Sphinx is a speech recognition system written in C++. Speech recognition systems are an important component of speech-based interfaces and applications such as Apple Siri, Google Assistant, and IBM Speech to Text. Speech recognition is a compute-intensive activity, involving probabilistically pruning a large search tree. Sphinx uses sophisticated acoustic, phonetic, and language models to improve efficiency and accuracy. Sphinx is driven by using randomly-chosen utterances from the CMU AN4 alphanumeric database.

It accepts audio files as input from the *tailbench.input* directory and uses microarchitectural characteristics of each application to process the audio files. It is a CPU intensive application and has been chosen as the application of choice for profiling the tail latencies.

General Workflow -
1. The *tailbench/sphinx* folder contains a run.sh script.
2. On running the script, it reads the CMU AN4 database from the tailbench.inputs directory
3. While processing, it keeps track of Service Times, Queue Times and End2End times of all the requests.
4. Once the processing is done, it passes the collected values to a central *harness* application.
5. The central *harness* reads and writes all the latency information into a file named *lats.bin.*
6. The *lats.bin* file generated in the previous step is passed through a python script in order to obtain the *mean, 95th percentile, 99th percentile* latencies.
7. The latency information is then used to profile the application.
8. This process is repeated for several times with varying configurations of the application.

In order to profile the Sphinx in different runtime environments, we have used various stressing tools in Linux.

The application has been profiled on the basis of performance on the server with a variety of following parameters:

1. CPU stress - stressing all the 32 cores of the system
2. Memory stress - fills the entire 64gb memory available
3. Disk stress - temporary read and writes to the disk
4. Combination of all the above stress simulation factors
5. Cache statistics are recorded during the execution.
6. Disk IO statistics are recorded during the execution.
7. Graphs showing the Tail Latencies under various stress simulations are plotted.
8. Function call graphs are also plotted and function call statistics are recorded.

The drive link for all the files and graphs shown in the report :
https://drive.google.com/drive/folders/1tnRcr3aO-WXUck0ZeC22yiASCi0XEd98?usp=sharing

<0.1> Baseline Sphinx without caching of inputs under no stress simulation

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1161.79
System time (seconds): 17.21
Percent of CPU this job got: 1543%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:16.38
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1739428
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 84
Minor (reclaiming a frame) page faults: 9256940
Voluntary context switches: 169507
Involuntary context switches: 3363
Swaps: 0
File system inputs: 194856
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1153.480 ms | p95 2501.867 ms | p99 3287.053 ms | max 4055.808 ms | p95/mean 2.169 | p99/mean 2.850
end2end: mean 32272.270 ms | p95 59762.979 ms | p99 62480.157 ms | max 63270.994 ms | p95/mean 1.852 | p99/mean 1.936
```

<0.2> Baseline Sphinx with caching of inputs under no stress simulation

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1118.84
System time (seconds): 6.87
Percent of CPU this job got: 1590%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:10.76
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1739180
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 3753442
Voluntary context switches: 165736
Involuntary context switches: 1172
Swaps: 0
File system inputs: 0
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1094.047 ms | p95 2276.824 ms | p99 3079.206 ms | max 4261.249 ms | p95/mean 2.081 | p99/mean 2.815
end2end: mean 30345.717 ms | p95 55864.293 ms | p99 58407.772 ms | max 59059.081 ms | p95/mean 1.841 | p99/mean 1.925
```

\<1.1\> Sphinx run with 100% CPU Stress without caching of inputs

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1086.51
System time (seconds): 16.71
Percent of CPU this job got: 756%
Elapsed (wall clock) time (h:mm:ss or m:ss): 2:25.74
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1734932
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 67
Minor (reclaiming a frame) page faults: 12909349
Voluntary context switches: 250145
Involuntary context switches: 69377
Swaps: 0
File system inputs: 191976
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 2209.998 ms | p95 4770.250 ms | p99 5882.759 ms | max 8900.264 ms | p95/mean 2.158 | p99/mean 2.662
end2end: mean 64530.664 ms | p95 121956.424 ms | p99 127193.320 ms | max 128966.486 ms | p95/mean 1.890 | p99/mean 1.971
```

<1.2> Sphinx run with 100% CPU Stress with caching of inputs

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1091.02
System time (seconds): 14.53
Percent of CPU this job got: 755%
Elapsed (wall clock) time (h:mm:ss or m:ss): 2:26.35
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1733928
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 10877392
Voluntary context switches: 319550
Involuntary context switches: 76696
Swaps: 0
File system inputs: 0
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 2224.816 ms | p95 4709.530 ms | p99 6115.799 ms | max 8399.061 ms | p95/mean 2.117 | p99/mean 2.749
end2end: mean 65111.344 ms | p95 122566.199 ms | p99 128125.660 ms | max 129633.443 ms | p95/mean 1.882 | p99/mean 1.968
```

<2.1> Sphinx run with 100% memory stress without caching of inputs

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1174.08
System time (seconds): 20.46
Percent of CPU this job got: 1007%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:58.53
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1725000
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 1753
Minor (reclaiming a frame) page faults: 9437300
Voluntary context switches: 191338
Involuntary context switches: 10698
Swaps: 0
File system inputs: 359696
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1184.538 ms | p95 2559.141 ms | p99 3357.898 ms | max 4234.687 ms | p95/mean 2.160 | p99/mean 2.835
end2end: mean 34357.529 ms | p95 62775.426 ms | p99 65503.540 ms | max 66237.082 ms | p95/mean 1.827 | p99/mean 1.907
```

<2.2> Sphinx run with 100% memory stress with caching of inputs

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1162.91
System time (seconds): 18.37
Percent of CPU this job got: 1070%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:50.36
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1727348
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 1265
Minor (reclaiming a frame) page faults: 9448113
Voluntary context switches: 175121
Involuntary context switches: 14856
Swaps: 0
File system inputs: 264072
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1181.361 ms | p95 2511.504 ms | p99 3241.546 ms | max 5184.172 ms | p95/mean 2.126 | p99/mean 2.744
end2end: mean 35434.577 ms | p95 64129.922 ms | p99 66829.971 ms | max 67465.058 ms | p95/mean 1.810 | p99/mean 1.886
```

