

author2un=0,uniquepart=base,hash=b9a95b2bf7ae9a32128a7ce471a4b27ffamily=Aitchison, familyi=A., given=Laurence, giveni=L., givenun=0un=0,uniquepart=base,hash=a561257682f27ac01b933e0829dc
ily=Lengyel, familyi=L., given=Máté, giveni=M., givenun=0 author
thor6un=0,uniquepart=base,hash=b9a95b2bf7ae9a32128a7ce471a4b27ffamily=Aitchison, familyi=A., given=Laurence, giveni=L., givenun=0un=0,uniquepart=base,hash=dcc2f0b795dad2e1fa3e59d368274
family=Jegminat, familyi=J., given=Jannes, giveni=J., givenun=0un=0,uniquepart=base,hash=76bbe67f6c7
ily=Menendez, familyi=M., given=Jorge Aurelio, giveni=J. A., givenun=0un=0,uniquepart=base,hash=89fbe
ily=Pfister, familyi=P., given=Jean-Pascal, giveni=J.-P., givenun=0un=0,uniquepart=base,hash=330aaa964
ily=Pouget, familyi=P., given=Alexandre, giveni=A., givenun=0un=0,uniquepart=base,hash=5d03d7d07ef2c
ily=Latham, familyi=L., given=Peter E, giveni=P. E., givenun=0 author
thor1un=1,uniquepart=given,hash=a52d97a4ce02b823196e8f9337e32c7ffamily=Amari, familyi=A., given=S-I, giveni=S.-I., givenun=1 author2un=0,uniquepart=base,hash=fe4f349b8031006e05f4bcb
ily=Andersen, familyi=A., given=R A, giveni=R. A., givenun=0un=0,uniquepart=base,hash=3b23e62bcd86a
ily=Mountcastle, familyi=M., given=V B, giveni=V. B., givenun=0 author
thor1un=0,uniquepart=base,hash=a2dfd34f44e4f4a19a3f24f036718170family=Angus Silver, familyi=A. S., given=R, giveni=R., givenun=0 author4un=0,uniquepart=base,hash=ddaae-
bacbb7231220965cb0706f1ed80family=Batista, familyi=B., given=C A S, giveni=C. A. S., givenun=0un=0,uniquepart=base,hash=81bccbadb2e6d169b13256568b95cd43family=Viana, fami-
lyi=V., given=R L, giveni=R. L., givenun=0un=0,uniquepart=base,hash=e32b9bd87639e50405444cb06fd8d4
ily=Lopes, familyi=L., given=S R, giveni=S. R., givenun=0un=0,uniquepart=base,hash=235df9f1052c7596b6
ily=Batista, familyi=B., given=A M, giveni=A. M., givenun=0 author
thor3un=0,uniquepart=base,hash=dc12bb6ec9059f9728ad6185de93996cfamily=Berkes, familyi=B., given=Pietro, giveni=P., givenun=0un=0,uniquepart=base,hash=cc62f095df458fd7811830a7ceadd6a6
ily=Turner, familyi=T., given=Richard, giveni=R., givenun=0un=0,uniquepart=base,hash=503921f59e2589d
ily=Fiser, familyi=F., given=Jozsef, giveni=J., givenun=0 author3un=0,uniquepart=base,hash=9b
ily=Bienenstock, familyi=B., given=E L, giveni=E. L., givenun=0un=0,uniquepart=base,hash=818261d37b6
ily=Cooper, familyi=C., given=L N, giveni=L. N., givenun=0un=0,uniquepart=base,hash=5e75a8192cb1730
ily=Munro, familyi=M., given=P W, giveni=P. W., givenun=0 author
thor2un=0,uniquepart=base,hash=7a92f9684ac04da1253e2443f75c9682family=Bliss, familyi=B., given=T V, giveni=T. V., givenun=0un=0,uniquepart=base,hash=05e8d9ad7ef06dcc9278704079adb9f5fam-
ily=Lomo, familyi=L., given=T, giveni=T., givenun=0 author3un=0,uniquepart=base,hash=b7b6
ily=Blohm, familyi=B., given=Gunnar, giveni=G., givenun=0un=0,uniquepart=base,hash=bc19386e95fe007
ily=Kording, familyi=K., given=Konrad P, giveni=K. P., givenun=0un=0,uniquepart=base,hash=c3839311c6
ily=Schrater, familyi=S., given=Paul R, giveni=P. R., givenun=0 author
thor2un=0,uniquepart=base,hash=62f3d84ab65921425e1ff6c5bbd34301family=Brito, familyi=B.,

