MioHash: An Memory-Efficient and I/O-Optimized Hashing Index on Hybrid PMem-DARM Memories

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Experiment 1

Uniform Insert Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.080309792	2.067467027	3.54139375	5.265225163	5.601201605	5.560437909
CCEH	0.6927915	1.33181725	2.43652025	4.08677525	5.44514925	5.66926275
Level	0.517253332	0.566679181	0.706762602	0.864436573	1.014259263	1.056101841
Clevel	0.14161	0.272089	0.504664	0.903298	1.399661	1.716833
Plush	0.438103	0.83422125	1.6048145	2.4292295	4.294831	5.97354325
Viper	1.916868	3.51213	6.477029	9.194919	12.335607	13.04946
MioHash	2.523302	4.3044485	7.770145	11.19255225	16.8236075	19.88255167
Uniform Positive Search Throughput (M	Thread=1	2	4	8	16	24
DASH	3.333146	5.646048	9.280315	13.539036	17.525591	18.408078
CCEH	2.145908	4.352373	9.02399	15.176016	19.615334	20.702171
Level	1.050534	1.738362	3.092409	4.906786	6.404106	7.143704
Clevel	0.990972	1.81147	3.56415	6.773919	12.12053	16.35713
Plush	0.66246525	1.2985415	2.479261	3.4266955	6.18491075	9.49267075
Viper	2.096916	4.012847	8.116097	12.593406	25.527122	37.48872
MioHash	3.134054	6.22590625	12.229869	14.0550155	26.7947485	38.912764
Uniform Negative Search Throughput (	Thread=1	2	4	8	16	24
DASH	3.33464	5.642306	9.312879	13.537437	17.621648	18.535994
CCEH	0.715493	1.414038	2.708599	4.740526	7.459968	7.946879
Level	1.051344	1.735256	3.113679	4.901411	6.449082	7.051144
Clevel	0.811196	1.542197	3.005827	5.733635	10.279313	13.616402
Plush	0.92998575	1.8471755	3.605941	4.82533025	9.25337825	13.745963
Viper	4.435612	8.763846	17.417176	21.866726	42.342509	61.9225
MioHash	3.62707425	7.2290625	14.08542675	19.298319	34.82591625	47.20718225
Uniform Delete Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.898662	3.598952	5.935547	8.094248	7.910209	8.000926
CCEH	1.229131	2.490614	4.70361	7.886595	8.918177	10.328562
Level	0.937153	1.531833	2.772285	4.398251	5.593817	5.666127
Clevel	0.299471	0.559957	1.03137	1.956335	3.418501	4.645158
Plush	0.39326175	0.77641925	1.513762	2.283574725	4.14544275	6.05539775
Viper	1.85327	3.519253	6.853577	10.342089	15.766681	17.652877
MioHash	1.690429	3.293858125	6.254388	8.86109575	15.02798225	19.60113467
Zipfian Insert Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.053913	2.036119	3.449268	5.292045	5.805819	5.4589
CCEH	0.589479	1.18045	2.285433	4.021246	5.582147	5.985942
Level	0.474362	0.757504	0.973837	1.374645	1.461386	1.382936
Clevel	0.137404	0.261074	0.491295	0.887227	1.380396	1.717355
Plush	0.372362	0.757704	1.534042	2.734872	3.891831	4.608914
Viper	1.918128	3.488715	6.433229	9.637801	12.175177	12.902454
MioHash	2.516055	4.243159	7.60807025	11.10811225	17.041096	20.1762295
Zipfian Positive Search Throughput (M	Thread=1	2	4	8	16	24
DASH	3.336167	5.586168	9.299656	13.530452	17.573843	18.276381
CCEH	2.046681	4.19717	8.781548	15.505613	19.346186	20.01743
Level	1.032295	1.740166	3.093239	4.901955	6.396258	7.103214
Clevel	0.997262	1.877826	3.626865	6.997729	13.112314	18.246416
Plush	0.585573	1.188494	2.514597	4.270248	7.509008	9.457597
Viper	2.102515	3.944174	8.176301	12.950664	24.569926	36.804304
MioHash	3.00255875	5.9849455	11.780668	13.1106245	23.660596	34.29530725
Zipfian Negative Search Throughput (M	Thread=1	2	4	8	16	24
DASH	3.332858	5.648635	9.31015	13.563526	17.526157	18.38305
CCEH	0.713374	1.405746	2.7034	4.67963	7.465958	7.823678
Level	1.05248	1.740997	3.098963	4.889724	6.410645	7.096786
Clevel	0.812245	1.534612	2.948581	5.728126	10.174163	12.411457
Plush	0.796609	1.654961	3.517741	6.129173	10.566435	13.902013
Viper	4.47395	8.295752	17.129539	22.372177	42.177021	60.593687
MioHash	3.64170925	7.18883175	14.346825	19.3584845	34.70292175	47.010148
Zipfian Delete Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.607616	3.240823	5.494735	7.556856	7.241076	7.64346
CCEH	1.224438	2.468547	4.720928	7.922391	9.215614	10.335044
Level	0.809582	1.383746	2.516669	4.048322	5.082029	5.198309
Clevel	0.295755	0.55504	1.008447	2.030666	3.581514	4.975246
Plush	0.337059	0.711316	1.453221	2.597762	3.946841	4.739526
Viper	1.863955	3.492423	6.891585	10.442913	15.672394	17.574828
MioHash	1.66992575	3.2749535	6.235328	8.60868725	14.852254	19.423247

