Digital Image Processing, 2nd Ed.
Gonzalez and Woods
Prentice Hall
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BOOK CORRECTIONS, CLARIFICATIONS, AND CORRECTIONS TO PROBLEM SOLUTIONS

NOTE: Depending on the country in which you purchase the book, your copy may have most of the following errors corrected. To tell which printing of the book you have, look on the page (near the beginning of the book) that contains the Library of Congress Catalog card. Toward the bottom of that page, you will see a line that says: "Printed in the United States of America." Below that line there is a series of numbers, starting with 10 on the left. The last number on the right is the printing of your book (e.g., if it is a 1, then you have the first printing of the book, a 2 indicates that you have the second printing, and so on). The first column of each row in the following table indicates the printing(s) to which the corrections shown in that row apply.

The following errata histories apply to U.S. printings. Printing histories of international editions do not always corresponds to the history of the books printed in the U.S.

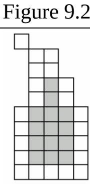
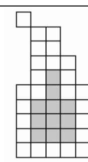
December 21, 2008

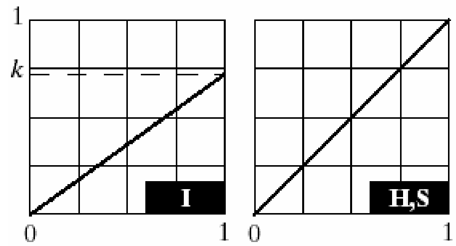
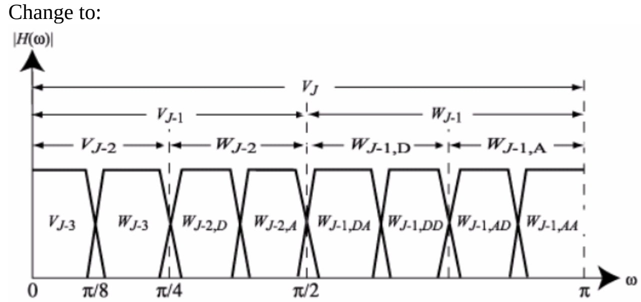
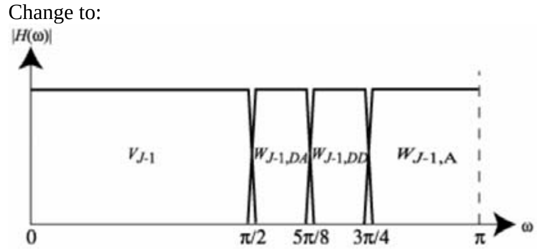
BOOK CORRECTIONS

