

1. First, open two separate terminal connections to the same machine, so that you can easily run something in one window and the other. Now, in one window, run `vmstat 1`, which shows statistics about machine usage every second. Read the man page, the associated README, and any other information you need so that you can understand its output. Leave this window running `vmstat` for the rest of the exercises below. Now, we will run the program `mem.c` but with very little memory usage. This can be accomplished by typing `./mem 1` (which uses only 1 MB of memory). How do the CPU usage statistics change when running `mem`? Do the numbers in the user time column make sense? How does this change when running more than one instance of `mem` at once?

What is the output of `vmstat 1`?

- `vmstat` reports information about processes, memory, paging, block IO, traps and cpu activity.
- first report gives averages since the last reboot. Additional reports are given on a delay, which is the 1 second. Process and memory reports are instantaneous
- default shows memory in KiB!

Field Description For Vm Mode

Procs

r: The number of processes waiting for run time.
b: The number of processes in uninterruptible sleep.

Memory

swpd: the amount of virtual memory used.
free: the amount of idle memory.
buff: the amount of memory used as buffers.
cache: the amount of memory used as cache.
inact: the amount of inactive memory. (-a option)
active: the amount of active memory. (-a option)

Swap

si: Amount of memory swapped in from disk (/s).
so: Amount of memory swapped to disk (/s).

IO

bi: Blocks received from a block device (blocks/s).
bo: Blocks sent to a block device (blocks/s).

System

in: The number of interrupts per second, including the clock.
cs: The number of context switches per second.

CPU

These are percentages of total CPU time.

us: Time spent running non-kernel code. (user time, including nice time)
sy: Time spent running kernel code. (system time)
id: Time spent idle. Prior to Linux 2.5.41, this includes IO-wait time.
wa: Time spent waiting for IO. Prior to Linux 2.5.41, included in idle.
st: Time stolen from a virtual machine. Prior to Linux 2.6.11, unknown.

cpu

The last five columns give the percentages of total CPU time:

us	Percentage of CPU cycles spent on user processes
sy	Percentage of CPU cycles spent on system (kernel) processes
id	Percentage of CPU cycles spent idle
wa	Percentage of CPU cycles spent waiting for I/O
st	Percentage of CPU cycles stolen from a virtual machine

How do the CPU usage statistics change when running mem? Do the numbers in the user

time column make sense?

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1
allocating 1048576 bytes (1.00 MB)
number of integers in array: 262144
loop 0 in 0.86 ms (bandwidth: 1158.97 MB/s)
loop 957 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 1914 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 2871 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 3828 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 4785 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 5742 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 6699 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 7656 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 8613 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 9570 in 0.24 ms (bandwidth: 4240.95 MB/s)
loop 10527 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 11484 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 12440 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 13395 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 14352 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 15308 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 16265 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 17221 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 18178 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 19134 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 20091 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 21048 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 22005 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 22962 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 23919 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 24876 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 25833 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 26790 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 27747 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 28704 in 0.22 ms (bandwidth: 4604.07 MB/s)
```

→ A) Before running ./mem 1

procs	-----memory-----	---swap---	-----io----	-system--	-----cpu-----
r b	swpd free buff cache	si so	bi bo	in cs us sy	id wa st
1 0	197464 787708 0 278128	0 0	0 216	2966 3391 0 0	100 0 0
4 0	197464 780832 0 278128	0 0	0 88	2610 2908 2 0	98 0 0
4 0	197464 787868 0 278128	0 0	0 144	3402 3271 11 0	89 0 0
1 0	197464 787868 0 278128	0 0	0 36	2516 2739 0 0	100 0 0
5 0	197464 787840 0 278128	0 0	0 168	2827 2930 13 0	87 0 0
1 0	197464 787840 0 278128	0 0	0 148	3621 3980 1 0	99 0 0
3 0	197464 779304 0 278128	0 0	768 168	3124 5199 2 0	98 0 0
5 0	197464 787816 0 278128	0 0	0 32	3815 4694 11 0	89 0 0
1 0	197464 787816 0 278128	0 0	0 80	2551 3002 0 0	100 0 0
4 0	197464 787772 0 278128	0 0	0 160	2774 3111 13 0	87 0 0
2 0	197464 787680 0 278128	0 0	0 244	3415 3697 0 0	100 0 0
4 0	197464 777572 0 278128	0 0	0 196	2622 2938 3 0	97 0 0
4 0	197464 787580 0 278128	0 0	0 64	3072 3136 10 0	90 0 0
3 0	197464 787608 0 278128	0 0	0 44	2897 3033 1 0	99 0 0
3 0	197464 787584 0 278128	0 0	0 4	3392 4112 12 0	88 0 0
3 0	197464 787580 0 278128	0 0	0 200	2944 3319 0 0	100 0 0
4 0	197464 776288 0 278128	0 0	768 184	4089 5833 4 0	96 0 0
2 0	197464 787544 0 278128	0 0	0 264	2801 3718 10 0	90 0 0
4 0	197464 787572 0 278128	0 0	0 76	3732 4021 0 0	100 0 0
1 0	197464 787480 0 278128	0 0	0 32	2827 2997 12 0	88 0 0
3 0	197464 787540 0 278128	0 0	0 0	2683 3330 0 0	100 0 0
3 0	197464 773892 0 278128	0 0	0 228	3129 2978 4 0	96 0 0

→ B) During running ./mem 1

procs		-----memory-----				---swap---		-----io-----		-system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
3	0	197464	787532	0	278128	0	0	0	172	2570	2962	9	0	91	0	0
4	0	197464	786272	0	278128	0	0	0	76	3010	2842	10	0	90	0	0
4	0	197464	786136	0	278128	0	0	0	132	3221	2982	37	0	63	0	0
4	0	197464	786268	0	278128	0	0	0	88	3333	3693	25	0	75	0	0
5	0	197464	771980	0	278128	0	0	768	140	4252	6621	28	0	72	0	0
3	0	197464	786456	0	278128	0	0	0	172	3478	3013	33	0	67	0	0
2	0	197464	786456	0	278128	0	0	0	100	3441	4141	24	0	76	0	0
6	0	197464	786424	0	278128	0	0	0	108	3327	2877	37	0	63	0	0
2	0	197464	786540	0	278128	0	0	0	68	3122	3220	25	0	75	0	0
6	0	197464	773308	0	278128	0	0	0	100	2772	2829	27	0	73	0	0
4	0	197464	786528	0	278128	0	0	0	276	3718	2990	33	0	67	0	0
1	0	197464	786528	0	278128	0	0	0	36	2517	2472	24	0	76	0	0
4	0	197464	786500	0	278128	0	0	0	140	3487	3274	36	0	64	0	0
4	0	197464	786500	0	278128	0	0	0	72	3575	3947	25	0	75	0	0
5	0	197592	772236	0	278128	0	0	768	56	3856	5929	28	0	72	0	0
4	0	197464	786368	0	278128	0	0	0	204	3265	2846	32	0	68	0	0
2	0	197464	786488	0	278128	0	0	0	108	3620	3785	24	0	76	0	0
3	0	197464	786352	0	278128	0	0	0	184	2976	2837	36	0	64	0	0
7	0	197464	786468	0	278128	0	0	0	116	3478	3503	24	0	76	0	0
4	0	197464	771168	0	278128	0	0	0	100	3084	2641	28	0	72	0	0
5	0	197464	786408	0	278128	0	0	0	288	3006	3297	33	0	67	0	0
2	0	197464	786288	0	278260	0	0	0	76	3400	2604	25	0	75	0	0

- In B) (during ./mem 1) at one point there are 6 or 7 processes waiting for runtime, while in A) the max of this number is at 5
- the amount of virtual memory used (swpd) didn't change
- idle memory decreased with 1024 Bytes. In A) 787K and in B) 786K
- cache didn't change
- memory swapped in and out didn't change
- blocks received and blocks sent to a disk device didn't really change
- interrupts per second increased, almost the whole column is above 3000 in B) and before in A) most of it was under 3000
- I don't see a pattern in context switches per seconds. Noting really that changed
- User time definitely increased in B). The percentage 0% isn't reached anymore. So about 30% of the cpu cycles, are user time in B).
- Idle time decreased in B). The percentage 100 % isn't reached anymore. Now only about 75% of the cpu cycles are spent idle.

How does this change when running more than one instance of mem at once?