given=Carlos S N, giveni=C. S. N., givenun=0un=0,uniquepart=base,hash=6b2c6d8dbc66b301f2a7077d805f0
ily=Gerstner, familyi=G., given=Wulfram, giveni=W., givenun=0 au-
thor4un=0,uniquepart=base,hash=1565ce82971194591b5780f8588fcc3afamily=Buesing, fami-
lyi=B., given=Lars, giveni=L., givenun=0un=0,uniquepart=base,hash=852500bedd14271687798be54db1677f
ily=Bill, familyi=B., given=Johannes, giveni=J., givenun=0un=0,uniquepart=base,hash=46903af2a234346e2
ily=Nessler, familyi=N., given=Bernhard, giveni=B., givenun=0un=0,uniquepart=base,hash=1b7071d23a59f
ily=Maass, familyi=M., given=Wolfgang, giveni=W., givenun=0 au-
thor3un=0,uniquepart=base,hash=5bad658a1393eb641ed95bd9bf9a80b0family=Carreira-Perpiñán,
familyi=C.-P., given=Miguel A, giveni=M. A., givenun=0un=0,uniquepart=base,hash=e524c8fded6bec50dd7
ily>Lister, familyi=L., given=Richard J, giveni=R. J., givenun=0un=0,uniquepart=base,hash=ca92b00cb695
ily=Goodhill, familyi=G., given=Geoffrey J, giveni=G. J., givenun=0 au-
thor3un=0,uniquepart=base,hash=f412fd5f68ed7387ee03ecb61ca935e8family=Cavallari, fami-
lyi=C., given=Stefano, giveni=S., givenun=0un=0,uniquepart=base,hash=ee00f1b90e13007c277094549628bb
ily=Panzeri, familyi=P., given=Stefano, giveni=S., givenun=0un=0,uniquepart=base,hash=59aedd2a09f6114
family=Mazzoni, familyi=M., given=Alberto, giveni=A., givenun=0 au-
thor3un=0,uniquepart=base,hash=8bb790a058340a50476d8e761688f639family=Chik, familyi=C.,
given=D T W, giveni=D. T. W., givenun=0un=0,uniquepart=base,hash=5fdbafb86d8e1cbadba0fbf1dffca4943f
ily=Coombes, familyi=C., given=S, giveni=S., givenun=0un=0,uniquepart=base,hash=121e3f90903affb798d6
ily=Wang, familyi=W., given=Z D, giveni=Z. D., givenun=0 au-
thor2un=0,uniquepart=base,hash=d1bb6d91ebdfc349d4a29e625c478a2cfamily=Connor, fami-
lyi=C., given=J A, giveni=J. A., givenun=0un=0,uniquepart=base,hash=5811ac86a02dbf9616689084972e728
ily=Stevens, familyi=S., given=C F, giveni=C. F., givenun=0 au-
thor3un=0,uniquepart=base,hash=d1bb6d91ebdfc349d4a29e625c478a2cfamily=Connor, fami-
lyi=C., given=J A, giveni=J. A., givenun=0un=0,uniquepart=base,hash=737bbb8ae41a2c2dfe741b1dbf03e64
ily=Walter, familyi=W., given=D, giveni=D., givenun=0un=0,uniquepart=base,hash=4b271614a1867ccfe542
ily=McKown, familyi=M., given=R, giveni=R., givenun=0 au-
thor2un=0,uniquepart=base,hash=2adf3021085e9f8b64cd83f04af3b72cfamily=Cooper, familyi=C.,
given=Leon N, giveni=L. N., givenun=0un=0,uniquepart=base,hash=35509afc68cfdc5711f0cc71d6db333dfam
ily=Bear, familyi=B., given=Mark F, giveni=M. F., givenun=0 au-
thor3un=0,uniquepart=base,hash=2adf3021085e9f8b64cd83f04af3b72cfamily=Cooper, familyi=C.,
given=Leon N, giveni=L. N., givenun=0un=0,uniquepart=base,hash=de5a9ba79d54c96e0c0a319b6aeb02cb-
family=Lieberman, familyi=L., given=Fishel, giveni=F., givenun=0un=0,uniquepart=base,hash=d2ed0997ec1
ily=Oja, familyi=O., given=Erkki, giveni=E., givenun=0 author4un=0,uniquepart=base,hash=0f02
ily=Cuntz, familyi=C., given=Hermann, giveni=H., givenun=0un=0,uniquepart=base,hash=4b81ed62ac4ac8
ily=Forstner, familyi=F., given=Friedrich, giveni=F., givenun=0un=0,uniquepart=base,hash=bae6200a7c7df

ily=Borst, familyi=B., given=Alexander, giveni=A., givenun=0un=0,uniquepart=base,hash=0eafa374d00d9e
 ily=Häusser, familyi=H., given=Michael, giveni=M., givenun=0 author1un=0,uniquepart=base,hash=51ab2490f36423c1b7047b3e1031246dfamily=Das, familyi=D.,
 given=Aniruddha, giveni=A., givenun=0 author2un=0,uniquepart=base,hash=ef0afbe0b4e15059c
 ily=Dayan, familyi=D., given=Peter, giveni=P., givenun=0un=0,uniquepart=base,hash=9fa6a891808f87d1e3
 ily=Abbott, familyi=A., given=Laurence F, giveni=L. F., givenun=0 author4un=0,uniquepart=base,hash=5a4a0fbe092daa29f1deebda89840ccbfamily=Deger, familyi=D.,
 given=Moritz, giveni=M., givenun=0un=0,uniquepart=base,hash=eb14f1985bed361a0e0522291cb6ce38fam-
 ily=Helias, familyi=H., given=Moritz, giveni=M., givenun=0un=0,uniquepart=base,hash=9664842afb007172
 ily=Boucsein, familyi=B., given=Clemens, giveni=C., givenun=0un=0,uniquepart=base,hash=b2f53c7f6e46d
 ily=Rotter, familyi=R., given=Stefan, giveni=S., givenun=0 author3un=0,uniquepart=base,hash=dd996621f2f152728a5bb3adc84729fafamily=Destexhe, fami-
 lyi=D., given=A, giveni=A., givenun=0un=0,uniquepart=base,hash=338c9d8a9fcfe5c74f6f8ed47ba1517bfam-
 ily=Mainen, familyi=M., given=Z F, giveni=Z. F., givenun=0un=0,uniquepart=base,hash=84f9dc1728c921fb
 ily=Sejnowski, familyi=S., given=T J, giveni=T. J., givenun=0 author2un=0,uniquepart=base,hash=9a1295a8d398c8b29a5dd0d7d03f17fbfamily=Dodla, familyi=D.,
 given=Ramana, giveni=R., givenun=0un=0,uniquepart=base,hash=2e33d9b4e019e474e0f284b5744bf0f6fam-
 ily=Rinzel, familyi=R., given=John, giveni=J., givenun=0 author4un=0,uniquepart=base,hash=a861030883af95ccaf9ef44ebffa8716family=Dordek, familyi=D.,
 given=Yedidiah, giveni=Y., givenun=0un=0,uniquepart=base,hash=07b30cf03223931cc6e46fff4b5b42e4fam-
 ily=Soudry, familyi=S., given=Daniel, giveni=D., givenun=0un=0,uniquepart=base,hash=a9cf89650dd0e179
 ily=Meir, familyi=M., given=Ron, giveni=R., givenun=0un=0,uniquepart=base,hash=034dd18bf3c7815bb71
 ily=Derdikman, familyi=D., given=Dori, giveni=D., givenun=0 author2un=0,uniquepart=base,hash=1e4e498cbe51acc9961a087b732b2714family=Dudek, fami-
 lyi=D., given=S M, giveni=S. M., givenun=0un=0,uniquepart=base,hash=89194e81c97d742b41876333e2b182
 ily=Bear, familyi=B., given=M F, giveni=M. F., givenun=0 author2un=0,uniquepart=base,hash=d0cc3bd390785b9edf80dd933ac556a2family=Durbin, fami-
 lyi=D., given=R, giveni=R., givenun=0un=1,uniquepart=given,hash=f6ed2c92da3c0449b770255d07807565fa
 ily=Willshaw, familyi=W., given=D, giveni=D., givenun=1 author2un=0,uniquepart=base,hash=517afe729b2eb59735ba80628d943bb0family=Durbin, fami-
 lyi=D., given=Richard, giveni=R., givenun=0un=0,uniquepart=base,hash=68624c959c638f6b14013aa431a34
 ily=Mitchison, familyi=M., given=Graeme, giveni=G., givenun=0 author3un=0,uniquepart=base,hash=898f4573f0506196f6a5814b599bd9fafamily=Echeveste, fami-
 lyi=E., given=R, giveni=R., givenun=0un=0,uniquepart=base,hash=4ef386b10e14d7a7cc1c20a1f756a0fb-
 family=Hennequin, familyi=H., given=G, giveni=G., givenun=0un=0,uniquepart=base,hash=e63a4a2bd274f

