Double Blind Listening Tests of Csound 5 Compiled with Single-Precision and Double-Precision Samples

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I compiled one version of Csound 5 and CsoundVST with `MYFLT` defined as `float`, i.e. with single-precision audio samples and arithmetic throughout, and a second version that was identical except that `MYFLT` was defined as `double`, i.e. with double-precision audio samples and arithmetic throughout. I then rendered three Csound compositions both with the `float` version of CsoundVST and with the `double` version. All pieces were rendered using WAV soundfiles with float samples at 96000 samples per second and 1 control sample per audio sample at the same amplitude level, for the highest possible rendering quality. I then auditioned the pieces using WinABX, a program that automates double-blind A/B/X listening tests. The user plays through the soundfile, at any point selecting a short segment of sound and comparing the A version, the B version, or the X version, which WinABX randomly chosen from A or B. Applying the binomial distribution to the number of successful guesses versus the total number of guesses provides a direct estimate of experimental error. This procedure is highly recommended for objective tests of the human ability to discriminate between different sources of audio. I could not reliably hear any difference between two of the pieces, despite hours of testing, but there were several segments of the third piece where I could easily and reliably hear differences in spectral color or resonant quality.

1 Introduction

Although software synthesis systems such as Csound [1] can be capable of extremely high rendering quality, it rarely seems — to me, anyway — that they are used to their fullest potential. To some extent, this may be due to untested beliefs by computer musicians that their normal practices produce audio of adequate quality.

I have always been interested in high fidelity, as well as somewhat sceptical of received wisdom in any field, so as soon as it became possible to build a double-precision version of Csound, I wondered if there would be an audible difference between it and the `float` version. After listening to some of my pieces rendered both ways, I thought the `double` versions did in fact sound clearer, sweeter, and less noisy.

I designed this study as a more objective test of my impression, using a double-blind comparator [2, 3, 4, 5] to rule out my own subjective bias.

2 Method

I selected three Csound scores ("Trapped in Convert" by Richard Boulanger [6], "f–2002-01-28–17-37-42.042.mml.9632" and "zodiac.py" by myself). I compiled two versions of Csound identical excepting only that the `float` version was compiled with `MYFLT` defined as `float`, which is the version most musicians use, and the `double` version was compiled with `MYFLT` defined as `double`, which is the version that I normally use. Each piece was rendered with both versions of Csound, using `sr = 96000` (the current professional audio standard), `nchnls = 2`, and `ksmps = 1`, with the soundfile output options `-RWdfo` (Microsoft WAV format soundfiles with single-precision floating-point samples, also a current professional audio standard as an alternative to 24 bit samples).

The Csound instruments in the pieces use variously noise generators, frequency modulation, amplitude modulation, additive synthesis, digital filters, and waveshaping, as well as the Karplus-Strong plucked string simulation. One of the pieces ("zodiac.py") also uses a few notes of sampled piano. Frequency modulation and digital filters can theoretically be quite sensitive to rounding errors, and so are plausible sources of any artifacts that might be more audible in the `float` version of Csound.

I listened to the pieces played using WinABX software [5], sometimes through an M-Audio Ozone USB audio interface, a Mackie Micro Series 1202 mixer, a Samson Servo-240 amplifier, and Alesis Monitor One near-field monitor speakers in a quiet room, and other times through a Tascam US-428 USB audio interface and Mackie HR824 near-field monitors. Both USB interfaces support 48 KHz audio at 24 bits per sample.

The WinABX software allows the user to play through the soundfile. At any point during playback, the user can select a segment of audio and switch back and forth between source A, source B, or source X, which WinABX randomly chooses from A or B. The user then guesses whether X is A or B, and the software records the results and writes them to a log file. The user can move around in the soundfiles at will and repeat the comparisons as often as he or she likes; the sole statistical control in the procedure in the mere randomization of X. However, this is sufficient to render the entire procedure completely foolproof, since nobody in the world but the software knows whether X is A or B. This is what it means to be double-blind: the subject doesn't know whether X is A or B, and the tester also doesn't know whether X is A or B. It doesn't matter that in this case the subject and the tester are the same. The one-tailed binomial test estimates the probability (p) that the result was obtained by chance.