<3.1> Sphinx run with Disk IO stress without caching

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1153.03
System time (seconds): 14.54
Percent of CPU this job got: 1256%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:32.95
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1741644
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 144
Minor (reclaiming a frame) page faults: 8175125
Voluntary context switches: 169569
Involuntary context switches: 4651
Swaps: 0
File system inputs: 196400
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1130.883 ms | p95 2338.379 ms | p99 3061.872 ms | max 4576.734 ms | p95/mean 2.068 | p99/mean 2.708
end2end: mean 34340.758 ms | p95 63343.126 ms | p99 66022.271 ms | max 66845.079 ms | p95/mean 1.845 | p99/mean 1.923
```

<3.2> Sphinx run with Disk IO stress with caching

```
Command being timed: "taskset -c 0-15 ./run.sh"
User time (seconds): 1192.35
System time (seconds): 12.85
Percent of CPU this job got: 1439%
Elapsed (wall clock) time (h:mm:ss or m:ss): 1:23.69
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1744392
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 5654889
Voluntary context switches: 166160
Involuntary context switches: 2816
Swaps: 0
File system inputs: 8
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 1162.155 ms | p95 2478.815 ms | p99 3177.210 ms | max 5075.731 ms | p95/mean 2.133 | p99/mean 2.734
end2end: mean 32356.380 ms | p95 60062.856 ms | p99 62491.039 ms | max 63349.906 ms | p95/mean 1.856 | p99/mean 1.931
```

<4.1> Sphinx run with all stress simulation without caching

```
Command being timed: "./run.sh"
User time (seconds): 1615.05
System time (seconds): 137.39
Percent of CPU this job got: 276%
Elapsed (wall clock) time (h:mm:ss or m:ss): 10:34.64
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 3438892
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 661
Minor (reclaiming a frame) page faults: 13687386
Voluntary context switches: 872308
Involuntary context switches: 159402
Swaps: 0
File system inputs: 541968
File system outputs: 48
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
```

```
svc: mean 3835.681 ms | p95 9401.788 ms | p99 13527.039 ms | max 17813.691 ms | p95/mean 2.451 | p99/mean 3.527
end2end: mean 63036.649 ms | p95 108691.447 ms | p99 112937.951 ms | max 113992.645 ms | p95/mean 1.724 | p99/mean 1.792
```

\<5\> Cache Statistics

```
Counting cache functions... Output every 1 seconds.
   HITS    MISSES  DIRTIES    RATIO   BUFFERS_MB    CACHE_MB
 219286     25520        0    89.6%            5         169
   1134       731        0    60.8%            6         172
   1246       520        0    70.6%            6         174
   1668       246        0    87.1%            6         175
   1595       286        0    84.8%            6         176
   1642       327        0    83.4%            6         177
   1263       333        0    79.1%            6         178
   1192       323        0    78.7%            6         180
   1194       291        0    80.4%            6         181
   1659       343        1    82.9%            6         182
   1692       194        0    89.7%            6         183
   1771       277        0    86.5%            6         184
   1728       143        0    92.4%            6         185
   1652       215        0    88.5%            6         186
   1743       322        0    84.4%            6         187
   1286       248        0    83.8%            6         188
   1264       175        0    87.8%            6         189
   1373       281        0    83.0%            6         190
   1284       127        0    91.0%            6         190
   1233       324        0    79.2%            6         191
   1350       377        1    78.2%            6         193
   1725       263        0    86.8%            6         194
   1695       219        0    88.6%            6         195
   1652       306        0    84.4%            6         196
   1690       343        0    83.1%            6         197
```

\<6\> Disk IO Statistics

```
Linux 4.15.0-161-generic (3-13)        11/10/21      _x86_64_      (32 CPU)

avg-cpu:  %user   %nice %system %iowait  %steal   %idle
           2.83    0.00    0.13    0.60    0.00   96.44

Device            tps    kB_read/s    kB_wrtn/s    kB_read     kB_wrtn
sda              9.56       110.37       690.72    5747053    35965384
sda1             8.99       110.22       690.72    5739181    35965384
```

