

# Results of the OSU benchmark

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In the following pages there are reported the exhaustive list of all the results obtained by running the benchmark written with python and Dask to assess the overhead introduced by Kubernetes, compared to the code executed on the same hardware but with the SLURM scheduler installed instead. All the technical details are reported in the third chapter of the thesis this document is related to.

In all the tables, the column “CPUs” refers to the number of CPUs used, while all the other columns are statistics computed over 30 runs of the benchmark and are expressed in MB/s.

## 1 Arrays

CPU's	Mean	Std	Min	Max
1	592.579	74.707	197.719	621.02
2	903.135	105.223	347.28	934.308
4	2312.675	270.393	882.899	2397.531
6	2342.565	348.79	1155.106	2694.167
8	2987.283	316.101	1316.121	3071.461
10	3206.639	366.664	1473.622	4120.154
12	4186.765	568.716	1668.286	5061.049
14	4701.013	647.689	1924.179	5130.792
16	9192.027	1334.177	2149.538	9529.213
18	6065.735	982.722	2452.222	8161.441
20	6797.123	1048.577	1985.201	8455.693
22	7186.401	890.776	3015.305	8207.502
24	8633.459	1005.589	3343.344	9231.778
26	8166.744	843.604	3818.917	8748.111
28	9189.864	1452.523	3395.895	11271.36
30	9636.395	1075.672	4056.025	10210.303
32	10316.909	1167.627	4621.84	12018.624
34	11148.952	1485.143	3670.367	12405.245
36	18915.527	3091.859	4609.785	20059.522
38	11418.962	1754.121	4282.235	12552.646
40	12927.58	1741.94	4154.516	14320.388
42	13129.484	1825.211	5177.909	15086.466
44	13898.048	1809.994	4788.721	16090.515
46	14406.035	2014.861	5669.822	15956.618
48	16040.679	2305.691	4136.588	17337.207

Table 1: Randomly initialization of a 2-D array – bare metal

CPU's	Mean	Std	Min	Max
1	493.394	113.895	163.577	592.225
2	792.387	171.951	295.149	900.332
4	2019.898	466.291	645.721	2336.896
6	2322.525	483.826	873.994	2538.222
8	2784.95	566.437	1093.279	3025.91
10	4239.048	945.124	1522.571	4698.461
12	4527.113	942.108	1724.605	4985.858
14	4714.088	936.803	1940.632	5087.245
16	7670.733	1768.271	2446.489	8594.715
18	7215.924	1529.36	2675.835	7955.831
20	7195.192	1469.94	2857.718	7889.271
22	7423.798	1254.509	3030.329	7985.609
26	7557.004	1387.729	3453.891	8209.189
28	8568.916	1795.617	3738.495	11495.759
30	10883.099	2207.106	4364.128	11846.148
32	10535.719	2123.917	4460.771	11719.805
34	10707.695	2077.336	4509.352	11682.082
36	15717.124	3597.389	5452.81	18400.296
38	14097.833	3241.118	5381.645	16699.811
40	13641.657	2916.507	5663.182	16184.586
42	12463.681	3134.323	5595.224	15505.392

Table 2: Randomly initialization of a 2-D array – Kubernetes

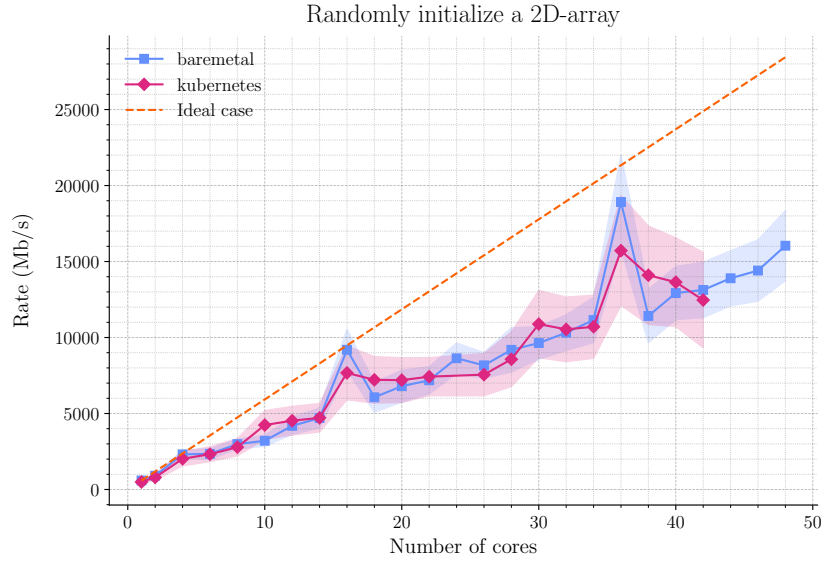


Figure 1: Randomly initialization of a 2-D array. Refer to tables 1 and 2 for the numerical values.

CPU's	Mean	Std	Min	Max
1	543.336	62.146	250.51	560.912
2	814.419	81.677	382.239	833.733
4	2121.921	201.081	1062.394	2178.838
6	2079.043	302.975	1093	2418.645
8	2294.809	196.247	1430.107	2586.489
10	2925.041	462.408	1824.853	4367.549
12	3738.261	430.557	2729.046	4596.935
14	4065.214	327.021	2670.359	4380.776
16	7873.086	891.425	4138.022	8153.804
18	4726.811	511.887	3019.639	5993.268
20	6031.676	677.625	3618.389	7266.317
22	6093.439	526.286	3969.111	6710.602
24	7362.972	584.038	4431.891	7670.478
26	6939.183	600.737	4335.845	8132.838
28	8323.319	669.339	5682.647	9653.065
30	8554.537	799.73	5200.627	10208.559
32	8813.617	792.972	5637.565	10624.205
34	9441.823	1162.095	5390.53	10524.813
36	15704.349	1387.204	8509.387	16708.47
38	9579.927	923.333	5959.208	10534.163
40	11438.825	1252.216	7247.615	13576.208
42	11191.678	1678.742	5921.375	13496.829
44	11806.097	1390.172	7521.903	14435.856
46	12351.065	1031.684	7701.826	13716.768
48	13197.679	1383.453	8431.658	14356.769

Table 3: “*Blockwise*” operation  $x \neq 1$  – bare metal

CPU's	Mean	Std	Min	Max
1	537.707	6.718	522.423	545.36
2	765.784	13.514	721.533	778.458
4	2046.942	99.198	1686.607	2112.143
6	2065.719	78.208	1902.666	2208.374
8	2508.57	71.196	2311.092	2606.525
10	3821.418	113.424	3640.991	4080.467
12	3978.169	117.221	3760.682	4194.381
14	4185.416	88.956	3966.938	4318.494
16	6415.966	186.951	6028.849	6812.723
18	6111.461	303.521	5048.463	6465.425
20	6096.581	462.375	4660.331	6583.511
22	6394.778	173.165	5905.493	6610.198
26	6472.678	223.512	5903.193	6832.626
28	7446.993	790.811	6666.486	9377.846
30	9077.944	379.681	8362.964	9753.454
32	9029.564	491.033	7230.325	9687.547
34	9377.45	257.203	8544.971	9658.683
36	12368.736	1223.343	9416.808	14022.484
38	11303.675	1083.645	8959.246	12990.239
40	11336.195	964.703	9420.576	12589.842
42	10670.907	1704.172	7141.44	12773.711

