Index

Abrahamsen, Adele, 222
advanced potential, 38–39, 41
agency theory, 24–27, 46–48
Ahn, Woo-Kyoung, 113
Albert, David, 79–80, 83
Allison, Henry E., 67
Anjum, Rani Lill, 33
Anscombe, G. E. M., 48
apoptosis, 125, 126–127, 131, 134, 135
Arthur, Brian, 224
assumptions
  causal modeling and, 76
asymmetry
  direction of causation versus, 37–38
  in graphical models, 194
  macroscopic, 82, 83
  of causation, 38, 55, 73
  of overdetermination, 40–41
  source of causal, 83
Au, Yin Chung, 9

backward causation, 7, 22, 27, 34–35, 41, 155
  counterfactuals and, 40
  impossibility of, 34
Bayesian networks, 11, 86
  cognition and, 112
  cycles and, 94–95
  definition, 88
  in psychology, 91–92
  interventions and, 88, 90, 102
  modeling cognition with, 114
Bechlivanidis, Christos, 86, 96
Bechtel, William, 117, 119, 121–123, 222
Beebee, Helen, 50
Bell experiment, 39
Benoit, Kenneth, 145, 152, 153, 155
biological mechanisms, 9
biological pathways
  mechanisms and, 120–123
biology
  causation in, 8
biomedical sciences, 8
Black, Max, 14, 34
Bohm, David, 73
Boltzmann, Ludwig, 44
Bramley, Neil R., 9, 91–93, 96–97, 99–102, 106, 109, 112–114
Bressler, Steven L., 11
Brown, Charlotte R., 50
Bruner, Jerome S., 92
Buehner, Marc J., 93, 96
Burt, Callie Harbin, 167

Cartwright, Nancy, 73–74, 77, 78, 81
causal ancestry, 57
causal asymmetry, *see* asymmetry
causal attribution, 99
causal Bayesian network, *see* Bayesian networks
causal concepts, 82
  asymmetry of, 83
causal connectibility, 55, 59
causal dependence
  estimation of, 215–216
causal dispositionalism, 33
causal identifiability, 189–193
causal inference, 11, 193
  challenges for, 3–4
  continuous variables and, 106
  estimating causal effects, 215–216
  evaluating methods for, 218–220
  methods for, 215

nonstationarity and, 3
structure learning, 216–217
time and, 216
causal innocence thesis, 50, 70
causal judgment
time delays and, 3
causal knowledge
possibility of, 77
causal learning
control and, 110–111
cyclic structures and, 103
dependence of trials in, 93–94
indirect effects and, 109
intervention choice in, 101–103
noise and, 101
causal locality, 120
causal loops, *see* loops
causal Markov condition, 42, 81, 190–191, 203, *see* CMC
counterexamples to, 194, 206
entanglement and, 39
identifiability and, 193
time asymmetry and, 81
causal modeling, 74–76
independence and, 42–43
mechanisms and, 226–230
of continuous-valued variables, 106–109
causal models, 187
limitations of, 214
mechanisms and, 11
temporalizing, 163–166
time free, 158
time in, 187
variables in, 194
causal ordering method, 198
causal pathways, 79
causal processes, 78
theory of causation, 22–24
time and, 20
causal reasoning
domain knowledge and, 113
causal sufficiency, 190
in practice, 120
causal theory of time, 52–54
arguments against, 58–61
physics and, 59
van Fraassen's, 54–56
causality
and dynamical laws, 76
asymmetry of, 55, 73
correlation and, 90
difficulty of defining, 14
direction of time and, 6
in biology, 8
in cell mechanisms, 118–120
instantaneous, 31–34
interventions and, 78
metaphysics of, 77
need for in science, 73
psychology and, 9
symmetry and, 55
without correlation, 43
causes
as strategies, 81
objectivity of, 85
Cheng, Patricia W., 89, 91, 93
child as scientist, 92
children
interventions and causal learning in, 92
Clark, Andy, 105
Coenen, Anna, 92, 93, 102, 112
Coleman's boat, 154
Colyvan, Mark, 61
common cause
time and, 19, 24
common cause principle, 19
computational problems
open, 12
confounding, 145, 215
mechanisms and, 150
conjunctive fork, *see* common cause
conserved quantity exchange
theory of causality, 44–45
Contessa, Gabriele, 117
counterfactual
dependence, 38
theory of causality, 5, 27–29, 51
Cowling, Sam, 61
Cramer, John, 39
Craver, Carl F., 117, 119, 121, 136, 224–227
cycles
interventions and, 102–103

