Project 5: Commentary

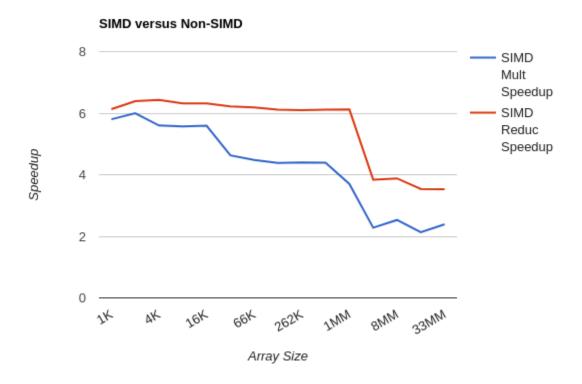
#### 1. What machine you ran this on

My main workhorse, a home-built machine running Ubuntu 16.04 LTS (64-bit). The processor is Intel® Core<sup>TM</sup> i5-4690K CPU @ 3.50GHz  $\times$  4 and it has 15.6 GiB of usable RAM.

The difference between peak and average performance was minimal, and the load averages were very low (less than 1) across the board. However, per Professor Bailey's warning, the SSE code for reduction wasn't 100% portable and was causing segfaults when run locally. Therefore, flip2 was used for this report. At the time, the load averages were in the low 3s.