Experiment 2

Uniform YCSB-A Throughput (Mops/s)	Thread=1	2	4	8	16	24
CCEH	1.941595	3.613314	6.282357	9.603273	10.940991	11.432127
Clevel	0.215008	0.419314	0.809303	1.53451	2.702261	3.576111
Plush	0.423265	0.95656	1.878408	2.619554	5.083122	7.476417
Viper	1.780937	3.28364	5.034586	5.644092	5.529003	4.956198
MioHash	1.9295995	3.779359	7.358267	9.924119	18.3813365	25.373776
Uniform YCSB-B Throughput (Mops/s)	Thread=1	2	4	8	16	24
CCEH	1.553614	3.214115	6.395054	10.17395	12.110555	13.752623
Clevel	0.547787	1.032996	1.977721	3.493462	4.435138	5.079593
Plush	0.62971	1.225157	2.422948	3.13946	6.263437	9.295119
Viper	1.778103	3.250971	4.995168	5.592824	5.477951	5.06256
MioHash	2.622453	5.198723	10.266235	12.136581	23.401413	33.741323
Uniform YCSB-D Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	2.547534	4.556558	7.806189	10.655705	9.969395	9.275043
CCEH	1.519133	3.087774	6.070746	9.841329	11.607526	12.588382
Level	0.872114	1.425969	1.972523	3.644325	4.716346	5.236053
Clevel	0.575072	1.102422	2.145923	4.137716	7.2416	9.988099
Plush	1.16033	1.20241	2.2662	4.880244	6.240233	9.361369
Viper	3.625560333	7.433447667	14.772049	21.772137	25.086287	25.97748067
MioHash	5.043314	5.3270765	10.502546	20.5088805	24.746811	36.5088485
Uniform YCSB-F Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.361149	2.770951	4.811631	7.28332	7.353183	7.086551
CCEH	0.732373	1.389933	2.745591	4.836576	6.132695	6.397954
Level	0.694532	1.239523	2.192028	3.537363	4.236918	4.501145
Clevel	0.237316	0.453495	0.884652	1.651285	2.836115	3.920888
Plush	0.446808	0.89648	1.7672565	2.413629	4.704921	6.940909
Viper	1.959922	4.22807	8.227409	10.98181	11.3979743	10.901977
MioHash	1.8972135	3.5556535	6.6841395	9.6083835	15.8329955	20.028024