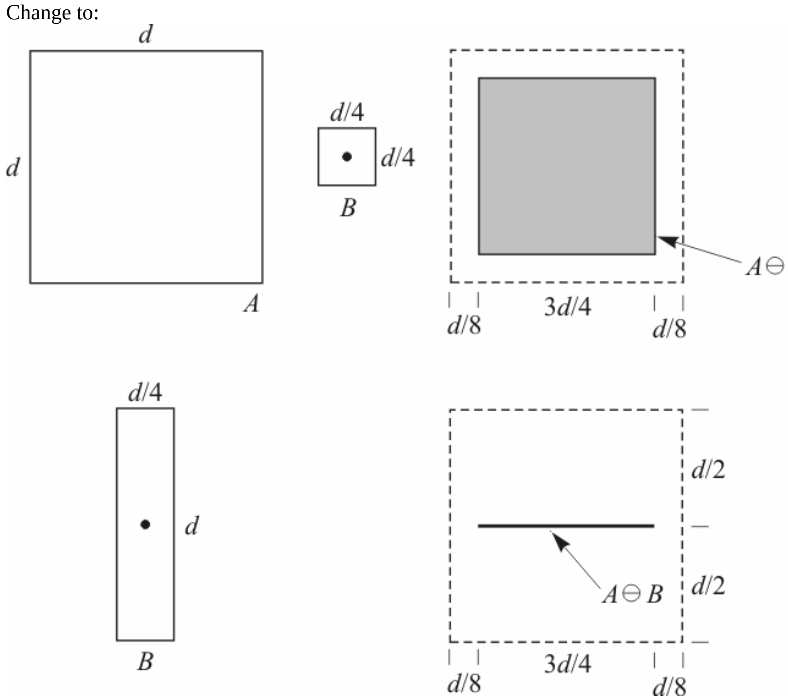
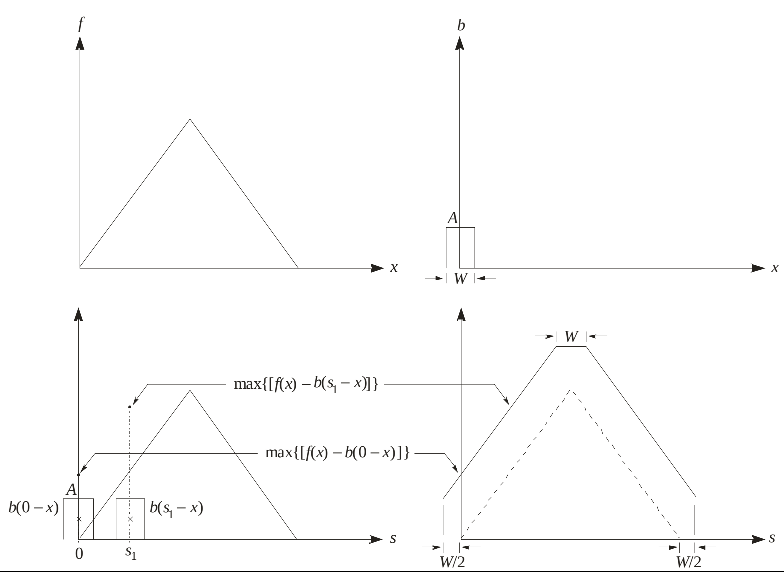
Printing	Page	Reads	Should Read
1	vii, Page numbers for Chapter 1	15, 15, 17 . . . , 44, 45	1, 3, 7, . . . ,30, 31 (Entries are off by 14)
1	xviii, 2nd paragraph, line 4	works	Works (for MathWorks)
1	7, Fig. 1.5	. . . 10^1 10^{-1} 10^{-1}. . .	. . . 10^1 10^0 10^{-1}. . .
1-3	23, Caption for Fig. 1.20	(2) Another . . .	(b) Another . . .
1-6	57, 6th line from the top	. . . is simply the smallest number . . .	. . . is simply the largest number . . .
1	72, Problem 2.10, 9th line	. . . 8 pixels each of . . .	. . . 8 bits each of . . .
1-3	87, 5th line	. . . between 129 and 255 . . .	. . . between 128 and 255 . . .
1	91, Fig. 3.16, (intersection of the *s* axis and the dashed line)	*t*	1
1	93, 1st line, 2nd paragraph	. . . continuos . . .	. . . continuous . . .
1	94, last line	. . . continuos . . .	. . . continuous . . .
1	97, 1st line below Eq. (3.3-14)	. . . continuos . . .	. . . continuous . . .
1	100, Fig. 3.20, caption	Photos	Phobos
1-3	113, line below Eq. (3.4-5)	. . . and $\sigma^2_{\bar{\eta}(x,y)}$ are . . .	. . . and $\sigma^2_{\eta(x,y)}$ are . . .(remove bar over η)
1-3	118, Eq. (3.5-3)	$R = w_1z_1 + w_2z_2 + \quad w_9z_9$	$R = w_1z_1 + w_2z_2 + \quad + w_9z_9$
1-3	124, last line in Example 3.10	. . . removal of additive salt and . . .	. . . removal of salt and . . .
1-3	128, Eqs. (3.7-2) and (3.7-3)	$\frac{\partial^2 f}{\partial^2 x^2}$, $\frac{\partial^2 f}{\partial^2 y^2}$	$\frac{\partial^2 f}{\partial x^2}$, $\frac{\partial^2 f}{\partial y^2}$
1-3	134, caption for Fig. 3.43	(a) Laplacian . . .	(b) Laplacian . . .
1=3	137, caption for Fig. 3.45	Optical image of . . .	(a) Optical image of . . .
1	143, Problem 3.2(c)	(c) What is the smallest value of *s* that . . .	(c) What is the smallest value of *E* that . . .
1	154, Eq. (4.2-18)	$\lvert F(u,v)\rvert = [R^2(x,y) + I^2(x,y)]^{1/2}$	$\lvert F(u,v)\rvert = [R^2(u,v) + I^2(u,v)]^{1/2}$

