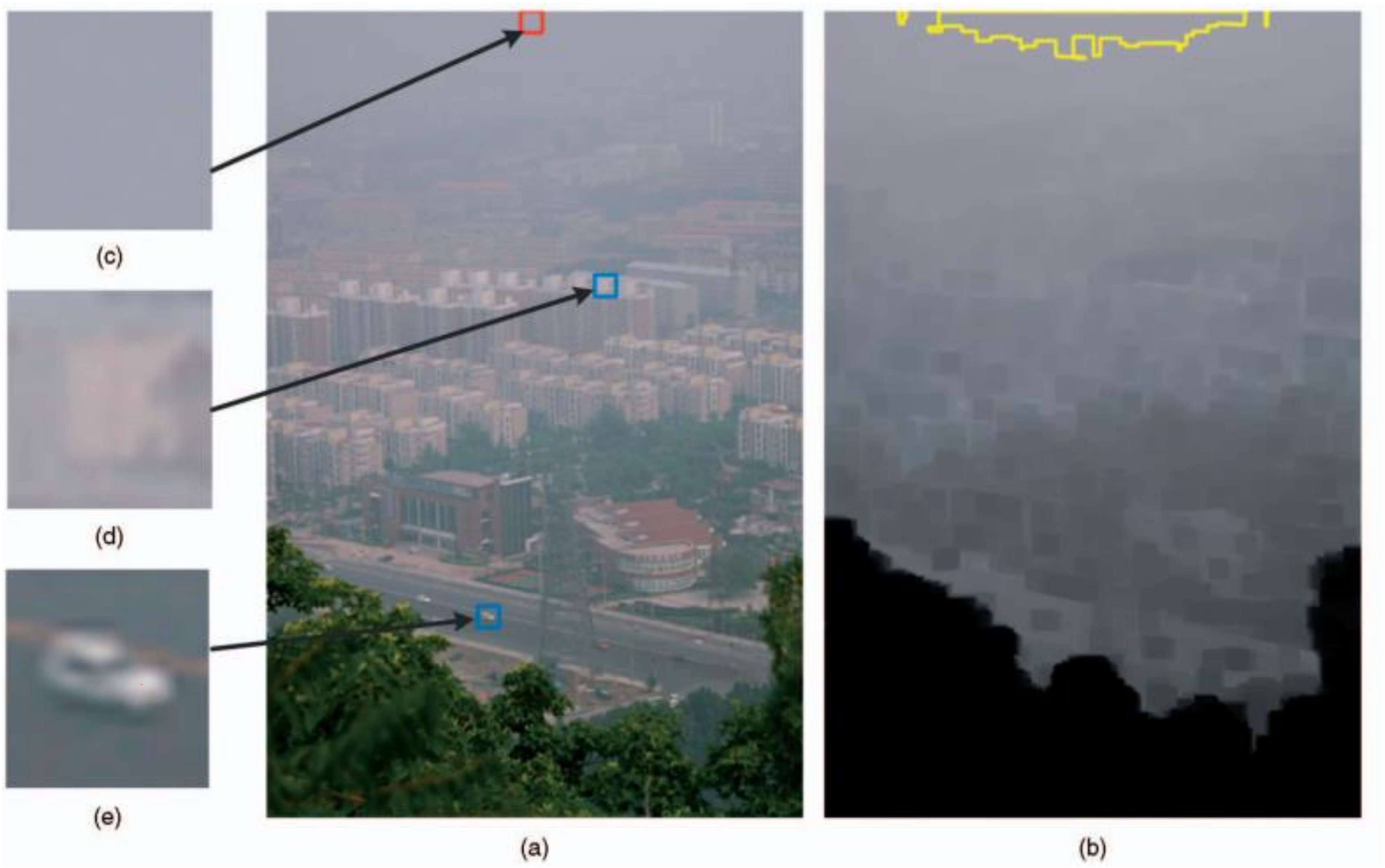
- Mostly the color of the "haze-opaque" region can be considered as atmospheric light.
- If we consider the brightest pixel as the haze opaque region by neglecting the sunlight…

$$J(\mathbf{x}) = R(\mathbf{x})A, \qquad I(\mathbf{x}) = R(\mathbf{x})At(\mathbf{x}) + (1 - t(\mathbf{x}))A$$

- At infinite distance $t \approx 0, I(x) \approx A$
- But considering the sunlight $J(\mathbf{x}) = R(\mathbf{x})(S + A)$;

$$I(\mathbf{x}) = R(\mathbf{x})St(\mathbf{x}) + R(\mathbf{x})At(\mathbf{x}) + (1 - t(\mathbf{x}))A.$$

- In this situation, the brightest pixel of the whole image can be brighter than the atmospheric light.



- Estimating the atmospheric light. (a) Input image. (b) Dark channel and the most haze-opaque region. (c) The patch from where our method automatically obtains the atmospheric light. (d), (e) Two patches that contain pixels brighter than the atmospheric light.