Table 4: “*Blockwise*” operation  $x \neq 1$  – Kubernetes

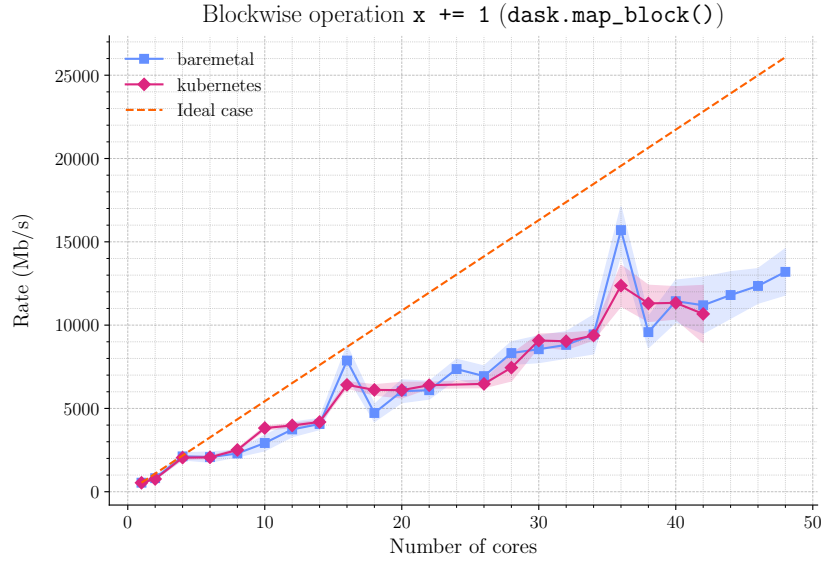


Figure 2: “*Blockwise*” operation  $x \neq 1$ . Refer to tables 3 and 4 for the numerical values.

CPU	Mean	Std	Min	Max
1	119.258	0.333	118.175	119.657
2	173.277	0.366	172.291	173.758
4	470.761	8.705	425.859	474.429
6	488.242	15.96	454.833	504.667
8	539.859	10.475	527.315	557.918
10	946.024	29.294	906.854	1003.735
12	945.627	21.737	918.635	985.522
14	928.17	19.998	892.157	956.27
16	1847.039	10.521	1805.052	1859.45
18	1583.554	29.679	1520.454	1653.489
20	1540.429	59.591	1332.67	1621.733
22	1473.262	30.483	1428.3	1520.225
24	1581.005	39.494	1398.96	1610.972
26	2461.013	72.199	2190.394	2553.601
28	2331.768	81.208	2061.69	2459.506
30	2248.897	29.044	2202.755	2328.405
32	2162.352	72.041	1879.111	2258.771
34	2175.745	49.62	2085.362	2245.823
36	3963.542	101.492	3436.532	4012.141
38	3435.087	49.421	3340.88	3512.993
40	3231.618	83.035	2869.736	3362.584
42	3092.945	81.08	2714.475	3187.466
44	3003.093	69.241	2911.736	3198.771
46	2913.849	61.998	2841.342	3056.044
48	3006.131	57.005	2902.021	3098.925

Table 5: “Blockwise” operation – bare metal

CPU	Mean	Std	Min	Max
1	114.463	0.684	112.296	115.222
2	163.655	1.948	160.397	167.275
4	453.971	3.255	447.461	459.923
6	473.411	3.35	467.269	483.014
8	551.239	5.698	540.784	564.21
10	948.969	9.648	911.524	963.635
12	925.226	7.589	899.121	938.967
14	927.996	7.642	914.255	944.925
16	1661.461	16.354	1637.023	1694.75
18	1566.127	11.484	1551	1592.47
20	1485.605	25.547	1382.116	1516.226
22	1448.354	19.016	1402.624	1487.392
26	1907.188	93.808	1750.874	2087.521
28	1990.563	150.208	1755.097	2329.595
30	2218.21	19.969	2179.247	2263.91
32	2143.925	29.916	2046.088	2202.415
34	2094.31	27.768	2014.24	2137.727
36	3541.665	52.37	3406.92	3650.394
38	3332.721	61.715	3193.995	3424.958
40	3191.022	66.867	2963.876	3267.903
42	2961.098	78.401	2778.943	3083.515

Table 6: “Blockwise” operation – Kubernetes

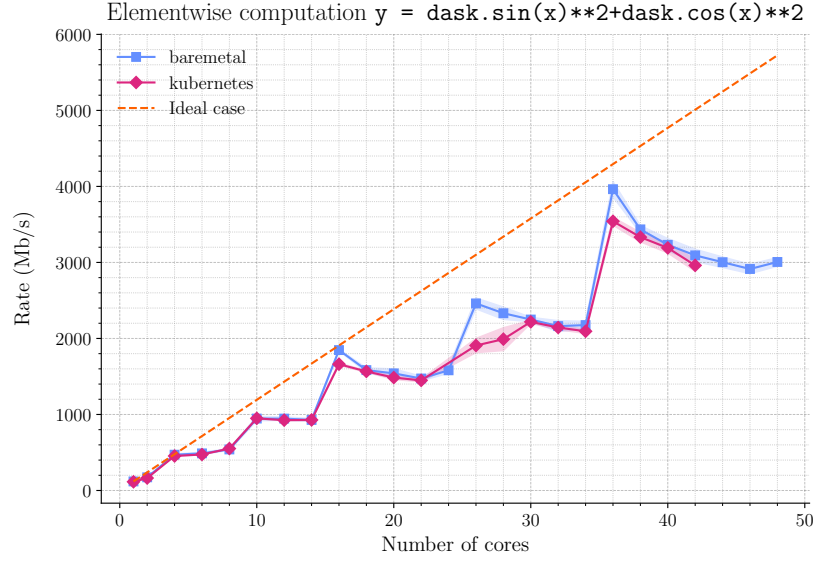


Figure 3: “Blockwise” operation  $y = \sin(x)**2 + \cos(x)**2$ . Refer to tables 5 and 6 for the numerical values.