1-3	152, Eq. (4.2-9)	$F(u)=\lvert F(u)\rvert e^{-j\phi(u)}$	$F(u)=\lvert F(u)\rvert e^{j\phi(u)}$
1-3	157, second line	. . . miscroscope . . .	. . . microscope . . .
1	167, 7th line from bottom	. . . origin . . .	. . . center . . .
1-3	184, caption for Fig. 4.26	using a GHPF of order 2 with . . .	. . . using a GHPF with . . .
1-6	185, Eq. (4.4-5)	. . . $= (ju)^n F(u)$	. . . $= (j2\pi u)^n F(u)$
1-6	185, Eq. (4.4-6)	. . . $= (ju)^2 F(u,v)+(jv)^2 F(u,v)$ $= -(u^2+v^2)F(u,v)$	. . . $= (j2\pi u)^2 F(u,v)+(j2\pi v)^2 F(u,v)$ $= -4\pi^2(u^2+v^2)F(u,v)$
1-6	185, Eq. (4.4-7)	. . . $= -(u^2+v^2)F(u,v)$	. . . $= -4\pi^2(u^2+v^2)F(u,v)$
1-6	185, Eq. (4.4-8)	. . . $= -(u^2+v^2)$	. . . $= -4\pi^2(u^2+v^2)$
1	187, 3rd parag., 3rd line	$H(u,v)=\left[1-[(u-M/2)^2........\right]$	$H(u,v)=\left[1+[(u-M/2)^2........\right]$
1	187, Eq. (4.4-13)	$...\left\{\left[1-((u-M/2)^2+...\right]\right\}$	$...\left\{\left[1+((u-M/2)^2+...\right]\right\}$
1-5	188, Fig. 4.28	Fig. 4.28(d) (printed incorrectly)	Should look like Fig. 3.40(d), pg. 130.
1- 3	189, 10th line from bottom	… is not as sharp as Fig. 4.43(d). The …	… is not as sharp as Fig. 3.43(d). The …
1	204, 2nd parag, line 2	… filter function to be inverse transformed …	… filter function to be multiplied by $(-1)^{u+v}$, inverse transformed …
1-3	209, line below Eq. (4.6-39)	$W_{2K}^{2uk} =$ . . .	$W_{2K}^{2ux} =$ . . . (replace *k* with *x* in the superscript)
1-3	209, Eq. (4.6-40)	. . . $f(2x)W_{2K}^{ux}$ . . .	$f(2x)W_{K}^{ux}$ (remove the 2 in the subscript)
1-6	210, Table 4.1, 10th entry	. . . $\Leftrightarrow (ju)^n F(u,v)$ $(-jx)^n f(x,y) \Leftrightarrow$ . . .	. . . $\Leftrightarrow (j2\pi u)^n F(u,v)$ $(-j2\pi x)^n f(x,y) \Leftrightarrow$ . . .
1-6	210, Table 4.1, 11th entry	. . . $= -(u^2+v^2)F(u,v)$	. . . $= -4\pi^2(u^2+v^2)F(u,v)$
1	211, Table 4.1, 4th entry from bottom, left side of equation	$A\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2(x^2+y^2)}$	$A2\pi\sigma^2 e^{-2\pi^2\sigma^2(x^2+y^2)}$
1	211, Table 4.1, 2nd entry from bottom, right side of equation	$\frac{1}{2}\left[\delta(u+u_0,v+v_0)+\delta(u-u_0,v-v_0)\right]$ (Note: This answer in the book is correct, but it is for continuous quantities.)	$\frac{1}{2}\left[\delta(u+Mu_0,v+Nv_0)+\delta(u-Mu_0,v-Nv_0)\right]$ (This answer is for discrete quantities.)
1	211, Table 4.1, last entry, right side of equation	$\frac{j}{2}\left[\delta(u+u_0,v+v_0)-\delta(u-u_0,v-v_0)\right]$ (Note: This answer in the book is correct, but it is for continuous quantities.)	$\frac{j}{2}\left[\delta(u+Mu_0,v+Nv_0)-\delta(u-Mu_0,v-Nv_0)\right]$ (This answer is for discrete quantities.)
1	215, Prob. 4.4, second equation.	$A\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2(x^2+y^2)}$	$A2\pi\sigma^2 e^{-2\pi^2\sigma^2(x^2+y^2)}$ (See **Corrections to Problem Solutions** toward the end of this document).
1-6	215, Prob. 4.4, last line	(*Hint:* Treat the variables as continuous to simplify manipulation.)	(These closed-form expressions are applicable only to continuous variables.)
1-3	236, 3rd line from the top	. . . $d=(mn-1)/2$ . . .	. . . $d=mn-1$ . . .
1-3	241, last line of Level A:	Else output z_{xy}.	Else output z_{med}.
1-3	242, 4th parag, 6th line	z_{xy}	z_{med}
1	244, Example 5.6, 3rd and 4th sentences	It is not difficult to show . . . pair of impulses. One impulse is located . . . mirror images of that point.	It is not difficult to show that the Fourier transform of a sine consists of two impulses that are mirror images of each other about the origin of the transform. Their locations are given in Table 4.1.
1	269, Eq. (5.9-13)	$\lVert\boldsymbol{\eta}\rVert^2 = MN\left[\sigma_\eta{}^2 - m_\eta\right]$	$\lVert\boldsymbol{\eta}\rVert^2 = MN\left[\sigma_\eta{}^2 + m_\eta{}^2\right]$ (Note: Two corrections)
1	279, Problem 5.14	. . . 2-D sine function . . .	. . . 2-D continuous sine function . . .
1-3	280, Prob. 5.21, 2nd equation.	$-\sqrt{2\pi}\sigma(u^2+v^2)e^{-2\pi^2\sigma^2(u^2+v^2)}$	$-2\pi\sigma^2(u^2+v^2)e^{-2\pi^2\sigma^2(u^2+v^2)}$