2. Show the table and graph.

1000         307.22         1780.67         5.80           2048         310.55         1862         6.00           4096         312.72         1751.16         5.60           8192         312.82         1743.01         5.57           16384         313.5         1753.08         5.59           32768         313.82         1453.39         4.63           66536         312.37         1399.06         4.48           131072         313.06         1370.13         4.38           262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           1677216         298.47         635.42         2.13           3355432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39	Array Size	Non-SIMD Mult	SIMD Mult	Speedup
4096         312.72         1751.16         5.60           8192         312.82         1743.01         5.57           16384         313.5         1753.08         5.59           32768         313.82         1453.39         4.63           66536         312.37         1399.06         4.48           131072         313.06         1370.13         4.38           262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           838608         298.95         755.02         2.53           1677216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32	1000	307.22	1780.67	5.80
8192         312.82         1743.01         5.57           16384         313.5         1753.08         5.59           32768         313.82         1453.39         4.63           66536         312.37         1399.06         4.48           131072         313.06         1370.13         4.38           262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SiMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           32768         291.59         1846.56         6.32 <th>2048</th> <th>310.55</th> <th>1862</th> <th>6.00</th>	2048	310.55	1862	6.00
16384       313.5       1753.08       5.59         32768       313.82       1453.39       4.63         66536       312.37       1399.06       4.48         131072       313.06       1370.13       4.38         262144       312.57       1376.5       4.40         524288       312.05       1369.84       4.39         1048576       306.06       1131.05       3.70         4194304       299.37       681.97       2.28         8388608       299.95       755.02       2.53         16777216       298.47       635.42       2.13         33554432       300.54       718.97       2.39         Array Size       Non-SiMD Reduc       SiMD Reduc       Speedup         1000       288.91       1771.85       6.13         2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11 <t< th=""><th>4096</th><th>312.72</th><th>1751.16</th><th>5.60</th></t<>	4096	312.72	1751.16	5.60
32768       313.82       1453.39       4.63         66536       312.37       1399.06       4.48         131072       313.06       1370.13       4.38         262144       312.57       1376.5       4.40         524288       312.05       1369.84       4.39         1048576       306.06       1131.05       3.70         4194304       299.37       681.97       2.28         838608       298.95       755.02       2.53         16777216       298.47       635.42       2.13         33554432       300.54       718.97       2.39         Array Size       Non-SIMD Reduc       SiMD Reduc       Speedup         1000       288.91       1771.85       6.13         2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10 <t< th=""><th>8192</th><th>312.82</th><th>1743.01</th><th>5.57</th></t<>	8192	312.82	1743.01	5.57
66536         312.37         1399.06         4.48           131072         313.06         1370.13         4.38           262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1840.96         6.32           32768         291.95         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10 <th>16384</th> <th>313.5</th> <th>1753.08</th> <th>5.59</th>	16384	313.5	1753.08	5.59
131072         313.06         1370.13         4.38           262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.08         6.1	32768	313.82	1453.39	4.63
262144         312.57         1376.5         4.40           524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1776.83         6.11           1048576         289.93         1773.96         6.12<	66536	312.37	1399.06	4.48
524288         312.05         1369.84         4.39           1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.83         6.11           1048576         289.93         1773.96         6.12<	131072	313.06	1370.13	4.38
1048576         306.06         1131.05         3.70           4194304         299.37         681.97         2.28           8388608         298.95         755.02         2.53           16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.83         6.11           1048576         289.93         1773.96         6.12           4194304         283.05         1085.52         3.84	262144	312.57	1376.5	4.40
4194304       299.37       681.97       2.28         8388608       298.95       755.02       2.53         16777216       298.47       635.42       2.13         33554432       300.54       718.97       2.39         Array Size       Non-SIMD Reduc       SIMD Reduc       Speedup         1000       288.91       1771.85       6.13         2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         838608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	524288	312.05	1369.84	4.39
8388608       298.95       755.02       2.53         16777216       298.47       635.42       2.13         33554432       300.54       718.97       2.39         Array Size       Non-SIMD Reduc       SIMD Reduc       Speedup         1000       288.91       1771.85       6.13         2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1048576	306.06	1131.05	3.70
16777216         298.47         635.42         2.13           33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.83         6.11           1048576         289.93         1773.96         6.12           4194304         283.05         1085.52         3.84           8388608         284.2         1103.08         3.88           16777216         283.39         1004.17         3.54	4194304	299.37	681.97	2.28
33554432         300.54         718.97         2.39           Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.83         6.11           1048576         289.93         1773.96         6.12           4194304         283.05         1085.52         3.84           8388608         284.2         1103.08         3.88           16777216         283.39         1004.17         3.54	8388608	298.95	755.02	2.53
Array Size         Non-SIMD Reduc         SIMD Reduc         Speedup           1000         288.91         1771.85         6.13           2048         290.78         1858.85         6.39           4096         291.33         1872.31         6.43           8192         291.81         1843.08         6.32           16384         291.95         1846.56         6.32           32768         291.59         1814         6.22           66536         291.39         1803.45         6.19           131072         290.41         1774.18         6.11           262144         291.32         1777.7         6.10           524288         290.73         1776.83         6.11           1048576         289.93         1773.96         6.12           4194304         283.05         1085.52         3.84           8388608         284.2         1103.08         3.88           16777216         283.39         1004.17         3.54	16777216	298.47	635.42	2.13
1000       288.91       1771.85       6.13         2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	33554432	300.54	718.97	2.39
2048       290.78       1858.85       6.39         4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	Array Size	Non-SIMD Reduc	SIMD Reduc	Sneedun
4096       291.33       1872.31       6.43         8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	Array Orze	TION CHILD HOUGE		Орссаир
8192       291.81       1843.08       6.32         16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54				•
16384       291.95       1846.56       6.32         32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000	288.91 290.78	1771.85	6.13 6.39
32768       291.59       1814       6.22         66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048	288.91 290.78	1771.85 1858.85	6.13 6.39
66536       291.39       1803.45       6.19         131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096	288.91 290.78 291.33	1771.85 1858.85 1872.31	6.13 6.39 6.43
131072       290.41       1774.18       6.11         262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192	288.91 290.78 291.33 291.81	1771.85 1858.85 1872.31 1843.08	6.13 6.39 6.43 6.32
262144       291.32       1777.7       6.10         524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192 16384	288.91 290.78 291.33 291.81 291.95	1771.85 1858.85 1872.31 1843.08 1846.56	6.13 6.39 6.43 6.32 6.32
524288       290.73       1776.83       6.11         1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192 16384 32768	288.91 290.78 291.33 291.81 291.95 291.59	1771.85 1858.85 1872.31 1843.08 1846.56 1814	6.13 6.39 6.43 6.32 6.32 6.22
1048576       289.93       1773.96       6.12         4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192 16384 32768 66536	288.91 290.78 291.33 291.81 291.95 291.59 291.39	1771.85 1858.85 1872.31 1843.08 1846.56 1814 1803.45	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11
4194304       283.05       1085.52       3.84         8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192 16384 32768 66536 131072	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32	1771.85 1858.85 1872.31 1843.08 1846.56 1814 1803.45 1774.18	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11
8388608       284.2       1103.08       3.88         16777216       283.39       1004.17       3.54	1000 2048 4096 8192 16384 32768 66536 131072 262144	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32 290.73	1771.85 1858.85 1872.31 1843.08 1846.56 1814 1803.45 1774.18 1777.7	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11 6.10 6.11
<b>16777216</b> 283.39 1004.17 3.54	1000 2048 4096 8192 16384 32768 66536 131072 262144 524288	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32 290.73	1771.85 1858.85 1872.31 1843.08 1846.56 1814 1803.45 1774.18 1777.7	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11 6.10 6.11
	1000 2048 4096 8192 16384 32768 66536 131072 262144 524288 1048576	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32 290.73 289.93	1771.85 1858.85 1872.31 1843.08 1846.56 1814 1803.45 1774.18 1777.7 1776.83 1773.96 1085.52	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11 6.10 6.11 6.12 3.84
<b>33554432</b> 284.26 1002.38 3.53	1000 2048 4096 8192 16384 32768 66536 131072 262144 524288 1048576 4194304	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32 290.73 289.93 283.05 284.2	1771.85  1858.85  1872.31  1843.08  1846.56  1814  1803.45  1774.18  1777.7  1776.83  1773.96  1085.52  1103.08	6.13 6.39 6.43 6.32 6.32 6.32 6.22 6.19 6.11 6.10 6.11 6.12 3.84
	1000 2048 4096 8192 16384 32768 66536 131072 262144 524288 1048576 4194304 8388608	288.91 290.78 291.33 291.81 291.95 291.59 291.39 290.41 291.32 290.73 289.93 283.05 284.2	1771.85  1858.85  1872.31  1843.08  1846.56  1814  1803.45  1774.18  1777.7  1776.83  1773.96  1085.52  1103.08	6.13 6.39 6.43 6.32 6.32 6.22 6.19 6.11 6.10 6.11 6.12 3.84



