References

Arendt, H., "The conquest of space and the stature of man," in *Between Future and Past*, Penguin, New York (1977a).

Arendt, H., "The concept of history: ancient and modern," in *Between Future and Past*, Penguin, New York (1977b).

Aquinas, T., *Summa Theologica*, *Great Books of the Western World* **19**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1485].

Aristotle, *Physics*, *Great Books of the Western World* **8**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published c. 335 BC].

Augustine, quoted in W. Durant, *The Age of Faith*, Simon and Schuster, New York (1950).

Bacon, F., *Novum Organum*, *Great Books of the Western World* **35**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1620].

Barrett, W., *The Illusion of Technique*, Anchor Books, New York (1979).

Barrett, W., *Death of the Soul*, Anchor Books, New York (1986).

Batchelor, E., A. Loewer, and G. Lahav, "The ups and downs of p53: understanding protein dynamics in single cells," *Nature Review Cancer* **9**, 371–377 (2009).

Bellarmine, R., quoted in G. de Santtillana, *The Crime of Galileo*, University of Chicago Press, Chicago (1955).

Berkeley, G., *Three Dialogues between Hylas and Philonous*, Cosimo, Inc., New York (2008) [originally published 1713].

Berkeley, G., *A Treatise Concerning the Principles of Human Knowledge*, *The Classics of Western Philosophy*, 8th edition, S. M. Cahn, Ed., Hackett Publishing, New York (2012) [originally published 1710].

Bernardo, J., "Reference posterior distributions for Bayesian inference," *J. Royal Statistical Society Series B* **41**, 113–147 (1979).

Bohr, N., in A. Plotnitsky, *Niels Bohr and Complementarity: An Introduction*, Springer Science & Business Media, Berlin (2012).

Braga-Neto, U. M., and E. R. Dougherty, *Error Estimation for Pattern Recognition*, Wiley-IEEE Press, New York (2015).

Bridgman, P. W., *Reflections of a Physicist*, Philosophical Library, New York (1950).

Cicero, *De Natura Deorum*, quoted in W. Durant, *Caesar and Christ*, Simon and Schuster, New York (1944) [written in 45 BC].

Congregation of the Holy Office, quoted in Will and Ariel Durant, *The Age of Reason Begins*, Simon and Schuster, New York (1961) [originally published 1616].

Copernicus, N., *De Revolutionibus Orbium Coelestium*, quoted in W. Durant, *The Reformation*, Simon and Schuster, New York (1957) [originally published 1543].

Cramér, H., *Mathematical Methods of Statistics*, Princeton University Press, Princeton (1945).

Dalton, L., and E. R. Dougherty, "Bayesian minimum mean-square error estimation for classification error—part I: definition and the Bayesian MMSE error estimator for discrete classification," *IEEE Transactions on Signal Processing* **59**, 115–129 (2011).

Dalton, L., and E. R. Dougherty, "Optimal classifiers with minimum expected error within a Bayesian framework—part I: discrete and Gaussian models," *Pattern Recognition* **46**, 1288–1300 (2013).

Dalton, L. A., and E. R. Dougherty, "Intrinsically optimal Bayesian robust filtering," *IEEE Transactions on Signal Processing* **62**, 657–670 (2014).

Dehghannasiri, R., B.-J. Yoon, and E. R. Dougherty, "Optimal experimental design for gene regulatory networks in the presence of uncertainty," *IEEE/ACM Transactions on Computational Biology and Bioinformatics* **14**(4), 938–950 (2015).

Descartes, R., *Meditations on First Philosophy*, Library of Liberal Arts, Prentice Hall, Englewood Cliffs (1951) [originally published 1641].

Descartes, R., quoted in F. Copleston, *A History of Philosophy* **4**, Doubleday, New York (1963).

Devroye, L., L. Györfi, and G. Lugosi, *A Probabilistic Theory of Pattern Recognition*, Springer-Verlag, New York (1996).

Dougherty, E. R., *Random Processes for Image and Signal Processing*, *SPIE/IEEE Series on Imaging Science and Engineering*, SPIE Press, Bellingham, Washington and IEEE Press, New York (1999).