```

vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1
& ./mem 1
[1] 12012
allocating 1048576 bytes (1.00 MB)
allocating 1048576 bytes (1.00 MB)
  number of integers in array: 262144
    number of integers in array: 262144
loop 0 in 0.86 ms (bandwidth: 1167.03 MB/s)
loop 0 in 0.87 ms (bandwidth: 1144.42 MB/s)
loop 930 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 957 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 1884 in 0.21 ms (bandwidth: 4788.02 MB/s)
loop 1899 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 2709 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 2723 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 3347 in 0.21 ms (bandwidth: 4809.98 MB/s)
loop 3360 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 3987 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 4019 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 4607 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 4658 in 0.34 ms (bandwidth: 2957.90 MB/s)
loop 5440 in 0.21 ms (bandwidth: 4804.47 MB/s)
loop 5512 in 0.21 ms (bandwidth: 4782.56 MB/s)
loop 6393 in 0.21 ms (bandwidth: 4788.02 MB/s)

```

→ kill the second one with top

→ Before running two instances

procs		-----memory-----				---swap--		-----io-----		--system--		-----cpu-----					
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st	
2	0	197464	772192	0	278588	0	0	0	136	2829	3027	4	0	96	0	0	
3	0	197464	786600	0	278588	0	0	0	164	2987	2970	9	0	91	0	0	
4	0	197464	786600	0	278588	0	0	0	36	3165	3287	0	0	100	0	0	
2	0	197464	786568	0	278588	0	0	0	336	2657	2567	12	0	88	0	0	
4	0	197464	786600	0	278588	0	0	0	104	3038	2979	0	0	100	0	0	
2	0	197464	769700	0	278588	0	0	0	96	2904	2999	5	0	95	0	0	
3	0	197464	786580	0	278588	0	0	0	100	2935	3311	8	0	92	0	0	
6	0	197464	786580	0	278588	0	0	768	112	4061	5572	0	0	100	0	0	
2	0	197464	786472	0	278588	0	0	0	180	3018	4087	12	0	88	0	0	
1	0	197464	786560	0	278588	0	0	0	72	3636	4290	0	0	100	0	0	
2	0	197464	767672	0	278588	0	0	0	72	3059	2989	5	0	95	0	0	
3	0	197464	786764	0	278588	0	0	0	108	2847	2799	7	0	93	0	0	
4	0	197464	786764	0	278588	0	0	0	176	3026	3661	0	0	100	0	0	
4	0	197464	786744	0	278588	0	0	0	168	3020	2622	12	0	88	0	0	
1	0	197464	786744	0	278588	0	0	0	48	2870	2911	0	0	100	0	0	
5	0	197464	765956	0	278588	0	0	0	36	2896	3295	6	0	94	0	0	
3	0	197464	786716	0	278588	0	0	0	144	3683	4041	7	0	93	0	0	
4	0	197464	786716	0	278588	0	0	768	36	3959	6214	0	0	100	0	0	
3	0	197464	786520	0	278588	0	0	0	80	3231	3077	12	0	88	0	0	
2	0	197464	786676	0	278588	0	0	0	192	3199	4221	0	0	100	0	0	
2	0	197464	764396	0	278588	0	0	0	104	3095	2982	6	0	94	0	0	
1	0	197464	786656	0	278588	0	0	0	104	3015	3027	6	0	94	0	0	

→ C) while running two instances of ./mem 1

procs		-----memory-----				---swap---		-----io-----		-system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
4	0	197464	771572	0	278588	0	0	0	208	3157	2852	50	0	50	0	0
7	0	197464	790812	0	277712	0	0	0	136	3616	2973	48	0	52	0	0
3	0	197464	790736	0	277712	0	0	0	96	3588	3700	50	0	50	0	0
7	0	197464	782968	0	277712	0	0	384	72	3662	4583	50	0	50	0	0
7	0	197464	790440	0	277712	0	0	384	108	3579	3986	47	0	53	0	0
4	0	197464	786672	0	277712	0	0	0	72	3735	4054	48	0	52	0	0
4	0	197464	785620	0	277712	0	0	0	136	3625	3121	49	0	51	0	0
6	0	197464	785032	0	277976	0	0	0	76	3401	2874	48	0	52	0	0
6	0	197464	784144	0	277976	0	0	0	0	3513	3089	48	0	52	0	0
4	0	197464	784800	0	278240	0	0	0	232	3272	3048	48	0	52	0	0
4	0	197464	784884	0	278240	0	0	0	36	3244	2609	49	0	51	0	0
5	0	197464	771124	0	278240	0	0	0	164	3369	2955	49	0	51	0	0
4	0	197464	784724	0	278240	0	0	0	76	4067	4008	48	0	52	0	0
5	0	197464	784724	0	278240	0	0	768	32	3799	4597	48	0	52	0	0
6	0	197464	780384	0	278240	0	0	0	100	3623	4168	50	0	50	0	0
5	0	197464	784804	0	278240	0	0	0	144	3846	4150	47	0	53	0	0
7	0	197464	784804	0	278240	0	0	0	104	3444	2941	48	0	52	0	0
4	0	197464	765228	0	278240	0	0	0	136	3596	3056	49	0	51	0	0
6	0	197464	784740	0	278240	0	0	0	72	3410	3204	48	0	52	0	0
6	0	197464	784740	0	278240	0	0	0	20	3294	2849	50	0	50	0	0
4	0	197464	784616	0	278240	0	0	0	104	2892	2551	48	0	52	0	0
4	0	197464	784736	0	278240	0	0	0	44	3478	2935	49	0	51	0	0

- r column, now there are more processes waiting for run time
- free column, decreased by 2000, now 784K
- cache column, at the beginning it decreased by 1000 for a time, then increased again
- bi and bo didn't really change
- in column, interrupts per second increased
- cs column, context switches per second didn't really change, maybe decreased for a little bit
- us time, increased even more as in B), because there are now two instances. It is now at 50%
- id column, idle time also decreased more. It is at 50%

2. Let's now start looking at some of the memory statistics while running mem. We'll focus on two columns: swpd (the amount of virtual memory used) and free (the amount of idle memory). Run `./mem 1024` (which allocates 1024 MB) and watch how these values change. Then kill the running program (by typing control-c) and watch again how the values change. What do you notice about the values? In particular, how does the free column change when the program exits? Does the amount of free memory increase by the expected amount when mem exits?