```
[7l--total-cpu-usage-- -dsk/total- -net/total- ---paging-- ---system--
usr sys idl wai stl| read  writ| recv  send|  in   out | int    csw
  3   0  96   1   0| 113k  689k|   0     0 |9112B  42k|4651    635
 22  13  63   2   0|  29M    0 | 600B    0 |   0    0 | 148k   497k
 47  12  41   0   0|   0    0 | 600B    0 |   0    0 | 331k   283k
 61   8  30   1   0|4936k   0 | 540B    0 |   0    0 |1507k  7110
 95   5   0   0   0| 256k   44k| 480B    0 |   0    0 |1229k  1295
 97   2   1   0   0|1648k 8192B| 600B    0 |   0    0 | 350k  2494
 98   1   1   0   0|1312k   0 | 600B    0 |   0    0 | 182k  1365
 98   2   0   0   0|1096k   0 | 600B    0 |   0    0 | 116k  1704
 98   1   0   0   0|1440k   0 | 540B    0 |   0    0 | 163k   851
 98   2   0   0   0| 956k   0 | 540B    0 |   0    0 | 175k   780
 97   2   1   0   0|1192k   12k| 600B    0 |   0    0 | 364k  1374
 98   1   1   0   0|1384k   0 | 600B    0 |   0    0 | 129k  1897
 98   1   1   0   0| 768k   0 | 600B    0 |   0    0 |  72k   451