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	389.702	4.111	375.28	392.098
2	619.058	53.134	557.522	682.573
4	1452.422	14.834	1409.549	1471.643
6	1823.084	134.242	1600.965	2030.358
8	1936.193	38.75	1768.949	1969.639
10	2102.218	161.266	1812.562	2329.864
12	2879.967	192.694	2600.257	3143.953
14	2802.082	129.033	2542.307	2957.96
16	5421.097	298.488	3908.978	5604.97
18	4651.761	66.323	4406.56	4757.132
20	5137.961	322.045	4755.925	5717.441
22	4689.312	239.477	4202.513	5158.851
24	4692.194	147.161	4325.079	4954.648
26	4697.748	325.726	3595.689	5081.328
28	5988.554	393.657	5283.614	6768.91
30	6051.748	420.561	4625.581	6800.812
32	6193.047	355.328	5756.62	7095.05
34	6531.037	300.967	5880.605	6990.093
36	10371.769	684.181	6878.6	10958.39
38	7008.929	699.671	5980.49	8682.973
40	8513.937	665.213	6163.978	9760.668
42	8487.381	652.834	6382.836	10069.958
44	9317.866	594.083	7815.872	10235.993
46	8811.637	642.689	6556.41	9688.911
48	8826.779	349.382	8191.861	9537.639

Table 7: Reduction operation among the whole matrix – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	366.78	31.768	263.177	383.284
2	595.301	78.56	487.29	724.067
4	1322.493	36.833	1244.422	1401.957
6	1795.642	47.02	1733.757	1883.273
8	1864.042	55.697	1780.495	1958.466
10	2615.212	131.454	2225.279	2784.67
12	2764.196	98.844	2305.157	2886.057
14	2903.652	69.036	2737.053	3005.753
16	4356.877	243.543	3546.862	4555.181
18	4593.025	226.154	3979.45	4790.048
20	5005.285	105.443	4796.023	5235.283
22	4857.204	71.458	4677.661	5047.363
26	4613.739	159.361	4201.735	4998.872
28	5177.281	363.977	4675.355	5987.89
30	5919.73	535.471	5012.378	6502.256
32	6082.999	329.353	5146.842	6450.206
34	6034.809	310.307	4724.901	6314.302
36	8553.802	543.087	6743.835	9006.241
38	8703.607	326.698	8070.025	9188.692
40	8492.231	415.654	7398.106	8935.797
42	7881.175	664.124	6296.128	8737.7

Table 8: Reduction operation among the whole matrix – Kubernetes

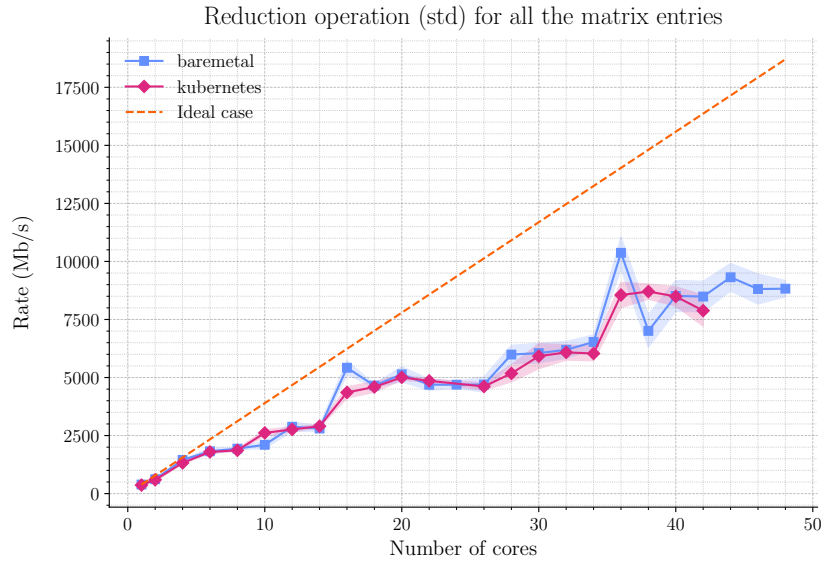


Figure 4: Reduction operation among the whole matrix. Refer to tables 7 and 8 for the numerical values.

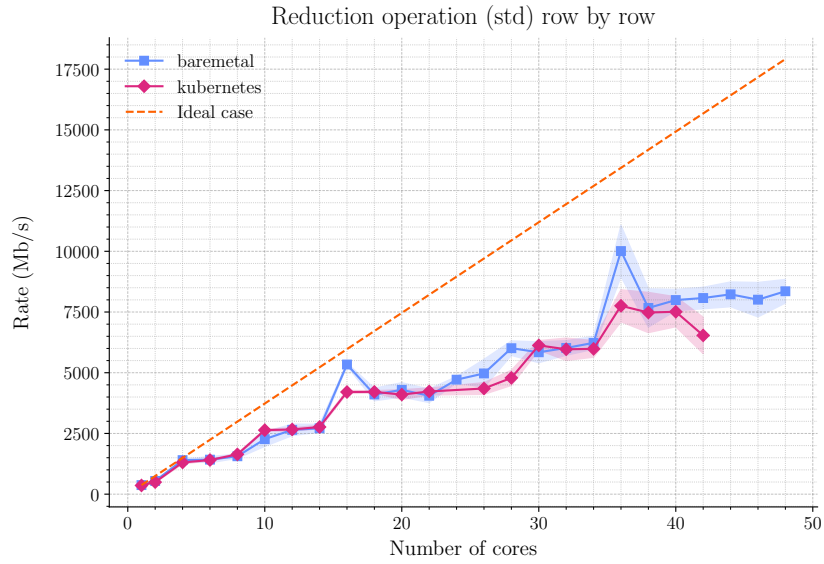


Figure 5: Reduction operation row by row. Refer to tables 9 and 10 for the numerical values.

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	373.218	2.575	361.579	374.923
2	543.362	3.54	531.575	547.286
4	1401.273	30.244	1255.302	1420.155
6	1420.904	127.8	1173.173	1557.395
8	1560.474	82.029	1352.12	1687.767
10	2265.775	295.857	1783.253	2877.498
12	2647.98	234.183	1991.751	2987.528
14	2712.204	158.803	2105.613	2852.902
16	5338.53	58.46	5155.552	5422.301
18	4104.19	257.21	3697.23	4621.044
20	4294.46	292.982	3844.492	4810.231
22	4051.771	277.863	3217.812	4446.847
24	4714.946	124.73	4365.408	4890.643
26	4971.158	575.686	4133.872	6172.659
28	6010.123	295.835	5448.046	6685.917
30	5843.237	426.882	3942.284	6562.378
32	6019.831	296.943	5585.072	6756.436
34	6230.152	263.467	5609.904	6717.974
36	10009.923	1051.409	5388.833	10492.992
38	7667.73	783.62	6222.961	8830.186
40	7992.589	434.687	6716.728	8587.453
42	8075.908	439.945	7516.567	9244.82
44	8227.927	508.028	7682.942	9364.184
46	8008.483	707.013	5579.35	9040.913
48	8355.156	483.292	6366.019	8921.775

Table 9: Reduction operation row by row – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	358.928	6.072	336.483	366.235
2	495.796	18.831	437.296	517.661
4	1305.58	62.004	1012.769	1357.585
6	1405.355	27.377	1350.016	1454.069
8	1638.625	42.784	1565.574	1707.927
10	2635.975	37.3	2492.596	2694.227
12	2663.337	68.818	2367.194	2776.2
14	2765.505	64.702	2481.671	2837.254
16	4206.671	63.889	4070.559	4324.425
18	4212.29	44.768	4082.502	4302.887
20	4100.058	200.051	3492.625	4401.698
22	4228.557	139.836	3742.623	4418.912
26	4351.108	238.93	3857.934	4921.72
28	4788.047	310.984	4409.123	5822.864
30	6126.991	193.781	5334.784	6306.519
32	5964.811	457.805	4897.672	6426.756
34	5983.188	341.108	4864.625	6297.801
36	7756.282	656.597	6353.678	8432.775
38	7479.228	825.126	5856.972	8544.789
40	7509.992	614.727	5362.583	8291.892
42	6537.138	745.561	4917.392	7646.283

