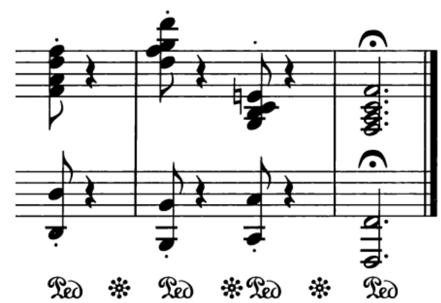
Chord Progressions



You have been hired by a sheet music company that produces transcriptions of popular songs for the piano. These transcriptions include the notes for chords in the chord progression of the song, as well as labels identifying the chords. Your job is to develop software to automatically generate chords and labels based on music recordings.

Your company's sheet music is targeted at beginners, so the songs you work with are not too complicated. All of the chords your program must process will be major, minor, or diminished triads, but they may appear in any inversion. To get you up to speed on the prerequisite knowledge, your manager has provided a brief explanation:

> *The root note is the note off of which the chord is based - it is not necessarily the lowest note in the chord, if it is in inversion. Chord quality is determined by the intervals between the constituent notes, relative to the root, when the chord is in root position. A major chord has a major third between the root and third, and a minor third between the third and fifth. A minor chord has a minor third, then a major third. A diminished chord has two minor thirds.*
>
> *Once the chord quality is determined, the lowest frequency note determines the inversion. If the root is the lowest note, the chord is in root position. If the third is the lowest note, the chord is in 1st inversion. If the fifth is the lowest note, the chord is in 2nd inversion. Note that the lowest note is the only determining factor in the inversion: the order of higher notes does not matter.*

Another engineer has already written software to take the recording, filter out audio other than main chords, and convert the result to discrete time series data for each chord. Your program must take the data for each song and return the constituent notes and chord type for each chord in the song.

Input

The first line of input will consist of the number of chords to be processed, $n \leq 1000$, the number of discrete amplitude samples of each chord waveform, $m = 2^k$ where $8 \leq k \leq 20$, and the duration of each chord waveform t in seconds where $0.1 \leq t \leq 2$. The next n lines of input contain m floating point values representing the amplitude of the signal sampled at evenly spaced time intervals over duration t. Each input waveform is guaranteed to represent a perfectly tuned chord consisting of three notes. All signals will be combinations of pure sine waves, so there will be no signal noise.

Output

Output should be $2n$ lines, one for each chord. For each chord, the first line contains the constituent notes in ascending order of frequency. For simplicity, all sharps or flats will be written as sharps, represented with a # after the note name. The second line identifies the chord in the format [root note] [chord quality] [inversion]. Chord quality is denoted by maj, min, or dim. Chord inversion is denoted by 0, 1, or 2. All notes should be capitalized.

Music Theory Reference

You will need to understand some basic music theory concepts to complete this assignment. Chords are, for the purposes of this assignment, three notes playing simultaneously, creating a compound waveform. The notes of a chord are a distance of a third from each other in root position (more on chord inversions later). In root position, the lowest note (the bass) is the root, the middle note is the third, and the highest note is the fifth. Make sure not to confuse a third (the interval) with the third of the chord (a middle note).

A third can be one of two concrete intervals: a major third ($2^{\frac{4}{12}} : 1$), or a minor third ($2^{\frac{3}{12}} : 1$). The given ratios are in equal temperament, which is the tuning system that will be used for this assignment. It is also important to note that notes an octave apart have the same name, and have a ratio of $2 : 1$.

Chords, for this assignment, can be major, minor, or diminished. A major chord has a major third between the root and third, and a minor third between the third and fifth. A minor chord has a minor third between the root and third, and a major third between the third and fifth. A diminished chord has a minor third between the root and third, and the third and fifth.