Dougherty, E. R., "Translational science: epistemology and the investigative process," *Current Genomics* **10**(2), 102–109 (2009a).

Dougherty, E. R., "Epistemology and the role of mathematics in translational science," *Festschrift in Honor of Jaakko Astola on the Occasion of his 60th Birthday*, I. Tabus, K. Egiazarian, and M. Gabbouj, Eds., Tampere International Center for Signal Processing, TICSP Series #47 (2009b).

Dougherty, E. R., "Scientific epistemology in the context of uncertainty," *Berechenbarkeit der Welt? Philosophie und Wissenschaft im Zeitalter von Big Data*, M. Ott, W. Pietsch, and J. Wernecke, Eds., Springer, Wiesbaden, Germany (2016).

Dougherty, E. R., and M. L. Bittner, *Epistemology of the Cell: A Systems Perspective on Biological Knowledge*, Wiley-IEEE, New York (2011).

Dougherty, E. R., and I. Shmulevich, "On the limitations of biological knowledge," *Current Genomics* **13**, 574–587 (2012).

Durant, W. *The Age of Faith*, Simon and Schuster, New York (1950).

Einstein, A., *Herbert Spencer Lecture*, Oxford University Press, New York (1933).

Einstein, A., in a letter to Robert A. Thornton, December, 1944 (1944a).

Einstein, A., "Remarks on Bertrand Russell's theory of knowledge," from *The Philosophy of Bertrand Russell*, *The Library of Living Philosophers* **5**, P. A. Schilpp, Ed., Tudor Publishers, Greensboro, North Carolina (1944b).

Einstein, A., "Einstein's reply to criticisms," in *Albert Einstein: Philosopher-Scientist*, from *The Library of Living Philosophers* Series, Cambridge University Press, Cambridge (1949).

Einstein, A., quoted in L. S. Feuer, *Einstein and the Generations of Science*, Transaction Publishers, New Brunswick, New Jersey (1982).

Einstein, A., an undated letter to Maurice Solovine, in *Letters to Solovine*, Carol Publishing Group, New York (1993).

Erigena, J. S., quoted in W. Durant, *The Age of Faith*, Simon and Schuster, New York (1950).

Esfahani, M. S., and E. R. Dougherty, "Incorporation of biological pathway knowledge in the construction of priors for optimal Bayesian classification," *IEEE/ACM Transactions on Computational Biology and Bioinformatics* **11**, 202–218 (2014).

Esfahani, M. S., and E. R. Dougherty, "An optimization-based framework for the transformation of incomplete biological knowledge into a probabilistic structure and its application to the utilization of gene/protein signaling pathways in

discrete phenotype classification," *IEEE/ACM Transactions on Computational Biology and Bioinformatics* **12**, 1304–1321 (2015).

Fauré, A., A. Naldi, C. Chaaouiya, and D. Thieffry, "Dynamical analysis of a generic Boolean model for the control of the mammalian cell cycle," *Bioinformatics* **22**, 124–131 (2006).

Fermilab Today, "Neutrino: Wave or particle?," Nov. 14, 2008, online publication of Fermi National Accelerator Laboratory, http://www.fnal.gov/pub/today/SpecialROWMINOS111408.html (2008).

Feynman, R., *QED The Strange Theory of Light and Matter*, Princeton University Press, Princeton (1985).

Feynman, R., R. B. Leighton, and M. Sands, *The Feynman Lectures on Physics*, Addison Wesley, Boston (1964).

Fisher, R. A., *Statistical Methods for Research Workers*, Oliver and Boyd, Edinburgh (1925).

Galileo, *Dialogues Concerning Two New Sciences*, Dover, New York (1954) [originally published 1638].

Galileo, *Dialogue Concerning the Two Chief World Systems*, Modern Library, New York (2001) [originally published 1632].

Galileo, *Letter to the Grand Duchess Christina of Tuscany*, http://www4.ncsu.edu/~kimler/hi322/Galileo-Letter.pdf (1615).

Galileo, *The Assayer*, http://web.stanford.edu/~jsabol/certainty/readings/Galileo-Assayer.pdf (1623).