Table 10: Reduction operation row by row – Kubernetes

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	27.551	0.276	26.525	27.784
2	28.302	0.506	26.989	28.885
4	27.806	0.194	27.034	28.027
6	28.489	0.442	26.936	28.908
8	27.433	0.398	26.026	27.815
10	27.393	0.456	25.896	27.845
12	28.141	0.677	26.703	28.809
14	27.426	0.424	26.258	27.807
16	28.877	0.156	28.456	29.154
18	27.08	0.667	25.274	27.786
20	28.241	0.436	26.929	28.86
22	27.293	0.404	25.934	27.755
24	28.268	0.48	26.96	28.819
26	27.003	1.31	23.782	28.979
28	27.598	0.97	25.018	28.664
30	27.607	0.696	25.916	28.77
32	26.939	3.333	9.817	28.65
34	27.709	0.768	25.662	28.995
36	27.993	0.595	27.088	29.012
38	27.742	0.905	25.258	28.864
40	27.608	0.85	24.327	28.598
42	27.82	0.742	26.301	28.924
44	27.812	0.492	26.653	28.605
46	27.76	0.868	25.935	28.817
48	27.804	0.793	26.084	28.873

Table 11: Random access to an element of the array – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	26.855	0.322	26.051	27.269
2	27.494	0.202	26.903	27.727
4	27.455	0.185	27.059	27.733
6	27.174	0.649	24.32	27.717
8	27.218	0.565	25.366	27.683
10	27.055	1.255	23.073	27.797
12	26.289	1.617	23.395	27.803
14	27.089	0.557	25.732	27.786
16	26.787	0.624	25.424	27.667
18	26.924	1.168	23.212	27.735
20	26.297	1.39	23.107	27.61
22	26.23	1.405	22.728	27.626
26	26.015	1.848	22.76	27.584
28	26.026	1.488	22.945	27.461
30	25.749	1.74	22.144	27.577
32	25.267	2.957	18.278	27.553
34	25.149	2.486	16.599	27.5
36	25.29	1.973	20.737	27.513
38	24.042	2.813	17.635	27.654
40	23.145	2.54	18.022	27.087
42	21.527	3.35	13.331	26.458

Table 12: Random access to an element of the array – Kubernetes



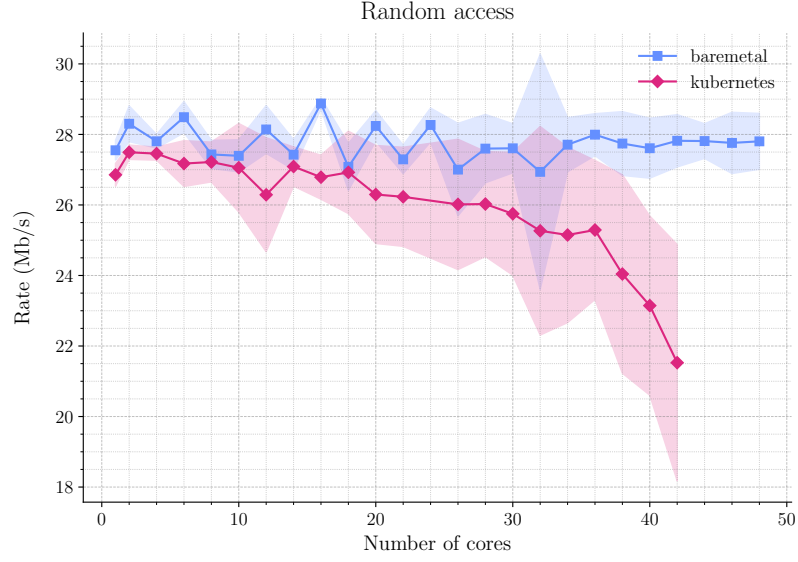


Figure 6: Random access to an element of the array. Refer to tables 11 and 12 for the numerical values.

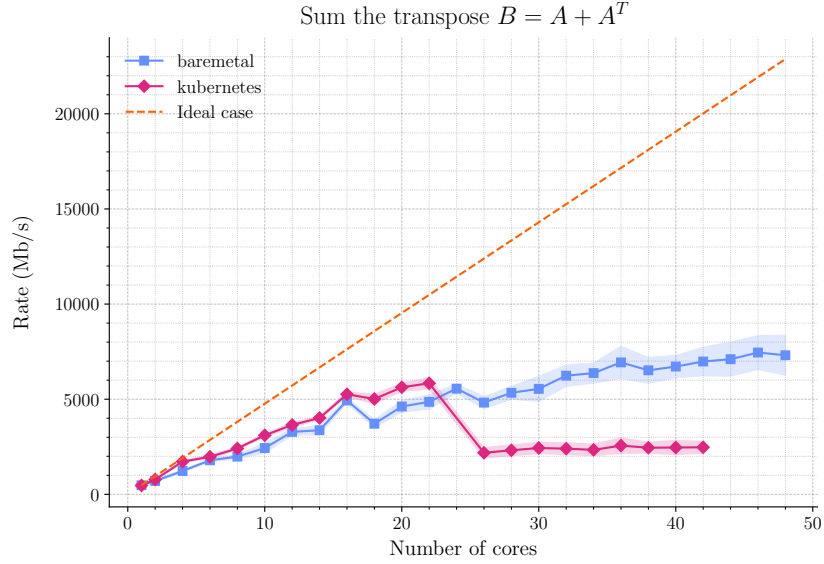


Figure 7: Sum of the transpose:  $B = A + A^T$ . Refer to tables 13 and 14 for the numerical values.

CPU <sub>s</sub>	Mean	Std	Min	Max
1	476.622	4.977	456.511	482.095
2	703.45	78.935	630.415	874.816
4	1226.495	45.818	1170.158	1325.744
6	1789.822	78.537	1628.942	1915.721
8	1981.376	104.131	1828.839	2143.325
10	2433.011	249.486	2035.201	2714.912
12	3283.103	170.513	2937.721	3645.163
14	3369.588	227.269	2923.254	3808.575
16	4934.869	129.997	4578.895	5177.015
18	3709.598	198.322	3404.115	4399.384
20	4617.184	290.86	4152.395	5233.697
22	4862.179	367.958	3439.66	5528.99
24	5556.214	236.93	5064.734	6056.77
26	4824.828	313.113	4234.843	5396.256
28	5337.343	330.577	4769.939	6196.865
30	5544.588	648.629	4270.513	7062.506
32	6236.697	552.891	5352.657	7221.356
34	6370.811	518.886	5068.892	7316.263
36	6934.428	839.293	5642.923	8824.347
38	6518.292	671.293	4730.213	7627.98
40	6717.397	575.157	5510.156	7785.888
42	6980.164	742.236	5942.036	8848.01
44	7103.271	888.365	5285.957	8812.088
46	7452.989	884.67	5836.597	9629.122
48	7310.622	1043.277	5561.819	9472.485