Experiment 4

Average Latency (μs)	Insert	Positive Search	Negative Search	Delete
DASH	1.044361667	0.373066833	0.5000925	0.718684667
CCEH	1.524968333	0.386246	1.176861667	0.728425333
Level	1.570881667	0.5450395	1.077073333	1.039588333
Clevel	7.030871667	1.033883333	1.263503333	3.415083333
Plush	2.420722	1.583204	1.154294	2.629362
Viper	0.62575	0.328	0.327	0.5745
MioHash	0.442224	0.5871938	0.348968	0.6487288
Tail Latency (μs)	Insert	Positive Search	Negative Search	Delete
DASH	1.835166667	0.924166667	0.814833333	1.379166667
CCEH	2.243333333	1.098333333	1.776166667	1.322833333
Level	3.057166667	1.446333333	1.527166667	1.833166667
Clevel	9.195833333	2.0745	1.710333333	4.414666667
Plush	248.0072	3.3296	2.7224	261.3952
Viper	41.24025	2.37875	2.37925	4.132
MioHash	6.6324	1.2416	1.0794	1.452

Experiment 5

Generality Throughput (Mops/s)	Thread=1	2	4	8	16	24
DASH	1.080309792	2.067467027	3.54139375	5.265225163	5.601201605	5.560437909
CCEH	0.6927915	1.33181725	2.43652025	4.08677525	5.44514925	5.66926275
Level	0.517253332	0.566679181	0.706762602	0.864436573	1.014259263	1.056101841
Clevel	0.14161	0.272089	0.504664	0.903298	1.399661	1.716833
Plush	0.438103	0.83422125	1.6048145	2.4292295	4.294831	5.97354325
Viper	1.916868	3.51213	6.477029	9.194919	12.335607	13.04946
MioHash-ADR	1.943972	3.540634	6.496861	9.368059	14.062237	15.435523
MioHash	2.523302	4.3044485	7.770145	11.19255225	16.8236075	19.88255167

Experiment 6

Storage Traffic	Write Traffic (GB)	Read Traffic (GB)
DASH	35.11431432	33.44651294
CCEH	21.9854815	128.2352502
Level	27.12402272	74.41524744
Clevel	41.02325344	102.6981823
Plush	12.37470412	7.149165392
Viper	7.8515625	0.803710938
MioHash	6.346679688	3.326171875