Grigoryan, A. M., and E. R. Dougherty, "Design and analysis of robust binary filters in the context of a prior distribution for the states of nature," *Mathematical Imaging and Vision* **11**, 239–254 (1999).

Grigoryan, A. M., and E. R. Dougherty, "Bayesian robust optimal linear filters," *Signal Processing* **81**, 2503–2521 (2001).

Heisenberg, W., quoted in the *Stanford Encyclopedia of Philosophy*, http://plato.stanford.edu/entries/qt-uncertainty/ (2006).

Heisenberg, W., quoted in H. Arendt, "The conquest of space and the stature of man," in *Between Future and Past*, Penguin, New York (1977a,b).

Hobbes, T., *Leviathan*, *Great Books of the Western World* **23**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1651].

Holton, G., *Einstein, History, and other Passions*, Harvard University Press, Cambridge (1996).

Hume, D., *An Enquiry Concerning Human Understanding*, *Great Books of the Western World* **35**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1751].

Hume, D., *A Treatise of Human Nature*, Oxford University Press, Oxford (1951) [originally published 1738].

Imani, M., and U. Braga-Neto, "Particle-based adaptive filtering for large partially observed Boolean dynamical systems," submitted 2016.

Jaynes, E. T., "Information theory and statistical mechanics," *Physical Review Letters* **106**, 620 (1957).

Jaynes, E. T., "Prior probabilities," *IEEE Transactions on Systems Science and Cybernetics* **4**, 227–241 (1968).

Jeans, J. H., *The Mysterious Universe*, Cambridge University Press, Cambridge (1930).

Jeffreys, H., "An invariant form for the prior probability in estimation problems," *Proceedings of the Royal Society of London. Series A: Mathematical and Physical Sciences* **186**, 453–461 (1946).

Kant, I. *Critique of Pure Reason*, 2nd edition, *Great Books of the Western World* **42**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago, 1952 [originally published 1781].

Kant, I., *Critique of Practical Reason*, Courier Corporation, North Chelmsford, Massachusetts (2004) [originally published 1788].

Kant, I., *Critique of Judgment*, Oxford University Press, Oxford (2007) [originally published 1790].

Kant, I., *Prolegomena to Any Future Metaphysics*, Hackett Publishing Company, Indianapolis (1977) [originally published 1783].

Kant, I., quoted in C. Orwin and N. Tarcov, *The Legacy of Rousseau*, University of Chicago Press, Chicago (1997).

Kassam, S. A., and T. I. Lim, "Robust Wiener filters," *Franklin Institute* **304**, 171–185 (1977).

Kauffman, S. A. *The Origins of Order*, Oxford University Press, Oxford (1993).

Kauffman, S. A., "Does science make belief in God obsolete?," John Templeton Foundation, http://www.templeton.org/belief/ (2007).

Kauffman, S. A., "Breaking the Galilean spell," *Edge*, http://www.edge.org/ (2008).

Kline, M., *Mathematics and the Search for Knowledge*, Oxford University Press, Oxford (1985).

Kolmogorov, A., "On the analytical methods of probability theory," *Mathematishe Anallen* **104**, 415–458 (1931).

Kolmogorov, A., "Stationary sequences in Hilbert space," *Bulletin Moscow University—Math.* **2**(6), 1–40 (1941).

Kuznetsov, V. P., "Stable detection when the signal and spectrum of normal noise are inaccurately known," *Telecommunications and Radio Engineering* **30-31**, 58–64 (1976).

Laplace, P.-S., *A Philosophical Essay on Probabilities*, Dover, New York (1953) [originally published 1814].

Layek, R., A. Datta, and E. R. Dougherty, "From biological pathways to regulatory networks," *Molecular BioSystems* **7**, 843–851 (2011).

Locke, J., *An Essay Concerning Human Understanding*, *Great Books of the Western World* **35**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1689].

Lucretius, *De Rerum Natura*, quoted from W. Durant, *Caesar and Christ*, Simon and Schuster, New York (1944) [originally published 56 BC].

Maxwell, J. C., "On Faraday's lines of force," *Transactions of the Cambridge Philosophical Society* **10**, 155–229 (1855).