Scene Recovery

$$\mathbf{J}(\mathbf{x}) = \frac{\mathbf{I}(\mathbf{x}) - \mathbf{A}}{\max(t(\mathbf{x}), t_0)} + \mathbf{A}.$$

0.1

(a) (b) (c) (d) (e)

Results

What about these images?

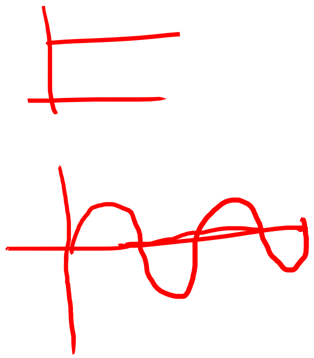
$s = c r^{\gamma}$

$c \downarrow 1$

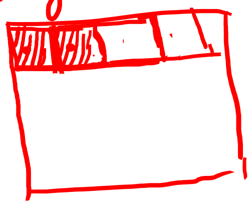
Spatial Filtering

“Filtering”

- Filtering refers to accepting or rejecting certain frequency components.
- Same effect can be achieved by using spatial filter (masks, kernels, templates, windows).



same intensity
change in ''



low freq ← smoother regions of image
high freq.
edges, corners, boundary points

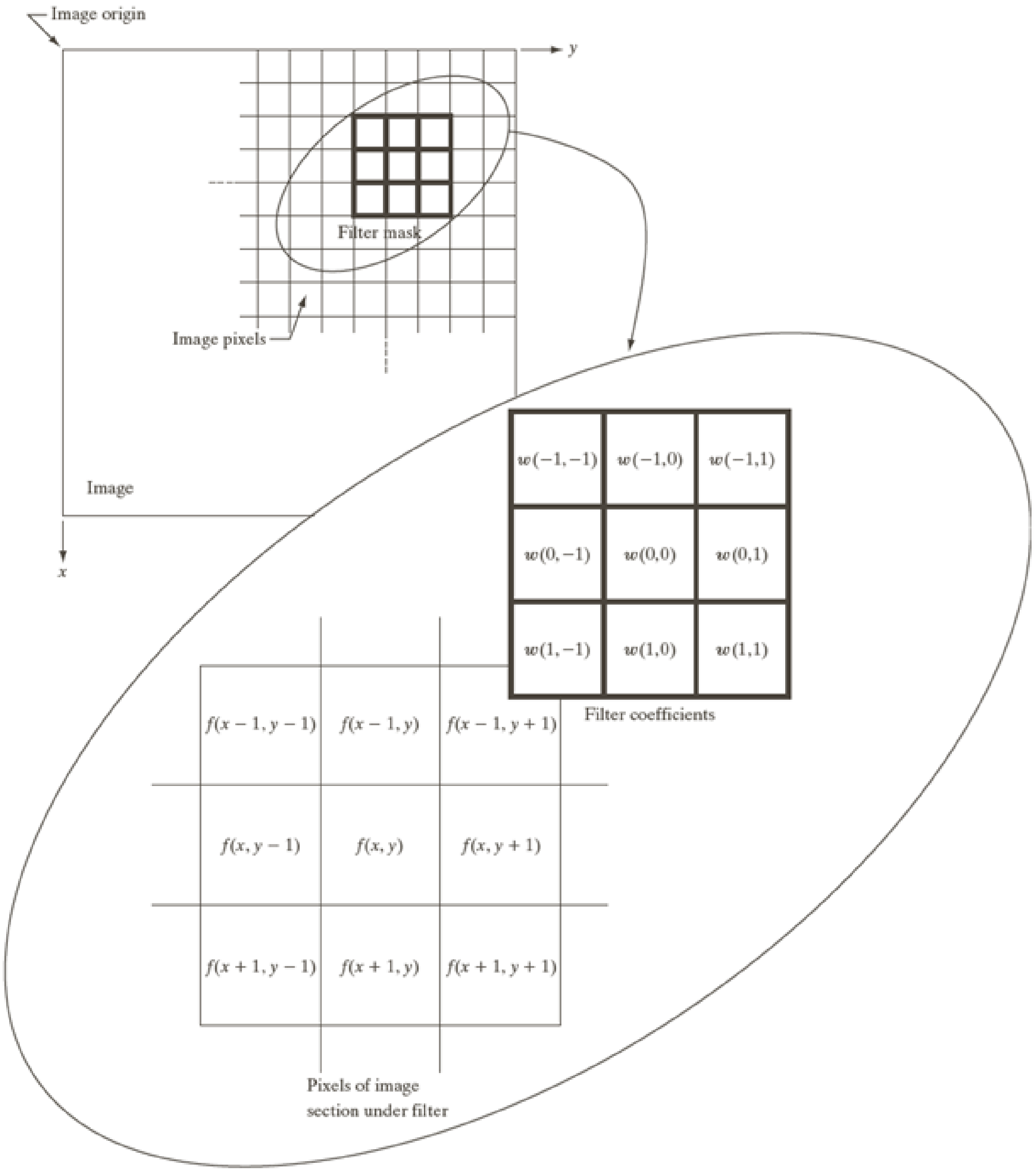
Mechanics of Spatial Filtering

- Spatial filter consists of
    - A neighbourhood
    - A pre-defined operation that is performed on the image pixels encompassed by the neighbourhood.
- Filtering creates a new pixel with coordinates equal to the coordinates of the centre of the neighbourhood.
- The value is the result of the filtering operation.
- Filtering could be linear as well as non-linear.