ily=Lengyel, familyi=L., given=M, giveni=M., givenun=0 author4un=0,uniquepart=base,hash=e491
 ily=Echeveste, familyi=E., given=Rodrigo, giveni=R., givenun=0un=0,uniquepart=base,hash=b9a95b2bf7ae
 ily=Aitchison, familyi=A., given=Laurence, giveni=L., givenun=0un=0,uniquepart=base,hash=e4267c6957f0
 ily=Hennequin, familyi=H., given=Guillaume, giveni=G., givenun=0un=0,uniquepart=base,hash=a56125768
 ily=Lengyel, familyi=L., given=Máté, giveni=M., givenun=0 au-
 thor1un=0,uniquepart=base,hash=a393faea2aeda01035eb54ef115e5316family=Fitzhugh, fami-
 lyi=F., given=R, giveni=R., givenun=0 author1un=0,uniquepart=base,hash=d5f139228c01bc378e
 ily=FitzHugh, familyi=F., given=Richard, giveni=R., givenun=0 au-
 thor2un=0,uniquepart=base,hash=9d465a7d0ea099006b8568ba523b2fecfamily=Flash, familyi=F.,
 given=T, giveni=T., givenun=0un=0,uniquepart=base,hash=cc932b13dba8154f485e5b0db13bbacd-
 family=Hogan, familyi=H., given=N, giveni=N., givenun=0 au-
 thor3un=0,uniquepart=base,hash=89eb03d502044800717976c087d50541family=Franzius, fami-
 lyi=F., given=Mathias, giveni=M., givenun=0un=0,uniquepart=base,hash=ce2435f6d35f9dc4e40f0b2cfdd30c
 ily=Sprekeler, familyi=S., given=Henning, giveni=H., givenun=0un=0,uniquepart=base,hash=1a32a99893f7c
 ily=Wiskott, familyi=W., given=Laurenz, giveni=L., givenun=0 au-
 thor6un=0,uniquepart=base,hash=9eb211438d70b6418778e34d7353df12family=George, fami-
 lyi=G., given=Tom M, giveni=T. M., givenun=0un=0,uniquepart=base,hash=9e9c2c20bb7473502e25f1c5b26a
 ily=Rastogi, familyi=R., given=Mehul, giveni=M., givenun=0un=0,uniquepart=base,hash=18efd0c93709fba
 ily=Cothi, familyi=C., given=William John, giveni=W. J., givenun=0, prefix=de, prefixi=d., pre-
 fixun=0un=0,uniquepart=base,hash=326600b0ad340d8e0cd5df377b62e046family=Clopath, fami-
 lyi=C., given=Claudia, giveni=C., givenun=0un=0,uniquepart=base,hash=2270062cd55c887966fece35c0101a
 ily=Stachenfeld, familyi=S., given=Kimberly, giveni=K., givenun=0un=0,uniquepart=base,hash=a617add32
 ily=Barry, familyi=B., given=Caswell, giveni=C., givenun=0 au-
 thor2un=0,uniquepart=base,hash=0b3943c3bfdbb5867b3760f7c7d488c2family=Glorot, fami-
 lyi=G., given=Xavier, giveni=X., givenun=0un=0,uniquepart=base,hash=40a8e4774982146adc2688546f54efb
 ily=Bengio, familyi=B., given=Yoshua, giveni=Y., givenun=0 au-
 thor4un=0,uniquepart=base,hash=33b345fe2eba33ea425db0fd35f15ea2family=Goldwyn, fami-
 lyi=G., given=Joshua H, giveni=J. H., givenun=0un=0,uniquepart=base,hash=1132bfd1b07fa62d9c15f32bcae
 ily=Slabe, familyi=S., given=Bradley R, giveni=B. R., givenun=0un=0,uniquepart=base,hash=fff8808c2719d
 ily=Travers, familyi=T., given=Joseph B, giveni=J. B., givenun=0un=0,uniquepart=base,hash=2bba44c6524
 ily=Terman, familyi=T., given=David, giveni=D., givenun=0 au-
 thor1un=0,uniquepart=base,hash=ca92b00cb695312b6d6247c06818d514family=Goodhill, fami-
 lyi=G., given=Geoffrey J, giveni=G. J., givenun=0 author1un=0,uniquepart=base,hash=ca92b00c
 ily=Goodhill, familyi=G., given=Geoffrey J, giveni=G. J., givenun=0 au-
 thor2un=0,uniquepart=base,hash=28a6378ad00955e8738375b23ecd6614family=Harris, fami-