d-separation, 190
Danks, David, 184–185
Darden, Lindley, 117, 119, 121, 224–227
Dash, Denver, 201, 205
Davis, Zachary, 106, 107, 109, 110, 112
Dayan, Peter, 97
de Bal, Inge, 9, 11
De Luca, Jayme, 39

de Souza, Daniel C., 39
decision theory, 26
decision-making, 12
Deverett, Ben, 93
diabetes, 4
Dickinson, Anthony, 96
difference-in-differences, 214
difference-making
  time and, 117
direct causation, 57
direct cause, 75
  interventionist definition of, 30
directed acyclic graph, 57, 75, 188
direction of causation, 52
  asymmetry versus, 37–38
  causal dependence and, 42
  problem definition, 37
direction of time, 52
  Reichenbach's theory of, 6
do calculus, 91
do operator, 45
Dowe, Phil, 7, 19, 22, 78
  causal process theory of, 23–24
Dummett, Michael, 34
Dupré, John, 140
Duverger's laws, 139
Duverger, Maurice, 145
dynamic Bayesian networks, 10
dynamic causal models, 187, 197–206
dynamical laws
  causality and, 74

Earman, John, 58–60
econometric models, 206–211
Edwards, Brian J., 92
Eells, Ellery, 6
Eichler, Michael, 106, 197
Einstein, Albert, 32, 53, 54
eleatic principle, 54, 61
electoral systems, 145–147
entanglement, 39
  Causal Markov Condition and, 39
entropy
  time asymmetry and, 80
epidemiology, 8
epistemology
  of causality, 6
EPR paradox, 32
equilibration, 205
evaluation
  of causal inference, 218–220
Evans, Peter W., 39
explanation
  of causation, 214

faithfulness condition, 42, 43
  violations of, 43
Faye, Jan, 34, 35
Fedorov, Valerii Vadimovich, 91, 112
feedback loop, 108
Fernbach, Philip M, 97, 109
Feynman, Richard P., 38, 39, 41
Field, Hartry, 74
fMRI, 11
free will, 46
free will variables, 46
Friedman, William, 68
Frisch, Mathias, 41, 80–81
Frosch, Caren A., 96
Futch, Michael J., 52, 53

genidentity, 54
Gerstenberg, Tobias, 87, 92
Giere, Ronald, 141
Gijsbers, Victor, 7
Glennan, Stuart, 8, 119, 151
Glymour, Clark, 10, 20, 158–159, 172, 185–186
Goodman, Noah D., 233
Gopnik, Alison, 86, 93
Grünbaum, Adolf, 54
Granger causality, 10, 106, 197
Granger, Clive W., 10, 86, 106
graphical models, 10, 168, 188, 215–217
  intervention and, 217
  mechanisms and, 228
  relational, 231–232
  time and, 191, 194
Greville, W. James, 93, 96
Grice, G. Robert, 96
Griffiths, Thomas L., 91, 105, 106, 113
Gureckis, Todd M., 92, 93, 102, 110, 112, 113

Haggard, Patrick, 96
Hagmayer, York, 91, 96
Hall, Ned, 119, 120, 124
Halpern, Joseph Y., 103
Hausman, Daniel, 41, 42
  operationalizing assumption, 43–44
Hill's considerations, 8
Hill, Austin Bradford, 8
history of physics
  causality in, 73–74
Hitchcock, Christopher, 74, 133, 191, 195

Hoefer, Carl, 58
Holyoak, Keith J., 91
Honavar, Vasant, 232
Hoover, Kevin, 206, 207, 209
Huemer, Michael, 32–34
Hume, David, 5, causal theory of, 67
  definition of cause, 5, 15–16, 49
  on direction of causation, 38
  on temporal priority, 5, 49–51
Humphreys, Gruffydd R., 96

identifiability
  causal Markov condition and, 193
Illari, Phyllis, 13, 18, 25, 30, 35, 117, 119, 137, 157, 222, 223, 227
instantaneous causation, 31–34
instrumental variables, 216
interdisciplinarity
  need for, 12
interrupted time-series analysis, 216
interventions, 45, 192
  agency and, 46
  Bayesian networks and, 86
  causal learning and, 101–102
  causal learning in children and, 92
  causality and, 88
  cycles and, 102–103
  direction of causation and, 45
  hypotheses and, 90
  preventative, 104
  quantiyfing the value of, 90–91
  theory of causation, 29–31
  time asymmetry and, 82
  timing of, 94, 102
INUS conditions, 21–22
Ismael, Jenann, 7
Iwasaki, Yumi, 187, 197, 205