Some people on the Csound mailing lists (also available through `csounds.com`) [1] expressed concern that even if there is an audible difference between versions, the `float` version would be significantly faster, so I also measured rendering speed for both versions using "Trapped in Convert."

3 Results

3.1 Double-Blind Tests

Over a period of several days, I performed several tests using the WinABX software. I recorded the results of every test without exception. The complete WinABX log files are as follows:

```
WinABX v0.42 test report
06/18/2005 11:49:33

A file: C:\utah\home\mkg\projects\csoundabx\trapped-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\trapped-float.wav

Start position 00:00.0, end position 04:50.1
11:51:22    1/1  p=50.0%
Start position 00:26.8, end position 04:50.1
11:53:50    2/2  p=25.0%
Start position 00:49.3, end position 04:50.1
11:56:55    2/3  p=50.0%
Start position 01:32.1, end position 01:55.3
11:59:27    3/4  p=31.2%
Start position 02:03.6, end position 02:24.3
12:01:45    4/5  p=18.8%
Start position 02:52.7, end position 03:01.3
12:04:34    4/6  p=34.4%
Start position 02:52.6, end position 03:01.3
12:05:29    4/7  p=50.0%
Start position 03:06.4, end position 03:26.0
12:08:18    4/8  p=63.7%
Start position 03:06.4, end position 03:52.8
12:12:55    5/9  p=50.0%
Start position 04:06.8, end position 04:22.6
12:14:56   6/10  p=37.7%
Start position 00:36.9, end position 00:50.7
12:17:25   7/11  p=27.4%
Start position 01:50.1, end position 01:56.0
12:19:51   8/12  p=19.4%
Start position 00:23.9, end position 00:34.8
12:25:09   8/13  p=29.1%
12:26:02  test finished

A file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-float.wav
```

```
Start position 00:00.0, end position 00:18.9
12:29:03    0/1  p=100.0%
Start position 00:34.2, end position 00:39.5
12:30:33    1/2  p=75.0%
Start position 00:41.5, end position 00:55.2
12:32:56    1/3  p=87.5%
Start position 01:07.7, end position 01:16.4
12:34:25    1/4  p=93.8%
Start position 00:44.4, end position 00:48.7
12:40:01    2/5  p=81.2%
Start position 01:22.9, end position 01:28.3
12:40:58    3/6  p=65.6%
12:41:51    4/7  p=50.0%
12:42:47    4/8  p=63.7%
Start position 00:47.6, end position 00:55.2
12:45:15    4/9  p=74.6%
Start position 01:35.4, end position 01:40.8
12:47:46   5/10  p=62.3%
Start position 01:53.7, end position 01:59.2
12:50:06   6/11  p=50.0%
Start position 02:15.6, end position 02:18.7
12:53:04   7/12  p=38.7%
Start position 02:36.3, end position 02:39.3
12:54:10   7/13  p=50.0%
Start position 02:24.7, end position 02:29.5
12:55:19   8/14  p=39.5%
Start position 02:31.7, end position 02:33.3
12:58:31   9/15  p=30.4%
12:59:10   9/16  p=40.2%
Start position 00:06.0, end position 00:09.2
13:01:03   9/17  p=50.0%
Start position 00:43.3, end position 00:49.3
13:02:31  10/18  p=40.7%
Start position 01:44.6, end position 01:48.4
13:03:44  10/19  p=50.0%
13:04:04  10/20  p=58.8%
13:04:36  11/21  p=50.0%
13:05:05  11/22  p=58.4%
Start position 02:13.3, end position 02:17.6