```

vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1024
allocating 1073741824 bytes (1024.00 MB)
number of integers in array: 268435456
loop 0 in 2337.29 ms (bandwidth: 438.11 MB/s)
loop 1 in 525.11 ms (bandwidth: 1950.05 MB/s)
loop 2 in 231.34 ms (bandwidth: 4426.33 MB/s)
loop 3 in 229.35 ms (bandwidth: 4464.75 MB/s)
loop 4 in 393.54 ms (bandwidth: 2602.05 MB/s)
loop 5 in 1054.20 ms (bandwidth: 971.35 MB/s)
loop 6 in 408.86 ms (bandwidth: 2504.51 MB/s)
loop 7 in 320.25 ms (bandwidth: 3197.47 MB/s)
loop 8 in 380.53 ms (bandwidth: 2690.98 MB/s)
loop 9 in 313.00 ms (bandwidth: 3271.55 MB/s)
loop 10 in 249.89 ms (bandwidth: 4097.75 MB/s)
loop 11 in 251.27 ms (bandwidth: 4075.30 MB/s)
loop 12 in 255.10 ms (bandwidth: 4014.19 MB/s)
loop 13 in 254.67 ms (bandwidth: 4020.86 MB/s)
loop 14 in 263.08 ms (bandwidth: 3892.37 MB/s)
loop 15 in 263.09 ms (bandwidth: 3892.19 MB/s)
loop 16 in 656.97 ms (bandwidth: 1558.67 MB/s)
loop 17 in 245.46 ms (bandwidth: 4171.83 MB/s)
loop 18 in 411.97 ms (bandwidth: 2485.62 MB/s)
loop 19 in 234.81 ms (bandwidth: 4360.99 MB/s)
loop 20 in 401.37 ms (bandwidth: 2551.26 MB/s)

```

→ A) before running

procs		-----memory-----				---swap--		-----io----		-system--		-----cpu-----					
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st	
1	0	203508	1082324	0	172872	0	0	0	120	2873	2765	6	0	94	0	0	
4	0	203508	1082444	0	172872	0	0	0	68	2646	4051	0	0	100	0	0	
3	0	203508	1082404	0	172872	0	0	0	168	3502	2907	13	0	88	0	0	
0	0	203508	1082440	0	172872	0	0	0	144	2615	3058	0	0	100	0	0	
7	0	203508	1077800	0	172872	0	0	0	68	2807	3338	7	0	93	0	0	
3	0	203508	1082412	0	172872	0	0	0	176	3157	2904	5	0	95	0	0	
0	0	203508	1082412	0	172872	0	0	0	72	2511	3017	0	0	100	0	0	
4	0	203508	1082368	0	172872	0	0	1352	100	3409	3509	12	0	88	0	0	
2	0	203508	1082368	0	172872	0	0	0	72	3828	4182	0	0	100	0	0	
6	0	203508	1075744	0	172872	0	0	0	32	3159	5032	8	0	92	0	0	
6	0	203508	1082364	0	172872	0	0	768	132	3502	4457	5	0	95	0	0	
0	0	203508	1082364	0	172872	0	0	0	204	3487	4266	0	0	100	0	0	
1	0	203508	1082332	0	172872	0	0	0	160	2675	2760	12	0	88	0	0	
3	0	203508	1082332	0	172872	0	0	0	108	3157	3027	0	0	100	0	0	
4	0	203508	1073552	0	172872	0	0	0	64	2835	3316	9	0	91	0	0	
3	0	203508	1082328	0	172872	0	0	0	80	2815	3063	4	0	96	0	0	
3	0	203508	1082328	0	172872	0	0	0	128	3043	3062	0	0	100	0	0	
1	0	203508	1082276	0	172872	0	0	0	188	2932	2514	12	0	88	0	0	
3	0	203508	1082276	0	172872	0	0	0	72	2929	3661	0	0	100	0	0	
7	0	203508	1072144	0	172872	0	0	768	68	3884	4945	9	0	91	0	0	
1	0	203508	1082436	0	172872	0	0	0	36	2744	4096	4	0	96	0	0	
4	0	203508	1082436	0	172872	0	0	0	88	3408	4131	0	0	100	0	0	

→ B) during running

procs		-----memory-----				---swap---		-----io-----		-system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
3	0	203556	323436	0	172872	12	0	12	112	3179	2583	28	0	72	0	0
3	0	203300	31592	0	172872	0	0	0	208	2583	2907	24	0	76	0	0
6	0	203300	23056	0	172872	0	0	0	100	3830	3182	33	0	67	0	0
2	0	203300	31600	0	172872	0	0	0	36	3108	3065	29	0	71	0	0
5	0	203300	31600	0	172872	0	0	0	56	2634	2633	25	0	75	0	0
3	0	203300	31544	0	172872	0	0	0	144	3500	2535	37	0	63	0	0
4	0	203300	31560	0	172872	0	0	0	40	2995	3480	24	0	76	0	0
8	0	203300	29208	0	172872	0	0	768	364	4088	5069	32	0	68	0	0
3	0	203300	31556	0	172872	0	0	0	100	3559	4220	31	0	69	0	0
4	0	203300	31556	0	172872	0	0	0	84	3328	4055	25	0	75	0	0
6	0	203300	31420	0	172872	0	0	0	184	3260	2512	37	0	63	0	0
1	0	203300	31528	0	172872	0	0	0	40	3174	2788	24	0	76	0	0
3	0	203300	11888	0	172872	0	0	0	64	3081	3440	30	0	70	0	0
6	0	203300	31472	0	172872	0	0	0	104	3566	2921	32	0	68	0	0
3	0	203300	31472	0	172872	0	0	0	52	2659	2543	25	0	75	0	0
5	0	203300	39396	0	171344	0	0	0	136	3000	2409	38	0	62	0	0
2	0	203300	39200	0	171344	0	0	0	148	3883	3334	25	0	75	0	0
4	0	203300	24448	0	171344	0	0	768	180	3937	5371	28	0	72	0	0
6	0	203300	35244	0	171344	0	0	0	68	3568	3880	35	0	65	0	0
4	0	203300	35352	0	171344	0	0	0	100	3701	4039	25	0	75	0	0
3	0	203300	33956	0	171344	0	0	0	36	3012	2520	39	0	61	0	0
3	0	203300	32608	0	172004	0	0	0	180	3354	2993	25	0	75	0	0

→ C) after running

procs		-----memory-----				---swap---		-----io-----		-system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
6	0	203300	21868	0	172400	0	0	0	140	3535	3235	27	0	73	0	0
4	0	203300	1082564	0	172532	4	0	4	220	2879	2853	27	0	73	0	0
6	0	203300	1082308	0	172532	0	0	0	104	3016	2841	0	0	100	0	0
1	0	203300	1082408	0	172532	0	0	0	36	2884	2658	12	0	88	0	0
2	0	203300	1082488	0	172532	0	0	0	144	2453	2956	0	0	100	0	0
4	0	203300	1073820	0	172532	0	0	768	108	4287	6232	2	0	98	0	0
2	0	203300	1082480	0	172532	0	0	0	96	2486	2904	10	0	90	0	0
5	0	203300	1082480	0	172532	0	0	0	88	2760	3014	0	0	100	0	0
1	0	203300	1082404	0	172532	0	0	0	108	3129	2536	13	0	87	0	0
2	0	203300	1082480	0	172532	0	0	0	40	2475	3029	0	0	100	0	0
7	0	203300	1071896	0	172532	0	0	0	176	3092	3280	3	0	97	0	0
2	0	203300	1082464	0	172532	0	0	0	32	2981	2772	10	0	90	0	0
2	0	203300	1082464	0	172532	0	0	0	88	2357	2900	0	0	100	0	0
3	0	203300	1082428	0	172532	0	0	0	172	3307	2904	12	0	88	0	0
0	0	203300	1082632	0	172532	0	0	0	108	2893	3462	0	0	100	0	0
5	0	203300	1069892	0	172532	0	0	768	116	3798	6601	4	0	96	0	0
3	0	203300	1082604	0	172532	0	0	0	64	3373	2994	9	0	91	0	0
3	0	203300	1082604	0	172532	0	0	0	52	2203	3020	0	0	100	0	0
7	0	203300	1082544	0	172532	0	0	0	56	2952	2676	12	0	88	0	0
1	0	203300	1082544	0	172532	0	0	0	188	3042	3173	0	0	100	0	0
5	0	203300	1068308	0	172532	0	0	0	260	2682	3355	4	0	96	0	0
4	0	203300	1082472	0	172532	0	0	0	136	3343	3303	8	0	92	0	0

What do you notice about the values? In particular, how does the free column change when the program exits? Does the amount of free memory increase by the expected amount when mem exits?

- swpd is in other words, how much memory has been swapped out
- swpd decreases in B) and in C) it remains the same
- free column is the amount of currently unused memory
- In a) is is high at around 1GiB. In b) it decreased by $1024 * 1024$ KiB, so it gets at

around 33000 KB. In c) it goes back up to 1GiB.

3. We'll next look at the swap columns (si and so), which indicate how much swapping is taking place to and from the disk. Of course, to activate these, you'll need to run mem with large amounts of memory. First, examine how much free memory is on your Linux system (for example, by typing `cat /proc/meminfo`; type `man proc` for details on the *proc file system and the types of information you can find there*). One of the first entries in `/proc/meminfo` is the total amount of memory in your system. Let's assume it's something like 8 GB of memory; if so, start by running `mem 4000` (about 4 GB) and watching the swap in/out columns. Do they ever give non-zero values? Then, try with 5000, 6000, etc. What happens to these values as the program enters the second loop (and beyond), as compared to the first loop? How much data (total) are swapped in and out during the second, third, and subsequent loops? (do the numbers make sense?)

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$  
cat /proc/meminfo  
MemTotal:        2097152 kB  
MemFree:         1082288 kB  
MemAvailable:    1254644 kB  
Buffers:         0 kB  
Cached:          172356 kB  
SwapCached:      0 kB  
Active:          237432 kB  
Inactive:        173216 kB  
Active(anon):    132524 kB  
Inactive(anon):  151488 kB  
Active(file):    104908 kB  
Inactive(file):  21728 kB  
Unevictable:     0 kB  
Mlocked:         191260 kB  
SwapTotal:       3145728 kB  
SwapFree:        2942508 kB  
Dirty:           0 kB  
Writeback:       0 kB  
AnonPages:       238628 kB  
Mapped:          85932 kB  
Shmem:           45384 kB
```

```

KReclaimable:    15271420 kB
Slab:            0 kB
SReclaimable:    0 kB
SUnreclaim:      0 kB
KernelStack:     40800 kB
PageTables:      100176 kB
NFS_Unstable:    0 kB
Bounce:          0 kB
WritebackTmp:    0 kB
CommitLimit:     49861052 kB
Committed_AS:    27142548 kB
VmallocTotal:    34359738367 kB
VmallocUsed:      200880 kB
VmallocChunk:    0 kB
Percpu:          80000 kB
HardwareCorrupted: 0 kB
AnonHugePages:   0 kB
ShmemHugePages:  0 kB
ShmemPmdMapped:  0 kB
FileHugePages:   0 kB
FilePmdMapped:   0 kB
CmaTotal:        0 kB
CmaFree:         0 kB
HugePages_Total: 0
HugePages_Free:  0
HugePages_Rsvd:  0
HugePages_Surp:  0
Hugepagesize:    2048 kB
Hugetlb:         0 kB
DirectMap4k:     1645568 kB
DirectMap2M:     27387904 kB
DirectMap1G:     6291456 kB