lyi=H., given=C M, giveni=C. M., givenun=0un=0,uniquepart=base,hash=29d1c6b6fe66810be6c3b2ce9c329a
 ily=Wolpert, familyi=W., given=D M, giveni=D. M., givenun=0 author4un=0,uniquepart=base,hash=b160026950ebb1e2286dfb40c15482f5family=Hassabis, fami-
 lyi=H., given=Demis, giveni=D., givenun=0un=0,uniquepart=base,hash=a425c81c03d315597e3f92690763e24
 ily=Kumaran, familyi=K., given=Dharshan, giveni=D., givenun=0un=0,uniquepart=base,hash=0e19fe61e6a
 ily=Summerfield, familyi=S., given=Christopher, giveni=C., givenun=0un=0,uniquepart=base,hash=9ac5fb3
 ily=Botvinick, familyi=B., given=Matthew, giveni=M., givenun=0 author1un=0,uniquepart=base,hash=7bef50141eb292f543e6a3e011056658family=Hebb, familyi=H.,
 given=Donald Olding, giveni=D. O., givenun=0 author2un=0,uniquepart=base,hash=f245ea6325fec5
 ily=Hodgkin, familyi=H., given=A L, giveni=A. L., givenun=0un=0,uniquepart=base,hash=7fdcc730bf64349
 ily=Huxley, familyi=H., given=A F, giveni=A. F., givenun=0 author1un=0,uniquepart=base,hash=9358686fc958d08cb3cffdebe832f513family=Hopfield, fami-
 lyi=H., given=J J, giveni=J. J., givenun=0 author3un=0,uniquepart=base,hash=11a10ba3c6476c3
 ily=Hopper, familyi=H., given=Amy J, giveni=A. J., givenun=0un=0,uniquepart=base,hash=6a19fe0e3e9536
 ily=Beswick-Jones, familyi=B.-J., given=Hana, giveni=H., givenun=0un=0,uniquepart=base,hash=6aceacba
 cea4450dc6df9bffafamily=Brown, familyi=B., given=Angus M, giveni=A. M., givenun=0 author2un=0,uniquepart=base,hash=875c571db4834acac1f5295f7c27e9dcfamily=Isomura, familyi=I.,
 given=Takuya, giveni=T., givenun=0un=0,uniquepart=base,hash=9f452a84796a900973333b32a5f8bc61fam-
 ily=Friston, familyi=F., given=Karl, giveni=K., givenun=0 author1un=0,uniquepart=base,hash=42f7fae3ea7fdb2a650d709ac8db0842family=Izhikevich, fami-
 lyi=I., given=Eugene M, giveni=E. M., givenun=0 author1un=0,uniquepart=base,hash=42f7fae3ea7f
 ily=Izhikevich, familyi=I., given=Eugene M, giveni=E. M., givenun=0 author4un=0,uniquepart=base,hash=762ab6ae3d1eb0518f9f20eac700c5a3family=Kappel, fami-
 lyi=K., given=David, giveni=D., givenun=0un=0,uniquepart=base,hash=88cb28903cf2425bac37bec6405bb89
 ily=Habenschuss, familyi=H., given=Stefan, giveni=S., givenun=0un=0,uniquepart=base,hash=b10a7d017c6
 ily=Legenstein, familyi=L., given=Robert, giveni=R., givenun=0un=0,uniquepart=base,hash=1b7071d23a59
 ily=Maass, familyi=M., given=Wolfgang, giveni=W., givenun=0 author2un=0,uniquepart=base,hash=d09e09d2cd56777abc7316017cc5b054family=Kingma, fami-
 lyi=K., given=D P, giveni=D. P., givenun=0un=0,uniquepart=base,hash=269e85c86b7191d8814ace202944f29
 ily=Ba, familyi=B., given=J, giveni=J., givenun=0 author8un=0,uniquepart=base,hash=2bb0289bfb
 ily=Koene, familyi=K., given=Randal A, giveni=R. A., givenun=0un=0,uniquepart=base,hash=4aa5a3f369b
 ily=Tijms, familyi=T., given=Betty, giveni=B., givenun=0un=0,uniquepart=base,hash=9ea2a84e86a60f418e
 ily=Hees, familyi=H., given=Peter, giveni=P., givenun=0, prefix=van, prefixi=v., pre-
 fixun=0un=0,uniquepart=base,hash=cc9598cf9eddec0d2f63e31d77ad2877family=Postma, fami-
 lyi=P., given=Frank, giveni=F., givenun=0un=0,uniquepart=base,hash=1c886add18cdd030790d8afb5c2cbbb

ily=Ridder, familyi=R., given=Alexander, giveni=A., givenun=0, prefix=de, prefixi=d., prefixun=0un=0,uniquepart=base,hash=8034f175687d4d058df9a637d85335fbfamily=Ramakers, familyi=R., given=Ger J A, giveni=G. J. A., givenun=0un=0,uniquepart=base,hash=5d0de37688657473f0cec9da0
ily=Pelt, familyi=P., given=Jaap, giveni=J., givenun=0, prefix=van, prefixi=v., prefixun=0un=0,uniquepart=base,hash=5d0de37688657473f0cec9da0
family=Ooyen, familyi=O., given=Arjen, giveni=A., givenun=0, prefix=van, prefixi=v., prefixun=0
author1un=0,uniquepart=base,hash=a239233dfb1d78ba7f02fe9e49b13503family=Kohonen, familyi=K., given=Teuvo, giveni=T., givenun=0
author1un=0,uniquepart=base,hash=a239233dfb1d78ba7f02fe9e49b13503family=Kohonen, familyi=K., given=Teuvo, giveni=T., givenun=0
author5un=0,uniquepart=base,hash=9ae8dc3a930d73
ily=LeCun, familyi=L., given=Y, giveni=Y., givenun=0un=0,uniquepart=base,hash=5eb35ff-fcf75e0932c31b19f424238fefamily=Chopra, familyi=C., given=S, giveni=S., givenun=0un=0,uniquepart=base,hash=5eb35ff-fcf75e0932c31b19f424238fef
ily=Hadsell, familyi=H., given=R, giveni=R., givenun=0un=0,uniquepart=base,hash=6cb5af0e649387de5bbf
ily=Ranzato, familyi=R., given=M, giveni=M., givenun=0un=0,uniquepart=base,hash=ef77e7504555b19034
ily=Huang, familyi=H., given=F, giveni=F., givenun=0
author4un=0,uniquepart=base,hash=e24bcc
ily=Li, familyi=L., given=Zhe, giveni=Z., givenun=0un=0,uniquepart=base,hash=e8202fa00d92abc9d04e9ca
ily=Mazzoni, familyi=M., given=Pietro, giveni=P., givenun=0un=0,uniquepart=base,hash=bce91e02748d1f5
ily=Song, familyi=S., given=Sen, giveni=S., givenun=0un=0,uniquepart=base,hash=ea12a5aa5be72e296f6e2
ily=Qian, familyi=Q., given=Ning, giveni=N., givenun=0
author4un=0,uniquepart=base,hash=3b76fe663ed65bdf4616f1775899852family=Lipshutz, familyi=L., given=David, giveni=D., givenun=0un=0,uniquepart=base,hash=1f744353eb893a3dce8e4cfaf50b6b87
ily=Windolf, familyi=W., given=Charlie, giveni=C., givenun=0un=0,uniquepart=base,hash=07b8e2a5bc11b
ily=Golkar, familyi=G., given=Siavash, giveni=S., givenun=0un=0,uniquepart=base,hash=28f17a58976c5fd3
ily=Chklovskii, familyi=C., given=D, giveni=D., givenun=0
author2un=0,uniquepart=base,hash=b2
ily=Maimon, familyi=M., given=Gaby, giveni=G., givenun=0un=0,uniquepart=base,hash=259736acfe198812
ily=Assad, familyi=A., given=John A, giveni=J. A., givenun=0
author1un=0,uniquepart=base,hash=a5cf8150f393d1cdc89fd48b190adc6bfamily=Malsburg, familyi=M., given=C, giveni=C., givenun=0, prefix=von der, prefixi=v. d., prefixun=0
author1un=0,uniquepart=base,hash=2cf5062b61963ac0956179a605c38d66family=Marr, familyi=M., given=David, giveni=D., givenun=0
author5un=0,uniquepart=base,hash=b96424fe6e635f3c66d83bf6
ily=Masset, familyi=M., given=Paul, giveni=P., givenun=0un=0,uniquepart=base,hash=1e15cbd5c175505a2
ily=Zavatone-Veth, familyi=Z.-V., given=Jacob A, giveni=J. A., givenun=0un=0,uniquepart=base,hash=86b
ily=Patrick Connor, familyi=P. C., given=J, giveni=J., givenun=0un=0,uniquepart=base,hash=3d815682443
ily=Murthy, familyi=M., given=Venkatesh N, giveni=V. N., givenun=0un=0,uniquepart=base,hash=f8d7471
ily=Pehlevan, familyi=P., given=Cengiz, giveni=C., givenun=0
author3un=0,uniquepart=base,hash=4ad67bc1d8ba83cd81d599e72be7548dfamily=Mongillo, familyi=M., given=David, giveni=D., givenun=0
author5un=0,uniquepart=base,hash=b96424fe6e635f3c66d83bf6