Finally, a chord can be in inversion. By moving notes in the chord up or down by an octave, the root and quality of the chord stay the same, but the lowest note (the bass) changes. For example, A C major chord (C-E-G) in inversion (E-G-C) is still a C major chord, but now E is in the bass. A chord with its third in the bass is said to be in 1st inversion; if the fifth is in the bass, it is in 2nd inversion. Here are some resources you may find useful:

Equal Temperament Interval Ratios
Musical Pitch Frequencies
Chord Inversions

Notes on Implementation

For this assignment, you are expected to implement a fast Fourier transform on your own. You are also expected to write your own code for determining chord characteristic from a set of frequencies. However, you are welcome to use existing library code for extracting frequencies from the Fourier transform results. Python's SciPy library includes functions for getting frequency bins for fft output, as well as peak finding utilities. Other languages may require you to write these functions yourself.

Sample Input

2 1024 0.1
0.0000 0.5989 1.1719 1.6940 2.1429 2.4997 2.7497 2.8834 2.8963 2.7899 2.5707 2.2504 1.8452 1.3746 0.8609 0.3275 -0.2016 -0.7034 -1.1568 -1.5437 -1.8497 -2.0646 -2.1829 -2.2039 -2.1314 -1.9736 -1.7424 -1.4526 -1.1211 -0.7659 -0.4053 -0.0566 0.2644 0.5443 0.7727 0.9426 1.0506 1.0969 1.0849 1.0213 0.9149 0.7766 0.6181 0.4517 0.2889 0.1403 0.0148 -0.0812 -0.1435 -0.1707 -0.1642 -0.1274 -0.0663 0.0118 0.0984 0.1843 0.2609 0.3199 0.3547 0.3603 0.3336 0.2742 0.1838 0.0662 -0.0724 -0.2246 -0.3817 -0.5342 -0.6729 -0.7891 -0.8751 -0.9248 -0.9342 -0.9014 -0.8270 -0.7139 -0.5671 -0.3934 -0.2014 -0.0004 0.1999 0.3897 0.5600 0.7031 0.8128 0.8849 0.9174 0.9105 0.8666 0.7901 0.6870 0.5645 0.4307 0.2938 0.1617 0.0415 -0.0611 -0.1418 -0.1983 - 0.2303 -0.2393 -0.2289 -0.2040 -0.1705 -0.1353 -0.1051 -0.0865 -0.0848 -0.1042 -0.1469 -0.2131 -0.3010 -0.4063 -0.5229 -0.6429 -0.7573 -0.8561 -0.9296 -0.9684 -0.9645 -0.9118 -0.8066 -0.6478 -0.4379 -0.1820 0.1111 0.4302 0.7617 1.0899 1.3985 1.6709 1.8913 2.0453 2.1212 2.1105 2.0085 1.8147 1.5332 1.1723 0.7448 0.2669 -0.2418 -0.7598 -1.2642 -1.7322 -2.1419 -2.4734 -2.7101 -2.8393 -2.8530 -2.7484 -2.5280 -2.1998 -1.7768 -1.2762 -0.7194 -0.1302 0.4660 1.0432 1.5762 2.0421 2.4207 2.6961 2.8571 2.8978 2.8177 2.6222 2.3215 1.9306 1.4685 0.9571 0.4199 -0.1185 -0.6343 -1.1054 -1.5120 -1.8384 -2.0728 -2.2081 -2.2424 -2.1786 -2.0240 -1.7902 -1.4922 -1.1474 -0.7747 -0.3935 -0.0229 0.3197 0.6192 0.8634 1.0440 1.1560 1.1990 1.1758 1.0932 0.9607 0.7900 0.5945 0.3883 0.1852 -0.0018 -0.1617 -0.2856 -0.3672 -0.4036 -0.3948 -0.3439 -0.2566 -0.1411 -0.0071 0.1343 0.2719 0.3948 0.4932 0.5588 0.5856 0.5701 0.5114 0.4117 0.2754 0.1096 -0.0768 -0.2736 -0.4696 -0.6536 -0.8151 -0.9446 -1.0343 -1.0785 -1.0743 -1.0209 -0.9206 -0.7780 -0.5998 -0.3949 -0.1730 0.0551 0.2787 0.4875 0.6722 0.8250 0.9402 1.0141 1.0452 1.0346 0.9852 0.9019 0.7912 0.6605 0.5177 0.3707 0.2271 0.0932 -0.0256 -0.1259 -0.2056 -0.2649 -0.3051 -0.3293 - 0.3416 -0.3468 -0.3501 -0.3564 -0.3699 -0.3937 -0.4297 -0.4778 -0.5366 -0.6026 -0.6709 -0.7353 -0.7885 -0.8231 -0.8316 -0.8073 -0.7448 -0.6404 -0.4927 -0.3028 -0.0744 0.1859 0.4689 0.7635 1.0564 1.3334 1.5798 1.7813 1.9246 1.9985 1.9946 1.9074 1.7355 1.4815 1.1519 0.7575 0.3126 -0.1656 -0.6572 -1.1410 -1.5956 -1.9997 -2.3339 -2.5814 -2.7289 -2.7673 -2.6924 -2.5051 - 2.2114 -1.8223 -1.3533 -0.8240 -0.2566 0.3244 0.8937 1.4266 1.8998 2.2927 2.5883 2.7741 2.8427 2.7920 2.6255 2.3520 1.9850 1.5423 1.0449 0.5159 -0.0203 -0.5396 -1.0191 -1.4383 - 1.7801 -2.0313 -2.1838 -2.2339 -2.1834 -2.0388 -1.8108 -1.5140 -1.1658 -0.7857 -0.3937 -0.0099 0.3471 0.6606 0.9172 1.1070 1.2238 1.2662 1.2365 1.1410 0.9894 0.7942 0.5698 0.3317 0.0954 -0.1241 -0.3137 -0.4624 -0.5621 -0.6082 -0.5994 -0.5380 -0.4296 -0.2826 -0.1078 0.0824 0.2747 0.4556 0.6127 0.7348 0.8128 0.8405 0.8146 0.7350 0.6049 0.4303 0.2201 -0.0148 -0.2620 -0.5082

