Bibliography of Self-Organizing Map (SOM) Papers: 1998-2001 Addendum

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Abstract

The Self-Organizing Map (SOM) algorithm has attracted a great deal of interest among researches and practitioners in a wide variety of fields. The SOM has been analyzed extensively, a number of variants have been developed and, perhaps most notably, it has been applied extensively within fields ranging from engineering sciences to medicine, biology, and economics. We have collected a comprehensive list of 5384 scientific papers that use the algorithms, have benefited from them, or contain analyses of them. The list is intended to serve as a source for literature surveys. The present addendum contains 2092 new articles, mainly from the years 1998-2002. We have provided a keyword index to help finding articles of interest, and additionally a modern automatically constructed variant of a thematic index: a WEBSOM interface to the whole article collection of years 1981-2000. The SOM of SOMs is available at `http://websom.hut.fi/websom/somref/search.cgi` for browsing and searching the collection.

1 INTRODUCTION

The Self-Organizing Map algorithm [3, 4, 5] was introduced in 1981. We have earlier [2] published a list of 3343 scientific papers from the years 1981–1997 that have benefited from the SOM. The list was later updated with 2092 new articles, mainly from the years 1998-2002. (There were some duplicate articles in the previous collection; that is why the sum of the old and the new articles is not equal to the current total size.) This paper includes the addendum and a keyword index to the new articles. In addition, we analyze the evolution of the thematic content of the collection and present a SOM of SOMs, i.e. a WEBSOM [1, 6] interface to the document collection.

1.1 Collection Method

The criterion for selecting papers to the collection has been that they should either use or analyze the SOM, or benefit from it in some other manner. Our intention has been to exclude papers that merely refer to the algorithm.

Several methods have been used: We have added references to papers that have appeared in the journals and conference proceedings that we personally follow. In addition, several authors have kindly helped us by sending us bibliographies of their own papers. Finally, we have made searches in commonly used bibliographic databases.

The bibliography will additionally be available in BibTeX format at the WWW address `http://www.cis.hut.fi/nnrc/refs/`.

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1.2 Contents of the Bibliography

We first studied how SOM research within certain application areas has evolved during the years. A set of 13 topical categories was selected, consisting of the most commonly occurring application areas in the article collection. The categories were formed by combining hierarchical classes used by the INSPEC (tm) database; classes within the same application but in different branches of the classification tree were grouped together. The number of articles in those categories was then plotted as a function of the year of publication. The plots only contain the articles available in the INSPEC collection. Years before 1988 were omitted from the figure because the number of publications was very low, and year 2000 because the records were still very incomplete at the time of the analysis.

The results shown in Figure 1 reveal, for instance, that speech recognition was a very popular topic already in the beginning of 90's, while there still are applications in that area. Some other disciplines, including "information science and documentation" and "business and administration," are still gaining popularity.

The SOM references were organized onto a document map to study the relationships between the topic categories, and to provide an interface for browsing and searching the collection. A WEBSOM [1, 6] was computed using the titles of the documents. For 849 documents also an abstract was available and it was used in the computation. The size of the SOM was 25 by 16 map units, and it was computed by encoding the documents as numerical vectors as in the traditional "vector space model" of information retrieval. Each word was assigned a separate dimension in the vectors, and the value of the dimension was the frequency of occurrence of the word in the document, times the inverse of the number of documents the word occurs in (so-called "TF-IDF" encoding). Only words occurring more than 5 times in the collection were selected, and words within a list of 1348 non-informative words were excluded. The resulting dimensionality of the vectors was 1678. The dimensionality was further reduced to 500 by random projection. The SOM was computed of the collection of 2426 documents having 5 or more words after the preprocessing. The rest of the documents were mapped to the SOM after the computation.