lyi=M., given=Gianluigi, giveni=G., givenun=0un=0,uniquepart=base,hash=e68ad86bc86b67a9cd511a4a75e
 ily=Barak, familyi=B., given=Omri, giveni=O., givenun=0un=0,uniquepart=base,hash=f34a78a1cfd971d87a
 ily=Tsodyks, familyi=T., given=Misha, giveni=M., givenun=0 authorun=0,uniquepart=base,hash=448265cc41c04773e3e357d98f166316family=N. V. Swindale,
 familyi=N. V. S., given=H-U Bauer, giveni=H.-U. B., givenun=0 authorun=0,uniquepart=base,hash=034bceb3110db323ee701425ef94f709family=Nagumo, fami-
 lyi=N., given=J, giveni=J., givenun=0un=0,uniquepart=base,hash=909fe1582c93bf0a03b3d25c83321f77fam-
 ily=Arimoto, familyi=A., given=S, giveni=S., givenun=0un=0,uniquepart=base,hash=8cb9bbb974e11e7c133
 ily=Yoshizawa, familyi=Y., given=S, giveni=S., givenun=0 authorun=0,uniquepart=base,hash=49b47530760ffc9c1956dd759f68ea4cfamily=Obermayer, fami-
 lyi=O., given=K, giveni=K., givenun=0un=0,uniquepart=base,hash=2cf7d4ab324e08ec60edf083cf696d14fam-
 ily=Ritter, familyi=R., given=H, giveni=H., givenun=0un=0,uniquepart=base,hash=a649352ae0f9a737e2d23
 ily=Schulten, familyi=S., given=K, giveni=K., givenun=0 authorun=0,uniquepart=base,hash=48133849896da3a35c6c57ab1455420dfamily=Oja, familyi=O.,
 given=E, giveni=E., givenun=0 authorun=0,uniquepart=base,hash=d2ed0997ec1c0ceec1f302a65
 ily=Oja, familyi=O., given=Erkki, giveni=E., givenun=0 authorun=0,uniquepart=base,hash=80d0f3fe7b2ab04c7d4182c9e413bdc2family=Olshausen, fami-
 lyi=O., given=B A, giveni=B. A., givenun=0un=0,uniquepart=base,hash=96fb35e5ec6261ac0ed319fdfd433c5
 ily=Field, familyi=F., given=D J, giveni=D. J., givenun=0 authorun=0,uniquepart=base,hash=80d0f3fe7b2ab04c7d4182c9e413bdc2family=Olshausen, fami-
 lyi=O., given=B A, giveni=B. A., givenun=0un=0,uniquepart=base,hash=96fb35e5ec6261ac0ed319fdfd433c5
 ily=Field, familyi=F., given=D J, giveni=D. J., givenun=0 authorun=0,uniquepart=base,hash=be11bd5bdbfb41f6fbace3da1d6eafcefamily=Ooyen, familyi=O.,
 given=Arjen, giveni=A., givenun=0, prefix=van, prefixi=v., prefixun=0 authorun=0,uniquepart=base,hash=be11bd5bdbfb41f6fbace3da1d6eafcefamily=Ooyen, familyi=O.,
 given=Arjen, giveni=A., givenun=0, prefix=van, prefixi=v., prefixun=0un=0,uniquepart=base,hash=ea32f65
 ily=Carnell, familyi=C., given=Andrew, giveni=A., givenun=0un=0,uniquepart=base,hash=11b07aaaf663ed
 ily=Ridder, familyi=R., given=Sander, giveni=S., givenun=0, prefix=de, prefixi=d., pre-
 fixun=0un=0,uniquepart=base,hash=ba55fb8ed0c12d205fcb56f91ed70afffamily=Tarigan, fami-
 lyi=T., given=Bernadetta, giveni=B., givenun=0un=0,uniquepart=base,hash=8ed4661af24db422a4e24dba55
 ily=Mansvelder, familyi=M., given=Huibert D, giveni=H. D., givenun=0un=0,uniquepart=base,hash=46c03b
 ily=Bijma, familyi=B., given=Fetsje, giveni=F., givenun=0un=0,uniquepart=base,hash=5e2197f4844681fb42
 ily=Gunst, familyi=G., given=Mathisca, giveni=M., givenun=0, prefix=de, prefixi=d., pre-
 fixun=0un=0,uniquepart=base,hash=5d0de37688657473f0cec9da0730dcb1family=Pelt, familyi=P.,
 given=Jaap, giveni=J., givenun=0, prefix=van, prefixi=v., prefixun=0 authorun=0