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1.9382 1.3301 0.5429 -0.3200 -1.1457 -1.8284 -2.2850 -2.4666 -2.3642 -2.0080 -1.4603 -0.8043
-0.1298 0.4812 0.9661 1.2891 1.4439 1.4501 1.3458 1.1775 0.9891 0.8127 0.6632 0.5365 0.4130

0.2645 0.0637 -0.2067 -0.5463 -0.9334 -1.3255 -1.6652 -1.8892 -1.9411 -1.7820 -1.4013 -0.8213 -0.0976 0.6871 1.4342 2.0434 2.4288 2.5323 2.3345 1.8583 1.1664 0.3529 -0.4714 -1.1954 -1.7248 -1.9964 -1.9871 -1.7165 -1.2430 -0.6527 -0.0451 0.4837 0.8564 1.0268 0.9856 0.7609 0.4112 0.0140 -0.3485 -0.6045 -0.7048 -0.6313 -0.3991 -0.0530 0.3417 0.7109 0.9861 1.1159 1.0755 0.8702 0.5335 0.1209 -0.3014 -0.6681 -0.9267 -1.0464 -1.0226 -0.8763 -0.6485 -0.3914 -0.1570 0.0135 0.0980 0.0973 0.0350 -0.0484 -0.1049 -0.0900 0.0265 0.2516 0.5659 0.9240 1.2615 1.5059 1.5902 1.4658 1.1142 0.5532 -0.1629 -0.9490 -1.7006 -2.3098 -2.6818 -2.7505 -2.4903 -1.9211 -1.1066 -0.1464 0.8387 1.7243 2.4002 2.7862 2.8435 2.5785 2.0409 1.3141 0.5013 -0.2903 -0.9661 -1.4570 -1.7275 -1.7776 -1.6393 -1.3672 -1.0269 -0.6815 -0.3812 -0.1549 -0.0079 0.0760 0.1281 0.1846 0.2774 0.4241 0.6231 0.8521 1.0717 1.2332 1.2884 1.2009 0.9554 0.5626 0.0611 -0.4878 -1.0090 -1.4255 -1.6720 -1.7067 -1.5193 -1.1345 -0.6086 -0.0213 0.5373 0.9814 1.2442 1.2892 1.1165 0.7633 0.2974 -0.1943 -0.6206 -0.9023 -0.9856 -0.8519 -0.5217 -0.0509 0.4781 0.9705 1.3354 1.5011 1.4279 1.1147 0.6004 -0.0432 -0.7221 -1.3358 -1.7933 -2.0274 -2.0048 -1.7310 -1.2479 -0.6264 0.0462 0.6801 1.1975 1.5435 1.6932 1.6526 1.4545 1.1504 0.7987 0.4539 0.1563 -0.0735 -0.2359 -0.3497 -0.4441 -0.5499 -0.6895 -0.8695 -1.0766 -1.2780 -1.4270 -1.4718 -1.3668 -1.0838 -0.6212 -0.0079 0.6967 1.4097 2.0358 2.4818 2.6724 2.5626 2.1476 1.4656 0.5938 -0.3611 -1.2785 -2.0413 -2.5530 -2.7523 -2.6217 -2.1897 -1.5257 -0.7286 0.0889 0.8177 1.3685 1.6845 1.7483 1.5817 1.2398 0.7994 0.3447 -0.0478 -0.3214 -0.4482 -0.4315 -0.3026 -0.1129 0.0777 0.2134 0.2535 0.1808 0.0041 -0.2436 -0.5123 -0.7452 -0.8905 -0.9114 -0.7945 -0.5523 -0.2216 0.1436 0.4819 0.7367 0.8664 0.8533 