Maxwell, J. C., "Address to the Mathematical and Physical Sections of the British Association," September 15, 1870, in *The Scientific Papers of James Clerk Maxwell* **2**, Courier Corporation, North Chelmsford, Massachusetts (2003).

Mill, J. S., *A System of Logic, Ratiocinative and Inductive*, University Press of the Pacific, Honolulu (2002) [originally published 1843].

Murphy, J., in E. Schrödinger, *Science Theory and Man*, Dover, New York (1957).

Newton, I., *Mathematical Principles of Natural Philosophy*, *Great Books of the Western World* **34**, R. M. Hutchins and M. J. Adler, Eds., Encyclopedia Britannica, Chicago (1952) [originally published 1687].

Ortega y Gasset, J., *The Revolt of the Masses*, W. W. Norton and Company, New York (1994).

Pascal, B., *Pensées*, Open Road Media, New York (2016) [originally published 1670].

Pascal, B., quoted in W. Barrett, *Death of the Soul*, Doubleday, New York (1986).

Poor, H. V., "On robust Wiener filtering," *IEEE Transactions on Automatic Control* **26**, 531–536 (1980).

Popper, K., *The Logic of Scientific Discovery*, Hutchinson, London (1959).

Qian, X., and E. R. Dougherty, "Effect of function perturbation on the steady-state distribution of genetic regulatory networks: optimal structural intervention," *IEEE Transactions on Signal Processing* **56**, 4966–4975 (2008).

Qian, X., and E. R. Dougherty, "Intervention in gene regulatory networks via phenotypically constrained control policies based on long-run behavior," *IEEE/ACM Transactions on Computational Biology and Bioinformatics* **9**, 123–136 (2012).

Ray, T., "FDA's Woodcock says personalized drug development entering 'long slog' phase," *GenomeWebNews*, Oct. 26 (2011).

Reichenbach, H., *The Rise of Scientific Philosophy*, University of California Press, Berkeley (1971).

Rissanen, J., "A universal prior for integers and estimation by minimum description length," *Annals of Statistics* **11**, 416–431 (1983).

Rousseau, J.-J., *A Discourse upon the Origin and the Foundation of the Inequality Among Mankind*, Internet History Sourcebooks Project, Fordham University, New York (1998) [originally published 1754].

Rousseau, J.-J., *The Social Contract*, Cosimo, New York (2004) [originally published 1762].

Rousseau, J.-J., "Rousseau to Voltaire, 18 August 1756," from *Correspondence Complète de Jean-Jacques Rousseau* **4**, J. A. Leigh, Ed., Geneva (1967) [written in 1756].

Russell, B., "On the notion of cause," *Proceedings of the Aristotelian Society* **13**, 1–26 (1913).

Schopenhauer, A., *The World and Will and Representation*, Dover, New York, (2012) [originally published 1818].

Schrödinger, E., *Science Theory and Man*, Dover, New York (1957).

Schrödinger, E., quoted in W. H. Cropper, *Great Physicists: The Life and Times of Leading Physicists from Galileo to Hawking*, Oxford University Press, Oxford (2004).

Sevencolors.org, http://sevencolors.org/post/hydrogen-atom-orbitals (2009).

Shmulevich, I., and E. R. Dougherty, *Probabilistic Boolean Networks: The Modeling and Control of Gene Regulatory Networks*, SIAM Press, New York (2010).

Smith, S. B., *Introduction to Political Philosophy*, Lecture 20, Yale Courses, New Haven (2008).

Smolin, L., *The Trouble with Physics*, Houghton Mifflin Harcourt, New York (2006).

Tibaldi, C., and R. Knutti, "The use of the multi-model ensemble in probabilistic climate projections," *Philosophical Transactions of the Royal Society A* **365**, 253–275 (2007).

Unamuno, M. de, *Tragic Sense of Life*, Dover, New York (1954).

Whitehead, A. N., quoted in V. Lowe, *Alfred North Whitehead: 1861–1910*, Cambridge University Press, Cambridge (1990).

Wiener, N., *Extrapolation, Interpolation, and Smoothing of Stationary Time* Series, MIT Press, Cambridge (1949).

Wikipedia, https://en.wikipedia.org/wiki/Bohr_model, Bohr model, shared under the Creative Commons Attribution-Share Alike 3.0 Unported license (2007).