Jensen, David, 11, 232
Jolly, Alison, 92
Jordan, Michael I., 105
Jung, Carl, 61

Kalish, Michael L., 106, 113
Kalogeras, Jeri, 96
Kant, Immanuel, 51, 63, 67
  second analogy of, 64–65
Keil, Frank C., 93, 94
Kemp, Charles, 92–93
Kirby, James B., 143, 150, 156
Kline, Rex, 159
Kominsky, Jonathan F, 87
Kovitz, Ben, 32
Kushnir, Tamar, 92, 93
Kutach, Douglas, 84

Lacey, Hugh M., 58
Lagnado, David A., 3, 91–93, 96, 104, 105
Lake, Brenden M., 113, 234
laws of motion, Newtonian, 79
Lee, Sanghack, 232
Leibniz, Gottfried W., 52, 53, 56
Leuridan, Bert, 7
Lewis, David, 5, 77
  counterfactual theory of, 27–29, 51
  on backward causation, 40
  on causal asymmetry, 38
  on the mind, 44
Livengood, Jonathan, 9, 195
Lodewyck, Thomas, 7
loops
  causal, 56
  temporal, 59
  token causal, 38
Lucas, Christopher G., 92

Machamer, Peter, 8, 222
Mackie, John Leslie, 6
  INUS conditions, 21–22
Maier, Marc, 232, 235
Marazopoulou, Katerina, 232, 235
mark transmission, 20, 22
Markov equivalence, 42, 90
  time and, 45
Marom, Shimon, 122, 123
Martignon, Laura, 91
Maudlin, Tim, 48
Maxwell, James C., 44
May, Jon, 96
Mayr, Ernst, 8
Mayrhofer, Ralf, 91
McCormack, Teresa, 92, 93, 96
McGregor, Stuart, 96
mechanisms, 8, 113
  biological pathways and, 120–123
  causal modeling and, 226–230
  defining, 221–225
  definition of, 151
  diagrams of, 136
  in causal models, 11, 214
  probabilistic programming and, 232–234
  scale and, 117
  social, 151–152
  time and, 117–118, 225

mechanistic evidence, 152
  in social sciences, 151
Mehlberg, Henry, 53
memory
  and time, 67, 68
mental causation, 44
Menzies, Peter, 17, 44
  agency theory of, 24–27, 46–48
metaphysics
  causal, 77, 83
  direction of causation and, 37
  of causality, 6
Michotte, Albert, 49
Mill, John Stuart, 14
  regularity theory of, 16–17
Mitchell, Sandra D., 122
Morris, William Edward, 50
Mumford, Stephen, 33
Murphy, Kevin, 10
mutual dependence thesis, 52, 63, 65

necessary connection, 16
Nelson, Jonathan D, 112
neuroscience, 7
Newton, Isaac, 73
  laws of motion, 79
nonstationarity, 3, 206–208
  causal inference and, 3
  causal models and, 188
  example, 209
Novick, Laura R., 93

Ornstein, Leonard S., 106, 111
Ornstein-Uhlenbeck process, 106
overdetermination
  asymmetry of, 40–41

Pacer, Michael D., 105, 106
past hypothesis, 80
pathways
  causal, 79
Patrick, Fiona, 92, 93, 96
Pearl, Judea, 10, 42, 45, 57, 74, 75, 86, 88, 90, 188, 190, 215, 216, 229
  do calculus, 91
perception, 69
  causality and, 49
  of causality, 49
  of time in biology, 118
  of timing, 2, 123, 128
  time and, 64
perspectivalism, 48
Peterson, F. Ryan, 167
philosophical anthropology, 47
physical laws
  causal asymmetry and, 9
  causality and, 73, 76
  temporal asymmetry and, 79
physics
  causal asymmetry in, 73
  causal theory of time and, 59
  causality in history of, 73–74
  time and, 60
Piaget, Jean, 92
political science, 9
possible worlds
  similarity of, 40, 51
post hoc ergo propter hoc, 2
potential outcomes framework, 215
preemption
  time delays and, 100
Price, Huw, 7, 17, 44, 77, 79, 84, 85
  agency theory of, 24–27, 46–48
probabilistic programs, 232–234
propensity score models, 216
prospective studies, 141
psychology
  Bayesian networks in, 91–92
  causality in, 9
public health, 8

quantum entanglement, 32
quantum mechanics, 39, 83
  simultaneous causation in, 32
quasi-experimental designs, 215, 216

randomized trials, 140
regression discontinuity, 216
regularity
  definition of causality, 5
  direction of causation and, 38
  theory of causation, 15–16
Rehder, Robert E., 93, 95
Reichenbach, Hans, 6, 54, 77, 79
  on asymmetry, 55–56
  theory of time, 17–20
relational models, 231–232
relativity
  general, 59–60
  special, 53
Rescorla, Robert A., 91
retrocausality, 39, 69, *see* backward causation
retrospective studies, 141–142
Rips, Lance J., 92