- $g(x,y) = w(-1,-1)f(x-1,y-$

3×3

⇒



Spatial Correlation and Convolution

- For a filter of size $1 \times m$, append $m-1$ zeros on either side of f.
- After the operation crop the result to original dimension.

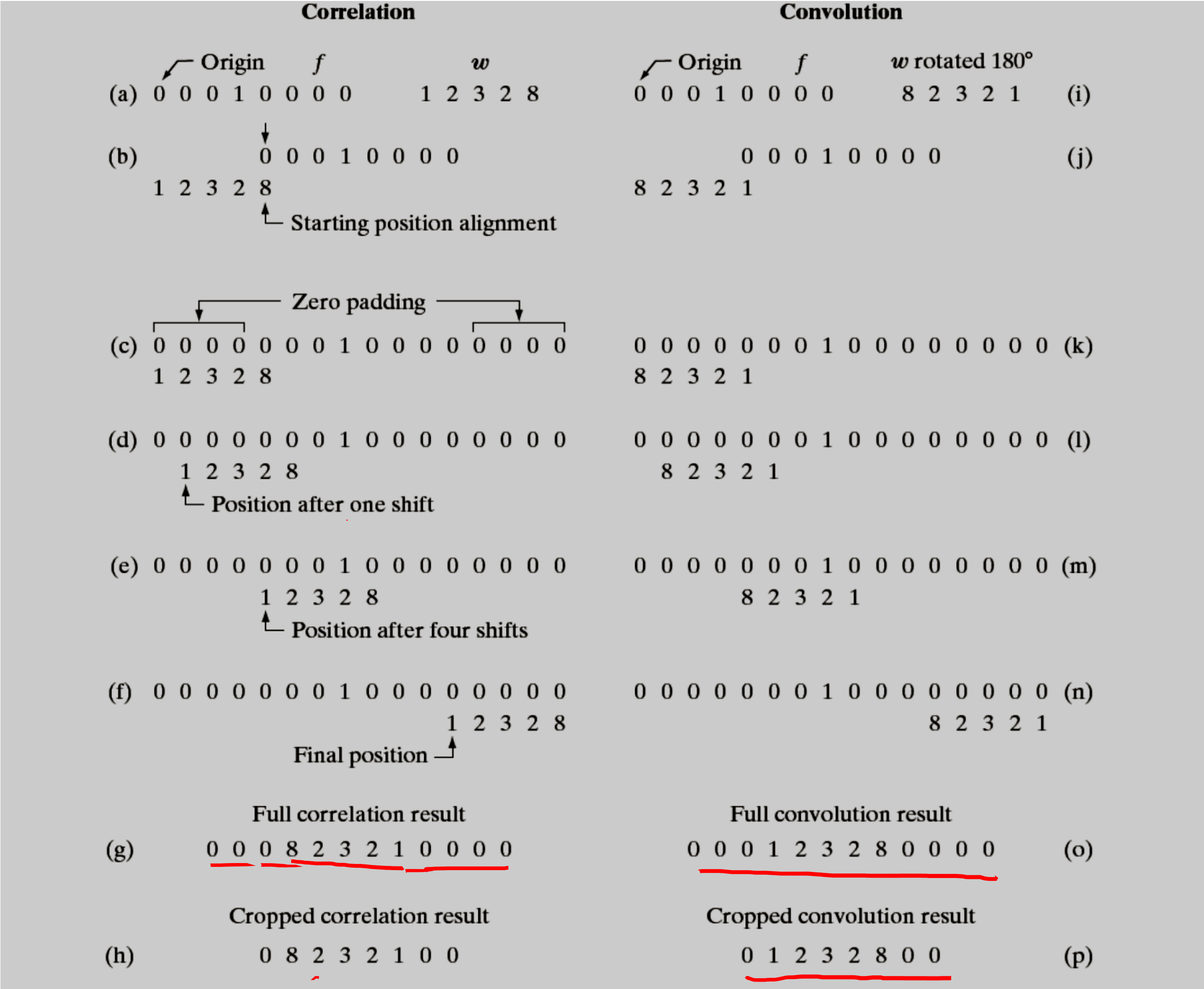


FIGURE 3.29 Illustration of 1-D correlation and convolution of a filter with a discrete unit impulse. Note that correlation and convolution are functions of *displacement*.

2D Correlation and Convolution

(i) Multiply

(ii) Add

(iii) Shift.