The distribution of the 13 topic categories of Figure 1 on the resulting SOM is shown in Figure 2. Some of the categories, such as "mathematical techniques" and "pattern recognition" are dispersed to a wide area on the map, reflecting the general nature of the categories. More specific categories such as "speech," "control," and "information science and documentation" have a sharper peak on the map. The SOM display provides an overall view of the relationships between the categories. For instance, an area close to the top left corner of the map contains articles from both "image and video" and "information theory + coding." After a closer look (not shown) it is evident that the area contains articles on image coding. Understanding the more detailed relationships requires, of course, studying the map more closely. A crude numerical measure for the similarities of the distribution of the categories can be found in Table 1. The table presents inner products between vectors representing the distributions of each category on the map display. The vectors are normalized to unit length in order to give equal weight to all categories. The inner products are between zero (non-similar vectors) and one (equal vectors). Note that one article may belong to several categories; the categories have been chosen by the authors of the articles or informaticians.

1.3 Advice on Using the Bibliography

We have constructed indices to aid in exploring the large bibliography. Since it would have been infeasible to manually compile a complete index of the whole collection of papers, we have constructed two different kinds of indices automatically.

The first, a *keyword index*, was constructed mostly automatically, based on the words that appear in the titles of the papers. Hence the index cannot be as well-organized as a manually generated one. For example, all of the papers that treat speech recognition cannot be found using the index entry "speech." On the other hand, some index terms may contain references to several kinds of papers. For example, it may be clear that all of the papers that contain the word "growing" need not analyze growing SOMs.

We have complemented the keyword index with an automatically constructed *thematic index*, the WEBSOM described in the previous section. The map is available for browsing and searching in the address `http://websom.hut.fi/websom/somref/search.cgi`. The map can either be browsed directly by inspecting the contents of the map nodes, or the browsing can be started with a search. It is possible to carry out conventional keyword searches or search based on whole new documents (or rather abstracts since the map has been computed based on abstracts), or textual descriptions. The best matching locations for the new abstracts indicate