Wikipedia, https://en.wikipedia.org/wiki/Double-slit_experiment, Double-slit experiment; electron buildup over time image provided by Dr. Tonomura and shared under the Creative Commons Attribution-Share Alike 3.0 Unported license (2012).

Windelband, W., *A History of Philosophy*, Harper and Brothers, New York (1958).

Yoon, B.-J., X. Qian, and E. R. Dougherty, "Quantifying the objective cost of uncertainty in complex dynamical systems," *IEEE Transactions on Signal Processing* **61**, 2256–2266 (2013).

Index

Age of Reason, 21
al-Ghazali, 16, 17, 28
analysis, 102
Aquinas, Thomas, 16, 17–18, 41, 125
Archimedes, 7, 15
Arendt, Hannah, 8, 125
argument from design, 15
Aristarchus of Samos, 19
Aristotle, 5, 9, 11–17, 21, 23–24, 26, 32, 44, 48, 58, 78–79, 125
asymptotic, 95
Augustine, Saint, 15–18, 34, 46, 125
Averroes, Ibn Rushd, 17
Avicenna, Ibn Sīnā, 16, 17

Bacon, Francis, 1, 7, 21–26, 27, 34–36, 39, 43, 44, 50, 54, 57–58, 72, 83, 125
Bacon, Roger, 18
Barrett, William, 36, 50–51, 53, 94, 125
Bayes classifier, 108
Bayes error, 109
Bayesian error estimate, 115
Bellarmine, Cardinal R., 28–29, 125
Berkeley, George, 40, 42–43, 46, 70, 125
Bernoulli, Jacob, 95
Bohr, Niels, 1, 8, 64–66, 70, 72, 126
Boolean network, 84
Brahe, Tycho, 19
Bridgman, Percy, 71–72, 76, 126

Caccini, Tommaso, 28
categorical imperative, 52
categories of the understanding, 47
Cicero, 15, 126
class-conditional distribution, 108
classification rule, 114
classifier, 108
conceptualist, 13
Constantine, 15
Copenhagen interpretation, 70
Copernicus, Nicolaus, 19–21, 29, 31, 126
cost function, 102
Cramér, Harald, 95, 126

d'Alembert, Jean le Rond, 54
da Vinci, Leonardo, 19
Darwin, Charles, 14, 19
data mining, 91
de Broglie, Louis, 1, 66
Democritus, 11
Descartes, René, 34–37, 41, 54–55, 126
Diderot, Denis, 54
Dini, Piero, 29
double-slit experiment, 64
Duns Scotus, John, 17, 18
Durant, Ariel, 19, 30
Durant, Will, 18–19, 30, 127, 130

effective characteristics, 115
effective class-conditional distribution, 111

effective power spectra, 118
efficient cause, 13
Einstein, Albert, 7, 45, 64, 66, 70, 72, 77–78, 80–82, 95–96, 127
Empedocles, 11, 14
empiricism, 40
epistemology, 6
expected value, 92

Faraday, Michael, 60–61
feature-label distribution, 108
Fermat, Pierre, 36
Feynman, Richard, 68, 74, 128
final cause, 13
Fisher, Ronald, 95, 128
formal cause, 13
forms, 12, 23

Galileo, 1, 7–8, 21, 26–32, 39, 41, 43, 45, 50–51, 57, 59, 72, 73, 83, 99, 128
gene regulatory network, 84
geocentric theory, 19

heliocentric theory, 19
Heisenberg, Werner, 69–71, 128
Hertz, Heinrich, 64
Hilbert, David, 72–73
Hobbes, Thomas, 32, 41, 128
Hume, David, 16, 40, 41–51, 53–54, 56–58, 60, 76, 79, 129
hypothetico-deductive method, 75

idealism, 41
intrinsically Bayesian robust classifier, 111
intrinsically Bayesian robust operator, 106

