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Signal Processing 60 (1997) 65–126

SIGNAL PROCESSING

Bibliography on higher-order statistics

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Received 13 June 1996; revised 10 March 1997

Keywords: Higher-order statistics; Cumulants; Polyspectra; Bispectrum; Trispectrum; Bicoherence; Tricoherence; Bicepstra; Tricepstra; Nonlinear models

Introduction

The last fifteen years have witnessed a tremendous resurgence in research and applications in the area of *higher-order statistics* (HOS), a broad term encompassing statistical descriptors of orders greater than two: higher-order moments and cumulants, moment spectra and polyspectra, which are natural generalizations of second-order statistics (SOS) – the correlation and the spectrum.

Although the roots of HOS literature can be traced back to Kolmogorov (and possibly Gauss), the pioneering work of statisticians in North America and Eastern Europe in the 1960s was – apart from scattered contributions in the physical sciences – largely ignored by the signal processing community until the early 1980s. Following the saturation point of advances in spectral estimation methods, HOS held out the promise of addressing the following "non" topics associated with signals and systems: non-Gaussianity, non-minimum phase, non-causality, non-linearity, and more recently, non-additivity and non-stationarity.

Special purpose hardware and faster computers allow us to handle the increased dimensionality and computational complexity of HOS-based algorithms, which have been developed for a wide range of applications, such as: time-delay estimation in sonar, EEG signal analysis, imaging through turbulence, nonlinear ocean wave interactions, radar, seismic deconvolution, blind channel equalization, removal of atmospheric effects in astronomical data, harmonic retrieval, bio-signal processing, detection and classification of non-Gaussian signals, array and image data processing, (source) separation of mixtures of signals, analysis of chaotic systems, non-stationary and cyclo-stationary signal analysis.

The revived popularity of HOS is due to some *unique* features and advantages which they offer over SOS, namely:

- HOS of non-Gaussian linear processes convey not only amplitude, but also complete phase information and, as such, they have been used for time-series modeling, and identification of non-minimum phase and non-causal systems. Relevant applications include signal reconstruction from speckle images, seismic deconvolution, and equalization of communication channels.

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PII S0165-1684(97)00065-0

- Gaussian processes are completely described by SOS: the HOS of Gaussian signals vanish. Thus, HOS "measure" non-Gaussianity and can be used to separate additive mixtures of independent non-Gaussian signals and Gaussian noise. Therefore, it is natural that tests for (non-)Gaussianity are based on HOS; similarly, researchers have exploited HOS-domains for the detection and classification of non-Gaussian signals, and for the suppression of additive Gaussian noise, whose covariance function may not be known.
- HOS appear naturally in the spectral analysis of nonlinear processes, in the identification of nonlinear systems (Volterra kernels), and in tests for (non-)linearity.
- HOS-based tools are natural candidates for the modeling and analysis of chaotic systems, and their performance evaluation.
- HOS are useful to characterize the dependence on random signals and show up even in the performance analysis of SOS-based estimators.
- HOS facilitate the modeling, estimation, analysis and application of *polynomial phase* signals which appear to be useful in a variety of scenarios, ranging from Doppler radar to speech to bio-signal processing.
- Multiplicative noise models are useful to model certain kinds of non-stationary behavior; and, multiplicative noise, itself, arises naturally in several applications; examples include scattering of acoustic returns in active sonar, analysis of signals recorded from rotating machinery (failure prediction and condition monitoring), image processing, and bio-signal processing. Signal analysis, in the presence of multiplicative noise, naturally involves HOS.
- Short-time and evolutionary polyspectra, higher-order and generalized Wigner-Ville distributions, offer new perspectives on the data, in addition to those offered by their second-order counterparts.
- Blind identification of multi-channel systems and blind source separation are two other areas where higher-order statistics have made critical contributions. Blind identification of multi-channel systems based on second-order statistics is unique only to within multiplication by a unitary matrix; with higher-order statistics, the multiplication ambiguity is reduced to the class of signed permutation matrices.

Of course, HOS do not offer a panacea for all problems; and, one may have to use statistics and tools other than SOS and HOS.