1-3	281, Prob. 5.24	. . . is linear and position invariant and show that . . .	. . . is linear and position invariant and that the noise and image are uncorrelated. Show that . . .
All	284, 1st parag., 10th line	In ALL printings, should read: . . . the achromatic notion . . .	
All	286, 2nd parag., 3rd line	In ALL printings, should read: . . . the achromatic notion . . .	
1	294, 5th line from top	. . . CCCCCC …	. . . CCFFFF . . .
1-3	296, four lines from bottom	. . . point is the HSI . . .	. . . point in the HSI . . .
1	299, Eq. (6.2-7)	$G = 1 - (R + B)$	$G = 3I - (R + B)$
1	300, Eq. (6.2-11)	$B = 1 - (R + G)$	$B = 3I - (R + G)$
1	300, Eq. (6.2-15)	$R = 1 - (G + B)$	$R = 3I - (G + B)$
1-3	301, 2nd line from top	. . . Fig. 6.15(d) . . .	. . . Fig. 6.15(c) . . .
1-3	311, 3rd parag, 2nd line	. . . those events our beyond	. . . those events are beyond
1-3	313, 2nd parag., 1st line	In this section be begin . . .	In this section we begin . . .
1-3	321, 2nd line below Eq. (6.5-8)	$(\mathrm{a}_1, \mathrm{a}_2, \quad, a_n)$ . . .	$(a_1, a_2, \quad, a_n)$ . . .
1-3	324, figure caption, 2nd sentence	. . . does not alter the image hues.	. . . does not always alter the image hues significantly.
1-3	328, Eqs. (6.6-1) and (6.6-2)	Variables inside the summation and on the lower limits are shown as (*x*, *y*).	Change (*x*, *y*) to (*s*, *t*) inside the summations and in the lower limits. S_{xy} remains as is.
1-3	343, caption for Fig, 6.51	abcd icons	ab icons (stacked vertically)
1	344, References, 2nd line	Gegenfurtne	Gegenfurtner
1-3	356, line below Eq. (7.1-13)	determinate	determinant
1-3	357, third line from top	determinate	determinant
1-3	357, 2nd line, 2nd paragraph	. . . biorthogonality of the . . .	. . . biorthogonality (defined below) of the. . .
1	359, Table 7.1, 2nd row, 2nd col.	$H_0{}^2(-z)H_0(-z^{-1}) = 2$	$H_0(-z)H_0(-z^{-1}) = 2$
1-3	361, 1st line	. . . transform itself is both separable and symmetric and can be . . .	. . . transform can be . . .
1-3	361, Eq. (7.1-24)	**T = HFH**	$\mathbf{T} = \mathbf{HFH}^T$
1	362, Eq. (7.1-27), Second row, 1st column	2 1 1 1	1 1 1 1
1-3	362, 1st line, last paragraph	. . . we note that Fig. 7.8(a) bears . . .	. . . we note that Fig. 7.8(a) is not the Haar transform of Eqs. (7.1-24)-(7.1-26), but it bears . . .
1-6	383, 2nd line of equation	. . . (2*k* – *l*) . . .	. . . (*l* – 2*k*) . . .
1	391, 3 lines above Example 7.13	. . . functions behave . . .	. . . vectors are used . . .
1-3	396, last and next-to-last lines in the 1st paragraph	in Fig. 7.29. Note the evenly. . . full packet decompositions.	in Fig. 7.29. Note that the "naturally ordered" outputs of the filter bank in Fig. 7.30(a) have been reordered based on frequency content in Fig. 7.30(b) (see Problem 7.25 for more "frequency ordered" wavelets).
1-3	396, Eq. (7.6-5)	$V_J = V_{J-1} \oplus W_{J-1,D} \oplus W_{J-1,AA} \oplus W_{J-1,AD}$	$V_J = V_{J-1} \oplus W_{J-1,A} \oplus W_{J-1,DA} \oplus W_{J-1,DD}$
1-3	397, Figures 7.30(b) and 7.31	Figures 7.30(b) and 7.31 are incorrect.	See corrected figures later in this document.
1-3	399, 2nd line from top	string of *A*'s and *D*'s . . .	string of *A*'s, *H*'s, *V*'s, and *D*'s
1-3	405, Problem 7.9(b), line 1	. . . transform is $\mathbf{F} = \mathbf{H}^{-1}\mathbf{T}\mathbf{H}^{-1}$, where **T** is the Haar transform of	… transform is $\mathbf{F} = \mathbf{H}^T\mathbf{T}\mathbf{H}$, where **T** is the Haar transform of **F**
1-3	405, Problem 7.9(b), line 2	and $\mathbf{H}^{-1}$ denotes the matrix inverse of Haar transformation matrix **H**. Find	and $\mathbf{H}^T$ is the matrix inverse of **H**. Show that $\mathbf{H}_2^{-1} = \mathbf{H}_2^T$
1-3	405, Problem 7.9(b), line 3	$\mathbf{H}_2^{-1}$ for Haar transformation matrix $\mathbf{H}_2$ and use it to compute the inverse	and use it to compute the inverse
1-3	407, Problem 7.25, last line	sions for determining them.	sions for determining them. Then order the basis functions according to frequency content and explain the results.
1-3	433, 2nd paragraph, 4th line	$K^r \leq J^n$	$K^r \geq J^n$
1-3	433, 2nd paragraph, 7th line	. . . equivalent to block encoding . . .	. . . equivalent to encoding . . .
1-3	433, 2nd paragraph, 8th line	. . . binary code words.	. . . 3-bit code words.
1-3	433, 3rd paragraph, 2nd line	formation units per symbol) . . .	formation units per source symbol) . . .