Table 13: Sum of the transpose:  $B = A + A^T$   
– bare metal

CPU <sub>s</sub>	Mean	Std	Min	Max
1	466.68	6.029	451.499	475.58
2	781.141	57.482	649.653	874.122
4	1719.373	39.753	1645.745	1802.974
6	1972.634	106.861	1642.429	2163.145
8	2410.857	65.979	2304.89	2578.044
10	3104.083	76.74	2965.986	3250.868
12	3648.626	120.729	3474.256	3932.247
14	4015.004	78.295	3896.342	4242.953
16	5259.151	119.216	5046.584	5496.167
18	5010.939	244.625	4252.016	5408.687
20	5627.768	205.501	5289.074	6206.987
22	5836.17	298.63	4857.032	6266.288
26	2182.26	260.848	1710.329	2705.084
28	2315.733	280.715	1665.145	2824.401
30	2435.104	284.734	1834.545	3045.267
32	2401.098	305.079	1687.483	2821.739
34	2337.338	296.521	1704.566	2740.236
36	2561.749	400.356	1692.723	3235.26
38	2450.043	276.877	1859.645	3039.672
40	2461.508	362.977	1692.801	3360.559
42	2471.69	303.697	1796.933	3221.471

Table 14: Sum of the transpose:  $B = A + A^T$   
– Kubernetes

## 2 Data frames

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	3.24	0.632	0.167	3.561
2	5.705	1.394	0.296	6.543
4	9.871	1.914	0.616	10.835
6	12.263	2.224	0.636	13.207
8	13.552	2.561	0.71	14.732
10	14.905	3.297	1.3	16.727
12	16.826	2.941	1.521	18.355
14	17.201	3.86	1.663	19.469
16	18.96	3.409	1.739	21.789
18	18.323	4.867	1.671	22.114
20	20.024	5.067	1.766	31.431
22	20.667	4.749	1.483	24.112
24	21.594	4.021	1.8	25.235
26	20.902	4.734	2.555	25.004
28	21.692	5.452	2.941	25.812
30	22.171	4.874	3.099	27.226
32	22.874	4.908	3.36	25.659
34	22.797	5.763	3.403	26.894
36	24.055	5.188	3.509	26.789
38	23.844	5.876	2.457	26.744
40	24.586	5.267	2.891	28.637
42	23.983	6.618	3.745	28.91
44	25.59	5.527	3.838	29.392
46	25.841	5.21	3.776	29.117
48	25.943	5.335	4.102	28.958

Table 15: Randomly initialize an data frame of integer numbers – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	2.37	1.009	0.099	3.609
2	3.368	1.31	0.202	4.861
4	4.215	1.509	0.398	5.645
6	4.817	1.636	0.582	6.079
8	5.167	1.602	0.734	6.179
10	5.532	1.638	0.959	6.628
12	5.717	1.594	1.102	6.66
14	6.063	1.628	1.31	7.028
16	6.042	1.654	1.468	7.388
18	5.94	1.966	0.159	7.205
20	6.337	1.599	1.757	7.569
22	6.318	1.572	1.879	7.467
26	10.411	3.142	2.376	12.756
28	10.727	3.011	2.5	13.283
30	11.136	2.987	2.662	13.017
32	10.573	2.848	2.822	13.039
34	10.898	2.877	2.925	12.98
36	11.133	2.867	3.145	13.257
38	11.125	2.933	3.202	13.537
40	10.863	2.867	3.34	13.664
42	10.489	2.825	3.359	13.385

Table 16: Randomly initialize an data frame of integer numbers – Kubernetes

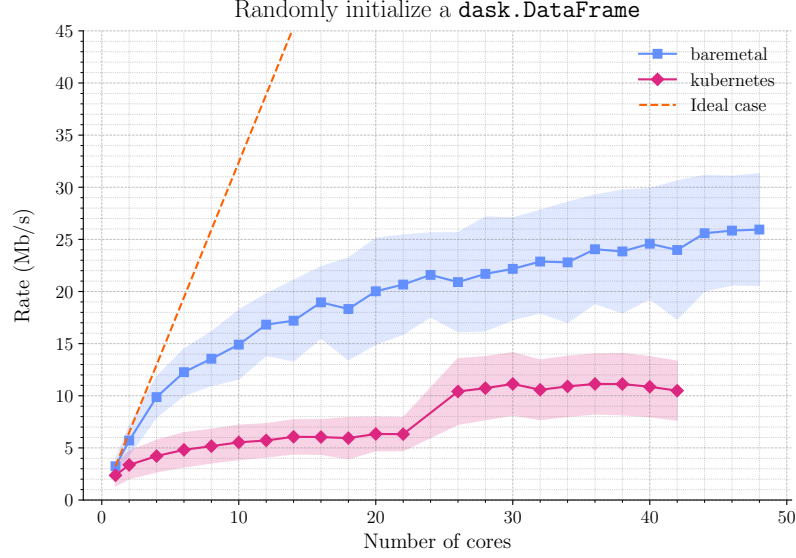


Figure 8: Randomly initialize an data frame of integer numbers. Refer to tables 15 and 16 for the numerical values.

CPUs	Mean	Std	Min	Max
1	4.295	0.268	3.548	4.59
2	7.926	0.393	7.126	8.626
4	12.582	1.761	4.402	14.369
6	16.72	2.673	3.545	19.053
8	20.355	3.127	8.346	23.785
10	21.892	4.116	9.538	26.992
12	23.863	4.989	11.807	30.923
14	27.124	5.652	12.153	37.423
16	27.491	5.362	11.77	33.464
18	30.51	5.075	14.761	41.598
20	28.854	9.088	6.503	39.48
22	31.265	6.934	13.062	38.086
24	29.802	8.703	6.945	41.027
26	32.67	8.888	7.976	43.275
28	35.615	8.077	9.371	44.939
30	36.644	7.096	18.633	44.19
32	36.789	9.45	7.688	46.111
34	37.853	8.62	19.501	48.679
36	38.543	10.764	9.019	50.791
38	40.161	10.452	9.323	49.145
40	39.035	10.506	8.861	48.328
42	43.927	6.771	28.967	53.784
44	41.345	10.019	8.985	53.84
46	43.553	9.153	7.195	51.254
48	40.401	12.529	8.114	54.881

Table 17: “Blockwise” operation – bare metal

CPUs	Mean	Std	Min	Max
1	3.411	1.009	2.148	4.994
2	5.079	1.206	2.546	7.952
4	6.453	1.229	2.938	8.762
6	7.281	1.739	3.593	12.388
8	8.055	1.292	4.641	10.696
10	8.568	1.018	6.559	10.501
12	8.696	1.056	5.573	9.828
14	9.316	0.511	8.039	10.097
16	9.36	0.583	7.005	10.382
18	9.43	0.892	6.728	10.572
20	9.552	0.641	7.808	10.42
22	9.618	0.768	7.272	10.407
26	15.473	2.462	9.034	18.201
28	15.394	1.957	9.814	17.804
30	15.657	1.774	10.89	17.895
32	16.113	1.9	10.58	18.594
34	15.964	1.945	10.027	17.761
36	16.462	1.629	12.328	18.459
38	16.986	1.993	10.944	18.655
40	16.988	1.443	12.549	18.836
42	15.398	2.199	11.696	18.937