thor4un=0,uniquepart=base,hash=2047a4d471e0be37f912670b94b280b2family=Orbán, fami-
 lyi=O., given=Gergő, giveni=G., givenun=0un=0,uniquepart=base,hash=dc12bb6ec9059f9728ad6185de9399c
 ily=Berkes, familyi=B., given=Pietro, giveni=P., givenun=0un=0,uniquepart=base,hash=3ecca6a4a90f8e2d6
 ily=Fiser, familyi=F., given=József, giveni=J., givenun=0un=0,uniquepart=base,hash=a561257682f27ac01b9
 ily=Lengyel, familyi=L., given=Máté, giveni=M., givenun=0 authorun=0,uniquepart=base,hash=ee238a78ec0cdd9ca34dc6742b8a74fdfamily=Orhan, familyi=O.,
 thor2un=0,uniquepart=base,hash=fd75c282ef5c8d05357464d48f7d4988fan
 given=A Emin, giveni=A. E., givenun=0un=0,uniquepart=base,hash=ma4ily=Ma, familyi=M., given=Wei Ji, giveni=W. J., givenun=0 authorun=0,uniquepart=base,hash=c6dc3de0e6740fa7f743e3a94156e1b7family=Pachitariu, fami-
 lyi=P., given=M, giveni=M., givenun=0un=0,uniquepart=base,hash=89db8e7f8416f16ca3dae1b654473718fan
 ily=Brody, familyi=B., given=C D, giveni=C. D., givenun=0un=0,uniquepart=base,hash=4f8e399f7c87988a0
 ily=Jun, familyi=J., given=Pdj, giveni=P., givenun=0un=0,uniquepart=base,hash=c53d258c3b419a097004f
 ily=Holmes, familyi=H., given=P J, giveni=P. J., givenun=0 author4un=0,uniquepart=base,hash=64
 ily=Papayan, familyi=P., given=Vardan, giveni=V., givenun=0un=0,uniquepart=base,hash=b2349f448cc200f2
 ily=Romano, familyi=R., given=Yaniv, giveni=Y., givenun=0un=0,uniquepart=base,hash=ea67c94d5fa35f0c
 ily=Sulam, familyi=S., given=Jeremias, giveni=J., givenun=0un=0,uniquepart=base,hash=20b8206f11f40a7
 ily=Elad, familyi=E., given=Michael, giveni=M., givenun=0 authorun=0,uniquepart=base,hash=5d0de37688657473f0cec9da0730dcb1family=Pelt, familyi=P.,
 thor2un=0,uniquepart=base,hash=cf2d892c
 given=Jaap, giveni=J., givenun=0, prefix=van, prefixi=v., prefixun=0un=0,uniquepart=base,hash=uy1ily=Uylings, familyi=U., given=Harry B M, giveni=H. B. M., givenun=0 authorun=0,uniquepart=base,hash=ea12a5aa5be72e296f6e28e632bf5b66family=Qian, familyi=Q.,
 thor4un=0,uniquepart=base,hash=c000f2d686c6fa4b94d8431f81320b45fam-
 ily=Jiang, familyi=J., given=Yu, giveni=Y., givenun=0un=0,uniquepart=base,hash=4ec50e9ce0bff0ee649793
 ily=Jiang, familyi=J., given=Zhong-Ping, giveni=Z.-P., givenun=0un=0,uniquepart=base,hash=e8202fa00d9
 ily=Mazzoni, familyi=M., given=Pietro, giveni=P., givenun=0 authorun=0,uniquepart=base,hash=062202bc25efb7f35aa991d71e9c1583family=Rall, familyi=R.,
 thor1un=0,uniquepart=base,hash=ee86ca8934b8f50cf0ec87ecf
 given=W, giveni=W., givenun=0 author2un=0,uniquepart=base,hash=7d104323f0f43271
 family=Rao, familyi=R., given=R P, giveni=R. P., givenun=0un=0,uniquepart=base,hash=ball1ily=Ballard, familyi=B., given=D H, giveni=D. H., givenun=0 authorun=0,uniquepart=base,hash=c4f6bad0bc08973bc3b2546c38252dc5family=Raudies, fami-
 lyi=R., given=Florian, giveni=F., givenun=0un=0,uniquepart=base,hash=7c84b4caeb0a2ee7da2e81c4d98251
 ily=Hasselmo, familyi=H., given=Michael E, giveni=M. E., givenun=0 authorun=0,uniquepart=base,hash=bc685130a720c723784d9b89ba8f1319family=Ringach, fami-
 lyi=R., given=Dario L, giveni=D. L., givenun=0 author4un=0,uniquepart=base,hash=9e3b7bd468
 ily=Rozell, familyi=R., given=Christopher J, giveni=C. J., givenun=0un=0,uniquepart=base,hash=debfe579