Experiment 7

Space(GB)	Number of inserted items=10M	20M	30M	40M	50M	60M
Plush-DRAM	0.249999746	0.262560851	0.250000104	0.249999771	0.249999632	0.250000264
Plush-PM	0.249999839	4.249999495	4.250000493	4.249998931	4.25000808	4.250006269
Viper-DRAM	0.396240234	0.794219971	1.047981263	1.587265016	2.0145607	2.093997956
Viper-PM	0.150764466	0.301551819	0.452316284	0.603103638	0.753890991	0.904655457
MioHash-DRAM	0.066098828	0.132199512	0.183785938	0.264400391	0.264400391	0.367154297
MioHash-PM	0.291180664	0.575436523	0.802583984	1.155664063	1.153710938	1.586894531
Space(GB)	Number of inserted items=70M	80M	90M	100M	110M	120M
Plush-DRAM	0.250000051	0.250000017	0.249999711	0.250000352	0.249970499	0.249999636
Plush-PM	4.250008685	4.250005096	4.249994726	4.250002624	4.250003643	4.25000454
Viper-DRAM	2.375648499	3.173919678	3.845325471	4.030708313	4.082023621	4.193206787
Viper-PM	1.055442811	1.206207275	1.356994629	1.507781982	1.658546448	1.809333802
MioHash-DRAM	0.528804688	0.528803711	0.528803711	0.529323242	0.533805664	0.739245117
MioHash-PM	2.282929688	2.296601563	2.296601563	2.298916016	2.333466797	3.203115234
Space(GB)	Number of inserted items=130M	140M	150M	160M	170M	180M
Plush-DRAM	0.250000085	0.250000074	0.249999896	0.249999777	0.249999799	0.249999666
Plush-PM	4.249996225	4.250001735	4.249998959	4.250003048	4.249998202	4.250003074
Viper-DRAM	4.428947449	4.85838318	5.520629883	6.344173432	7.139011384	7.690620423
Viper-PM	1.960116893	2.11088562	2.261672974	2.412437439	2.563224793	2.714005627
MioHash-DRAM	0.739245117	1.057611328	1.057610352	1.057610352	1.057609375	1.057608398
MioHash-PM	3.203115234	4.553066406	4.601894531	4.595058594	4.595058594	4.597988281
Space(GB)	Number of inserted items=190M	200M	210M	220M	230M	240M
Plush-DRAM	0.250000195	0.250000172	0.24999976	0.250000245	0.249999726	0.250000213
Plush-PM	4.250001257	4.250002091	68.2499742	68.24978246	68.24991443	68.24981132
Viper-DRAM	7.961681366	8.058933259	8.105636598	8.168132782	8.254638672	8.382823944
Viper-PM	2.864776611	3.015563965	3.16632843	3.317115784	3.467903137	3.618667603
MioHash-DRAM	1.057608398	1.058648438	1.059292969	1.068192383	1.145938477	1.476976563
MioHash-PM	4.593105469	4.591884766	4.595302734	4.645605469	5.025908203	6.390634766
Space(GB)	Number of inserted items=250M	260M	270M	280M	290M	300M
Plush-DRAM	0.249999631	0.249999887	0.249999807	0.249999916	0.250000147	0.250000207
Plush-PM	68.25001036	68.25005041	68.25025806	68.24994929	68.250072	68.25005004
Viper-DRAM	8.573005677	8.845458984	9.217933655	9.708759309	10.31484985	11.03757095
Viper-PM	3.769481659	3.920246124	4.071033478	4.221820831	4.372585297	4.52337265
MioHash-DRAM	1.974335938	2.112382813	2.115224609	2.115224609	2.115224609	2.115224609
MioHash-PM	8.364619141	8.966396484	9.056240234	9.113857422	9.167568359	9.184169922

Experiment 8

Variable Size Throughput (Mops/s)	Value size=16B	32B	64B	128B	256B
DASH	4.761206	4.370462	4.012544	3.648672	2.531003
Clevel	1.75256215	1.7737998	1.7562037	1.771669775	1.741172375
Plush	4.0494265	3.61212125	3.46075975	3.36415675	3.05871875
Viper	12.55229975	12.30331375	9.808057	7.12537625	4.50371775
MioHash	14.092812	12.9155135	10.503505	7.34719125	4.3792125