13:07:16  11/23  p=66.1%
Start position 02:27.4, end position 02:32.3
13:08:14  11/24  p=72.9%
Start position 02:43.7, end position 02:49.1
13:09:42  11/25  p=78.8%
13:10:47  12/26  p=72.1%
Start position 02:51.3, end position 02:52.8
13:11:46  13/27  p=64.9%
13:11:56  14/28  p=57.5%
13:12:24  15/29  p=50.0%
13:12:37  16/30  p=42.8%
13:13:31  17/31  p=36.0%
Start position 03:16.7, end position 03:18.9
13:15:57  17/32  p=43.0%
Start position 01:05.0, end position 01:07.7
13:16:51  18/33  p=36.4%
13:17:19  18/34  p=43.2%
Start position 00:22.7, end position 00:27.6
13:17:56  18/35  p=50.0%
Start position 03:11.3, end position 03:14.5
13:19:11  19/36  p=43.4%
13:19:26  20/37  p=37.1%
13:19:37  21/38  p=31.4%
13:20:26  22/39  p=26.1%
13:20:42  23/40  p=21.5%
13:20:52  23/41  p=26.6%
13:21:12  24/42  p=22.0%
13:21:28  25/43  p=18.0%
13:22:03  26/44  p=14.6%
13:22:26  26/45  p=18.6%
13:22:49  26/46  p=23.1%
13:23:12  27/47  p=19.1%
13:23:27  28/48  p=15.6%
13:23:39  29/49  p=12.6%
13:23:46  29/50  p=16.1%
13:24:09  29/51  p=20.1%
13:24:34  30/52  p=16.6%
13:24:50  30/53  p=20.5%
Start position 02:55.6, end position 02:59.9
13:26:29  31/54  p=17.0%
13:26:58  32/55  p=14.0%
13:27:07  32/56  p=17.5%
13:27:15  33/57  p=14.5%
13:27:24  34/58  p=11.9%
13:27:35  35/59  p=9.6%
13:27:44  35/60  p=12.3%
13:28:07  36/61  p=10.0%
13:29:07  37/62  p=8.1%
13:29:51  37/63  p=10.4%
13:30:05  38/64  p=8.4%
13:30:24  39/65  p=6.8%
13:31:00  40/66  p=5.4%
13:31:42  41/67  p=4.3%
13:32:29  41/68  p=5.7%
13:33:33  41/69  p=7.4%
13:34:05  41/70  p=9.4%
13:34:25  41/71  p=11.7%
13:34:34  41/72  p=14.4%
13:34:45  41/73  p=17.5%
13:34:53  41/74  p=20.8%
13:34:59  41/75  p=24.4%
13:35:06  42/76  p=21.1%
13:35:15  42/77  p=24.7%
13:35:21  43/78  p=21.4%
13:35:28  43/79  p=25.0%
13:35:32  44/80  p=21.7%
13:35:39  44/81  p=25.3%
Start position 01:52.1, end position 01:55.9
13:38:27  45/82  p=22.0%
13:38:34  46/83  p=19.0%
13:38:42  47/84  p=16.3%
```

```
13:38:51  reset

13:39:23    1/1  p=50.0%
13:39:32    2/2  p=25.0%
13:39:40    3/3  p=12.5%
13:39:48    3/4  p=31.2%
13:39:56    4/5  p=18.8%
13:40:29    5/6  p=10.9%
13:40:51    6/7  p=6.2%
13:41:01    7/8  p=3.5%
13:41:09    8/9  p=2.0%
13:41:19   9/10  p=1.1%
13:41:57  10/11  p=0.6%
13:42:38  10/12  p=1.9%
13:42:53  10/13  p=4.6%
13:43:03  10/14  p=9.0%
13:43:13  11/15  p=5.9%
13:43:23  12/16  p=3.8%
13:43:32  13/17  p=2.5%
13:43:42  14/18  p=1.5%
13:43:49  15/19  p=1.0%
13:44:39  16/20  p=0.6%
13:45:15  17/21  p=0.4%
13:45:57  18/22  p=0.2%
13:46:37  19/23  p=0.1%
13:53:16  reset

Start position 01:23.4, end position 01:25.0
13:55:42    1/1  p=50.0%
13:56:00    1/2  p=75.0%
13:56:12    2/3  p=50.0%
13:56:27    3/4  p=31.2%
13:56:56    3/5  p=50.0%
13:57:07    4/6  p=34.4%
13:57:21    5/7  p=22.7%
13:57:34    5/8  p=36.3%
13:57:47    5/9  p=50.0%
13:57:55   5/10  p=62.3%
13:58:06   5/11  p=72.6%
13:58:18   6/12  p=61.3%
13:58:50   7/13  p=50.0%
13:59:00   7/14  p=60.5%
13:59:10   8/15  p=50.0%
14:00:19   8/16  p=59.8%
14:00:23  reset

14:00:24  test finished