ily=Johnson, familyi=J., given=Don H, giveni=D. H., givenun=0un=0,uniquepart=base,hash=f1f805a4cc5203
 ily=Baraniuk, familyi=B., given=Richard G, giveni=R. G., givenun=0un=0,uniquepart=base,hash=278e76f0
 ily=Olshausen, familyi=O., given=Bruno A, giveni=B. A., givenun=0 author1un=0,uniquepart=base,hash=80a1a88f0
 thor1un=0,uniquepart=base,hash=3489cc28bbd0e3cec0ceb2fa487b2f09family=Schwiening, fami-
 lyi=S., given=Christof J, giveni=C. J., givenun=0 author1un=0,uniquepart=base,hash=80a1a88f0
 family=Shatz, familyi=S., given=C J, giveni=C. J., givenun=0 au-
 thor1un=0,uniquepart=base,hash=1412f70278a2490451d2ec6a99ec62f2family=Shimazaki, fami-
 lyi=S., given=Hideaki, giveni=H., givenun=0 author3un=0,uniquepart=base,hash=8b714c4ce1bb426dc
 ily=Shinomoto, familyi=S., given=Shigeru, giveni=S., givenun=0un=0,uniquepart=base,hash=59750e925ef91
 ily=Shima, familyi=S., given=Keisetsu, giveni=K., givenun=0un=0,uniquepart=base,hash=d460c09692788c7
 ily=Tanji, familyi=T., given=Jun, giveni=J., givenun=0 author3un=0,uniquepart=base,hash=ce24
 ily=Sprekeler, familyi=S., given=Henning, giveni=H., givenun=0un=0,uniquepart=base,hash=c25af27140e3b
 ily=Michaelis, familyi=M., given=Christian, giveni=C., givenun=0un=0,uniquepart=base,hash=1a32a99893f
 ily=Wiskott, familyi=W., given=Laurenz, giveni=L., givenun=0 au-
 thor2un=0,uniquepart=base,hash=cecd1c1588d27b0809f37e5ba1fc6394family=Takeuchi, fami-
 lyi=T., given=A, giveni=A., givenun=0un=1,uniquepart=given,hash=38a01cc459979a21bdbfea2e3460c5a6fa
 ily=Amari, familyi=A., given=S, giveni=S., givenun=1 author3un=0,uniquepart=base,hash=7a578
 ily=Tanaka, familyi=T., given=Shigeru, giveni=S., givenun=0un=0,uniquepart=base,hash=9bc9ef5823cc7e5
 eff9d4d8dfamily=Miyashita, familyi=M., given=Masanobu, giveni=M., givenun=0un=0,uniquepart=base,has
 ily=Ribot, familyi=R., given=Jérôme, giveni=J., givenun=0 au-
 thor1un=0,uniquepart=base,hash=c1728ca5539e29b102f5773072f37272family=Turrigiano, fami-
 lyi=T., given=Gina G, giveni=G. G., givenun=0 author2un=0,uniquepart=base,hash=7eb0323945
 family=Wainwright, familyi=W., given=Martin J, giveni=M. J., givenun=0un=0,uniquepart=base,hash=c611
 ily=Simoncelli, familyi=S., given=Eero, giveni=E., givenun=0 author3un=1,uniquepart=given,hash=1
 family=Willshaw, familyi=W., given=D J, giveni=D. J., givenun=1un=0,uniquepart=base,hash=003c4e5a96
 ily=Von Der Malsburg, familyi=V. D. M., given=C, giveni=C., givenun=0un=0,uniquepart=base,hash=080b
 ily=Longuet-Higgins, familyi=L.-H., given=Hugh Christopher, giveni=H. C., givenun=0
 author2un=0,uniquepart=base,hash=1a32a99893f7cb5a5f0da14f6d31a3b9family=Wiskott, fami-
 lyi=W., given=Laurenz, giveni=L., givenun=0un=0,uniquepart=base,hash=2df660039cf6a702dff622b6410682
 ily=Sejnowski, familyi=S., given=Terrence J, giveni=T. J., givenun=0 au-
 thor5un=0,uniquepart=base,hash=1a32a99893f7cb5a5f0da14f6d31a3b9family=Wiskott, fami-
 lyi=W., given=Laurenz, giveni=L., givenun=0un=0,uniquepart=base,hash=dc12bb6ec9059f9728ad6185de939
 ily=Berkes, familyi=B., given=Pietro, giveni=P., givenun=0un=0,uniquepart=base,hash=89eb03d502044800
 ily=Franzius, familyi=F., given=Mathias, giveni=M., givenun=0un=0,uniquepart=base,hash=ce2435f6d35f9
 ily=Sprekeler, familyi=S., given=Henning, giveni=H., givenun=0un=0,uniquepart=base,hash=43ab6c13f11e9

family=Wilbert, familyi=W., given=Niko, giveni=N., givenun=0 author4un=0,uniquepart=base,hash=bc9c1895de3f26901bdf41289e004157family=Yazdani, fami-
lyi=Y., given=Mehrdad, giveni=M., givenun=0un=0,uniquepart=base,hash=5295cb38bf7579a8c6e20fb43eda7
ily=Gamble, familyi=G., given=Geoffrey, giveni=G., givenun=0un=0,uniquepart=base,hash=ae643ec94fe363
ily=Henderson, familyi=H., given=Gavin, giveni=G., givenun=0un=0,uniquepart=base,hash=894084aa14dd
ily=Hecht-Nielsen, familyi=H.-N., given=Robert, giveni=R., givenun=0 author3un=0,uniquepart=base,hash=e8b0a032b0991e301e5b1f014e9562c7family=Yee, familyi=Y.,
given=Ada X, giveni=A. X., givenun=0un=0,uniquepart=base,hash=4c4b01bb3c9b31def75612090d3de958fam
ily=Hsu, familyi=H., given=Yu-Tien, giveni=Y.-T., givenun=0un=0,uniquepart=base,hash=54a3c319195500
ily=Chen, familyi=C., given=Lu, giveni=L., givenun=0 author3un=0,uniquepart=base,hash=66d0
ily=Zenke, familyi=Z., given=Friedemann, giveni=F., givenun=0un=0,uniquepart=base,hash=6b2c6d8dbc66
ily=Gerstner, familyi=G., given=Wulfram, giveni=W., givenun=0un=0,uniquepart=base,hash=05b3e391388
ily=Ganguli, familyi=G., given=Surya, giveni=S., givenun=0 author4un=0,uniquepart=base,hash=98ce0567b94943ee60e943e940a2131bfamily=Zhang, familyi=Z.,
given=Wen-Hao, giveni=W.-H., givenun=0un=0,uniquepart=base,hash=56442cb9b37ab2b9aa2e150abdfc2f12
ily=Wu, familyi=W., given=Si, giveni=S., givenun=0un=0,uniquepart=base,hash=52918cf06cafc58c28d91a1
ily=Josić, familyi=J., given=Krešimir, giveni=K., givenun=0un=0,uniquepart=base,hash=61af3dbe8ef74197
ily=Doiron, familyi=D., given=Brent, giveni=B., givenun=0 author2un=0,uniquepart=base,hash=97e849840775eb11c150164bbbd7cffeefamily=Zipser, familyi=Z.,
given=D, giveni=D., givenun=0un=0,uniquepart=base,hash=fe4f349b8031006e05f4bcb85a65d330fam-
ily=Andersen, familyi=A., given=R A, giveni=R. A., givenun=0 author1un=0,uniquepart=base,hash=4daa759402ffe46719d3b0cb3749248cfamily=田中, familyi=田.,
given=繁, giveni=繁., givenun=0