The first bibliography on HOS was compiled by Tryon [1527] in 1981; it offers a collection of 134 papers – primarily on the bispectrum, and catalogs HOS-related research and applications in the 1960s and 1970s. The second bibliography by Nielsen and Walsh [1042] represents a collection of 258 entries. This bibliography contains 1759 entries, and is indicative of the explosive research in the area in the period 1984–1996.

We have made every effort to include conference and journal papers, and theses up to the end of December 1996; however, the area is rapidly expanding, and omissions are inevitable; we apologize for those papers which are not included here; some citations may have been omitted because we were unable to obtain enough information to ensure uniqueness. HOS-based publications are available in several other languages, but in order to ensure a list of widely accessible publications, we have limited most of our entries to publications in English.

The bibliography is divided into two parts: (1) Alphabetical/chronological; and (2) By subject. The classification keys reflect the authors' background (and hence, biases) in statistical signal processing, as do the journals which we have exhaustively searched (primarily the engineering databases). Corrections and additions may be e-mailed to the first author at `a.swami@ieee.org`.

Acknowledgements

This bibliography is a direct outcome of the IEEE Signal Processing Workshop on Higher-Order Statistics held on 4–6 June 1993 at South Lake Tahoe, California. The workshop was partially funded by the Office of Naval Research (ONR) under grant N00014-93-1-0065, and the US Army Research Office (ARO) under grant DAAH04-93-G-0180, for which we are grateful; in particular, we would like to thank Dr. Neil Gerr (ONR) and Dr. W. Sander (ARO) for their encouragement and support.

We would like to thank Computing Services Support Solutions (CS-3), Los Angeles; the University of

Virginia (UVA), Charlottesville, VA, the Indian Institute of Science (IISc), Bangalore, and the University of Southern California (USC), Los Angeles, for sharing the costs of this project either directly (personnel, materials and supplies) or indirectly (computing resources, internet access). Special thanks to L. Srinivas (CDOT, Bangalore) for his help with the first version of this bibliography.

We would like to thank the following individuals and organizations who were generous enough to provide us with material for the bibliography: Boualem Boashash, Sandro Bellini, Pascal Bondon, Jean-Francois Cardoso, Sergio Carrato, Enis Cetin, Chong-Yung Chi, Pierre Comon, Amod Dandawate, Athanasios Delopoulos, Mithat Dogan, Roger F. Dwyer, Steve Elgar, Justin W. Fackrell, Javier Fonollosa, Jose A.R. Fonollosa, Gordon Frazer, Muhammad R. Hajj, Yujiro Inouye, George E. Ioup, Juliette W. Ioup, LeRoux Joel, Ismail Jouny, Ram Kakarala, Sung Bae Kim, Kenneth Lever, Elias S. Manolakos, Jerry Mendel, Raghuveer Mysore, Max Nikias, Leif Persson, Athina Petropulu, Lisa Pflug, Edward J. Powers, Maria Rangoussi, Branco Ristich, Noel Rozario, Brian Sadler, Josep Salavedra, Erlan Sangfelt, Gaetano Scarano, Christine Serviere, Sanyogita Shamsunder, D. Sherman, Andreas Spanias, Ronald Stearman, David Thomson, Michail Tsatsanis, John Tsimbinos, Jitendra Tugnait, United Signals & Systems, Jose Vidal, and Abdelhak Zoubir.

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1. Theory

12 84 301 379 1471 1627 1678 1748

1.1. Estimators, asymptotics, and performance analysis

21 22 23 145 150 152 163 164 193 218 241 320 328 334 438 440 452 480 531 627 756 816 840 841 842 866 879 887 985 986 909 916 1017 1019 1015 1023 1098 1103 1119 1121 1129 1163 1170 1187 1198 1199 1224 1244 1246 1250 1280 1337 1351 1352 1355 1394 1395 1399 1452 1454 1510 1511 1526 1528 1640 1697 1707 1706 1740 1736 1741 1747 1749 1750

1.2. Detection and classification

1 6 41 68 77 89 90 208 211 286 302 313 325 333 341 343 344 369 391 392 389 403 485 502 503 521 549 550 551 552 548 647 650 665 684 689 699 710 737 784 786 787 808 809 872 909 910 935 987 992 1029 1043 1094 1112 1117 1135 1136 1134 1140 1141 1142 1152 1154 1156 1170 1216 1223 1266 1267 1268 1271 1273 1275 1276 1287 1293 1361 1364 1369 1372 1400 1457 1476 1481 1486 1500 1528 1531 1532 1533 1535 1536 1604 1605 1611 1613 1620 1634 1643 1659 1677 1680 1679 1684 1732 1737 1758