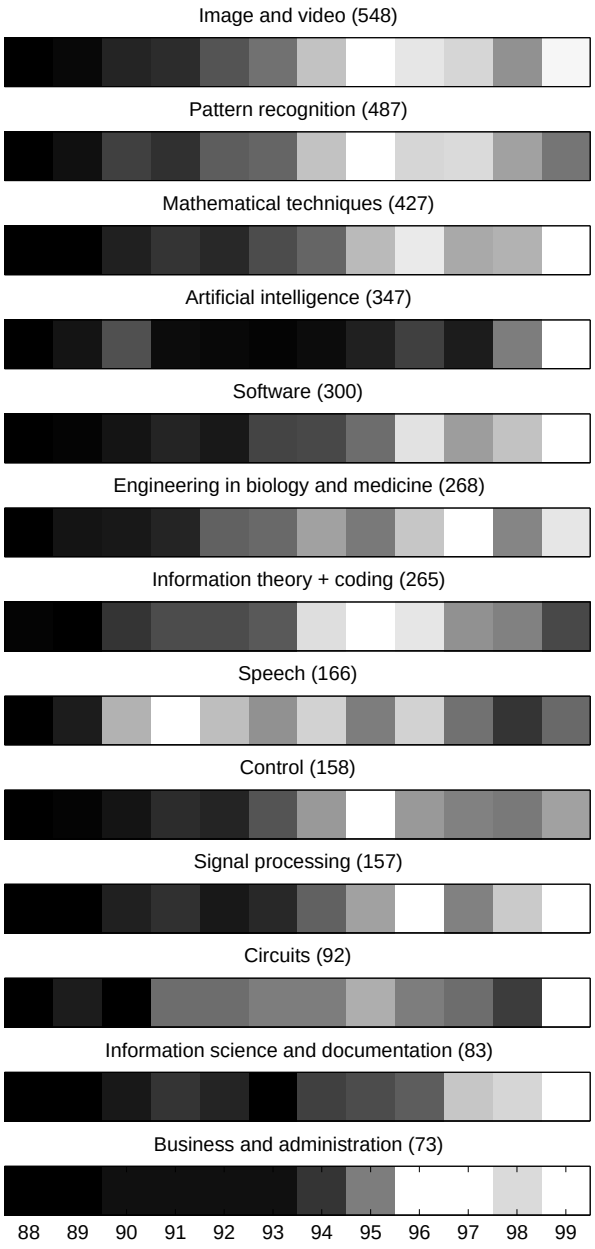


Figure 1: Evolution of SOM research. Each horizontal bar shows the number of published SOM works within a certain topic category, as a function of the publication year shown in the bottom. The total number of works in the