1-3	433, 3rd paragraph, 5th line	. . . is $\log(\varphi/r)$ and . . .	is $r^{-1}\log\varphi$ (information units per code symbol) and . . .
1-3	433, Eq. (8.3-22)	$R = \log\dfrac{\varphi}{r}$	$R = \dfrac{1}{r}\log\varphi$
1-3	457, Eq. (8.4-8)	$\hat{f}_n(x,y) =$	$\hat{f}(x,y) =$
1	472, last paragraph, line 2	… frequently used transformation …	… frequently used transformations …
1-6	499, 1st matrix, row 6 col 6	68	63
1-6	505, 2nd matrix, row 6 col 6 last line in the example	11 5.9	6 5.8
1-3	508, Fig. 8.46, bottom, left subimage	$a_{2HH}(u,v)$	$a_{1LH}(u,v)$
1-6	515, Problem 8.8.	**Q** = [ ].	**Q** = [ ]^T
1-3	526, Fig. 9.6	Square in (a) shows no size. The scale of (c) and (e) is too large.	See corrected image later in this document.
1	531, Fig. 9.11 (caption) (Note that changes are to labels only).	(d) Dilation of the opening. (e) Closing of the opening.	(e) Dilation of the opening. (f) Closing of the opening.
1-3	541, 6th line from bottom. This change corresponds to the revised Fig. 9.21. See comment on pg 542.	. . . B^4.	. . . B^6.
1-3	This change corresponds to the revised Fig. 9.21. See comment on pg 542.	Figure 9.21(k) . . . Fig. 9.21(l) . . .	Figure 9.21(l) . . . Fig. 9.21(m) . . .
1-3	542, Fig. 9.21	Figure 9.21 is incorrect.	See corrected figure later in this document.
1	545, Fig. 9.24, 1st column, 2nd row (remove shading from some of the squares)		
1-6	551, Fig. 9.27	Figure 9.27 is incorrect.	See corrected figure later in this document.
1-6	572, 1st parag, 12th line 572, 2nd parag, last line	in such as way . . . for the sake continuity . . .	in such a way . . . for the sake of continuity . . .
1	573, 11 lines from bottom of page	… would be reversed for an adge …	… would be reversed for an edge …
1-3	575, Fig. 10.7, 3rd column	Incorrect signs for 2nd derivative.	The signs of the 2nd derivatives in the 3rd column of the figure should be as in Fig. 10.6.
1-3	605, Eq. (10-3-13)	. . . + $2\sigma_1^2 2\sigma_2^2$ . . .	. . . + $2\sigma_1^2\sigma_2^2$ . . .
1-3	606, 2nd line from top	continuos	continuous
1-3	612, 6th line from bottom	(e) $P(R_i \cup R_j)$ = FALSE . . .	(e) $P(R_i \cup R_j)$ = FALSE for any adjacent regions R_i and R_j.
1-3	611, 3rd line from top	theresholding	thresholding
1-4	612, 6th line from bottom	(e) $P(R_i \cup R_j) =$ FALSE for $i \neq j$.	(e) $P(Ri \cup Rj) =$ FALSE for any adjacent regions R_i and R_j.
1-4	612, 5th line from bottom	. . . $P(R_i)$ . . . . R_i . . .	Change the sub i to sub k for clarity.
All	621, Fig. 10.45(d)	See below for corrected figure.	
1-3	632, 2nd to last line in Ex. 10.21	. . . the peak at in	. . . the peak at $u_2 = 4$ in
1	640, figure for Prob. 10.23	. . . $(x-a)$ . . .	Replace all x's with z's
1-3	679, end of 10th line from bottom	$\mathbf{C_x}$	$\mathbf{C_y}$
1	687, 3rd line from bottom and going into 1st paragraph of pg. 688	… . Interest in polygonal representation of boundaries (see Section 11.1.2) is considerable because of its usefulness and simplicity. Typical work being done in this area …	… . For a detailed discussion and algorithm to compute minimum-perimeter polygons (Section 11.1.2) see Sklansky et al. [1972]. Typical work on polygonal approximations …
1-3	699, Eq. (12.2-6)	. . . $(\mathbf{m}_i - \mathbf{m}_j)^T(\mathbf{m}_i - \mathbf{m}_j)$	. . . $(\mathbf{m}_i - \mathbf{m}_j)^T(\mathbf{m}_i + \mathbf{m}_j)$
1-3	734, 2nd line below 12.3.2	. . denoted $a_1a_2, \ ,a_n$ and $b_1b_2, \ ,b_m$ . .	. . denoted $a_1a_2 \ \ a_n$ and $b_1b_2 \ \ b_m$ . .
1-3	734, line below Eq. (12.3-5)	. . . of the symbols in a	. . . of the corresponding symbols in a

1-3	734, 9 lines from bottom	. . . the measure *R* for five…	. . . the measure *R* for six…
1-6	784, Index	Gray code, 446	Gary code, 449
1	774, 8th reference from bottom	Shi	Shih
1	318, Fig. 6.31(e) (The two graphs in the bottom, right). (Note that only the labels are changed—the graphs remain the same).	Change to: 	
1-3	397, Fig. 7.30(b)	Change to: 	
1-3	397, Fig. 7.31	Change to: 	