 98   1   1   0   0|1084k   0 | 540B    0 |   0    0 | 126k   839
 98   2   1   0   0| 884k   0 | 480B    0 |   0    0 | 331k  1004
```

Sphinx run time statistics (No. of cores - 16)

Simulation	CPU %	Memory %	Minor Page Faults	Major Page Faults	Voluntary Context Switches	Involuntary Context Switches
Baseline Sphinx	1543	2.641	9256940	84	169507	3363
Baseline Sphinx With Inputs Cached	1590	2.641	3753442	0	165736	1172
100% CPU Stress, no Caching	756	2.634	12909349	67	250145	69377
100% CPU Stress, with Caching	755	2.633	10877392	0	319550	76696
100% Memory Stress, no Caching	1007	2.619	9437300	1753	191338	10698
100% Memory Stress, with Caching	1070	2.623	9448113	1265	175121	14856
With Disk Stress, no Caching	1256	2.644	8175125	144	169569	4651
With Disk Stress, with Caching	1439	2.649	5654889	0	166160	2816
All Stress enabled, no caching	276	5.222	13687386	661	872308	159402

Sphinx In Depth Analysis Table

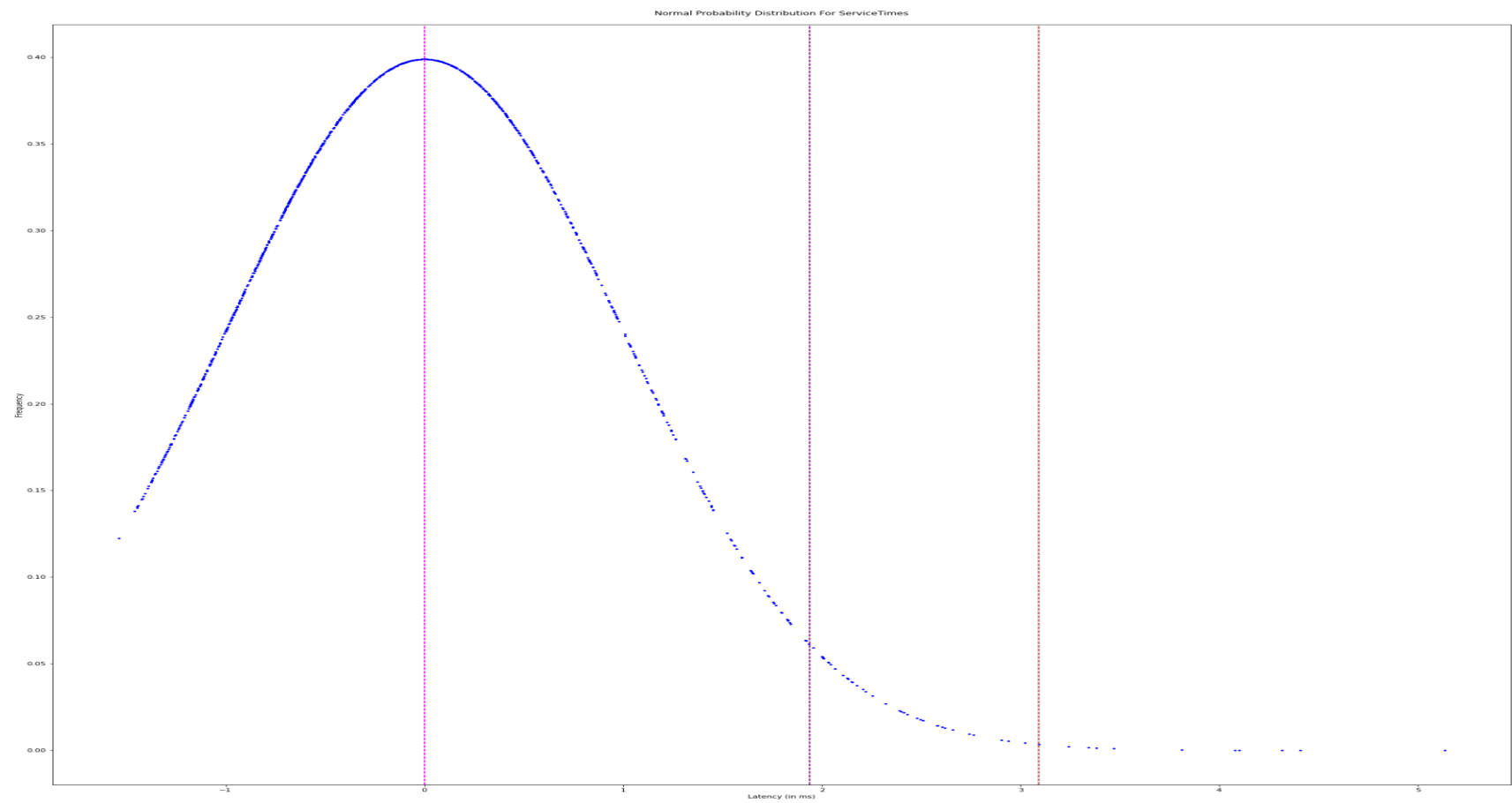| Simulation	SVC				End2End			