0.7064 0.4606 0.1695 -0.1044 -0.3025 -0.3815 -0.3227 -0.1366 0.1383 0.4416 0.7019 0.8505 0.8352 0.6309 0.2469 -0.2727 -0.8541 -1.4054 -1.8312 -2.0486 -2.0020 -1.6741 -1.0901 -0.3158 0.5515 1.3968 2.1048 2.5776 2.7491 2.5953 2.1374 1.4380 0.5910 -0.2929 -1.1030 -1.7449 -2.1529 -2.2982 -2.1899 -1.8705 -1.4060 -0.8735 -0.3471 0.1132 0.4698 0.7104 0.8461 0.9051 0.9226 0.9315 0.9534 0.9927 1.0355 1.0531 1.0088 0.8679 0.6072 0.2239 -0.2604 -0.7995 -1.3279 -1.7706 -2.0550 -2.1245 -1.9494 -1.5344 -0.9204 -0.1800 0.5918 1.2923 1.8262 2.1213 2.1397 1.8846 1.3996 0.7620 0.0707 -0.5703 -1.0678 -1.3550 -1.4011 -1.2158 -0.8464 -0.3694 0.1240 0.5430 0.8135 0.8898 0.7625 0.4590 0.0383 -0.4204 -0.8314 -1.1178 -1.2249 -1.1290 -0.8416 -0.4062 0.1094 0.6250 1.0624 1.3579 1.4728 1.3987 1.1574 0.7955 0.3747 -0.0396 -0.3906 -0.6392 -0.7699 -0.7916 -0.7331 -0.6354 -0.5414 -0.4857 -0.4858 -0.5381 -0.6182 -0.6855 -0.6924 -0.5955 -0.3664 -0.0008 0.4770 1.0148 1.5391 1.9655 2.2133 2.2197 1.9523 1.4174 0.6620 -0.2305 -1.1513 -1.9816 -2.6097 -2.9482 -2.9479 -2.6051 -1.9629 -1.1050 -0.1432 0.7995 1.6064 2.1842 2.4754 2.4651 2.1807 1.6851 1.0648 0.4147 -0.1771 -0.6428 -0.9433 -1.0717 -1.0505 -0.9241 -0.7475 -0.5743 -0.4458 -0.3833 -0.3850 -0.4282 -0.4756 -0.4851 -0.4202 -0.2595 -0.0033 0.3251 0.6817 1.0097 1.2501 1.3527 1.2872 1.0500 0.6665 0.1887 -0.3134 -0.7630 -1.0899 -1.2431 -1.2002 -0.9721 -0.6019 -0.1573 0.2802 0.6300 0.8270 0.8333 0.6454 0.2962 -0.1507 -0.6111 -0.9950 -1.2226 -1.2382 -1.0211 -0.5906 -0.0032 0.6551 1.2827 1.7789 2.0600 2.0734 1.8065 1.2886 0.5867 -0.2049 -0.9798 -1.6351 -2.0879 -2.2862 -2.2160 -1.9012 -1.3980 -0.7839 -0.1447 0.4401 0.9086 1.2242 1.3789 1.3903 1.2945 1.1364 0.9589 0.7937 0.6555 0.5400 0.4271 0.2880 0.0939 -0.1741 -0.5171 -0.9142 -1.3231 -1.6850 -1.9343 -2.0104 -1.8704 -1.4987 -0.9142 -0.1702 0.6508 1.4474 2.1143 2.5584 2.7135 2.5517 2.0889 1.3834 0.5277 -0.3647 -1.1765 -1.8039 -2.1722 -2.2465 -2.0355 -1.5891 -0.9889 -0.3344 0.2741 0.7509 1.0381 1.1139 0.9932 0.7237 0.3746 0.0240 -0.2565