Table 18: “Blockwise” operation – Kubernetes

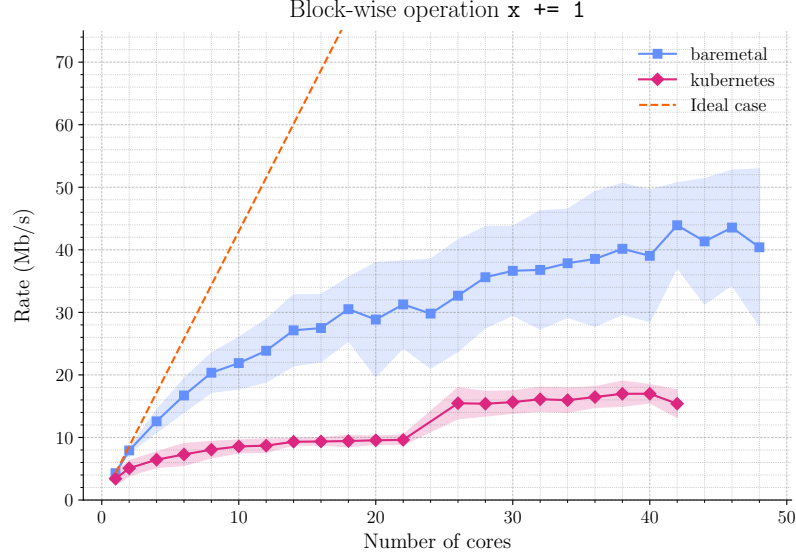


Figure 9: “Blockwise” operation. Refer to tables 17 and 18 for the numerical values.

CPUs	Mean	Std	Min	Max
1	235.464	35.379	55.939	255.332
2	247.176	17.089	224.584	315.385
4	249.949	14.053	203.522	274.793
6	255.927	18.488	210.654	312.903
8	253.662	13.201	214.081	274.057
10	254.691	12.846	215.83	271.173
12	247.005	42.654	30.054	267.962
14	255.316	10.625	222.191	268.483
16	254.19	18.045	203.249	276.159
18	258.366	12.765	223.294	293.518
20	250.424	14.199	216.197	267.671
22	244.345	19.57	189.263	264.761
24	241.254	16.43	206.864	262.892
26	231.862	44.88	16.438	264.04
28	239.702	14.778	194.57	261.327
30	227.804	19.042	180.504	249.979
32	223.88	18.447	164.756	249.834
34	221.119	18.549	158.229	248.211
36	220.844	20.389	156.346	261.476
38	219.448	19.678	173.719	242.239
40	221.597	19.704	189.368	272.238
42	221.517	13.23	192.204	245.577
44	205.899	40.251	12.325	232.524
46	208.25	15.83	170.043	231.562
48	206.66	13.871	177.944	234.926

Table 19: Random access to a row of the dataframe – bare metal

CPUs	Mean	Std	Min	Max
1	148.745	69.921	17.559	250.949
2	169.739	55.691	79.411	261.894
4	154.397	56.842	60.641	243.056
6	169.742	55.925	83.164	251.126
8	168.731	56.957	66.632	243.153
10	164.867	63.462	37.804	241.38
12	150.851	56.564	32.52	226.424
14	149.999	44.124	77.535	223.275
16	144.511	47.533	49.357	223.03
18	145.277	51.478	4.712	219.758
20	146.326	52.967	36.019	216.359
22	146.386	47.889	59.014	216.159
26	125.96	38.316	29.665	193.202
28	103.452	33.085	40.925	195.224
30	116.518	33.662	64.725	190.085
32	112.204	23.904	60.917	154.617
34	103.933	25.971	58.873	169.067
36	109.133	33.63	51.473	182.963
38	116.003	25.333	71.024	182.91
40	104.46	32.735	56.042	185.106
42	94.218	41.732	37.458	175.427

Table 20: Random access to a row of the dataframe – Kubernetes

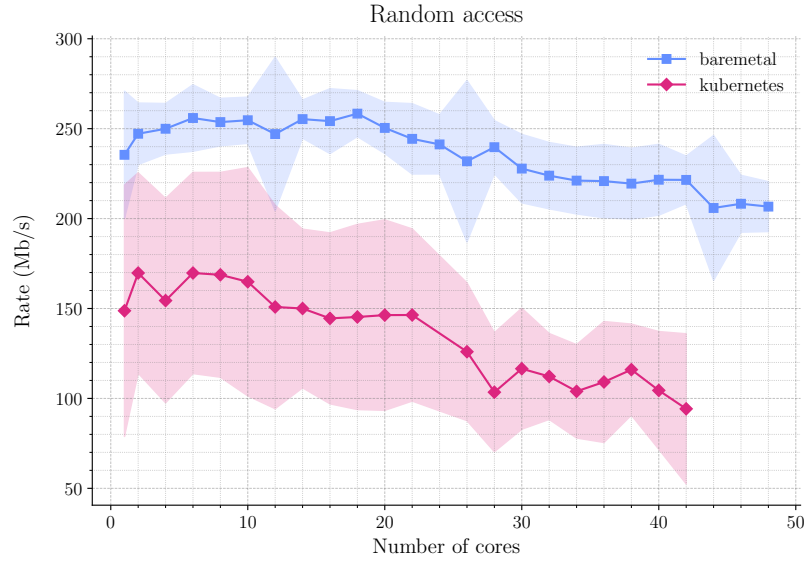


Figure 10: Random access to a row of the dataframe. Refer to tables 19 and 20 for the numerical values.

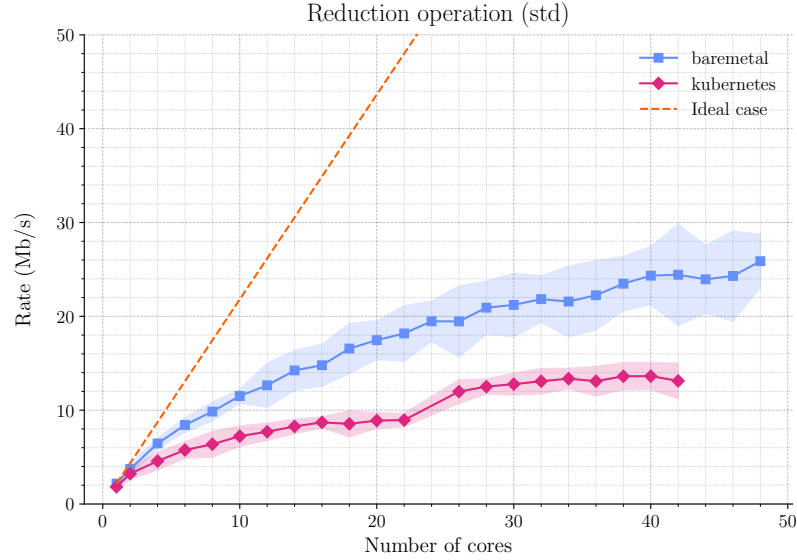


Figure 11: Compute an reduction operation (std) over all the numerical entries of the data frame. Refer to tables 21 and 22 for the numerical values.