	Mean μ (ms)	P_{95} (ms)	P_{99} (ms)	Max (ms)	Mean μ (ms)	P_{95} (ms)	P_{99} (ms)	Max (ms)
Baseline Sphinx	1153.480	2501.867	3287.053	4055.808	32272.270	59762.979	62480.157	63270.994
Baseline Sphinx With Inputs Cached	1094.047	2276.824	3079.206	4261.249	30345.717	55864.293	58407.772	59059.081
100% CPU Stress, no Caching	2209.998	4770.250	5882.759	8900.264	64530.664	121956.424	127193.320	128966.486
100% CPU Stress, with Caching	2224.816	4709.530	6115.799	8399.061	65111.344	122566.199	128125.660	129633.443
100% Memory Stress, no Caching	1184.538	2559.141	3357.898	4234.687	34357.529	62775.426	65503.540	66237.082
100% Memory Stress, with Caching	1181.361	2511.504	3241.546	5184.172	35434.577	64129.922	66829.971	67465.058
With Disk Stress, no Caching	1130.883	2338.379	3061.872	4576.734	34340.758	63343.126	66022.271	66845.079
With Disk Stress, with Caching	1162.155	2478.815	3177.210	5075.731	32356.380	60062.856	62491.039	63349.906
All Stress enabled, no caching	3835.681	9401.788	13527.039	17813.691	63036.649	108691.447	112937.951	113992.645

Sphinx Tail Latency Ratio

Simulation	SVC		End2End	
	Ratio (P95/μ)	Ratio (P99/μ)	Ratio (P95/μ)	Ratio (P99/μ)
Baseline Sphinx	2.169	2.850	1.852	1.936
Baseline Sphinx With Inputs Cached	2.081	2.815	1.841	1.925
100% CPU Stress, no Caching	2.158	2.662	1.890	1.971
100% CPU Stress, with Caching	2.117	2.749	1.882	1.968
100% Memory Stress, no Caching	2.160	2.835	1.827	1.907
100% Memory Stress, with Caching	2.126	2.744	1.810	1.886
With Disk Stress, no Caching	2.068	2.708	1.845	1.923
With Disk Stress, with Caching	2.133	2.734	1.856	1.931
All Stress enabled, no caching	2.451	3.527	1.724	1.792

Tail Latency Graphs (svcTimes)

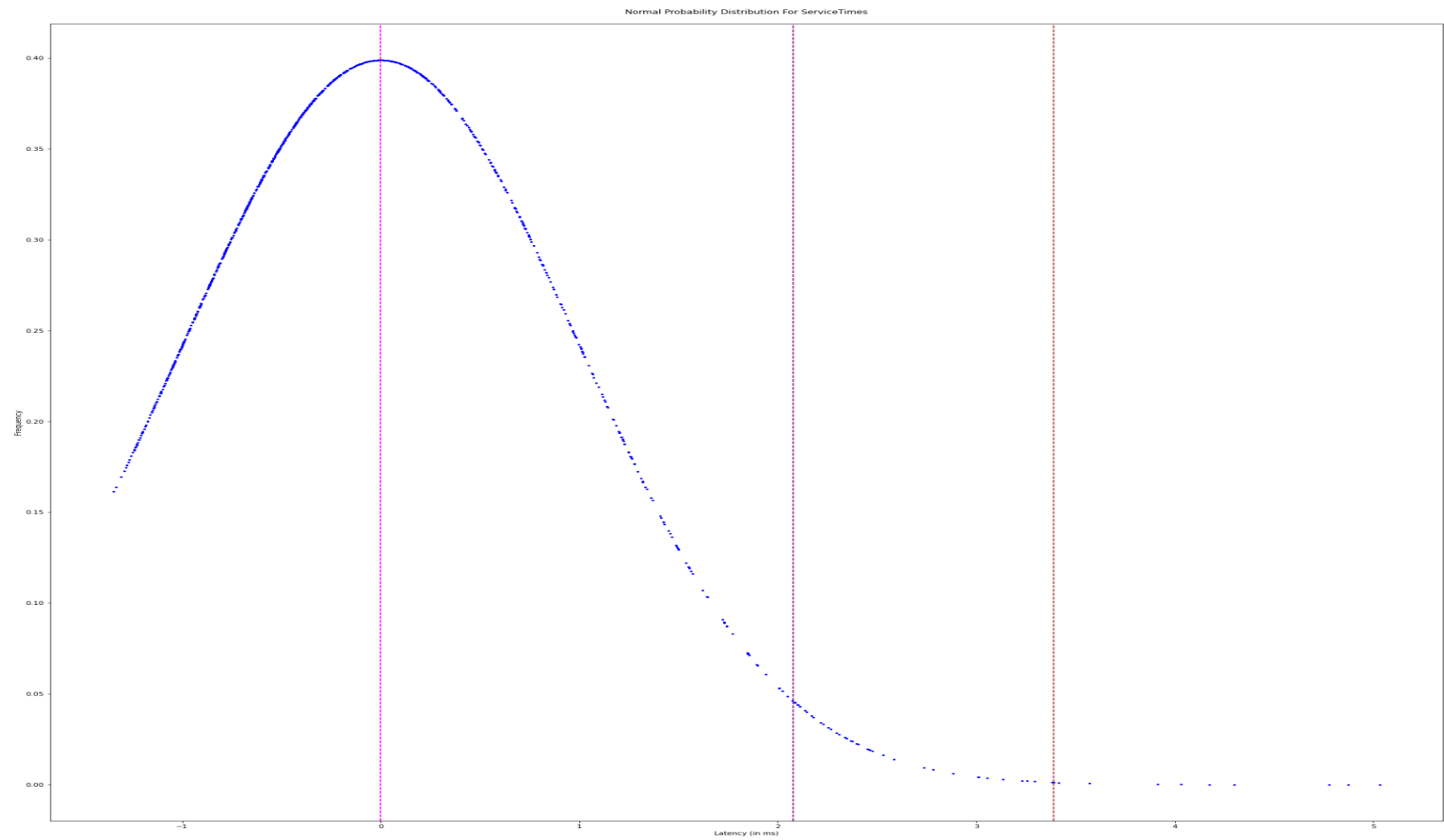## <0.1> Baseline Sphinx without caching of inputs under no stress simulation
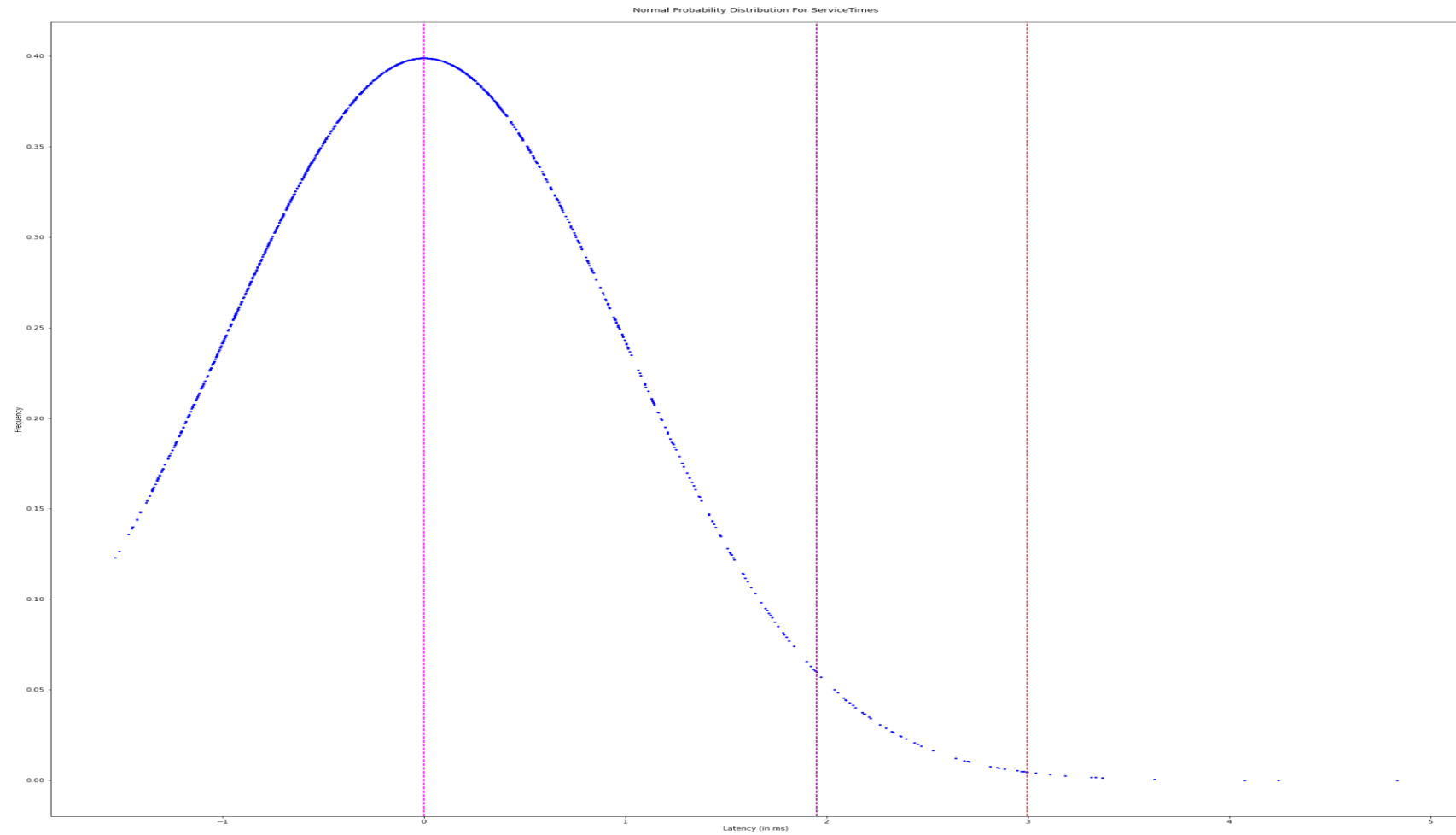
Normal Probability Distribution For ServiceTimes

<0.2> Baseline Sphinx with caching of inputs under no stress simulation