category is shown in parentheses. The categories are scaled individually. White: largest number within the category, black: zero articles.

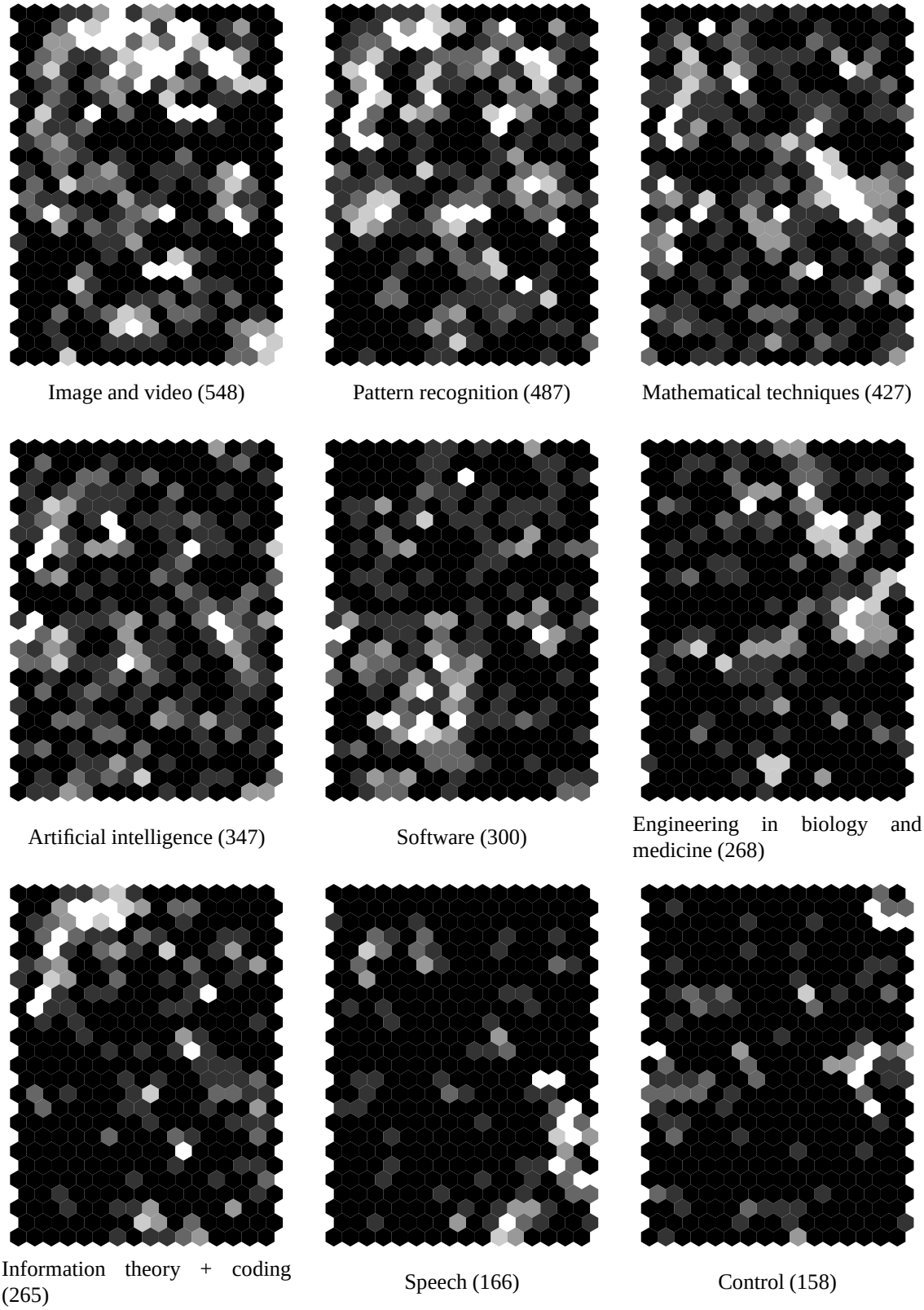
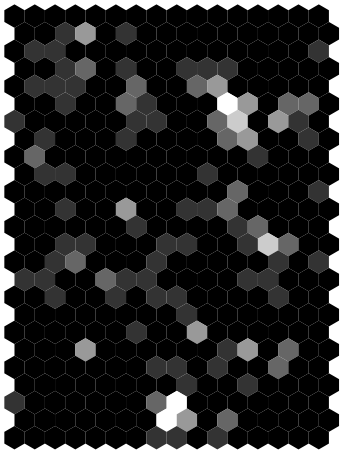
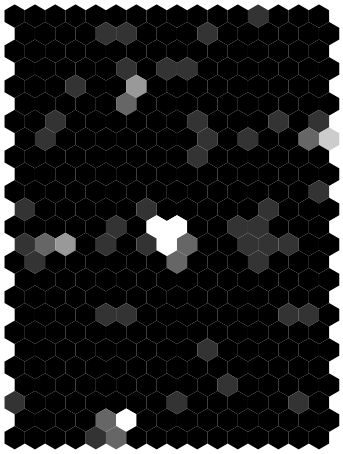