1.3. Identification

78 150 432 549 336 926 929 940 984 1152 1201 1202 1214 1253 1284 1466 1467 1474 1501 1512 1528 1563 1567 1568 1581 1591 1600 1610 1641 1658 1669 1675

1.3.1. Linear model identifiability

311 355 454 457 459 520 521 522 546 1466 1474 1543 1618 1615 1673

1.3.2. Nonlinear – Volterra expansion

27 40 81 87 100 103 114 116 117 134 139 140 151 155 272 352 363 670 699 795 796 798 797 802 805 844 1072 1150 1151 1181 1183 1184 1439 1537 1548

1.4. Information: entropy and prediction

43 139 243 244 247 248 246 292 340 376 496 547 612 874 1060 1157 1185 1641 1653 1656 1657 1676 1703 1750

1.5. Nonstationary processes

11 23 71 152 323 330 331 334 335 340 527 528 529 851 871 1114 1360 1439 1445 1477 1504 1682 1681 1711 1729 1740 1732 1759

1.6. Point processes

152 154 161 871 996 1298 1477 1504 1689

1.7. Statistical hypothesis testing

36 61 63 79 150 167 166 270 280 294 303 310 312 321 333 476 503 551 552 548 594 596 597 621 636 643 649 688 890 899 923 987 988 1170 1271 1437 1445 1513 1534 1535 1541 1598 1601 1604 1605 1609 1611 1617 1620 1624 1756 1754 1758

2. Modeling

300 708 780 791 1322 1489 1490 1491

2.1. Linear parametric (AR, MA, ARMA)

4 5 15 17 16 18 19 29 39 31 32 33 35 38 105 143 168 173 179 180 197 203 215 234 230 243 244 245 247 248 246 250 252 254 256 255 257 263 265 277 345 346 349 373 376 456 453 458 482 483 484 496 505 513 514 517 520 521 522 533 534 535 536 537 538 543 544 545 546 541 552 558 560 556 561 606 668 675 700 722 723 732 823 1251 854 856 862 863 865 867 868 876 888 915 948 959 971 995 1010 1011 1013 1018 1020 1022 1025 1026 1027 1028 1039 1046 1050 1051 1054 1055 1056 1066 1069 1070 1083 1084 1100 1125 1161 1167 1205 1208 1215 1218 1219 1220 1255 1259 1281 1283 1284 1285 1289 1294 1321 1339 1349 1408 1410 1413 1411 1412 1432 1433 1434 1442 1444 1445 1455 1462 1463 1464 1468 1470 1475 1485 1494 1497 1498 1510 1518 1525 1528 1555 1556 1557 1558 1559 1560 1561 1562 1564 1565 1566 1567 1568 1570

1571 1572 1573 1574 1579 1580 1581 1582 1591 1595 1598 1599 1606 1607 1554 1611 1619 1618 1616 1617 1623 1635 1645 1646 1647 1648 1649 1653 1654 1669 1676 1686 1709 1718 1716 1717 1721 1722 1727 1729 1730 1753 1751

2.2. Multichannel

34 169 171 172 180 184 192 226 287 289 291 292 297 298 532 539 663 672 674 673 678 680 681 704 337 906 907 917 921 976 1077 1128 1195 1203 1340 1359 1365 1408 1442 1459 1461 1503 1515 1516 1517 1519 1520 1521 1522 1524 1525 1528 1578 1605 1610 1615 1622 1650 1662 1699 1700 1707 1745 1746

2.3. Multidimensional

52 55 178 207 217 265 279 356 357 359 426 431 433 434 429 430 514 595 598 599 600 724 725 734 834 1200 1204 1265 1314 1317 1416 1442 1458 1460 1495 1497 1496 1531 1592 1594 1600 1602 1608 1637 1652 1701 1715 1732

2.4. Nonlinear

7 40 47 48 62 78 87 100 114 133 135 136 137 138 140 141 159 231 271 274 307 308 309 352 377 386 387 441 442 488 489 490 564 336 644 645 746 744 745 777 778 801 802 859 873 930 993 1031 1030 1085 1086 1182 1181 1183 1184 1211 1256 1344 1397 1415 1416 1435 1439 1636 1675 1714 1755