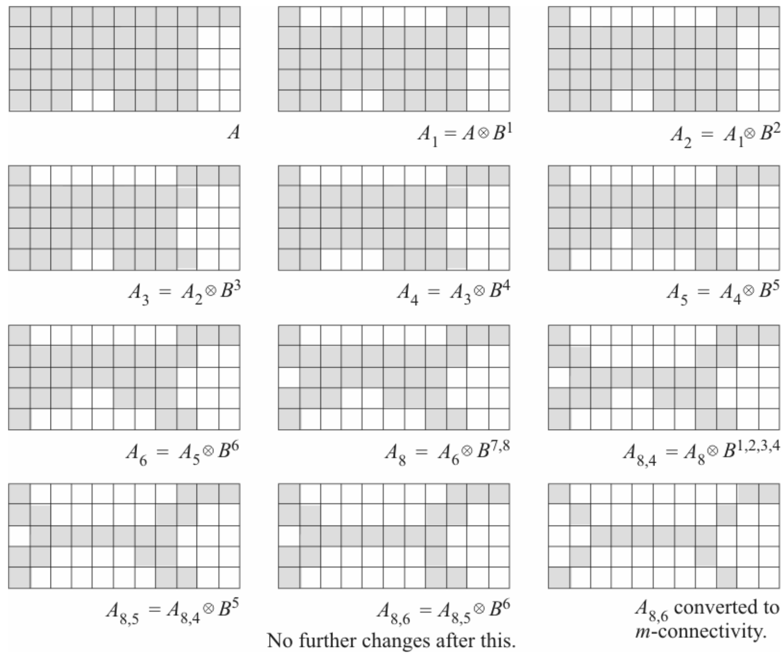
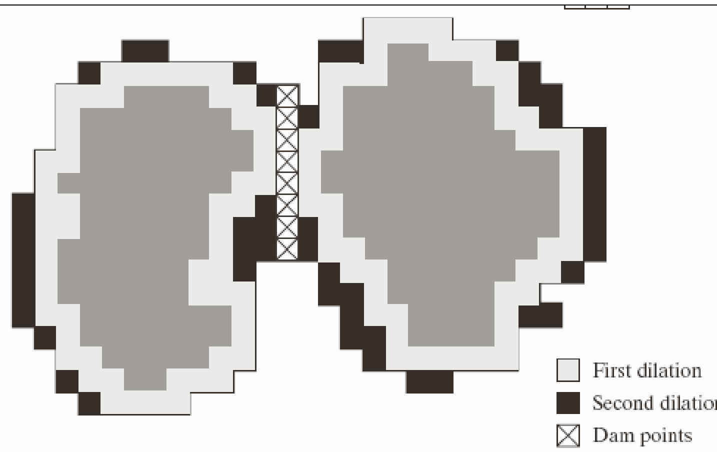
1-3	526, Fig. 9.6	Change to: 
1-6	551, Fig. 9.27	Change to: 

<table>
<tr>
<td>1-3</td>
<td>Page 542

In addition to correcting some errors, the figures below Part (a) in Fig. 9.21 are improved considerably if replaced with the figures shown on the right. Note that the figure captions will run now from (a) through (m), so add another box containing an “m” at the bottom, right of the little icons.

Then, make the following minor changes in the text.

In page 541, Section 9.5.5:
3rd line from the bottom of the last paragraph, change the superscript on B from 4 to 6.
2nd line from the bottom of that same paragraph: Change 9.21(k) to 9.21(l). Change 9.21(l) to 9.21(m).

In page 542, caption of Fig. 9.21, 2nd line from bottom: . . . first element again (there was no change for the next two elements). Change that portion of the 2nd line to: . . . first four elements again.
Last line: Change (k) to (l) and (l) to (m).</td>
<td>
</td>
</tr>
<tr>
<td>All</td>
<td>The figure shows the corrected version of Fig. 10.45. The correction is on the left part of Fig. 10.45(d), in the light gray segment toward the top right.</td>
<td>
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CLARIFICATIONS

1) It has been pointed out to us that the black backgrounds in a few images throughout the book have small white specs. This appears to be a totally random printing problem that affected different images. Generally, the specs are clearly not part of the original images, but there are some cases in

which confusion car arise if the size of the specs are comparable to white dots that are supposed to be there. A good example is Fig. 4.13(c), which consists of 5 symmetrically placed small white dots. Random, small white specs have been known to cause confusion on images like this.

2) Restating the line above Eq. (3.3-21), page 105, in the following way might make it clearer that the objective is to compute the mean value of the gray levels of the pixels in the neighborhood S_{xy}:

. . . the mean gray-level value, $m_{S_{xy}}$, of the pixels contained the neighborhood S_{xy} can be computed using the expression . . .

Also in page 105, replace the material starting at the second line from the bottom, beginning with "The values of this constant. . . and ending on the fourth line on the top of page with k1 < k2," with the following clarification:

Keeping in mind that we are interested in enhancing dark areas, and using the standard deviation as a measure of contrast, we will consider a pixel at point (x, y) to be a candidate for enhancement only if the standard deviation of its neighborhood, $\sigma_{S_{xy}}$, is in the range $k_1 D_G \le \sigma_{S_{xy}} \le k_2 D_G$, where D_G is the global standard deviation, and k_1 and k_2 are positive constants such that $k_1 < k_2$. In other words, $k_1 D_G$ and $k_2 D_G$ are the lower and upper limits of local contrast that determine whether a pixel is a candidate for modification. For example, if we choose $k_2 < 1$, then only pixels whose local contrast is less than the global contrast become candidates for enhancement. The principal function of the lower limit is to prevent constant areas (whose standard deviation is 0) from being modified.