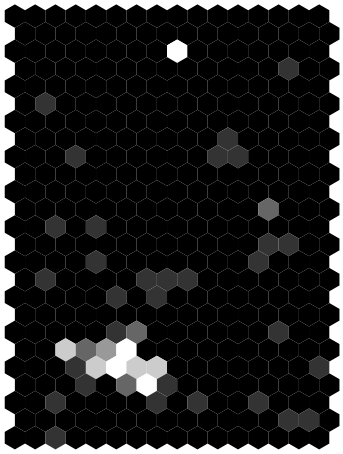
Figure 2: Distribution of articles from 13 topic categories on the SOM of the SOM article collection. Gray shades denote the number of articles mapped to a SOM node Black: zero articles, white: 5 or more articles. The gray scale is cut at 5 to give better resolution to areas around the highest peak of hits (highest 7-9) and to highlight the high density areas.



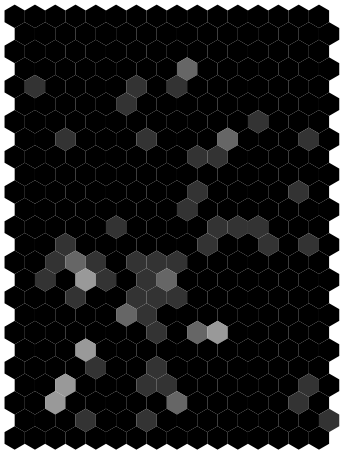
Signal Processing (157)



Circuits (92)



Information science and documentation (83)



Business and administration (73)

Figure 2: continued.

Image . . .	1.00												
Pattern reg.	0.73	1.00											
Math. tech.	0.45	0.63	1.00										
AI	0.45	0.63	0.64	1.00									
Software	0.39	0.40	0.45	0.65	1.00								
Biology . . .	0.46	0.46	0.38	0.42	0.35	1.00							
Inf. theory	0.61	0.66	0.55	0.40	0.23	0.30	1.00						
Speech	0.17	0.21	0.39	0.33	0.19	0.27	0.35	1.00					
Control	0.30	0.33	0.34	0.36	0.27	0.28	0.14	0.12	1.00				
Signal proces.	0.36	0.47	0.42	0.44	0.33	0.62	0.44	0.34	0.21	1.00			
Circuits	0.19	0.19	0.21	0.30	0.22	0.20	0.15	0.12	0.14	0.15	1.00		
Documentation	0.15	0.12	0.15	0.19	0.54	0.09	0.04	0.09	0.05	0.08	0.02	1.00	
Business	0.32	0.35	0.35	0.34	0.40	0.25	0.19	0.10	0.15	0.29	0.13	0.19	1.00
	Img	Pat	Mat	AI	Sof	Bio	Inf	Spe	Con	Sig	Cir	Doc	Bus