A file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-float.wav

Start position 02:42.7, end position 02:46.3
14:19:39    0/1  p=100.0%
14:19:52    0/2  p=100.0%
14:20:03    1/3  p=87.5%
14:20:31    2/4  p=68.8%
14:20:44    2/5  p=81.2%
14:21:21    2/6  p=89.1%
Start position 03:03.5, end position 03:04.8
14:22:00    2/7  p=93.8%
14:22:07    2/8  p=96.5%
14:22:14    2/9  p=98.0%
14:22:39   2/10  p=98.9%
Start position 03:18.1, end position 03:20.5
14:23:48   2/11  p=99.4%
14:23:59   2/12  p=99.7%
14:24:11   3/13  p=98.9%
14:24:23   3/14  p=99.4%
14:24:41   4/15  p=98.2%
14:24:50   4/16  p=98.9%
14:25:23   5/17  p=97.5%
14:26:01   5/18  p=98.5%
14:26:18   5/19  p=99.0%
14:26:35   5/20  p=99.4%
14:27:14   5/21  p=99.6%
Start position 00:53.1, end position 00:57.4
14:28:16   6/22  p=99.2%
14:28:36   7/23  p=98.3%
14:28:56   7/24  p=98.9%
14:29:17   8/25  p=97.8%
14:29:53   8/26  p=98.6%
14:30:09   9/27  p=97.4%
14:30:29  10/28  p=95.6%
14:30:55  11/29  p=93.2%
14:31:57  12/30  p=90.0%
14:32:13  13/31  p=85.9%
14:32:59  13/32  p=89.2%
14:33:16  14/33  p=85.2%
14:33:40  15/34  p=80.4%
14:34:01  15/35  p=84.5%
14:34:17  16/36  p=79.7%
14:34:39  16/37  p=83.8%
14:34:50  16/38  p=87.2%
14:35:09  16/39  p=90.0%
Start position 01:25.7, end position 01:28.8
14:35:58  17/40  p=86.6%
14:36:05  18/41  p=82.6%
14:36:15  18/42  p=86.0%
14:36:45  18/43  p=88.9%
Start position 01:58.4, end position 01:59.7
14:37:36  19/44  p=85.4%
Start position 01:17.9, end position 01:19.6
14:38:32  19/45  p=88.4%
Start position 01:39.2, end position 01:41.3
14:39:42  19/46  p=90.8%
Start position 00:00.0, end position 00:03.7
14:40:42  19/47  p=92.8%
14:40:56  19/48  p=94.4%
14:41:23  20/49  p=92.4%
14:41:41  20/50  p=94.1%
14:41:56  20/51  p=95.4%
```

```
14:42:07  20/52  p=96.5%
14:42:11  21/53  p=95.1%
14:42:26  21/54  p=96.2%
Start position 01:15.9, end position 01:17.5
14:43:08  22/55  p=94.8%
14:43:17  22/56  p=95.9%
Start position 03:24.8, end position 03:27.5
14:43:57  23/57  p=94.4%
14:44:14  23/58  p=95.7%
14:58:29  reset

Start position 02:41.0, end position 02:45.3
15:02:19    0/1  p=100.0%
15:02:31    1/2  p=75.0%
15:03:00    2/3  p=50.0%
15:03:24    3/4  p=31.2%
15:03:59    3/5  p=50.0%
15:04:50    4/6  p=34.4%
15:05:34    4/7  p=50.0%
Start position 03:16.8, end position 03:18.9
15:07:55    4/8  p=63.7%
15:08:03    5/9  p=50.0%
15:08:18   5/10  p=62.3%
15:08:23  reset

15:08:24  test finished

A file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-float.wav

Start position 00:00.0, end position 00:05.4
15:17:20    0/1  p=100.0%
15:17:30    1/2  p=75.0%
15:17:41    1/3  p=87.5%
Start position 01:36.4, end position 01:40.8
15:22:40    1/4  p=93.8%
Start position 02:08.9, end position 02:12.2
15:25:46    2/5  p=81.2%
15:25:58    2/6  p=89.1%
15:26:10    2/7  p=93.8%
Start position 02:26.3, end position 02:32.8
15:27:18    2/8  p=96.5%
Start position 02:28.4, end position 02:32.8
15:28:10    2/9  p=98.0%
Start position 02:42.8, end position 02:44.7
15:28:37   3/10  p=94.5%
15:28:45   3/11  p=96.7%
