modeled as a square array of dimensions 1.5 mm × 1.5 mm, and that the cones and spaces between the cones are distributed uniformly throughout this array.

2.2 When you enter a dark theater on a bright day, it takes an appreciable interval of time before you can see well enough to find an empty seat. Which of the visual processes explained in Section 2.1 is at play in this situation?

★2.3 Although it is not shown in Fig. 2.10, alternating current certainly is part of the electromagnetic spectrum. Commercial alternating current in the United States has a frequency of 60 Hz. What is the wavelength in kilometers of this component of the spectrum?

2.4 You are hired to design the front end of an imaging system for studying the boundary shapes of cells, bacteria, viruses, and protein. The front end consists, in this case, of the illumination source(s) and corresponding imaging camera(s). The diameters of circles required to enclose individual specimens in each of these categories are 50, 1, 0.1, and 0.01 μm, respectively.

(a) Can you solve the imaging aspects of this problem with a single sensor and camera? If your answer is yes, specify the illumination wavelength band and the type of camera needed. By "type," we mean the band of the electromagnetic spectrum to which the camera is most sensitive (e.g., infrared).

(b) If your answer in (a) is no, what type of illumination sources and corresponding imaging sensors would you recommend? Specify the light sources and cameras as requested in part (a). Use the *minimum* number of illumination sources and cameras needed to solve the problem.

By "solving the problem," we mean being able to detect circular details of diameter 50, 1, 0.1, and 0.01 μm, respectively.

2.5 A CCD camera chip of dimensions 7 × 7 mm, and having 1024 × 1024 elements, is focused on a square, flat area, located 0.5 m away. How many line pairs per mm will this camera be able to resolve? The camera is equipped with a 35-mm lens. (*Hint:* Model the imaging process as in Fig. 2.3, with the focal length of the camera lens substituting for the focal length of the eye.)

★2.6 An automobile manufacturer is automating the placement of certain components on the bumpers of a limited-edition line of sports cars. The components are color coordinated, so the robots need to know the color of each car in order to select the appropriate bumper component. Models come in only four colors: blue, green, red, and white. You are hired to propose a solution based on imaging. How would you solve the problem of automatically determining the color of each car, keeping in mind that *cost* is the most important consideration in your choice of components?

2.7 Suppose that a flat area with center at (x_0, y_0) is illuminated by a light source with intensity distribution

$$i(x, y) = Ke^{-[(x-x_0)^2+(y-y_0)^2]}$$

Assume for simplicity that the reflectance of the area is constant and equal to 1.0, and let $K = 255$. If the resulting image is digitized with k bits of intensity resolution, and the eye can detect an abrupt change of eight shades of intensity between adjacent pixels, what value of k will cause visible false contouring?

2.8 Sketch the image in Problem 2.7 for $k = 2$.

★2.9 A common measure of transmission for digital data is the *baud rate*, defined as the number of bits transmitted per second. Generally, transmission is accomplished

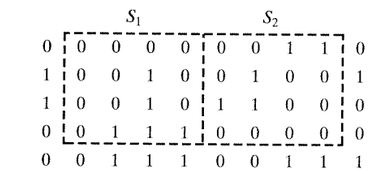
in packets consisting of a start bit, a byte (8 bits) of information, and a stop bit. Using these facts, answer the following:

(a) How many minutes would it take to transmit a 1024 × 1024 image with 256 intensity levels using a 56K baud modem?

(b) What would the time be at 3000K baud, a representative medium speed of a phone DSL (Digital Subscriber Line) connection?

2.10 High-definition television (HDTV) generates images with 1125 horizontal TV lines interlaced (where every other line is painted on the tube face in each of two fields, each field being 1/60th of a second in duration). The width-to-height aspect ratio of the images is 16:9. The fact that the number of horizontal lines is fixed determines the vertical resolution of the images. A company has designed an image capture system that generates digital images from HDTV images. The resolution of each TV (horizontal) line in their system is in proportion to vertical resolution, with the proportion being the width-to-height ratio of the images. Each pixel in the color image has 24 bits of intensity resolution, 8 bits each for a red, a green, and a blue image. These three "primary" images form a color image. How many bits would it take to store a 2-hour HDTV movie?

★2.11 Consider the two image subsets, S_1 and S_2, shown in the following figure. For $V = \{1\}$, determine whether these two subsets are (a) 4-adjacent, (b) 8-adjacent, or (c) m-adjacent.



★2.12 Develop an algorithm for converting a one-pixel-thick 8-path to a 4-path.

2.13 Develop an algorithm for converting a one-pixel-thick m-path to a 4-path.

2.14 Refer to the discussion at the end of Section 2.5.2, where we defined the background as $(R_u)^c$, the complement of the union of all the regions in an image. In some applications, it is advantageous to define the background as the subset of pixels $(R_u)^c$ that are not region hole pixels (informally, think of holes as sets of background pixels surrounded by region pixels). How would you modify the definition to exclude hole pixels from $(R_u)^c$? An answer such as "the background is the subset of pixels of $(R_u)^c$ that are not hole pixels" is not acceptable. (*Hint:* Use the concept of connectivity.)

2.15 Consider the image segment shown.

★(a) Let $V = \{0, 1\}$ and compute the lengths of the shortest 4-, 8-, and m-path between p and q. If a particular path does not exist between these two points, explain why.

(b) Repeat for $V = \{1, 2\}$.