-0.4138 -0.4226 -0.2886 -0.0463 0.2488 0.5317 0.7400 0.8266 0.7681 0.5691 0.2605 -0.1059 -0.4682 -0.7658 -0.9507 -0.9965 -0.9028 -0.6946 -0.4170 -0.1255 0.1246 0.2898 0.3468 0.2973 0.1677 0.0030 -0.1417 -0.2139 -0.1746 -0.0082 0.2725 0.6264 0.9903 1.2894 1.4503 1.4160 1.1573 0.6809 0.0312 -0.7143 -1.4552 -2.0839 -2.5016 -2.6353 -2.4496 -1.9537 -1.2016 -0.2848 0.6811 1.5728 2.2777 2.7100 2.8227 2.6136 2.1235 1.4288 0.6286 -0.1717 -0.8754 -1.4090 -1.7303 -1.8323 -1.7396 -1.5012 -1.1784 -0.8329 -0.5155 -0.2577 -0.0689 0.0626 0.1630 0.2645 0.3955 0.5713 0.7890 1.0255 1.2414 1.3879 1.4173 1.2938 1.0026 0.5565 -0.0037 -0.6130 -1.1914 -1.6564 -1.9367 -1.9851 -1.7869 -1.3647 -0.7754 -0.1024 0.5571 1.1080 1.4722 1.6018 1.4865 1.1555 0.6725 0.1245 -0.3924 -0.7899 -1.0021 -0.9965 -0.7796 -0.3950 0.0839 0.5670 0.9633 1.1965 1.2182 1.0161 0.6164 0.0791 -0.5124 -1.0648 -1.4910 -1.7241 -1.7278 -1.5019 -1.0815 -0.5296 0.0732 0.6431 1.1065 1.4112 1.5329 1.4777 1.2774 0.9821 0.6489 0.3308 0.0667

NOTE: Lines of input are split so that they can fit into this document. In real test cases, each sequence of samples will be on a single line and should be handled accordingly. You may assume that test cases will have appropriate sample rates and durations to allow for proper determination of frequency peaks.

Sample Output

C E G
C maj 0
G# C F
F min 1