15:29:09   3/12  p=98.1%
15:29:14  test finished

A file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\f--2002-01-28--17-37-42.042.mml.9632-float.wav

Start position 01:39.1, end position 01:46.7
21:17:02    1/1  p=50.0%
21:17:43    2/2  p=25.0%
21:18:41    2/3  p=50.0%
21:19:44    2/4  p=68.8%
Start position 01:45.6, end position 01:46.7
21:20:23    2/5  p=81.2%
Start position 02:02.5, end position 02:05.2
21:21:28    3/6  p=65.6%
21:22:05    4/7  p=50.0%
21:22:54    4/8  p=63.7%
21:23:21    4/9  p=74.6%
Start position 02:36.4, end position 02:38.8
21:24:24   5/10  p=62.3%
21:25:02   6/11  p=50.0%
21:25:46   7/12  p=38.7%
21:26:10   8/13  p=29.1%
21:26:41   8/14  p=39.5%
21:26:52   8/15  p=50.0%
21:27:41   9/16  p=40.2%
21:28:49   9/17  p=50.0%
Start position 02:52.5, end position 02:56.6
21:30:36  10/18  p=40.7%
21:31:39  11/19  p=32.4%
21:32:27  12/20  p=25.2%
21:33:17  12/21  p=33.2%
Start position 03:11.0, end position 03:14.5
21:34:30  13/22  p=26.2%
21:35:11  14/23  p=20.2%
21:35:42  15/24  p=15.4%
23:06:35  15/25  p=21.2%
23:06:39  test finished

A file: C:\utah\home\mkg\projects\csoundabx\zodiac-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\zodiac-float.wav

Start position 00:05.2, end position 00:11.2
16:33:16    1/1  p=50.0%
16:33:25    2/2  p=25.0%
16:33:37    3/3  p=12.5%
16:34:10    4/4  p=6.2%
16:34:35    5/5  p=3.1%
16:34:40    6/6  p=1.6%
16:34:46    7/7  p=0.8%
16:34:52    8/8  p=0.4%
16:34:57    9/9  p=0.2%
16:35:02  10/10  p< 0.1%
16:35:07  11/11  p< 0.1%
16:35:09  12/12  p< 0.1%
Start position 01:04.4, end position 01:05.4
16:36:23  13/13  p< 0.1%
16:37:05  reset

Start position 03:20.8, end position 03:23.1
16:37:48    1/1  p=50.0%
16:37:59    2/2  p=25.0%
16:38:09    3/3  p=12.5%
16:38:16    4/4  p=6.2%
```

```
16:38:20    5/5  p=3.1%
16:38:25    6/6  p=1.6%
16:38:29    7/7  p=0.8%
16:38:34    8/8  p=0.4%
16:38:39    9/9  p=0.2%
16:41:00  reset

16:41:38  test finished

A file: C:\utah\home\mkg\projects\csoundabx\zodiac-double.wav
B file: C:\utah\home\mkg\projects\csoundabx\zodiac-float.wav

Start position 03:40.7, end position 03:46.8
16:43:40    1/1  p=50.0%
16:44:05    2/2  p=25.0%
16:44:13    3/3  p=12.5%
16:44:41    4/4  p=6.2%
16:44:49    5/5  p=3.1%
16:45:06    5/6  p=10.9%
16:45:18    5/7  p=22.7%
16:45:42    6/8  p=14.5%
16:46:23  reset

Start position 05:49.5, end position 05:55.5
16:47:43    1/1  p=50.0%
16:47:56    2/2  p=25.0%
16:48:07    3/3  p=12.5%
16:48:17    4/4  p=6.2%
16:48:27    5/5  p=3.1%
16:48:47    6/6  p=1.6%
16:48:56    7/7  p=0.8%
16:49:08    8/8  p=0.4%
16:49:21    9/9  p=0.2%
16:49:37  10/10  p< 0.1%
16:49:43  reset

Start position 01:47.8, end position 01:51.7
16:50:27    1/1  p=50.0%
16:50:36    2/2  p=25.0%
16:50:45    3/3  p=12.5%
16:50:53    4/4  p=6.2%
16:51:00    5/5  p=3.1%
16:51:09    6/6  p=1.6%
16:51:19    7/7  p=0.8%
16:51:32    8/8  p=0.4%
16:51:40    9/9  p=0.2%
16:51:48  10/10  p< 0.1%
16:51:51  reset

Start position 02:36.9, end position 02:41.4
17:27:45    1/1  p=50.0%
17:27:50  test finished
```