A pixel at (x, y) that meets . . .

3) Page 153-155. Units of frequency.

If $f(x, y)$ is an intensity function, and *x* and *y* are spatial coordinates, then the frequency variables of the Fourier transform represent changes in intensity per units of spatial distance. The units of frequency then are the reciprocal of the units of *x* and *y*, as Equations (4.2-25) and (4.2-26) show.

4) This clarification is in the second paragraph of pg. 204.

The spatial representation, $h(x, y)$, of the filter transfer function, $H(u,v)$, is obtained by taking the inverse DFT of this function. We know from the discussion earlier in this section that periodicity causes four adjacent periods of a DFT to "meet" in the center of the frequency rectangle (see Fig. 4.34). We handled this difficulty by multiplying the function by $(-1)^{x+y}$ before computing its forward transform. We must do exactly the same when computing $h(x, y)$ via the inverse DFT. Failure to do this will yield incorrect convolution results. Even if all filtering is done in the frequency domain, we still need to compute $h(x, y)$ because padding is done in the spatial domain. Thus, to "pad" $H(u,v)$ we must: (1) multiply this function by $(-1)^{u+v}$; (2) compute its inverse Fourier transform to obtain $h(x, y)$; (3) pad this function with zeros; and (4) compute the forward DFT of the padded function to obtain the final representation of $H(u,v)$ that we can use in frequency domain filtering.

Note that we do not multiply $h(x, y)$ by $(-1)^{x+y}$ prior to computing the forward transform because doing so would "undo" the centering of $h(x, y)$. In other words, the convolution theorem tells us that convolution of $h(x, y)$ and $f(x, y)$ is being performed automatically even when the filtering operations are done in the frequency domain. Multiplying $h(x,y)$ by $(-1)^{x+y}$ before computing its forward DFT to obtain our "padded" $H(u,v)$ would undo the original centering obtained when we multiplied $H(u,v)$ by $(-1)^{u+v}$ prior to computing its inverse DFT.

5) Page 351, Caption of Fig. 7.2. Add the following clarifying statement to the end of the figure caption:

Note that all operations, including filtering, downsampling, and upsampling, are two-dimensional.

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CORRECTIONS TO PROBLEM SOLUTIONS

PROBLEM 4.4: The second equation in the problem statement should be revised to

$$h(x,y) = A2\pi\sigma^2 e^{-2\pi^2\sigma^2(x^2+y^2)}$$

We want to show that the inverse Fourier transform of $Ae^{-(u^2+v^2)/2\sigma^2}$ is equal to this function. Rather than doing it as shown in the original problem solution, it will be clearer if we start with one variable and show that, if

$$H(u) = e^{-u^2/2\sigma^2}$$

then

$$\begin{aligned} h(x) &= \Im^{-1}[H(u)] \\ &= \int_{-\infty}^{\infty} e^{-u^2/2\sigma^2} e^{j2\pi ux} du \\ &= \sqrt{2\pi}\sigma e^{-2\pi^2 x^2 \sigma^2}. \end{aligned}$$

We can express the integral in the preceding equation as

$$h(x) = \int_{-\infty}^{\infty} e^{-\frac{1}{2\sigma^2}\left[u^2 - j4\pi\sigma^2 ux\right]} du .$$

We now make use of the identity

$$e^{-\frac{(2\pi)^2 x^2\sigma^2}{2}} e^{\frac{(2\pi)^2 x^2\sigma^2}{2}} = 1.$$

Inserting this identity into the preceding integral yields,

$$\begin{aligned} h(x) &= e^{-\frac{(2\pi)^2 x^2\sigma^2}{2}} \int_{-\infty}^{\infty} e^{-\frac{1}{2\sigma^2}\left[u^2 - j4\pi\sigma^2 ux - (2\pi)^2\sigma^4 x^2\right]} du \\ &= e^{-\frac{(2\pi)^2 x^2\sigma^2}{2}} \int_{-\infty}^{\infty} e^{-\frac{1}{2\sigma^2}\left[u - j2\pi\sigma^2 x\right]^2} du. \end{aligned}$$

Next we make the change of variables $r = u - j2\pi\sigma^2 x$. Then $dr = du$ and the preceding integral becomes

$$h(x) = e^{-\frac{(2\pi)^2 x^2\sigma^2}{2}} \int_{-\infty}^{\infty} e^{-\frac{r^2}{2\sigma^2}} dr .$$

Finally, we multiply and divide the right side of this equation by $\sqrt{2\pi}\sigma$ and obtain

$$h(x) = \sqrt{2\pi}\sigma e^{-\frac{(2\pi)^2 x^2\sigma^2}{2}} \left[\frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{\infty} e^{-\frac{r^2}{2\sigma^2}} dr \right].$$

The expression inside the brackets is recognized as a Gaussian probability density function, whose value from $-\infty$ to ∞ is 1. Therefore,

$$h(x) = \sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 x^2} .$$

With this result as background, we are now ready to show that

$$\begin{aligned} h(x,y) &= \Im^{-1}[Ae^{-(u^2+v^2)/2\sigma^2}] \\ &= A2\pi\sigma^2 e^{-2\pi^2\sigma^2(x^2+y^2)}. \end{aligned}$$