Jaynes, E. T., 122, 129
Jeans, James, 73
Jeffreys, Harold, 122

Kant, Immanuel,16–19, 25, 26, 36–37, 41, 42, 46–54, 56–58, 72, 79, 83, 129
Kauffmann, Stuart, 84, 97–98, 129
Kepler, Johannes, 20, 29–30, 39
Kline, Morris, 62, 63, 73, 129
Knutti, R., 91–92, 96–97, 132
Kolmogorov, Andrey, 82, 102, 130

Laplace, Pierre-Simon, 33, 50, 58–59, 70, 130
Leibniz, Gottfried Wilhelm, 41–42, 47
Locke, John, 17, 19, 40–42, 46, 130
Lucretius, 14–15
Luther, Martin, 16, 18

macroevolution, 14
material cause, 13
Maxwell, James Clerk, 60–62, 79–80, 94, 130
mean objective cost of uncertainty, 120
mean-square error, 116
microevolution, 14
Mill, John Stuart, 57–59, 130
minimax optimization, 119
minimum mean-square estimate, 92
Murphy, James, 42–43, 130

natural selection, 14
Newton, Sir Isaac, 1, 5, 7, 8, 19–21, 30–33, 39–40, 41, 43, 45, 49, 50, 54, 57, 58, 62–64, 70, 72, 130
Newton's three laws of motion, 30
Nicholas of Cusa, 19
nominalist, 13
noumena, 48

objective cost of uncertainty, 120
Ockham, William of, 18–19
Ockham's razor, 18

ontological argument, 35
operational definitions, 76
optimal Bayesian classifier, 113
optimal Bayesian operator, 112
optimal experimental design, 121
Oresme, Nicole, 19
Ortega y Gasset, José, 6, 55–56, 130
Osiander, Andreas, 20

Pascal, Blaise, 36–37, 130
photoelectric effect, 64
photons, 64
Planck, Max, 64, 66, 69, 82, 96
Planck's constant, 64
Plato, 12–13, 16, 24, 28, 33, 76, 78
Popper, Karl, 75, 130
posterior distribution, 112
power spectral density, 116
primary qualities, 40
prior probability distribution, 106
probabilistic Boolean network, 87
Ptolemy, 19, 39
pure practical reason, 51
pure theoretical (speculative) reason, 48
Pyrrho, 16

quantum jump, 65
quantum states, 65

realist, 13
regression, 92
regression line, 92
Reichenbach, Hans, 8, 60, 77–78, 80, 92, 131
Rousseau, Jean-Jacques, 21, 46, 54–57, 79–80, 131
Russell, Bertrand, 31, 59–60, 87
Rutherford, Ernest, 65–66

sample mean, 90
sample regression line, 92
Schopenhauer, Arthur, 47, 50, 131
Schrödinger, Erwin, 42–43, 46, 68, 74, 81, 97, 131
Schrödinger's wave equation, 68
secondary qualities, 41
Smith, Stephen, 56, 131
Smolin, Lee, 98, 131
Socrates, 12, 13, 27–30, 123
Spinoza, Baruch, 70
steady-state distribution, 103
synthesis, 102

teleological argument, 15
Thales, 11
things-in-themselves, 48
Thomson, J. J., 65
Tibaldi, C., 91–92, 96–97, 132
Tonomura, Akira, 67
transcription, 84
translation, 84
translational science, 101

Unamuno, Miguel de, 53, 132
uncertainty class, 90
uncertainty principle, 69
universal, 13
Urban VIII, Pope, 29

Voltaire, 54, 56

wave function collapse, 70
wave–particle duality, 66
Wiener, Norbert, xiii, 102, 116–119, 132
Wiener filter, 117
Wiener–Kolmogorov theory, 103
Windelband, Wilhelm, 6, 9, 12, 132
Whitehead, Alfred North, 39, 132
Woodcock, Janet, 8, 98

Young, Thomas, 64

Edward R. Dougherty is a Distinguished Professor in the Department of Electrical and Computer Engineering at Texas A&M University in College Station, Texas, where he holds the Robert M. Kennedy '26 Chair in Electrical Engineering and is Scientific Director of the Center for Bioinformatics and Genomic Systems Engineering. He holds a Ph.D. in mathematics from Rutgers University and an M.S. in Computer Science from Stevens Institute of Technology, and has been awarded the *Doctor Honoris Causa* by the Tampere University of Technology in Finland.