```

- the proc filesystem provides an interface to kernel data structures.
- *procmeminfo* reports statistics about memory usage on the system. It used by free to report the amount of free and used memory (both physical and swap). Look up [proc\(5\) - Linux manual page](#) on meminfo for details about each row.
- MemTotal: 2097152 kB → 2 GiB

```

vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1000
allocating 1048576000 bytes (1000.00 MB)
  number of integers in array: 262144000
loop 0 in 872.08 ms (bandwidth: 1146.69 MB/s)
loop 1 in 227.43 ms (bandwidth: 4396.92 MB/s)
loop 2 in 224.42 ms (bandwidth: 4455.85 MB/s)
loop 3 in 224.07 ms (bandwidth: 4462.97 MB/s)
loop 4 in 223.38 ms (bandwidth: 4476.76 MB/s)
loop 5 in 225.22 ms (bandwidth: 4440.15 MB/s)
loop 6 in 240.98 ms (bandwidth: 4149.70 MB/s)
loop 7 in 230.25 ms (bandwidth: 4343.05 MB/s)
loop 8 in 236.23 ms (bandwidth: 4233.14 MB/s)
loop 9 in 223.38 ms (bandwidth: 4476.78 MB/s)
loop 10 in 239.52 ms (bandwidth: 4175.07 MB/s)
loop 11 in 230.27 ms (bandwidth: 4342.80 MB/s)
loop 12 in 240.76 ms (bandwidth: 4153.44 MB/s)
loop 13 in 224.12 ms (bandwidth: 4461.85 MB/s)
loop 14 in 231.77 ms (bandwidth: 4314.55 MB/s)
loop 15 in 222.17 ms (bandwidth: 4501.09 MB/s)
loop 16 in 223.37 ms (bandwidth: 4476.96 MB/s)
loop 17 in 237.07 ms (bandwidth: 4218.23 MB/s)
loop 18 in 228.88 ms (bandwidth: 4369.01 MB/s)
loop 19 in 234.89 ms (bandwidth: 4257.27 MB/s)
loop 20 in 225.82 ms (bandwidth: 4428.27 MB/s)

```

→ during running

procs		memory				swap		io		system		cpu				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
6	0	202816	384712	0	175536	0	0	0	36	3373	2745	22	0	78	0	0
1	0	202688	52296	0	175536	0	0	0	124	3022	2831	25	0	75	0	0
6	0	202688	52196	0	175536	0	0	0	208	3258	3107	38	0	62	0	0
4	0	202688	52276	0	175536	0	0	768	0	4388	5710	25	0	75	0	0
3	0	202688	38004	0	175536	0	0	0	212	2461	3570	29	0	71	0	0
8	0	202688	52264	0	175536	0	0	0	148	3417	2619	34	0	66	0	0
3	0	202688	52352	0	175536	0	0	0	208	3906	4645	25	0	75	0	0
5	0	202688	52212	0	175536	0	0	0	108	2791	2941	38	0	62	0	0
3	0	202692	52352	0	175536	0	0	0	36	3691	2784	25	0	75	0	0
3	0	202688	42788	0	175536	0	0	0	68	2744	3010	27	0	73	0	0
6	0	202688	52348	0	175536	0	0	0	124	3338	2853	33	0	67	0	0
2	0	202688	53580	0	175536	0	392	252	544	3614	3155	24	0	76	0	0
3	0	202688	54228	0	175536	0	288	28	360	3583	3920	36	0	64	0	0
6	0	202688	54936	0	175536	0	92	1084	540	4056	5109	25	0	75	0	0
8	0	202688	44476	0	175536	0	132	12	164	3184	3553	27	0	73	0	0
3	0	202688	55052	0	175536	0	0	0	124	2901	2620	34	0	66	0	0
3	0	202688	55792	0	175536	0	136	8	368	3553	3370	24	0	76	0	0
3	0	202688	55700	0	175536	0	8	0	80	3600	3111	35	0	65	0	0
3	0	202688	55784	0	175536	0	0	0	0	2566	2892	25	0	75	0	0
5	0	202688	51356	0	175536	0	40	0	108	3470	2968	25	0	75	0	0
3	0	202688	55864	0	175536	0	0	0	76	3118	2818	36	0	64	0	0
5	0	202688	55864	0	175536	0	0	0	196	2993	2929	24	0	76	0	0