By substituting directly into the definition of the inverse Fourier transform we have:

$$\begin{aligned} h(x,y) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Ae^{-(u^2+v^2)/2\sigma^2} e^{j2\pi(ux+vy)} du dv \\ &= \int_{-\infty}^{\infty} \left[\int_{-\infty}^{\infty} Ae^{(-\frac{u^2}{2\sigma^2} + j2\pi uy)} du \right] e^{(-\frac{v^2}{2\sigma^2} + j2\pi vy)} dv. \end{aligned}$$

The integral inside the brackets is recognized from the previous discussion to be equal to $A\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 x^2}$. Then, the preceding integral becomes

$$h(x,y) = A\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 x^2} \int_{-\infty}^{\infty} e^{(-\frac{v^2}{2\sigma^2} + j2\pi v y)} dv.$$

We now recognize the remaining integral to be equal to $\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 y^2}$, from which we have the final result:

$$\begin{aligned} h(x,y) &= (A\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 x^2})(\sqrt{2\pi}\sigma e^{-2\pi^2\sigma^2 y^2}) \\ &= A2\pi\sigma^2 e^{-2\pi^2\sigma^2(x^2+y^2)}. \end{aligned}$$

PROBLEM 4.15(a): There is a discrepancy in sign between the problem statement and the solution. To be consistent with the problem statement, the solution should start with

$$g(x,y) = f(x+1,y) - f(x,y) + f(x,y+1) - f(x,y) .$$

In practice, one sees both formulations used interchangeably since ultimately we use squares or absolute values, which are independent of the sign used in the definition of the derivative.

PROBLEM 5.3: The images shown in the solution of this problem are incorrect. They should be identical to the ones in PROBLEM 5.5.

PROBLEM 6.16(a): 5th line: Delete the words “the entire”. 6th line: Change 255/360 to 360/255.

PROBLEM 7.9. (a) Equation (7.1-28) defines the 2×2 Haar transformation matrix as

$$\mathbf{H}_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}.$$

Thus, using Eq. (7.1-24), we get

$$\mathbf{T} = \mathbf{HFH}^T = \left(\frac{1}{\sqrt{2}}\right)^2 \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}\begin{bmatrix} 3 & -1 \\ 6 & 2 \end{bmatrix}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = \begin{bmatrix} 5 & 4 \\ -3 & 0 \end{bmatrix}.$$

(b) First, compute

$$\mathbf{H}_2^{-1} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

such that

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

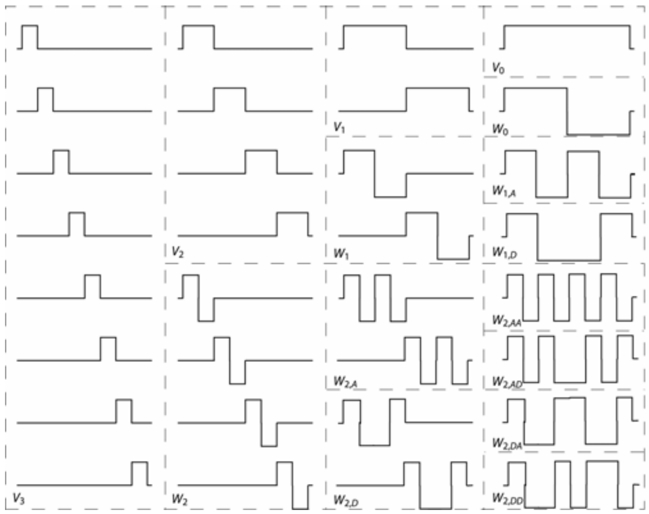
Solving this matrix equation yields

$$\mathbf{H}_2^{-1} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = \mathbf{H}_2^T = \mathbf{H}_2 .$$

Thus,

$$\mathbf{F} = \mathbf{H}^T\mathbf{T}\mathbf{H} = \left(\frac{1}{\sqrt{2}}\right)^2 \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} 5 & 4 \\ -3 & 0 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = \begin{bmatrix} 3 & -1 \\ 6 & 2 \end{bmatrix}.$$

PROBLEM 7.25. The table is completed as follows:



The functions are determined using Eqs. (7.2-18) and (7.2-28) with the Haar scaling and wavelet vectors from Examples 7.5 and 7.6:

$$\varphi(x) = \varphi(2x) - \varphi(2x-1)$$
$$\psi(x) = \varphi(2x) - \varphi(2x-1)$$

To order the wavelet functions in frequency, count the number of transitions that are made by each function. For example, V_0 has the fewest transitions (i.e., only 2) and correspondingly lowest frequency content, while $W_{2,AA}$ has the most (i.e., 9) transitions and correspondingly highest frequency content. From top to bottom in the figure, there are 2, 3, 5, 4, 9, 8, 6, and 7 transitions, respectively. Thus, the frequency ordered subspaces are (from low to high frequency) V_0, W_0, $W_{1,D}$, $W_{1,A}$, $W_{2,DA}$, $W_{2,DD}$, $W_{2,AD}$, and $W_{2,AA}$.