2.5. Polynomial

71 72 73 124 128 135 431 430 446 479 557 940 993 1086 1104 1106 1107 1108 1109 1110 1105 1158 1169 1230 1231 1360 1362 1367 1453 1454 1456 1498 1730 1735 1731 1744

2.6. Time-varying

123 126 323 324 326 317 463 509 527 528 561 1024 1192 1530 1538 1543 1596 1679 1729

3. Signals, systems and communications

3.1. Chaos, fractals and physical systems

2 10 11 62 411 410 417 419 449 450 492 508 573 581 890 896 898 959 960 969 970 1036 1130 1131 1132 1133 1295 1333 1334 1401 1644 1652 1655 1664

3.2. Channel estimation and equalization

25 91 92 93 94 95 96 97 98 102 103 104 105 109 107 143 171 174 179 225 229 228 236 237 257 258 309 361 364 365 372 373 407 436 471 494 536 537 553 561 567 569 576 583 608 609 611 612 613 615 616 617 618 619 673 700 701 702 732 804 813 819 823 851 853 863 862 864 894 901 915 918 917 943 975 990 1033 1049 1050 1051 1062 1118 1126 1127 1128 1148 1149 1162 1165 1167 1186 1187 1210 1227 1246 1247 1257 1258 1286 1311 1312 1313 1314 1346 1348 1349 1350 1396 1431 1480 1514 1523 1529 1530 1538 1539 1540 1544 1545 1547 1576 1577 1586 1587 1588 1589 1590 1596 1597 1599 1606 1607 1612 1616 1623 1630 1648 1657 1658 1667 1668 1669 1676 1713 1720 1723 1724 1725 1722 1727 1726 1753

3.3. Cyclostationarity

23 319 323 324 325 326 327 330 331 332 334 335 317 500 501 527 528 529 540 559 560 556 603 621 690 727 1024 1182 1270 1359 1361 1360 1362 1366 1367 1409 1530 1540 1599 1667 1680 1681 1729 1730 1735 1738 1739 1752

3.4. Coherence and coupling

46 85 106 153 156 198 214 222 266 362 415 418 420 439 438 555 577 586 587 591 590 592 629 650 729 770 775 808 810 859 1035 1041 1091 1096 1097 1099 1176 1179 1188 1196 1197 1200 1203 1236 1263 1292 1337 1376 1377 1378 1379 1380 1381 1397 1510 1740 1734 1738 1739 1741

3.5. Controls and state space

14 351 516 524 542 930 1344 1345 1382 1383 1384 1435 1469 1472 1555 1558 1636

3.6. Delay and Doppler estimation

174 259 262 263 295 323 329 396 398 402 425 436 580 601 648 687 779 785 850 875 999 1000 1057 1058 1075 1076 1141 1146 1147 1155 1186 1300 1301 1304 1305 1307 1308 1315 1327 1353 1361 1391 1392 1409 1569 1583 1585 1603 1621 1696 1697 1715 1740 1734

3.7. Harmonic analysis and frequency estimation

52 55 56 49 57 209 224 260 261 279 299 360 362 393 394 408 409 445 497 499 509 555 559 601 662 692 696 815 855 870 872 893 963 985 1082 1096 1097 1099 1168 1188 1221 1260 1304 1319 1323 1341 1354 1358 1363 1382 1385 1384 1388 1389 1435 1436 1442 1465 1473 1479 1484 1511 1679 1681 1714 1730 1740 1735 1741 1742 1731 1744

3.8. Modulation and synchronization

89 90 299 460 567 604 608 687 716 966 1041 1068 1124 1158 1223 1269 1597 1642 1714 1730 1740

3.9. Multiplicative noise

130 327 330 397 402 554 555 558 560 559 556 1085 1362 1367 1443 1448 1451 1453 1450 1454 1457 1729 1730 1740 1733 1734 1736 1738 1741

3.10. Noise cancellation

110 318 322 384 443 525 530 526 999 1038 1209 1276 1282 1341 1342 1343 1374 1387 1390 1483 1499