→ there are non zero values for the so column, which means that during the running of mem, some pages are swapped out.

```

vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1200
allocating 1258291200 bytes (1200.00 MB)
number of integers in array: 314572800
loop 0 in 1655.87 ms (bandwidth: 724.69 MB/s)
loop 1 in 287.37 ms (bandwidth: 4175.74 MB/s)
loop 2 in 309.49 ms (bandwidth: 3877.38 MB/s)
loop 3 in 271.58 ms (bandwidth: 4418.56 MB/s)
loop 4 in 267.40 ms (bandwidth: 4487.73 MB/s)
loop 5 in 279.47 ms (bandwidth: 4293.77 MB/s)
loop 6 in 268.60 ms (bandwidth: 4467.56 MB/s)
loop 7 in 279.64 ms (bandwidth: 4291.16 MB/s)
loop 8 in 290.90 ms (bandwidth: 4125.14 MB/s)
loop 9 in 341.44 ms (bandwidth: 3514.56 MB/s)

```

procs		memory				swap		io		system		cpu				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
2	0	202816	850856	0	175536	0	0	0	80	3297	3439	12	0	88	0	0
3	0	202696	968	0	172636	0	8	768	104	3663	5984	25	0	75	0	0
5	0	202712	26656	0	167212	0	16	0	100	3808	2809	41	0	60	0	0
2	0	202712	26656	0	167212	0	0	0	284	3044	3811	25	0	75	0	0
8	0	202712	22856	0	167212	0	0	0	220	3062	3287	26	0	74	0	0
3	0	202712	26660	0	167212	0	0	0	192	3695	2858	36	0	64	0	0
1	0	202712	26644	0	167212	0	0	0	32	3040	3336	24	0	76	0	0
6	0	202712	7048	0	167212	0	0	0	120	2978	2898	37	0	63	0	0
3	0	202712	26644	0	167212	0	0	0	128	3278	2655	26	0	74	0	0
4	0	202712	26644	0	167212	0	0	0	232	2361	2763	25	0	75	0	0
9	0	202712	26644	0	167212	0	0	0	216	4187	4517	37	0	63	0	0
1	0	202712	26644	0	167212	0	0	768	92	3604	5233	25	0	75	0	0
4	0	202712	13888	0	167212	0	0	0	180	2814	2620	35	0	65	0	0
3	0	202712	26644	0	167212	0	0	0	84	4126	3953	27	0	73	0	0
3	0	202712	26644	0	167212	0	0	0	56	2395	2629	25	0	75	0	0
5	0	202712	26632	0	167212	0	0	0	172	3446	3007	38	0	62	0	0
2	0	202712	26632	0	167212	0	0	0	68	2991	2637	25	0	75	0	0
7	0	202712	19364	0	167212	0	0	656	172	3510	3798	33	0	67	0	0
6	0	202712	26428	0	167212	0	0	0	216	2966	2562	29	0	71	0	0
5	0	202712	26528	0	167212	0	0	0	72	2889	2811	24	0	76	0	0
4	0	202712	26528	0	167212	0	0	0	64	3897	4720	38	0	62	0	0
7	0	202712	26544	0	167212	0	0	768	216	3767	4934	24	0	76	0	0

→ less pages swapped out

```

vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1400
allocating 1468006400 bytes (1400.00 MB)
number of integers in array: 367001600
loop 0 in 1883.45 ms (bandwidth: 743.32 MB/s)
loop 1 in 389.89 ms (bandwidth: 3590.72 MB/s)
loop 2 in 2102.22 ms (bandwidth: 665.96 MB/s)
loop 3 in 323.79 ms (bandwidth: 4323.80 MB/s)
loop 4 in 327.28 ms (bandwidth: 4277.67 MB/s)
loop 5 in 320.74 ms (bandwidth: 4364.91 MB/s)
loop 6 in 327.88 ms (bandwidth: 4269.87 MB/s)
loop 7 in 311.50 ms (bandwidth: 4494.41 MB/s)
loop 8 in 327.51 ms (bandwidth: 4274.63 MB/s)
loop 9 in 320.57 ms (bandwidth: 4367.15 MB/s)

```

procs	-----memory-----					---swap---		-----io-----		--system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
2	0	202712	1264128	0	167672	0	0	0	96	2329	3282	0	0	100	0	0
5	0	202840	614632	0	167672	0	0	8	144	3496	2979	26	0	74	0	0
3	0	202860	140	0	161968	0	144	0	224	3034	2582	23	0	77	0	0
7	0	202820	36	0	126292	540	704	564	1732	3888	3839	30	0	70	0	0
4	0	202980	39724	0	125844	0	96	0	304	3662	3341	34	0	66	0	0
2	0	202980	39736	0	125844	0	0	768	68	3877	4649	25	0	75	0	0
3	0	202980	39704	0	125844	32	0	32	32	3627	4250	38	0	62	0	0
10	0	202980	39732	0	125844	0	0	0	136	3155	2926	25	0	75	0	0
4	0	202980	32492	0	125844	0	0	0	108	3250	3221	27	0	73	0	0
3	0	202980	39960	0	125844	0	0	0	108	2613	2549	36	0	64	0	0
4	0	202980	39960	0	125844	0	0	0	68	3892	3880	25	0	75	0	0
2	0	202980	39808	0	125844	0	0	0	100	3417	3196	37	0	63	0	0
5	0	202980	39984	0	125844	0	0	0	72	2766	2725	25	0	75	0	0
6	0	202980	37076	0	125844	0	0	0	120	3638	3377	26	0	74	0	0
1	0	202980	39968	0	125844	0	0	0	152	3488	3668	36	0	64	0	0
6	0	202980	39968	0	125844	0	0	768	156	3806	5420	25	0	75	0	0
7	0	202980	20740	0	125844	0	0	0	68	3810	3807	37	0	63	0	0
2	0	202980	39812	0	125844	0	0	0	0	2378	2708	26	0	74	0	0
10	0	202980	39912	0	125844	0	0	0	164	3354	3102	25	0	75	0	0
1	0	202980	39912	0	125844	0	0	0	152	3422	3203	38	0	62	0	0
2	0	202980	44624	0	126372	0	0	760	176	2753	3548	26	0	74	0	0
6	0	202980	30540	0	126372	0	0	0	108	3865	3060	34	0	66	0	0