Normal Probability Distribution For ServiceTimes

<1.1> Sphinx run with 100% CPU Stress without caching of inputs

Normal Probability Distribution For ServiceTimes

<1.2> Sphinx run with 100% CPU Stress with caching of input

Normal Probability Distribution For ServiceTimes

Normal Probability Distribution For ServiceTimes

<2.2> Sphinx run with 100% memory stress with caching of inputs

Normal Probability Distribution For ServiceTimes

Normal Probability Distribution For ServiceTimes

<3.2> Sphinx run with Disk IO stress with caching

Normal Probability Distribution For ServiceTimes

<4.1> Sphinx run with all stress simulation without caching

Normal Probability Distribution For ServiceTimes
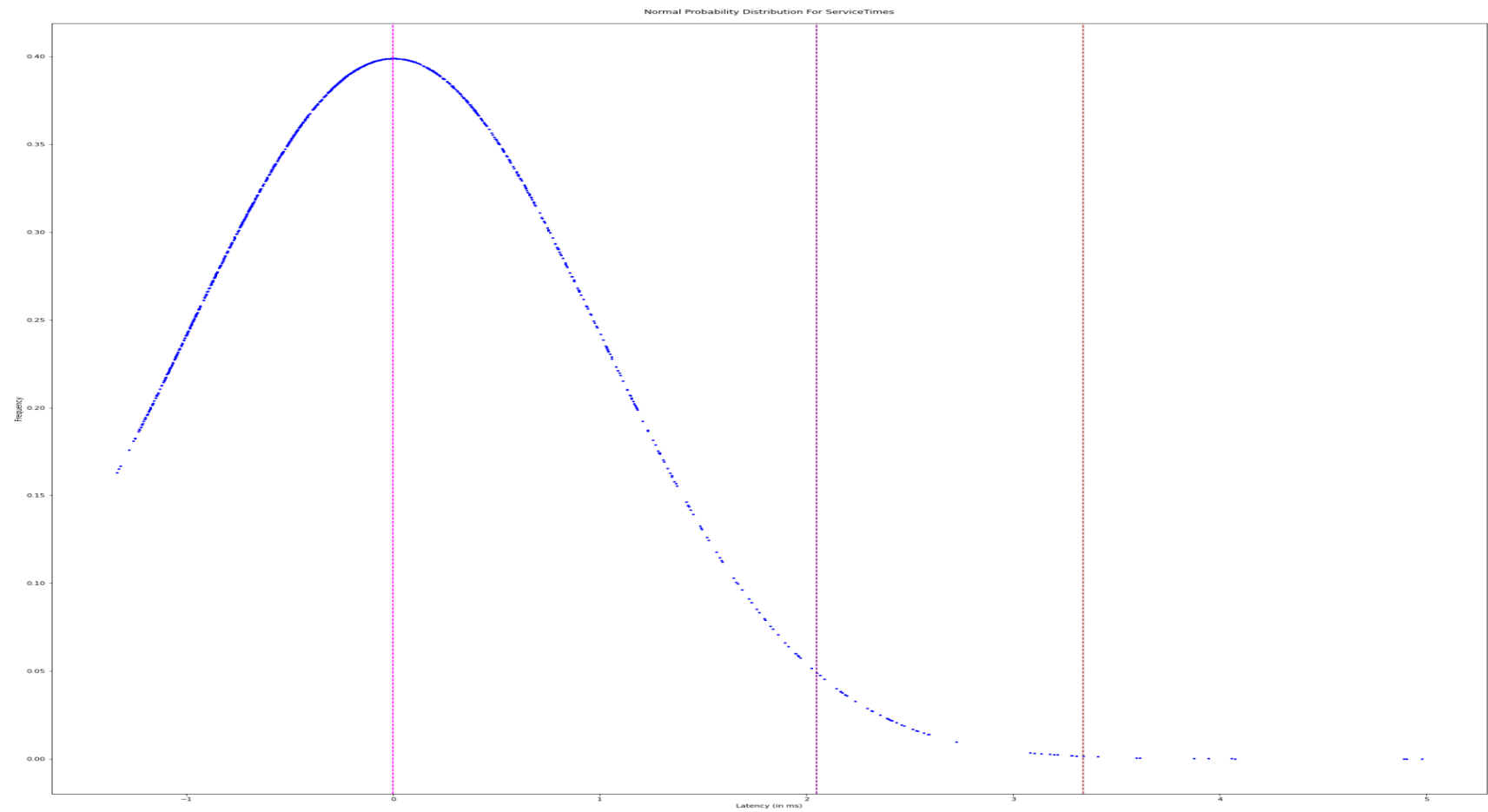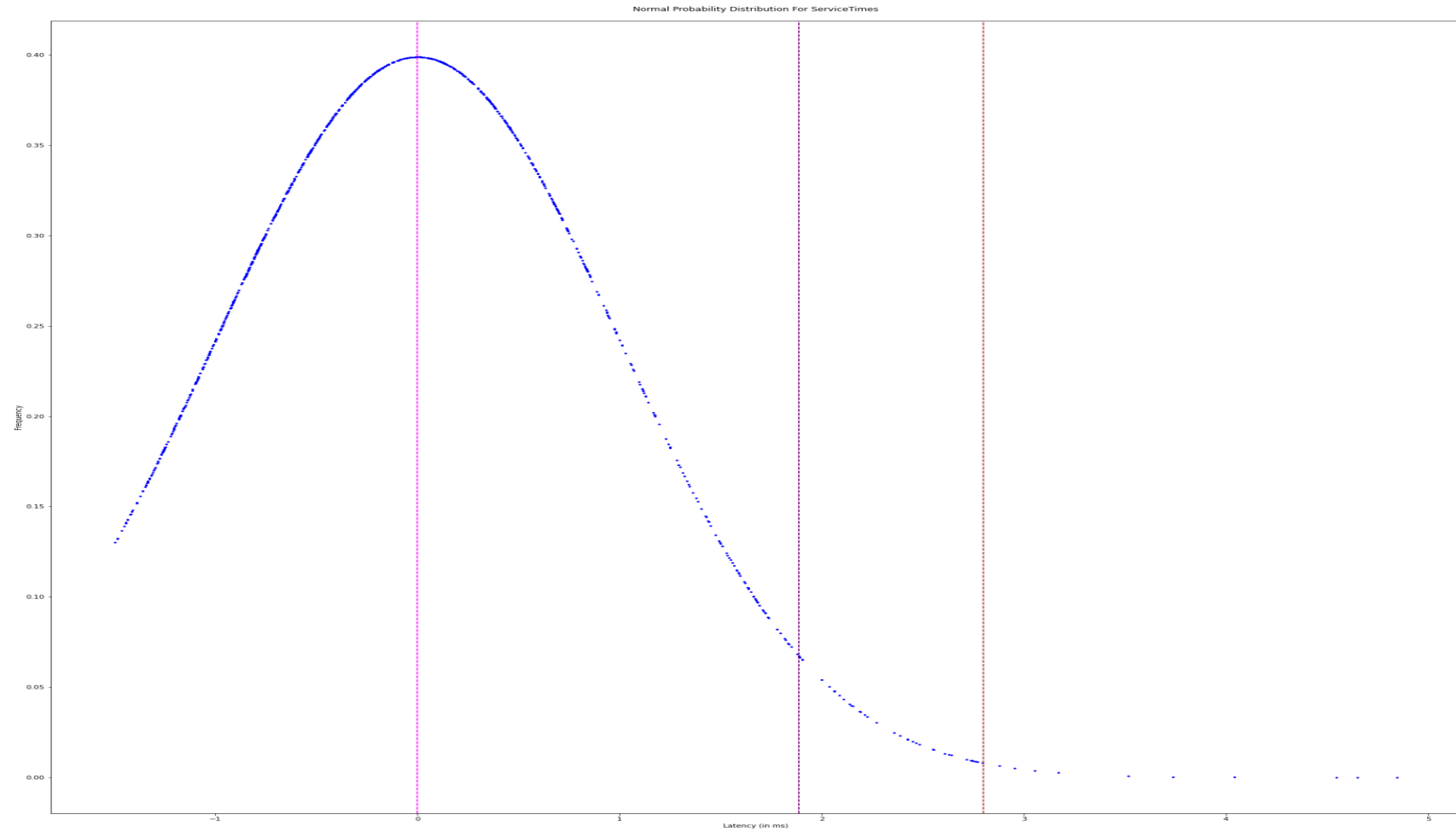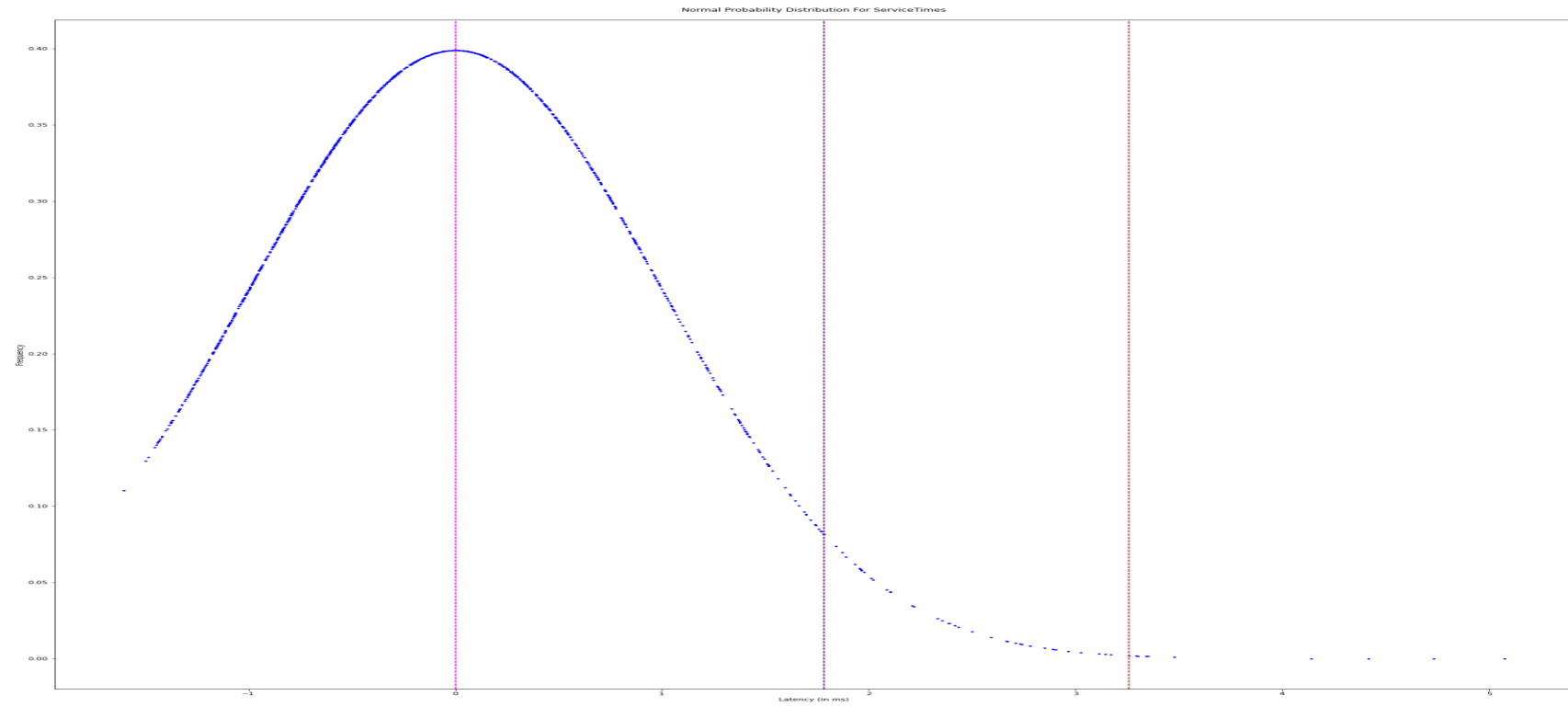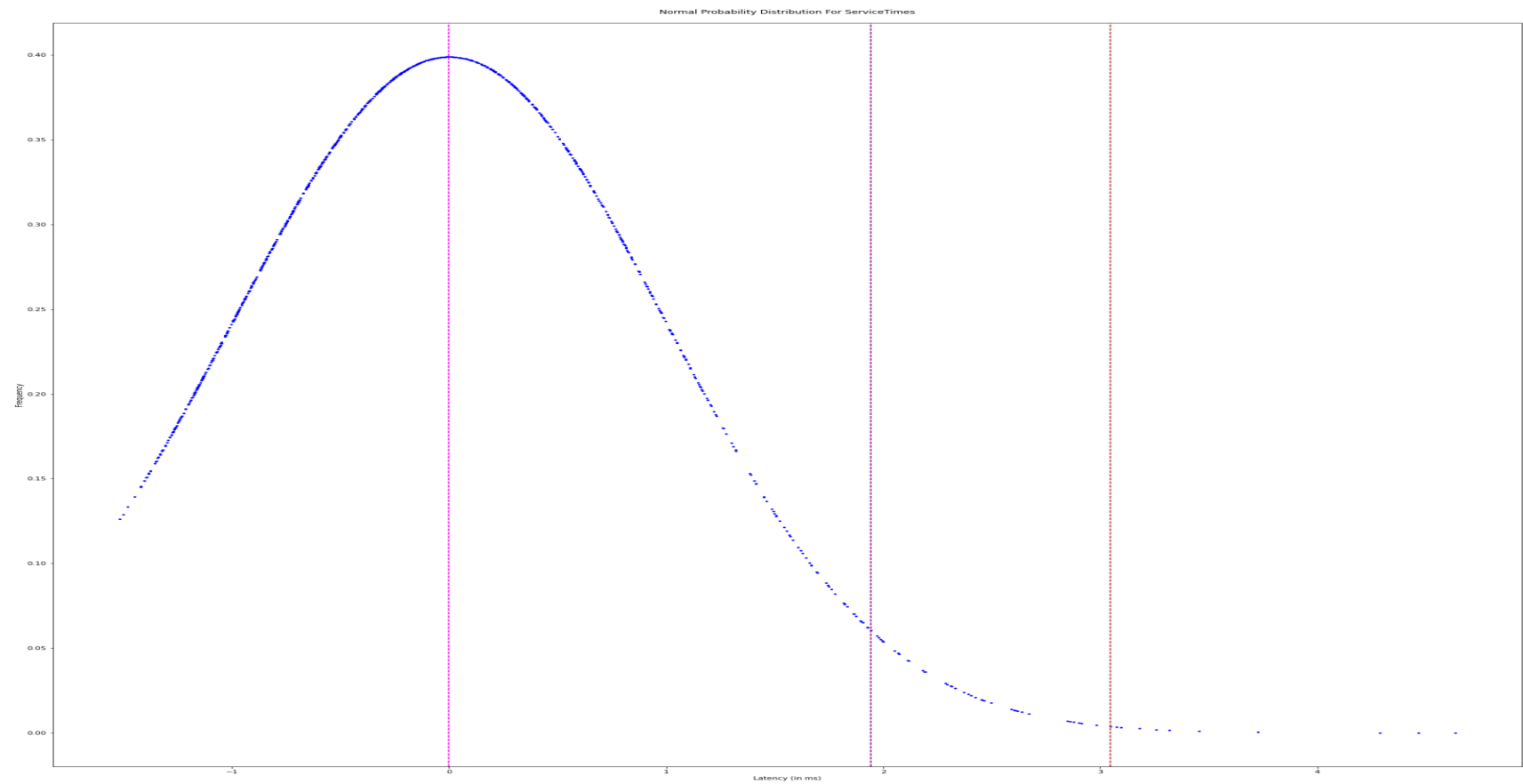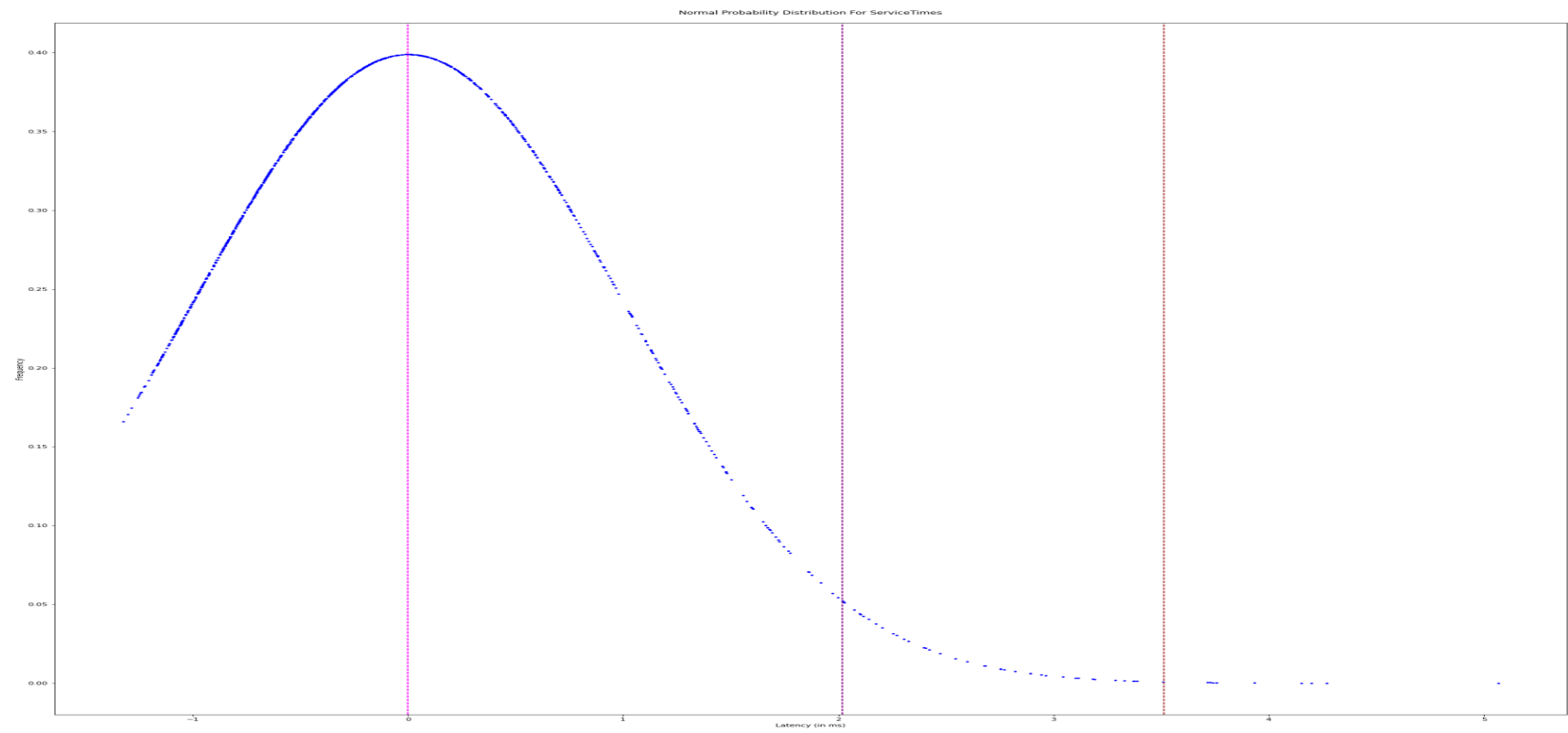
Function call statistics during the execution of sphinx