Ross, Lauren N., 121
Rothe, Anselm, 91
Rottman, Benjamin M., 87, 93, 94, 105, 106
Rumelhart, David E., 105
Russell, Bertrand, 22, 23, 73, 78, 85
Russo, Federica, 18, 25, 30, 35

Salakhutdinov, Ruslan, 113, 234
Salmon, Wesley, 22, 24, 77
  causal process theory of, 22–24
sample granularity, 3
Scheines, Richard, 10, 20, 172
Schlottmann, Anne, 2, 96
Schulz, Eric, 106
Schulz, Laura E., 92, 93
second law of thermodynamics, 44
Seth, Anil K., 11
Shanks, David R., 3, 96
Shannon, Claude E., 91
Simon, Herbert A., 187, 197, 205
Simons, Leslie Gordon, 167
simultaneity
  in graphical models, 195
  interpreting, 195–196
  of measurements, 149
simultaneous causation, 12, 27
  in quantum mechanics, 32
simultaneous equation models, 187
Sloman, Steven A., 3, 72, 91–93, 96, 97, 104, 109
Smart, John JC, 58–61
Smith, Nicholas J. J., 49
Sobel, David M., 92, 93
Sober, Elliott, 206–207
social sciences, 9, 197
  causal inference in, 138
  confounding in, 139
Soo, Kevin W., 105, 106
spatial contiguity, 16
special relativity
  topological simultaneity in, 55
Speekenbrink, Maarten, 96, 105
Spirtes, Peter, 10, 42, 74, 165, 173, 185, 188, 215, 216
stationarity, 187
Steel, Daniel, 138, 145, 146
Stephan, Simon, 99–100
Steyvers, Mark, 91, 92
Strawson, Peter, 66–67
Strotz, Robert H., 159, 196
structural equation models, 188
Suppes, Patrick, 6
surrogative reasoning, 117
survey data
  time and, 169–171
Swoyer, Chris, 117
Sylva, Kathy, 92
synchronicity, 61–63

temporal asymmetry, 6, 78–82
temporal judgments
  causality and, 69
temporal order
  defining, 17–20
  epistemology of, 67
temporal perception
  causal judgment and, 2
temporal priority, 5, 6, 15, 16, 159
temporal skepticism, 69
temporalization
  of causal models, 163–166
Tenenbaum, Joshua B., 87, 91, 113
theory of causation
  agency based, 24–27
  causal process, 22–24
  counterfactual, 27–29
  interventionist, 29–31
  INUS conditions, 21–22
theory of time
  physics and, 59
thermodynamics
  causality and, 79–81
  second law of, 44
Timberlake, Michael, 172
time
  as a heuristic, 2
  causal inference and, 3–4
  causal theory of, 52–54
  definition of causality and, 6
  interventions and, 124, 197
  memory and, 67, 68
  metaphysics and, 7
  perception of, 123
  survey data and, 170–171
  variable aggregation and, 176
  variable definition and, 160
time and causality
  epistemology of, 67
  mutual dependence of, 52, 63, 65, 70

time delay
  causal judgment and, 3
  causal learning and, 96–97
time series
  causal inference in, 86
  in biology, 117
time travel, 38, 49
token causality, 1, 37
  asymmetry and, 37
  loops, 38
  time delays and, 99
topological simultaneity, 55
transcendental idealism, 52, 66, 67
transitivity, 133
type-level causality, 1, 37, 75

Uhlenbeck, George E., 106, 111
uncertainty, 5

Valsiner, Jaan, 92
van Fraassen, Bas, 54, 60
  causal theory of time , 54–56
variables
  aggregated over time, 176
  changing definition of, 4
  derivatives as, 201
  time and, 160, 195
virtual interventions, 91

Wagenmakers, Eric-Jan, 91, 92
Wagner, Allan R, 91
Waldmann, Michael R., 91, 93, 96
Wallace, David, 81
Wang, Hsiu-Yun, 137
Weber, Erik, 9, 11
Weinberger, Naftali, 11
Wheeler, John A., 38
Williams, Joseph, 106, 113
Williams, Kirk R., 172
Williamson, Jon, 119, 222, 223, 227
Wiseman, Howard M., 47
Wold, Herman OA., 159, 196
Wolfe, John B., 96
Woodward, James, 25, 45, 72, 75, 85, 86, 88, 146
  interventionist theory of, 29–31

Yang, Bei-Chang, 137

Zwart, P.J., 56
Zwier, Karen R., 9, 195