→ now pages swapped in and swapped out

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1800
allocating 1887436800 bytes (1800.00 MB)
number of integers in array: 471859200
loop 0 in 4042.16 ms (bandwidth: 445.31 MB/s)
loop 1 in 1736.27 ms (bandwidth: 1036.70 MB/s)
loop 2 in 426.00 ms (bandwidth: 4225.37 MB/s)
loop 3 in 424.73 ms (bandwidth: 4238.00 MB/s)
loop 4 in 461.62 ms (bandwidth: 3899.29 MB/s)
loop 5 in 469.11 ms (bandwidth: 3837.02 MB/s)
loop 6 in 503.88 ms (bandwidth: 3572.26 MB/s)
loop 7 in 431.19 ms (bandwidth: 4174.54 MB/s)
loop 8 in 411.47 ms (bandwidth: 4374.52 MB/s)
loop 9 in 426.37 ms (bandwidth: 4221.72 MB/s)
loop 10 in 403.01 ms (bandwidth: 4466.37 MB/s)
```

procs	-----memory-----					---swap---		-----io-----		--system--		-----cpu-----				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
3	0	202980	1480996	0	126372	0	0	768	144	3181	5485	2	0	98	0	0
7	0	203088	329308	0	126372	32	0	32	156	3301	3433	25	0	75	0	0
2	0	203980	20	0	111312	32	1052	288	1180	3674	3009	45	0	55	0	0
3	0	246948	44	0	34648	36	42896	5808	42964	5173	4439	32	0	68	0	0
5	0	343300	84	0	30088	0	86308	8928	86428	7744	3632	28	0	72	0	0
0	2	357680	48	0	33256	52904	48108	56988	48148	7878	10169	18	0	82	0	0
8	1	376420	21436	0	36752	18068	28564	25884	28680	5663	5815	40	0	60	0	0
2	0	375872	20880	0	37148	432	0	808	100	3434	3119	25	0	75	0	0
4	0	375200	16080	0	38864	976	0	2836	36	2529	2589	25	0	75	0	0
7	0	378540	22552	0	37600	76	2160	320	2352	4209	4282	39	0	61	0	0
4	0	378532	22548	0	37600	24	0	24	0	2996	2724	26	0	74	0	0
6	1	378480	11988	0	37600	1112	612	1904	692	3989	5473	35	0	65	0	0
2	0	378588	22404	0	37600	732	532	732	764	3503	3440	29	0	71	0	0
3	0	378264	22044	0	37732	436	0	436	0	3422	3863	25	0	75	0	0
5	0	378952	22724	0	37732	296	604	300	768	3212	3047	38	0	62	0	0
3	0	378952	22624	0	37732	60	0	60	0	3844	3524	24	0	76	0	0
5	0	378896	19824	0	37732	116	144	116	288	2832	2448	31	0	69	0	0
6	0	378888	22644	0	37732	48	0	48	104	3220	2901	31	0	69	0	0
4	0	378820	22044	0	38128	84	0	528	312	2830	2449	25	0	75	0	0
4	0	378932	22344	0	37996	60	92	60	232	3430	3863	38	0	62	0	0
4	0	378748	22460	0	37996	24	0	24	100	3324	3019	25	0	75	0	0
5	0	378624	2816	0	37996	272	0	1040	80	4160	5939	31	0	69	0	0

→ a lot more pages swapped in and out

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 2048
allocating 2147483648 bytes (2048.00 MB)
number of integers in array: 536870912
loop 0 in 4129.20 ms (bandwidth: 495.98 MB/s)
loop 1 in 31518.43 ms (bandwidth: 64.98 MB/s)
```

procs	-----memory-----	---swap--	-----io----	---system--	-----cpu-----											
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
4	0	365668	1430436	0	45784	156	0	156	76	2242	2581	10	0	90	0	0
5	0	365532	280288	0	45784	8	0	8	132	4435	4325	37	0	63	0	0
5	1	407852	164	0	31008	0	41616	1088	41876	4545	3372	24	0	76	0	0
10	0	518720	32	0	35240	32	110752	12860	110864	12795	6033	34	0	66	0	0
2	0	608668	64	0	34172	15824	102912	16992	103036	11727	4320	37	0	63	0	0
2	0	608000	16	0	33512	59312	57880	59312	57952	4851	6594	19	0	81	0	0
6	0	628420	92	0	33248	58036	74252	58200	74416	10216	6913	28	0	72	0	0
1	0	607632	0	0	33248	86628	62344	86636	62472	10294	9167	27	0	73	0	0
9	0	607808	0	0	33248	63664	63024	63804	63136	5990	6694	19	0	81	0	0
4	0	621828	9052	0	32984	68048	80788	68428	80916	12360	7664	32	0	68	0	0
3	0	608000	104	0	33380	75516	58980	76356	58984	9341	7636	25	0	75	0	0
8	1	607632	52	0	32984	64808	61660	64808	61832	6512	8274	19	0	81	0	0
6	0	620308	20	0	32720	71208	81484	71876	81592	12911	9531	34	0	66	0	0
1	1	607528	124	0	32720	74204	58840	74588	58884	8925	9107	23	0	77	0	0
5	0	607160	12	0	32588	65472	62804	65472	62972	5843	6988	20	0	80	0	0
6	0	625660	148	0	32456	67836	83956	68068	83988	13688	7565	36	0	64	0	0
2	0	607724	100	0	32456	77480	57032	77480	57124	6934	7984	20	0	80	0	0
3	0	607448	20	0	32456	64816	63556	64816	63808	6401	8020	20	0	80	0	0
2	0	623036	15536	0	32456	67036	82244	67300	82272	14435	7209	38	0	62	0	0
3	0	607736	100	0	32456	72780	57680	72780	57840	6107	7590	20	0	80	0	0
7	0	609856	32	0	32456	64172	66732	64256	66764	6402	6695	21	0	79	0	0
3	0	607492	200	0	32588	74028	70812	74156	70908	13449	8922	34	0	66	0	0

→ big increase in swap ins and swap outs

→ on the first loop, the row at si column gets pretty big and in the next loops this value decreases dramatically. I got this with ./mem 1600

To get this behaviour you must give the system some idle time and then run it. You will get a spike for swap in on the first loop and the next loops go in direction 0. The swap in column is in KB, so yeah it does make sense.

→ Nonzero **si** and **so** numbers indicate that there is not enough physical memory and that the kernel is swapping memory to disk.

4. Do the same experiments as above, but now watch the other statistics (such as CPU utilization, and block I/O statistics). How do they change when mem is running?

→ for cpu utilisation see first exercise

→ the bi, blocks received from a block device, increases when the allocated memory by mem increases. There will be more rows with non zero values. Theoretically when so increases, also bo should increase and the same for si and bi. But remember bi and bo show blocks received or sent to a disk device. So although memory is swapped, it may now show in block statistics, because I think the memory gets clustered first and then sent.

5. Now let's examine performance. Pick an input for mem that comfortably fits in memory (say 4000 if the amount of memory on the system is 8 GB). How long does loop 0 take (and subsequent loops 1, 2, etc.)? Now pick a size comfortably beyond the size of memory (say 12000 again assuming 8 GB of memory). How long do the loops take here? How do the bandwidth numbers compare? How different is performance when constantly swapping versus fitting everything comfortably in memory? Can you make a graph, with the size of memory used by mem on the x-axis, and the bandwidth of accessing said memory on the y-axis? Finally, how does the performance of the first loop compare to that of subsequent loops, for both the case where everything fits in memory and where it doesn't?