Table 1: Similarities in the distribution of the topics on the SOM. Similarity is measured by inner product distances between map displays of Fig. 2. The categories are in the same order as in Fig. 2, where the complete names for the categories can be found.

suitable locations in which to start browsing. A sample search is illustrated in Figure 3. More information about the interface and possible ways of using it can be obtained from the WEBSOM publications (for references, type WEBSOM in the interface and click "search").

The relationship of the map units to the manually constructed thematic categories presented in the previous SOM reference collection [2] can be found in the web interface as well. The articles in the manually constructed categories were projected to the WEBSOM and their places on the map can be viewed on the WEBSOM display. The user can select a thematic category from a list at `http://websom.hut.fi/websom/somref/thematic.html` and follow a link to a page presenting the projection of the category. This display is also a functional WEBSOM and can be explored to find more articles of interest.

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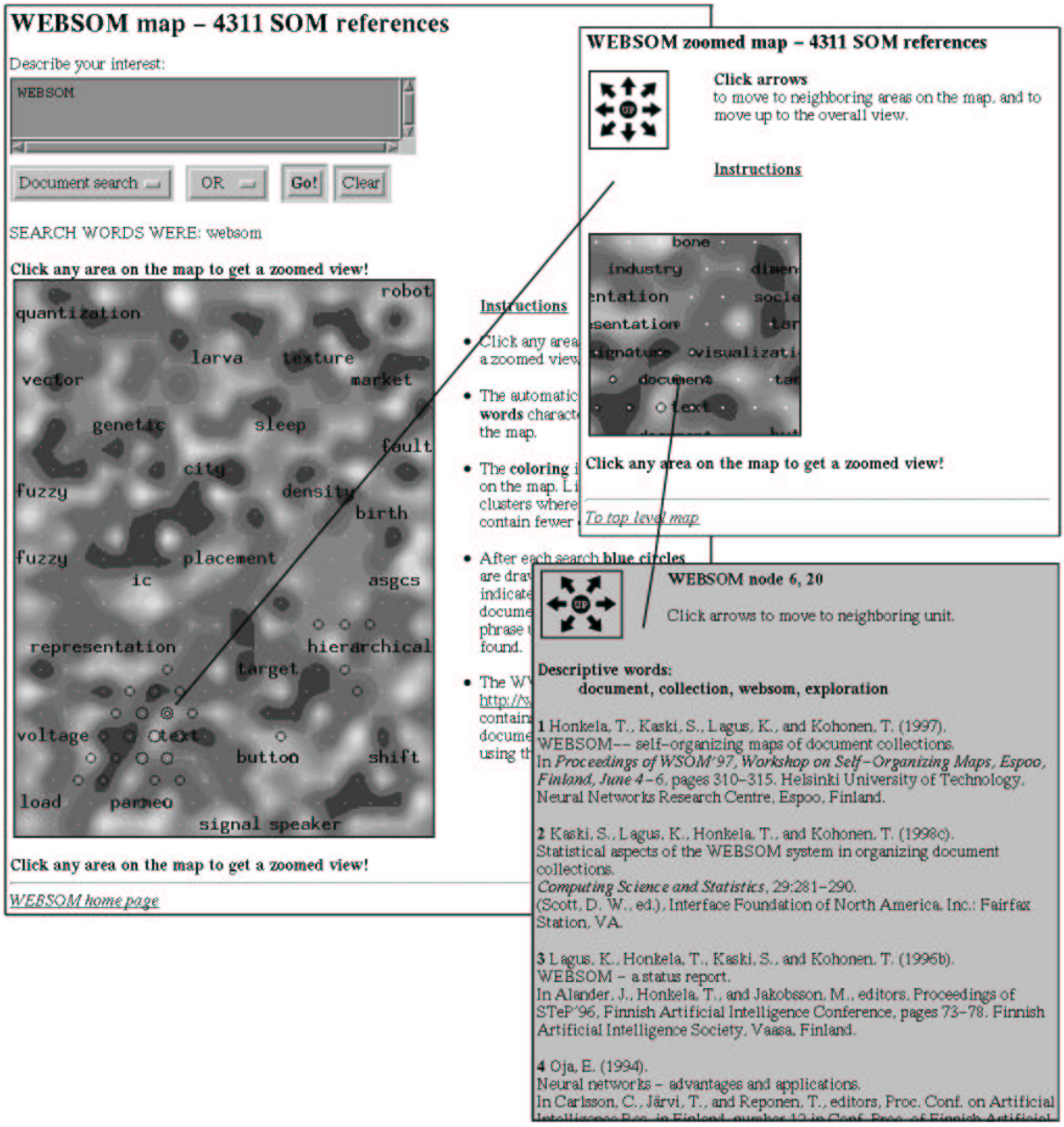