3.11. Reconstruction of deterministic signals

26 37 82 170 172 173 200 201 202 240 251 253 332 354 356 357 358 380 405 477 515 517 518 519 523 565 566 602 654 653 652 706 724 725 726 734 781 788 790 822 823 828 833 834 837 838 852 880 881 910 914 931 932 936 955 956 1037 1071 1081 1083 1084 1120 1122 1123 1127 1204 1215 1220 1239 1242 1265 1274 1276 1290 1335 1347 1393 1406 1407 1440 1441 1458 1484 1488 1492 1528 1531 1536 1584 1672 1683 1701

3.12. Sampling issues

30 213 579 642 835 1251 836 858 1040 1137 1138 1139 1145 1368 1369 1370 1371 1372 1449 1552

3.13. Source localization and separation

181 182 183 184 185 187 189 190 191 192 193 194 195 204 218 235 238 239 241 260 261 186 284 285 286 287 288 290 292 293 296 297 298 304 367 368 369 370 371 383 385 435 437 469 470 493 495 498 532 539 540 570 571 572 582 674 673 695 692 693 694 696 718 721 815 816 817 818 337 826 848 849 906 907 920 919 950 957 974 976 985 986 997 1096 1128 1164 1166 1188 1261 1262 1264 1277 1319 1326 1323 1324 1325 1340 1353 1355 1357 1358 1363 1364 1365 1366 1354 1383 1385 1384 1442 1459 1461 1465 1473 1481 1487 1503 1519 1520 1522 1524 1622 1662 1671 1685 1699 1700 1702 1704 1705 1707 1706 1715 1746

3.14. System identification (I/O linear and nonlinear)

13 14 32 47 48 52 53 51 67 74 87 91 100 99 103 114 115 116 117 118 119 120 135 138 151 159 170 176 266 267 269 271 272 273 274 347 348 350 351 352 374 386 423 424 478 489 490 526 542 564 336 578 666 667 669 671 676 677 679 684 698 747 749 753 774 758 759 760 792 795 796 797 798 800 801 802 803 811 805 827 839 859 892 912 913 926 929 930 937 993 1001 1002 1003 1004 1005 1006 1024 1072 1080 1085 1178 1212 1222 1328 1329 1330 1331 1398 1435 1450 1485 1501 1510 1512 1541 1545 1546 1547 1548 1549 1550 1551 1552 1575 1593 1616 1614 1625 1626 1628 1675 1695 1755

3.15. Time–frequency representations

43 44 71 122 123 124 126 128 127 129 130 131 132 388 444 461 462 463 464 465 466 467 468 472 473 474 507 529 832 1112 1224 1230 1231 1414 1446 1447 1538 1712

3.16. Transient analysis

43 41 86 264 461 462 603 637 662 682 683 687 685 686 464 467 944 1040 1087 1089 1088 1135 1136

1140 1141 1142 1144 1145 1143 1146 1147 1156 1193 1224 1260 1293 1442 1659 1735

4. Algorithms

4.1. Adaptive and recursive

5 7 17 31 33 42 67 177 178 197 259 262 345 360 365 377 456 455 481 526 614 665 746 744 745 776 748 751 752 873 875 921 973 991 1004 1037 1113 1114 1178 1216 1222 1242 1257 1288 1348 1373 1428 1430 1442 1455 1456 1462 1463 1475 1480 1502 1533 1539 1549 1564 1576 1577 1586 1621 1630 1648 1668 1710 1718

4.2. Architectures and implementation

6 8 20 421 451 563 635 728 730 736 788 789 790 846 845 904 905 903 951 1113 1189 1278 1279 1424 1425 1426 1427 1428 1429 1430 1502

4.3. Estimation: cumulants and polyspectra

42 46 58 60 88 108 205 206 212 223 312 439 438 491 501 531 560 568 579 610 640 664 709 714 783 793 812 833 1252 842 846 858 860 861 869 902 953 991 1008 1009 1044 1052 1101 1103 1112 1114 1172 1195 1205 1206 1207 1208 1228 1250 1294 1302 1320 1376 1380 1381 1432 1434 1435 1436 1469 1478 1505 1506 1507 1508 1513 1553 1629 1631 1682 1686 1719 1759