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1000
allocating 1048576000 bytes (1000.00 MB)
  number of integers in array: 262144000
loop 0 in 877.15 ms (bandwidth: 1140.05 MB/s)
loop 1 in 233.81 ms (bandwidth: 4276.90 MB/s)
loop 2 in 225.29 ms (bandwidth: 4438.76 MB/s)
loop 3 in 227.07 ms (bandwidth: 4403.89 MB/s)
loop 4 in 227.98 ms (bandwidth: 4386.35 MB/s)
loop 5 in 236.02 ms (bandwidth: 4236.89 MB/s)
loop 6 in 222.92 ms (bandwidth: 4485.81 MB/s)
loop 7 in 224.15 ms (bandwidth: 4461.22 MB/s)
loop 8 in 232.75 ms (bandwidth: 4296.42 MB/s)
loop 9 in 224.73 ms (bandwidth: 4449.82 MB/s)
loop 10 in 234.75 ms (bandwidth: 4259.81 MB/s)
```

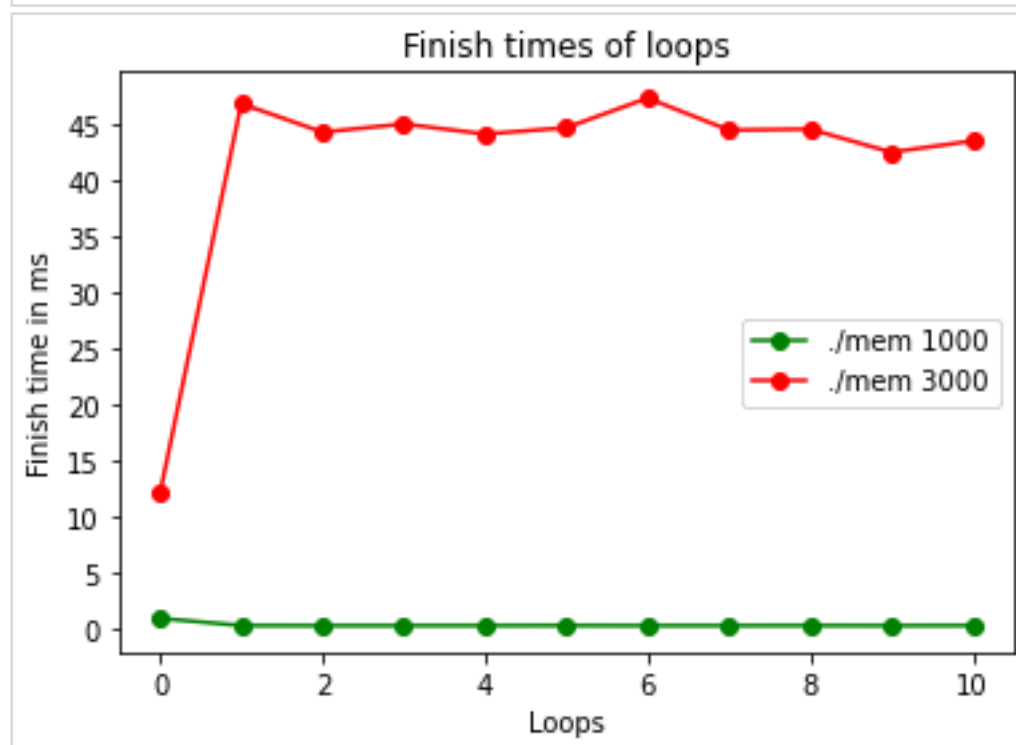
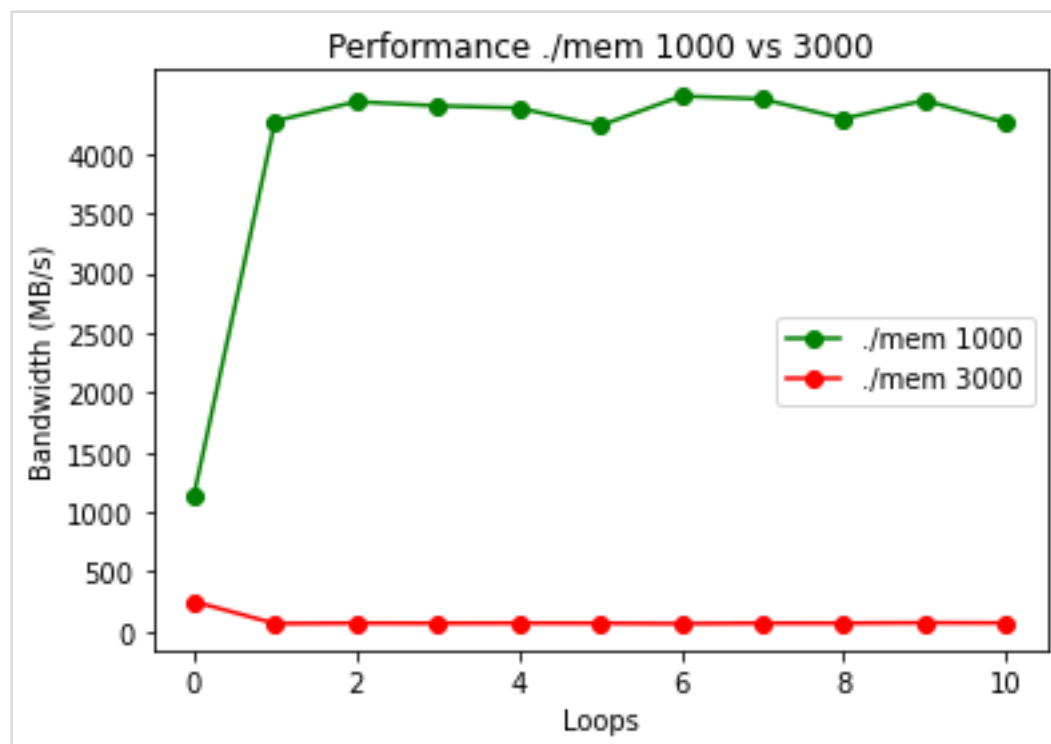
```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 3000
allocating 3145728000 bytes (3000.00 MB)
  number of integers in array: 786432000
loop 0 in 12063.20 ms (bandwidth: 248.69 MB/s)
loop 1 in 46904.24 ms (bandwidth: 63.96 MB/s)
loop 2 in 44353.43 ms (bandwidth: 67.64 MB/s)
loop 3 in 45090.48 ms (bandwidth: 66.53 MB/s)
loop 4 in 44183.05 ms (bandwidth: 67.90 MB/s)
loop 5 in 44751.04 ms (bandwidth: 67.04 MB/s)
loop 6 in 47400.83 ms (bandwidth: 63.29 MB/s)
loop 7 in 44539.24 ms (bandwidth: 67.36 MB/s)
loop 8 in 44624.18 ms (bandwidth: 67.23 MB/s)
loop 9 in 42557.00 ms (bandwidth: 70.49 MB/s)
loop 10 in 43569.75 ms (bandwidth: 68.86 MB/s)
```

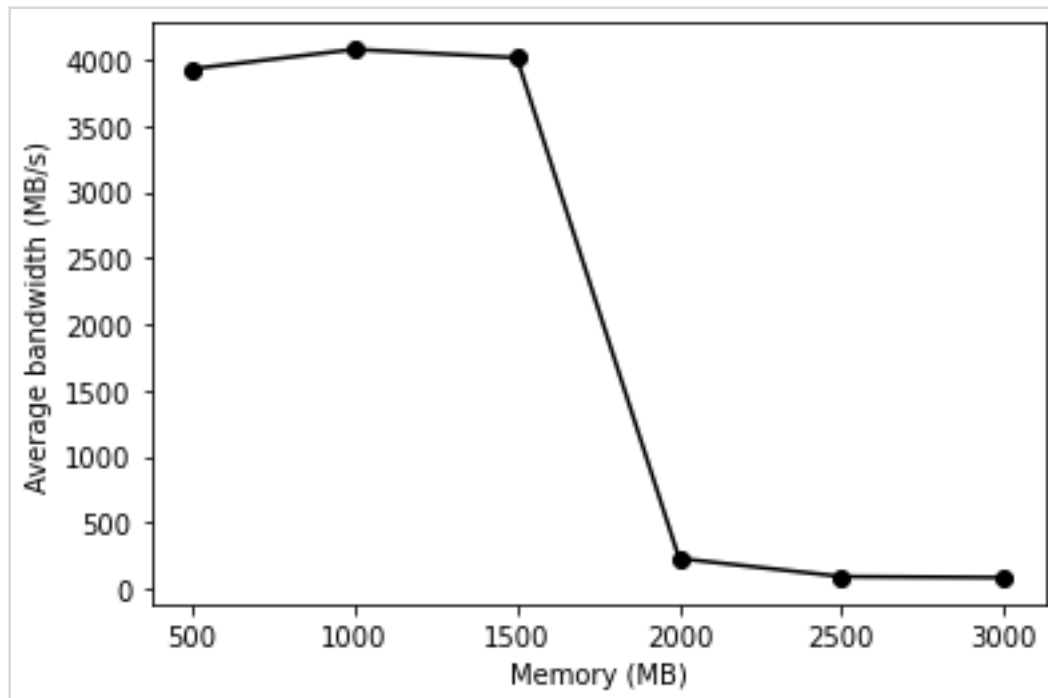
```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 500
allocating 524288000 bytes (500.00 MB)
  number of integers in array: 131072000
loop 0 in 438.68 ms (bandwidth: 1139.79 MB/s)
loop 2 in 115.58 ms (bandwidth: 4325.97 MB/s)
loop 4 in 113.97 ms (bandwidth: 4387.24 MB/s)
loop 6 in 112.47 ms (bandwidth: 4445.82 MB/s)
loop 8 in 113.04 ms (bandwidth: 4423.25 MB/s)
loop 10 in 113.90 ms (bandwidth: 4389.96 MB/s)
loop 12 in 113.91 ms (bandwidth: 4389.40 MB/s)
```

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 1500
allocating 1572864000 bytes (1500.00 MB)
  number of integers in array: 393216000
loop 0 in 1318.61 ms (bandwidth: 1137.56 MB/s)
loop 1 in 340.31 ms (bandwidth: 4407.75 MB/s)
loop 2 in 336.83 ms (bandwidth: 4453.30 MB/s)
loop 3 in 348.67 ms (bandwidth: 4302.11 MB/s)
loop 4 in 350.41 ms (bandwidth: 4280.73 MB/s)
loop 5 in 348.38 ms (bandwidth: 4305.58 MB/s)
loop 6 in 355.87 ms (bandwidth: 4215.02 MB/s)
loop 7 in 345.05 ms (bandwidth: 4347.13 MB/s)
loop 8 in 360.21 ms (bandwidth: 4164.24 MB/s)
loop 9 in 362.42 ms (bandwidth: 4138.86 MB/s)
loop 10 in 341.30 ms (bandwidth: 4394.91 MB/s)
loop 11 in 352.15 ms (bandwidth: 4259.60 MB/s)
loop 12 in 389.51 ms (bandwidth: 3850.96 MB/s)
```