Figure 3: Search example: The user has searched for documents about WEBSOM. The circles in the map indicate best matches. A closer view is obtained by clicking an interesting area. Clicking the zoomed map reveals the articles at the map nodes.

[6] Teuvo Kohonen, Samuel Kaski, Krista Lagus, Jarkko Salojärvi, Jukka Honkela, Vesa Paatero, and Antti Saarela. Self organization of a massive document collection. *IEEE Transactions on Neural Networks*, 11:574–585, 2000.

accounting [25, 576, 1912]
acoustic [152, 166, 393, 414, 413, 415, 534, 811, 908, 1038, 1080, 1111, 1137, 1204, 1453, 1556, 1564, 1565, 1566, 1717, 1751, 2025]
adaptive control [651, 1793, 2087]
adaptive filtering [1840, 1847]
adaptive-subspace SOM (ASSOM) [2086, 923, 1147, 1514, 1515, 1513, 1657, 1847, 2057]
AES [1242, 1243, 1309, 1312, 1313, 1777, 1780]
agent [367, 580, 584, 583, 607, 657, 708, 713, 821, 1287, 1355, 1577, 1900, 1983]
agglomerative hierarchical clustering [34, 380, 1175]
agriculture [1248, 1247, 1817]
AI [1238, 1613, 1757]
aircraft [400, 413, 541, 744, 1717, 1815]
alphanumeric characters [1906]
aluminum [1791, 1836]
amino acids [670]
analog [135, 223, 406, 405, 828, 904, 1089, 1087, 1088, 1101, 1206, 1606, 1605, 2043]
antenna [656, 655]
arrhythmia [1157, 1470, 1606, 1605, 1942, 1943]
articulatory [1235]
ARTMAP [426, 509, 627, 737, 1077, 1305, 1615, 1716, 1811]
associative memory [239, 602, 702, 847, 1345, 1465, 1486, 1509, 1690, 1995]
astronomy [563, 993]
ATR [80, 81, 206, 212, 242, 693, 692, 771, 1023, 1047, 1124, 1125, 1489, 1490]
attribute trees [1390, 1389, 1388]
audio [309, 557, 656, 944, 945, 943, 1431, 2092, 1543]
audio documents [944, 945, 943]
audio-visual sequences [1543]
auditory [309, 393, 394, 420, 496, 578, 1011, 1431, 1567, 1690]
auditory tumors [393]
auto-associative [2, 1060, 2053]
auto-correlation [223, 421, 422, 768]
autonomous [45, 264, 580, 584, 640, 713, 727, 963, 1071, 1114, 1148, 1256, 1254, 1480, 1670, 1802, 2074]
autonomous agents [580, 584, 713]
autoregressive (AR) model [87, 253, 723, 919, 958, 1083, 1955, 1956]
backpropagation (BP) [30, 51, 165, 190, 189, 191, 237, 311, 327, 374, 393, 636, 580, 591, 618, 637, 660, 707, 728, 731, 733, 737, 786, 918, 917, 947, 954, 951, 956, 1009, 1017, 1046, 1049, 1075, 1068, 1105, 1110, 1164, 1305, 1345, 1356, 1434, 1542, 1645, 1684, 1818, 1903, 1910, 1381, 1923, 1954, 1953, 1974, 2021, 2060]
bankruptcy [25, 218, 2086, 802, 800, 801, 790, 856, 857]
Bayesian [441, 446, 445, 833, 750, 860, 1026, 1068, 1120, 1138, 1211, 1210, 1252, 1263, 1264, 1625, 1684, 1729, 1742, 1800, 1817, 1829, 1831, 1832, 1955, 1956, 2007, 2039]
benchmark [17, 172, 190, 189, 191, 213, 323, 354, 384, 484, 981, 1190, 1318, 1988, 1319, 1847, 1020, 1982]
BGA [1499, 2051]
binding problem [937]
binocular [103, 1963]
biochemical [868, 1163]
biological [15, 31, 136, 158, 194, 207, 260, 263, 268, 285, 376, 428, 453, 480, 479, 689, 741, 887, 923, 948, 1017, 1057, 1139, 1146, 1148, 1163, 1164, 1235, 1219, 1372, 1371, 1370, 1392, 1414, 1426, 1511, 1513, 1519, 1560, 1668, 1736, 1861, 1912, 1913, 1923, 1928, 1950, 2029]
biological macromolecules [1163, 1372, 1371, 1370]
biomedical [35, 393, 394, 1911]
Boltzmann machine [1274]
brain [9, 54, 74, 126, 133, 149, 231, 243, 268, 359, 420, 423, 422, 470, 527, 531, 537, 623, 781, 783, 887, 893, 1044, 1059, 1149, 1230, 1290, 1384, 1392, 1421, 1420, 1570, 1762, 2088, 1969, 1970, 1971]
brain image [1044]
brain voxels [422]
brainstem [393, 394, 1011]
breast cancer [223, 367, 1542, 1599, 1684, 1962]
bus [239, 246, 247, 734, 904, 1007, 1092, 1091, 2028]
c-means [124, 258, 556, 775, 778, 780, 822, 939, 938, 1017, 1044, 1347, 1373, 1372, 1371, 1370, 1578, 1638, 1763, 1792, 1930]
CAD [30, 84, 162, 939]
cancer [90, 223, 228, 241, 261, 367, 384, 395, 820, 1086, 1139, 1141, 1140, 1542, 1599, 1684, 1962]
cardiology [352, 448, 1469, 1606, 1756, 1755]
CDMA [498, 657, 653, 654, 656, 655]
cepstrum [254, 305, 2056]