3.2 Rendering Speed

With the `float` version of Csound, "Trapped in Convert" rendered at 96000 samples per second and 1 control sample per audio sample to a floating-point soundfile in 124.516 seconds on my HP Pavilion zd7000 notebook, which has a 3.06 GHz Pentium 4 processor and 1 GB RAM. With the `double` version, "Trapped" rendered in 135.36 seconds.

4 Discussion

The most important result is that in double-blind tests, I *could* hear a differences between the `float` and `double` versions of Csound, and in some places I could hear it with almost complete reliability. The differences were, to my ears, obvious. The double-blind test confirms that the differences *are* obvious. In several segments of "zodiac.py," I correctly identified the source in every trial.

The next most important result is that audible differences occur only in certain short segments and then only in certain pieces. I could hear no difference in "Trapped in Convert" no matter how hard I tried, and in "f–2002-01-28–17-37-42.042.mml.9632" I could hear a difference in only one short section, which might well have been a false positive. Only in "zodiac.py" are the results of outstanding statistical significance. Evidently, a few Csound instrument definitions, opcodes, and signal processing algorithms are far more sensitive than others to the difference in magnitude of arithmetic rounding errors that, on the face of it, should be the only difference between the versions. Of course, it is possible that the C code in some places is actually defined differently depending on the value of the `MYFLT` macro. Obviously, this possibility should be investigated further.

I was able to reliably discriminate the sources only after hours of learning and experimentation. I could only hear a difference in short segments, and I had to force myself to zoom in on those, and test only those.

The musical nature of the differences is also instructive. In most cases, the different-sounding segments have different spectral colors, with the `float` version sounding somewhat more shrill. In a few cases, there are resonant sounds that ring more in the `float` version than in the `double` version — in one segment the `float` version even has a clearly audible overtone that I could not hear at all in the `double` version.

My original subjective impression, before this study, was that the `double` version is cleaner, sweeter, and less noisy. After the intensive listening required for this study, I have modified my opinion a little. I do not really hear the `double` version as less noisy. Both versions, in fact, sound very quiet and undistorted. But this study *has* confirmed my judgment that the `double` version is cleaner and sweeter. These differences, and how frequently they occur for certain sounds, could — to my taste, at any rate — easily be musically significant in pieces that use such sounds.

In conclusion, I find that there *are* musically perceptible differences between the `float` and `double` versions of Csound. The presumption must be that the `double` version performs more accurate signal processing. Therefore, I recommend that the `double` version become the standard version of Csound.

The `float` version does run slightly faster than the `double` version, but the speed advantage is only 9.25%.

If future investigations show significant differences in the C code between the versions of Csound, this study should be repeated with a corrected version of Csound.

Authors of Csound instruments and opcodes, and other music or digital signal processing software, may wish to consider adding blind testing to their development procedures.

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