```
# Children      Self    Command          Shared Object               Symbol
# ........    ........  ...............  .......................    ..............................
#
    34.58%    28.56%  decoder_integra  libpocketsphinx.so.3.0.0    [.] prune_channels
    18.36%    17.37%  decoder_integra  libpocketsphinx.so.3.0.0    [.] ptm_mgau_frame_eval
    11.44%    10.97%  decoder_integra  libpocketsphinx.so.3.0.0    [.] hmm_vit_eval
    11.27%     0.01%  decoder_integra  [kernel.kallsyms]           [k] page_fault
    11.06%     0.01%  decoder_integra  [kernel.kallsyms]           [k] do_page_fault
    10.05%     0.07%  decoder_integra  [kernel.kallsyms]           [k] __do_page_fault
     8.78%     7.91%  decoder_integra  libpocketsphinx.so.3.0.0    [.] acmod_activate_hmm
     7.39%     0.05%  decoder_integra  [kernel.kallsyms]           [k] handle_mm_fault
     6.67%     0.34%  decoder_integra  [kernel.kallsyms]           [k] ftrace_graph_caller
     6.51%     0.13%  decoder_integra  [kernel.kallsyms]           [k] __handle_mm_fault
     6.27%     0.35%  decoder_integra  [kernel.kallsyms]           [k] prepare_ftrace_return
     6.22%     0.24%  decoder_integra  [kernel.kallsyms]           [k] return_to_handler
     6.21%     2.88%  decoder_integra  libsphinxbase.so.3.0.0      [.] bitarr_read_int25
     5.79%     0.58%  decoder_integra  [kernel.kallsyms]           [k] function_graph_enter
     5.64%     0.54%  decoder_integra  [kernel.kallsyms]           [k] ftrace_return_to_handler
     4.84%     0.14%  decoder_integra  [kernel.kallsyms]           [k] do_numa_page
     4.84%     0.89%  decoder_integra  [kernel.kallsyms]           [k] trace_graph_entry
     4.76%     0.41%  decoder_integra  [kernel.kallsyms]           [k] trace_buffer_lock_reserve
     4.72%     0.65%  decoder_integra  [kernel.kallsyms]           [k] trace_graph_return
     3.86%     0.32%  decoder_integra  [kernel.kallsyms]           [k] __trace_graph_return
     3.68%     0.31%  decoder_integra  [kernel.kallsyms]           [k] __trace_graph_entry
     3.61%     1.36%  decoder_integra  [kernel.kallsyms]           [k] ring_buffer_lock_reserve
     3.02%     2.81%  decoder_integra  libpocketsphinx.so.3.0.0    [.] ngram_fwdflat_search
     2.62%     0.00%  decoder_integra  [unknown]                   [k] 0000000000000000
     2.59%     2.50%  decoder_integra  libsphinxbase.so.3.0.0      [.] middle_find
     2.29%     2.11%  decoder_integra  libpocketsphinx.so.3.0.0    [.] ngram_fwdtree_search
     2.00%     0.33%  decoder_integra  [kernel.kallsyms]           [k] trace_clock_local
     1.80%     0.12%  decoder_integra  [kernel.kallsyms]           [k] trace_buffer_unlock_commit_nostack
     1.75%     1.42%  decoder_integra  libsphinxbase.so.3.0.0      [.] ngram_model_set_score
```