### 3. What patterns are you seeing in the speedups?

For both array multiplication (represented on the graph as "SIMD Mult") and multiplication-reduction (on the graph as "SIMD Reduc"), speedup is consistently high until some time after the array size crosses one million elements. Beyond that threshold, the speedup of both drops considerably.

After the threshold, SIMD Mult's SSE alternative offers a speedup factor of only slightly better than 2.

After the threshold, SIMD Reduc's SSE alternative offers a speedup factor of around 3.5.

# 4. Are they consistent across a variety of array sizes?

The speedups appear to be steady before and after the drop-off at one million array elements. SIMD Mult hovers in speedups in the late 5s (with some variance at the 32k mark, when the speedup becomes 4.4), while SIMD Reduc remains in the low 6s. After one million element arrays are encountered, both speedups are slightly better than half the speedups under lighter loads.

# 5. Why or why not, do you think?

The drop-off is likely due to a hardware limitation. As someone on the discussion board pointed out, flip's L3 cache can handle roughly three million floats, which means that two float arrays of 1.5 million elements would bring it to capacity. This neatly coincides with the performance hit between the 1M and 4M mark.

6. Knowing that SSE SIMD is 4-floats-at-a-time, why could you get a speed-up of <4.0 or >4.0 in the array multiplication?

#### and

7. Knowing that SSE SIMD is 4-floats-at-a-time, why could you get a speed-up of <4.0 or >4.0 in the array multiplication-reduction?

Though the SSE SIMD expects 4-floats, the compiler notices when not all four spaces are used and can optimize automatically, leading to a greater-than-four speedup. Similarly, in the multiplication-reduction code, there is an FMA, which the compiler uses to its advantage to deliver higher speedups than the code itself would be able to produce (until the hardware bottleneck, of course).