Julia で学ぶ計算論的神経科学

山本 拓都

2025 年 4 月 7 日

目次

0.1	シナプス結合強度の不均一性	4
-----	---------------	---

0.1 シナプス結合強度の不均一性

(概要) シナプス結合強度は正規分布に従わず、対数正規分布のような裾の重い分布 (heavy-tailed distribution) に従う。すなわち、多くの弱いシナプス結合と少数の強いシナプス結合が存在する。これは電気生理学的な EPSP (シナプス後電位) の測定や電子顕微鏡によるコネクトームの解析により明らかになっている。本章では (Lynn, Holmes & Palmer, Nature Physics. 2024) で提案された、シナプス結合が裾の重い分布に従うネットワークを生成する発達モデルを紹介する。コードに関しては https://github.com/ChrisWLynn/Heavy_tailed_connectivity を参考に作成した。

```
using PyPlot, Random, Distributions, LinearAlgebra, StatsBase
using ProgressMeter
using Graphs, GraphPlot
using SpecialFunctions
rc("axes.spines", top=false, right=false)
```

まず、活動に非依存的なモデルを紹介する。このモデルではネットワーク全体のシナプス結合強度の和 (S) が一定になるようにシナプスの枝刈りと 2 通りの増強を行う。枝刈りの過程ではシナプスの結合強度に「よらず」、一様にシナプスが選択されて枝刈りされる。その際に減少した結合強度分を次のように他のシナプス結合に付与する。確率 p でシナプス結合強度に応じた確率でシナプスを選択し、増強する。確率 $1 - p$ でランダムなシナプスを増強する。前者の過程により、強いシナプス結合はより増強される (The rich get richer)。

```
function generate_scale_free_network(;
    N=200, s_avg=1, p=0.5, num_iter=1000,
    num_prune_edge=50)
    # set params
    num_max_edge = N * (N - 1)
    S = s_avg * num_max_edge

    # initialization
    edge_indices = findall((ones{Int64, N, N} - I{N}) .== 1);
    indices_sample = sample(1:num_max_edge, S, replace=false);
    A = zeros{N, N};
    A[edge_indices[indices_sample]] .= 1;

    @showprogress for t in 1:num_iter
        # pruning
        prune_indices = sample(1:num_max_edge, num_prune_edge, replace=false)
        ΔS = Int(sum(A[edge_indices[prune_indices]]))
        A[edge_indices[prune_indices]] .= 0;

        # hebbian update
        ΔS_hebb = Int(sum(rand{Binomial{1, p}}, ΔS))
        hebb_indices = sample(1:num_max_edge, Weights{A[edge_indices]}, ΔS_hebb,
            replace=false)
```

```

# random update
ΔS_rand = ΔS - ΔS_hebb
rand_indices = sample(1:num_max_edge, ΔS_rand, replace=false);

growth_indices = [hebb_indices; rand_indices]
A[edge_indices[growth_indices]] .+= 1;
end

A_flat = vcat(A[edge_indices]...);
order_dict = sort(countmap(A_flat));
order_arr = hcat(collect(keys(order_dict)), collect(values(order_dict)));
order_arr[:, 2] ./= S;
return A, A_flat, order_arr
end

```

ニューロン数 ($N = 20$) でグラフを描画しよう。少数の強い結合が存在していることが分かる。

```

A_small, A_small_flat, _ = generate_scale_free_network(;N=20, s_avg=1, p=0.5, num_iter=1000, num_prune_edge=1)

```

```

g = SimpleDiGraph(A_small)
plot(g, layout=circular_layout, arrowlengthfrac=0, edgelinewidth=A_small_flat, plot_size=(5cm,5cm))

```

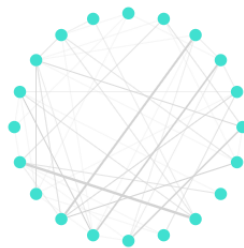


図1 cell006.png

ニューロン数を ($N = 200$) に増やし、各結合強度の出現頻度を描画しよう。

```

A, _, order_arr = generate_scale_free_network(N=200, s_avg=1, p=0.5, num_iter=5000, num_prune_edge=50);

```

各結合強度の出現頻度を予測する理論的式は以下で与えられる。

```

P(s, s_avg, p) = gamma(s + s_avg * (1/p - 1)) / gamma(s + s_avg * (1/p - 1) + 1/p + 1)
s_arr = exp10.(range(1e-8, stop=2, length=50));
P_arr = P.(s_arr, 1, 0.5);

```

```
figure(figsize=(3,3))
scatter(order_arr[:, 1], order_arr[:, 2], label="Numeric")
plot(s_arr, P_arr, c="k", label="Analytic")
xscale("log")
yscale("log")
legend()
ylim(minimum(order_arr[:, 2]), )
xlabel("Connection strengths")
ylabel("Probability")
tight_layout()

#hist(A_flat, bins=exp10.(range(0,stop=2,length=10)), log=true, density=true);
#xscale("log")
```

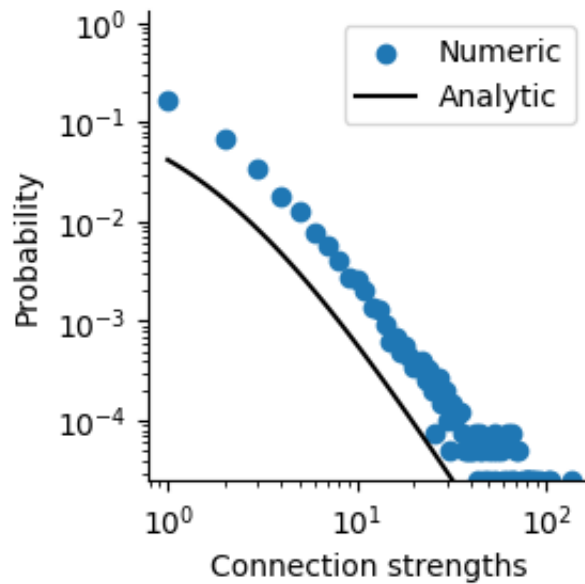


図 2 cell011.png