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	2.182	0.135	1.753	2.357
2	3.736	0.598	1.679	4.174
4	6.45	0.553	5.095	7.355
6	8.419	0.765	6.471	10.53
8	9.854	1.018	5.743	10.946
10	11.511	0.717	10.149	12.655
12	12.647	2.349	4.384	15.544
14	14.234	2.117	4.367	18.758
16	14.791	2.22	3.924	16.965
18	16.565	2.677	4.717	20.144
20	17.466	2.051	12.289	22.461
22	18.178	2.965	5.876	23.206
24	19.474	2.137	14.635	23.123
26	19.46	3.784	6.116	24.296
28	20.925	2.829	12.668	25.775
30	21.216	3.383	6.276	25.898
32	21.833	2.485	15.079	25.078
34	21.58	3.75	7.177	27.113
36	22.246	3.689	7.018	27.68
38	23.481	2.891	16.435	28.102
40	24.336	3.112	17.154	30.135
42	24.434	5.41	7.32	30.499
44	23.944	3.611	9.438	28.005
46	24.305	4.784	8.112	30.059
48	25.88	2.834	18.872	32.069

Table 21: Compute an reduction operation (std) over all the numerical entries of the data frame. – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	1.833	0.505	0.734	2.563
2	3.226	0.568	2.326	4.66
4	4.575	0.938	2.177	5.899
6	5.752	0.87	3.758	7.052
8	6.37	1.36	3.631	7.878
10	7.229	1.087	4.149	8.842
12	7.703	0.906	5.27	9.252
14	8.269	0.761	6.606	9.282
16	8.699	0.574	7.592	9.86
18	8.546	1.376	3.788	10.006
20	8.892	0.83	6.656	10.098
22	8.944	0.703	7.371	10.098
26	11.983	1.262	8.839	13.911
28	12.51	0.804	10.59	13.916
30	12.776	1.168	9.773	14.588
32	13.08	1.347	9.993	15.298
34	13.359	1.093	10.131	14.622
36	13.092	1.565	9.744	15.169
38	13.609	1.443	10.6	15.663
40	13.63	1.421	10.283	15.725
42	13.117	1.894	9.879	15.956

Table 22: Compute an reduction operation (std) over all the numerical entries of the data frame. – Kubernetes

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	1.54	0.268	0.635	1.701
2	2.797	0.265	1.586	3.029
4	4.645	0.434	2.768	5.033
6	5.486	0.55	3.589	5.882
8	3.272	0.477	1.594	3.649
10	3.738	0.571	1.871	4.233
12	4.012	0.519	2.442	4.546
14	4.376	0.578	2.473	4.863
16	4.738	0.575	2.061	5.178
18	4.939	0.763	1.776	5.909
20	5.069	0.979	2.415	5.939
22	5.686	0.918	2.802	6.679
24	5.594	0.958	2.407	6.839
26	5.396	0.708	2.81	6.129
28	5.616	0.517	3.924	6.292
30	5.647	0.802	3.628	6.56
32	5.85	0.763	3.618	6.473
34	5.897	0.709	3.938	6.676
36	6.186	0.639	3.838	6.761
38	6.206	0.673	4.163	6.783
40	6.179	1.005	2.775	7.113
42	6.513	0.934	4.295	7.545
44	7.256	0.695	4.985	8.164
46	7.093	0.944	4.521	8.316
48	7.48	0.896	4.862	8.636

Table 23: Perform a “groupby” operation considering 1 column – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	1.276	0.393	0.579	1.865
2	1.916	0.499	1.178	2.701
4	2.249	0.751	1.177	3.442
6	2.704	0.572	1.577	3.507
8	1.452	0.19	0.915	1.659
10	1.507	0.181	1.165	1.774
12	1.514	0.186	0.98	1.792
14	1.627	0.147	1.211	1.81
16	1.619	0.124	1.373	1.842
18	1.615	0.203	1.099	1.994
20	1.65	0.149	1.401	1.913
22	1.616	0.131	1.257	1.825
26	2.442	0.319	1.832	3.014
28	2.386	0.371	1.524	3.043
30	2.426	0.284	1.882	3.017
32	2.48	0.292	1.897	2.841
34	2.419	0.304	1.763	2.981
36	2.536	0.339	1.722	3.091
38	2.569	0.311	1.898	3.058
40	2.561	0.304	1.783	3.351
42	2.453	0.547	1.515	3.304

Table 24: Perform a “groupby” operation considering 1 column – Kubernetes



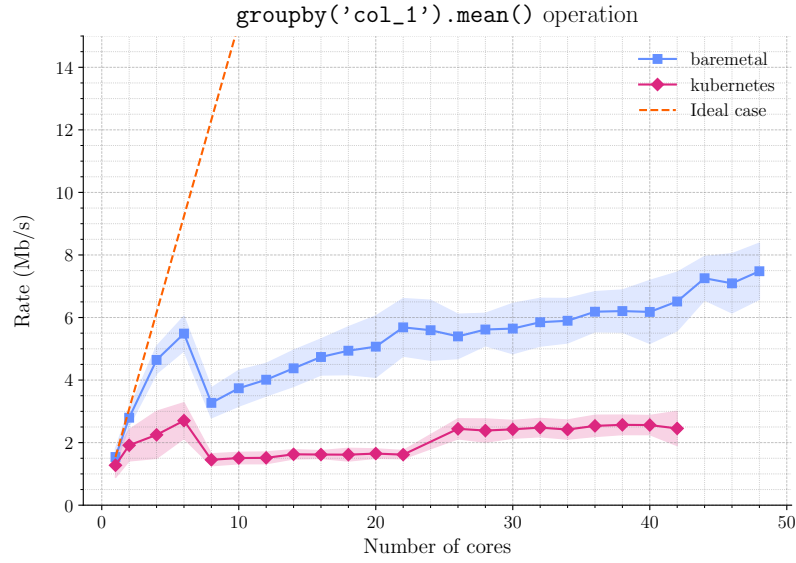


Figure 12: Perform a “groupby” operation considering 1 column. Refer to tables 23 and 24 for the numerical values.