cerebral cortex [231, 948]
chaos [329, 530, 1875]
character recognition [117, 167, 235, 326, 610, 766, 946, 965, 987, 986, 1062, 1063, 1197, 1348, 1406, 1450, 1549, 1804, 1381, 2008, 2013, 2047]
characters [167, 326, 610, 766, 946, 1905, 1906, 1908, 1993]
chemical analysis [1242, 1243, 1312, 1313, 1775, 1785, 1777, 1780, 1784, 1944, 1945, 1946]
chemical databases [119, 1502]
chemical spectra [1243, 1309, 1310]
chinese character recognition [235, 946, 1062, 1450, 1804]
chip [382, 419, 486, 926, 1006, 1089, 1087, 1088, 1499, 1527, 1528, 1606, 1605]
chromosomes [381, 380, 552, 961, 960, 1141, 1291]
circuit [358, 406, 405, 486, 488, 580, 617, 734, 840, 926, 996, 1024, 1088, 1392, 1499, 1509, 1516, 1554, 1605, 1611, 1653, 1759, 1776, 1967, 2028, 2043]
climate [192, 395, 1113]
clinical [126, 207, 243, 550, 588, 725, 949, 1141, 1140, 1392, 1566, 1604, 1732, 1755, 1812, 1854, 1890, 1942, 1962, 1943, 2056]
cloud classification [34, 2086, 962, 1764, 1765]
cloud images [255, 962]
CMOS [926, 996, 1089, 1087, 1088, 1418, 1509, 1605]
central nervous system (CNS) [1399, 1538]
co-occurrence [51, 2086, 387, 604, 696, 860, 1046, 1133, 1407, 1744, 1764, 1837, 1854]
coarticulation [1806]
cognitive [423, 477, 580, 1392, 1907, 1950, 1980]
coherence [134, 168, 1194, 1269, 1345, 1744]
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color segmentation [1017, 2041]
color-based segmentation [2041]
coloring [307, 626, 804, 795, 803, 897, 2037]
complexity [4, 5, 47, 57, 71, 82, 127, 278, 636, 437, 506, 628, 719, 720, 836, 920, 974, 989, 1047, 1131, 1153, 1263, 1330, 1331, 1344, 1378, 1390, 1389, 1426, 1493, 1502, 1577, 1742, 1744, 1771, 1919, 1918, 1962, 2034, 2037, 2063]
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compressing images [1162]
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control system [165, 265, 366, 377, 428, 494, 584, 1940, 2003, 2004, 1997]
convergence [1, 80, 81, 93, 94, 104, 112, 115, 113, 202, 213, 233, 372, 381, 384, 433, 435, 453, 460, 576, 680, 691, 737, 827, 831, 846, 866, 914, 959, 998, 1051, 1052, 1199, 1252, 1250, 1281, 1328, 1524, 1529, 1532, 1551, 1553, 1639, 1656, 1745, 1808, 1857, 1855, 1860, 1858, 1930, 1973, 1982, 1987, 2040, 2062]
coronary [271, 447, 1684]
cortex [74, 100, 99, 231, 434, 444, 480, 481, 483, 478, 477, 482, 479, 496, 614, 751, 757, 948, 1009, 1021, 1146, 1147, 1172, 1173, 1180, 1181, 1196, 1233, 1235, 1219, 1240, 1241, 1384, 1397, 1396, 1398, 1421, 1538, 1619, 1624, 1649, 1647, 1648, 1724, 1723, 1725, 1726, 1752, 1762, 1907, 1914, 1950]
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1726]
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cursive character [167, 610, 1227]
curvilinear component analysis (CCA) [530, 1013, 1875]
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data-analysis [469, 789]
database [21, 30, 35, 50, 69, 71, 86, 95, 116, 113, 120, 119, 125, 167, 168, 207, 210, 215, 229, 248, 279, 304, 305, 311, 326, 357, 373, 399, 400, 425, 431, 443, 448, 472, 562, 607, 608, 638, 657, 678, 710, 711, 708, 709, 728, 769, 766, 821, 823, 862, 863, 890, 872, 927, 939, 944, 958, 966, 967, 970, 988, 1006, 1001, 1033, 1023, 1065, 1064, 1062, 1103, 1130, 1129, 1157, 1174, 1245, 1258, 1271, 1312, 1310, 1307, 1311, 1308, 1317, 1316, 1322, 1377, 1390, 1399, 2092, 1502, 1519, 1532, 1589, 1603, 1620, 1622, 1668, 1669, 1684, 1705, 1710, 1716, 1744, 1758, 1787, 1790, 1789, 1796, 1797, 2088, 1831, 1888, 1887, 1895, 1897, 1908, 1933, 1940, 1962, 2014, 2026]
discrete cosine transform (DCT) [150, 1065, 1136, 1285, 1592, 1837]
densitometric [359]
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