4.4. Neural networks

25 68 113 304 339 340 341 843 853 951 952 1171 1663

5. Applications – real data

1402 1632

5.1. Astronomy

9 45 59 64 65 306 652 653 735 824 881 886 891 955 954 998 1240 1243 1393 1672 1683

5.2. Atmospheric sciences

276 448 623 735 743 824 895 1159 1226 1508 1509

5.3. Acoustics

109 110 176 281 400 401 629 641 658 729 972 1032 1193 1229 1296 1297 1305 1308 1310 1482 1550 1551 1643 1665

5.4. Biomedicine and physiology

3 80 111 112 121 133 159 302 353 381 382 422 578 628 655 658 659 664 666 698 729 739 738 779 794 795 797 798 799 800 801 820 825 877 878 884 885 902 905 903 911 912 958 994 999 1000 1067 1063 1064 1065 1066 1091 1111 1225 1290 1291 1292 1303 1336 1375 1377 1378 1379 1380 1476 1493 1633 1634 1643 1690 1689

5.5. Economics

568 643 644 645

5.6. Geophysics and seismic

28 144 153 221 222 342 520 569 574 575 576 510 620 640 733 813 829 862 899 922 1092 1093 1115 1116 1656 1657 1658 1676 1708

5.7. Images and vision

3 10 54 50 52 66 83 196 210 216 232 305 306 341 353 390 427 428 562 565 566 593 594 595 596 597 598 599 600 654 653 691 703 705 706 719 720 731 806 809 820 821 822 828 831 834 880 881 889 908 914 931 932 933 934 956 1021 1034 1038 1071 1078 1209 1213 1214 1243 1268 1272 1274 1296 1315 1316 1318 1317 1335 1347 1393 1400 1406 1407 1440 1488 1493 1495 1497 1496 1528 1531 1532 1536 1602 1608 1666 1672 1687 1737

5.8. Mechanical, turbulence, and fluid dynamics

75 76 77 119 120 175 199 268 269 275 278 283 315 316 401 589 587 591 590 588 592 622 623 624 625 632 633 634 661 703 717 743 770 771 750 761 763 768 765 757 764 766 767 762 754 755 769 772 807

828 861 869 887 892 893 900 923 934 935 939 942 963 962 964 965 966 967 968 1012 1014 1016 1073 1074 1174 1175 1177 1179 1180 1233 1234 1235 1236 1232 1237 1263 1299 1306 1309 1310 1404 1405 1417 1418 1419 1420 1421 1422 1423 1638 1639 1688 1698 1743 1757

5.9. Oceanography

142 165 166 227 315 316 363 409 413 414 412 416 420 586 607 630 631 660 814 927 928 937 938 939 989 996 1014 1035 1241 1693 1694 1691 1692

5.10. Optics and lasers

6 64 65 66 69 70 82 83 106 180 305 306 380 404 405 477 565 566 602 605 651 652 697 703 735 781 828 881 900 955 954 956 998 1239 1240 1242 1307 1655 1666 1672 1683

5.11. Plasma and crystallography

577 657 707 772 773 883 1102 1176 1237

5.12. Radar

656 710 711 712 713 715 743 830 831 850 897 1153 1154 1155 1169 1173 1403 1483 1660 1661 1671

5.13. Sensor arrays

185 186 188 191 194 204 219 220 239 242 367 368 370 371 383 539 572 582 695 696 721 818 923 919 950 1264 1277 1324 1356 1385 1522 1685 1705

5.14. Sonar

122 282 315 316 344 380 392 395 397 399 398 401 403 419 472 475 604 646 641 685 830 977 1169 1229 1238 1282 1300 1305 1486 1736

5.15. Speech

24 146 147 233 249 366 378 486 487 506 557 813 924 925 978 979 980 981 982 991 992 1007 1029 1079 1216 1217 1287 1288 1338 1651 1674 1677 1730

5.16. Vibrations

101 419 420 893 1386

6. Books and conference proceedings

125 148 149 157 338 1042 406 447 504 512 511 585 626 742 941 961 983 1048 1059 1090 1160 1190 1438 1245 1249 1254 1332 1356 1527 1670 1675 1710 1748

7. Tutorials

158 160 162 179 186 511 638 639 664 782 857 881 882 945 946 947 948 949 1045 1047 1053 1061 1191 1248 1356 1449