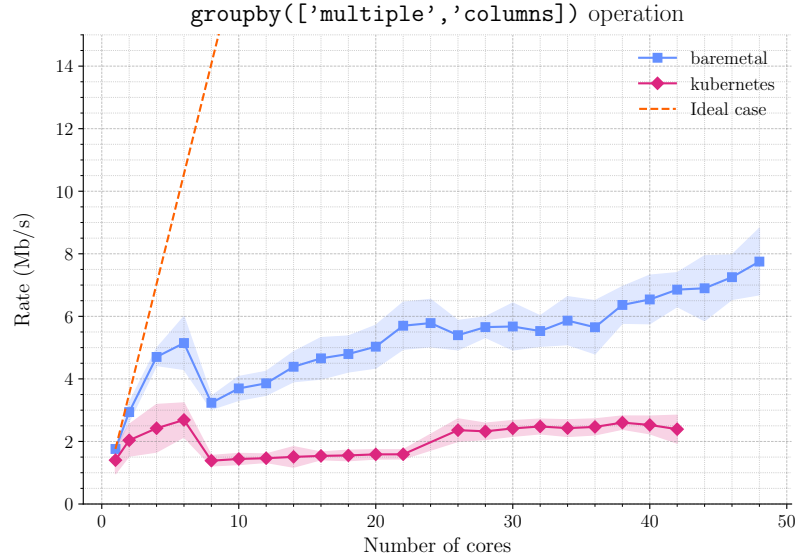


Figure 13: Perform a “groupby” operation considering 2 columns. Refer to tables 25 and 26 for the numerical values.

CPU	Mean	Std	Min	Max
1	1.759	0.052	1.579	1.816
2	2.939	0.293	1.49	3.131
4	4.702	0.27	3.916	4.98
6	5.146	0.842	2.522	5.745
8	3.236	0.208	2.531	3.539
10	3.696	0.378	2.441	3.998
12	3.859	0.379	2.196	4.274
14	4.388	0.476	2.839	4.847
16	4.657	0.661	2.835	5.258
18	4.796	0.572	3.061	6.082
20	5.03	0.681	2.95	6.307
22	5.7	0.748	3.804	7.369
24	5.784	0.756	3.475	6.873
26	5.397	0.466	3.666	5.788
28	5.656	0.325	4.994	6.046
30	5.675	0.748	3.352	6.292
32	5.53	0.485	3.608	6.174
34	5.863	0.764	3.424	6.598
36	5.651	0.847	3.627	6.914
38	6.365	0.583	4.093	7.975
40	6.54	0.773	4.081	8.279
42	6.854	0.539	5.387	8.365
44	6.897	1.034	4.46	7.88
46	7.252	0.709	4.498	8.496
48	7.751	1.059	4.645	8.897

Table 25: Perform a “groupby” operation considering 2 columns – bare metal

CPU	Mean	Std	Min	Max
1	1.402	0.431	0.762	1.973
2	2.038	0.504	1.239	2.762
4	2.421	0.758	1.322	3.448
6	2.688	0.543	1.681	3.437
8	1.385	0.163	1.04	1.576
10	1.44	0.175	1.15	1.699
12	1.464	0.133	1.186	1.663
14	1.506	0.326	0.004	1.762
16	1.538	0.12	1.287	1.786
18	1.554	0.167	1.167	1.806
20	1.587	0.147	1.264	1.802
22	1.589	0.143	1.344	1.811
26	2.361	0.359	1.402	2.985
28	2.323	0.259	1.785	2.926
30	2.417	0.249	1.977	2.814
32	2.479	0.233	1.917	2.957
34	2.426	0.264	1.956	3.016
36	2.465	0.253	1.798	2.923
38	2.603	0.209	2.247	3.026
40	2.528	0.28	1.942	3.047
42	2.392	0.444	1.595	2.976

Table 26: Perform a “groupby” operation considering 2 columns – Kubernetes

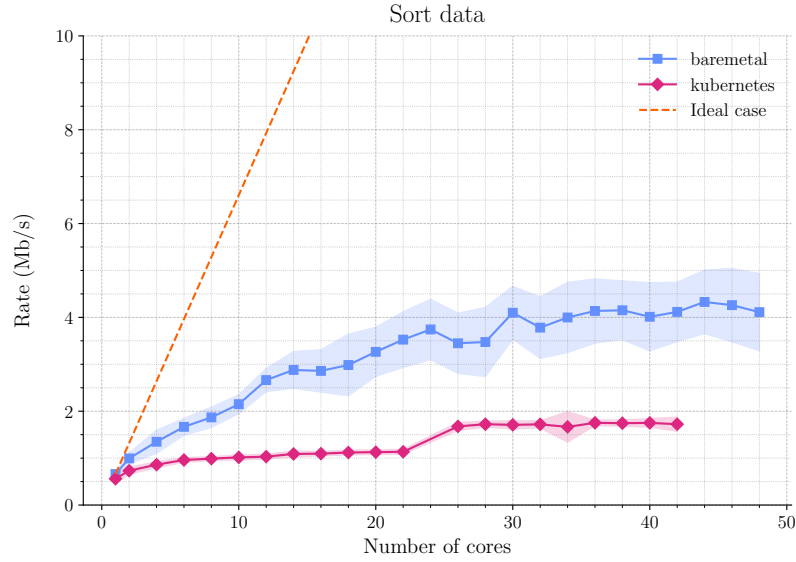


Figure 14: Sort the data. Refer to tables 27 and 28 for the numerical values.

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	0.661	0.035	0.509	0.694
2	0.994	0.118	0.557	1.095
4	1.349	0.246	0.48	1.571
6	1.667	0.18	0.965	1.849
8	1.869	0.215	1.379	2.139
10	2.149	0.198	1.468	2.444
12	2.664	0.246	2.079	3.112
14	2.88	0.391	2.2	3.515
16	2.86	0.45	1.761	3.676
18	2.985	0.656	1.318	4.03
20	3.266	0.522	2.212	4.11
22	3.526	0.592	2.419	4.459
24	3.743	0.644	2.231	4.759
26	3.448	0.64	1.578	4.304
28	3.475	0.735	1.885	4.593
30	4.099	0.561	2.897	4.916
32	3.782	0.655	2.271	4.716
34	3.998	0.747	2.068	4.897
36	4.137	0.683	2.511	5.11
38	4.151	0.624	2.552	5
40	4.013	0.727	2.547	5.064
42	4.117	0.631	3.108	5.121
44	4.329	0.675	2.96	5.119
46	4.261	0.781	2.402	5.329
48	4.112	0.822	2.521	5.684

Table 27: Sort the data – bare metal

<b>CPUs</b>	<b>Mean</b>	<b>Std</b>	<b>Min</b>	<b>Max</b>
1	0.56	0.103	0.379	0.707
2	0.732	0.072	0.605	0.832
4	0.861	0.065	0.67	0.945
6	0.96	0.05	0.857	1.036
8	0.989	0.04	0.883	1.063
10	1.016	0.052	0.923	1.096
12	1.032	0.051	0.945	1.119
14	1.089	0.062	0.94	1.213
16	1.096	0.045	1.03	1.202
18	1.12	0.052	1.022	1.203
20	1.128	0.048	1.005	1.22
22	1.135	0.052	1.001	1.216
26	1.677	0.082	1.498	1.798
28	1.723	0.064	1.548	1.842
30	1.709	0.085	1.451	1.859
32	1.72	0.077	1.571	1.881
34	1.666	0.324	0.01	1.868
36	1.752	0.059	1.657	1.865
38	1.745	0.065	1.631	1.897
40	1.751	0.091	1.544	1.902
42	1.723	0.15	1.393	1.894

Table 28: Sort the data – Kubernetes