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 2000
allocating 2097152000 bytes (2000.00 MB)
  number of integers in array: 524288000
loop 0 in 3691.32 ms (bandwidth: 541.81 MB/s)
loop 1 in 14479.20 ms (bandwidth: 138.13 MB/s)
loop 2 in 18891.40 ms (bandwidth: 105.87 MB/s)
loop 3 in 13580.93 ms (bandwidth: 147.27 MB/s)
loop 4 in 10366.94 ms (bandwidth: 192.92 MB/s)
loop 5 in 18773.23 ms (bandwidth: 106.53 MB/s)
loop 6 in 4892.12 ms (bandwidth: 408.82 MB/s)
loop 7 in 17257.76 ms (bandwidth: 115.89 MB/s)
loop 8 in 4982.48 ms (bandwidth: 401.41 MB/s)
loop 9 in 22270.14 ms (bandwidth: 89.81 MB/s)
loop 10 in 7788.53 ms (bandwidth: 256.79 MB/s)
```

```
vl161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ ./mem 2500
allocating 2621440000 bytes (2500.00 MB)
  number of integers in array: 655360000
loop 0 in 7854.91 ms (bandwidth: 318.27 MB/s)
loop 1 in 36969.00 ms (bandwidth: 67.62 MB/s)
loop 2 in 37522.77 ms (bandwidth: 66.63 MB/s)
loop 3 in 36812.00 ms (bandwidth: 67.91 MB/s)
loop 4 in 37116.18 ms (bandwidth: 67.36 MB/s)
loop 5 in 37581.88 ms (bandwidth: 66.52 MB/s)
loop 6 in 29837.11 ms (bandwidth: 83.79 MB/s)
loop 7 in 37401.14 ms (bandwidth: 66.84 MB/s)
loop 8 in 38946.78 ms (bandwidth: 64.19 MB/s)
loop 9 in 37780.56 ms (bandwidth: 66.17 MB/s)
loop 10 in 38297.47 ms (bandwidth: 65.28 MB/s)
```





6. Swap space isn't infinite. You can use the tool `swapon` with the `-s` flag to see how much swap space is available. What happens if you try to run `mem` with increasingly large values, beyond what seems to be available in swap? At what point does the memory allocation fail?

→ `swapon` doesn't work on the container so I used `free`:

```
v1161bra@ct-bsys-ws20-12:~/htwg/S3/BS/Homeworks/HW21-Paging-BeyondPhys-Real$ free
```

	total	used	free	shared	buff/cache	available
Mem:	2097152	174440	1865132	3552	57580	1922712
Swap:	3145728	398808	2746920			

→ there is about 3GiB swap space available. `Free` shows in kb.

→ We have about 2GiB RAM and 3GiB swap space so 5GiB in total

→ Between 4550 and 4600. That's roughly 90% of the total 5 GiB

```
v1161bra@ct-bsys-ws20-12:~$ /sbin/swapon -s
```

Filename	Type	Size	Used	Priority
none	virtual	3145728	2857388	0

7. Finally, if you're advanced, you can configure your system to use different swap devices using `swapon` and `swapoff`. Read the man pages for details. If you have access to different hardware, see how the performance of swapping changes when swapping to a classic hard drive, a flash-based SSD, and even a RAID array. How much can swapping performance be improved via newer devices? How close can you get to in-memory performance?

→ **swapon** is used to specify devices on which paging and swapping are to take place.

→ **swapoff** disables swapping on the specified devices and files. When the **-a** flag is given, swapping is disabled on all known swap devices

and files (as found in *procsuaps* or *etcfstab*).

→ Option -d enables swap discards if the swap backing device supports the trim operation. Trim operation allows an OS to inform a SSD which blocks of data are no longer considered in use can be be wiped internally. This may improve performance on some SSDs.

→ Swap on SSD is much faster than HDD, but still pretty bad compared to RAM. Thrashing on SSD is still a problem. And you will not see the difference, unless you are severely starving for free memory and constantly swapping.

→ However, the page file is often disabled on SSDs to limit the number of writes and thus increase lifespan a little bit.

→ When your system starts to swap, you are already in trouble. You don't want to get there, ever.

→ **RAID** is a data storage virtualization technology that combines multiple physical disk drive components into one or more logical units for the purposes of data redundancy, performance improvement, or both.

→ Swapping on mirrored RAID (RAID 1) can help survive a failing disk. If a disk fails, then data for swapped processes would be inaccessible in a non-mirrored environment. If you run in a mirrored environment, then the system can go on running even if a disk fails in service. There's not much reason to use RAID0 (splits data evenly across two or more disks) for swap performance reasons.

→ Übrigens: Ganz voll wird der Swap nicht geschrieben ... warum wohl ... ?

→ I think it is because swap space is meant to be a buffer for RAM, and if memory is full and swap also, then the system gets into some kind of deadlock.