Experiment 9

Load Factor (%)	Number of inserted items=10M	20M	30M	40M	50M	60M
DASH	66.0554	66.0554	53.2927	66.0554	82.4597	53.3501
CCEH	59.5719	59.5737	47.6062	59.5728	69.9493	47.5765
Level	90.8261	90.8261	68.1196	90.8261	56.7663	68.1196
Clevel	79.4729	34.0598	59.6046	79.4729	49.6705	59.6046
Plush	59.6046	7.01231	10.5185	14.0246	17.308	21.0369
Viper	37.7066	37.668	42.8273	37.7237	37.1483	42.9255
MioHash	56.0727	56.0856	61.5157	56.092	70.1151	61.5264
Load Factor (%)	Number of inserted items=70M	80M	90M	100M	110M	120M
DASH	57.7984	66.0554	74.3123	82.434	79.1072	53.3446
CCEH	52.1537	59.5742	66.6419	70.1075	59.5115	47.6101
Level	79.4729	90.8261	51.0897	56.7663	62.443	68.1196
Clevel	69.5388	34.0598	44.7035	49.6705	54.6376	59.6046
Plush	24.5431	28.0492	31.5554	35.0616	38.5677	42.0739
Viper	43.2452	37.7426	35.0398	37.1422	40.3423	42.8817
MioHash	49.0834	56.953	63.1072	70.1191	76.5192	61.3701
Load Factor (%)	Number of inserted items=130M	140M	150M	160M	170M	180M
DASH	53.6829	57.7984	61.9269	66.0554	70.1838	74.3117
CCEH	48.4817	52.1525	55.8725	59.5756	63.2159	66.6449
Level	73.7962	79.4729	85.1495	90.8261	48.2514	51.0897
Clevel	64.5717	69.5388	74.5058	34.0598	42.22	44.7035
Plush	45.58	49.0862	52.5923	56.0985	59.6046	63.1108
Viper	43.9789	43.1678	40.6975	37.7694	35.6577	35.0449
MioHash	45.6442	49.0848	52.5908	56.0969	59.6029	63.109
Load Factor (%)	Number of inserted items=190M	200M	210M	220M	230M	240M
DASH	78.4342	82.4434	84.9072	79.1159	63.3772	53.3364
CCEH	69.3263	70.0462	66.8545	59.503	51.8082	47.5918
Level	53.928	56.7663	59.6046	62.443	65.2813	68.1196
Clevel	47.187	49.6705	52.1541	54.6376	57.1211	59.6046
Plush	66.617	70.1231	4.58497	4.8033	5.02164	5.23997
Viper	35.7313	37.1574	38.7904	40.3647	41.7568	42.9049
MioHash	66.615	70.1168	73.6002	76.5144	74.8935	61.2596

Experiment 10

Recovery Time (s)	Number of inserted items=10M	20M	30M	40M	50M	60M
Thread-1	0.560193	1.089347	1.614449	2.549051	2.559382	3.447411
Thread-2	0.331689	0.644957	0.923353	1.445274	1.507391	1.922619
Thread-4	0.235937	0.416497	0.614051	0.916964	0.923644	1.172099
Thread-8	0.159552	0.301159	0.420544	0.64551	0.640922	0.864405
Thread-16	0.154403	0.233623	0.332565	0.494526	0.502285	0.743899
Thread-24	0.122917	0.216846	0.310919	0.471374	0.4684	0.642067
Recovery Time (s)	Number of inserted items=70M	80M	90M	100M		
Thread-1	4.971479	5.305649	5.405138	5.512479		
Thread-2	2.75402	2.958968	2.966657	3.025063		
Thread-4	1.704711	1.787486	1.785323	1.811582		
Thread-8	1.248624	1.263118	1.254723	1.289331		
Thread-16	0.968667	1.017342	1.034704	1.021178		
Thread-24	0.881894	0.923817	0.944532	0.945199		

Experiment 11

Collecting Table Throughput (Mops/s)	Thread=1	2	4	8	16	24
# of CT=4	2.533653	4.293149	7.137802	8.904839	10.007422	8.26563
# of CT=8	2.545541	4.268679	7.45585	10.502003	13.94874	14.238366
# of CT=16	2.526699	4.32143	7.621123	10.50557	15.644961	17.940957
# of CT=64	2.529887	4.301137	7.665617	10.878732	16.60617	19.671948
# of CT=256	2.536601	4.338474	7.88022	11.090656	16.991854	20.213206
# of CT=1024	2.551242	4.373844	7.852751	11.811766	17.486818	20.370545

Experiment 12

Variable D-Bucket Size Throughput (M	Insert	Positive Search
D-bucket=32B	1.85281225	2.94434275
D-bucket=64B	2.16642825	2.9541595
D-bucket=128B	2.42965825	2.9828735
D-bucket=256B	2.54010175	2.980101
D-bucket=512B	2.50579775	3.006221
Variable P-Bucket Size Throughput (M	Insert	Positive Search
P-bucket=1KB	2.23251575	3.08697575
P-bucket=2KB	2.410912	3.06805275
P-bucket=4KB	2.54756875	2.97051575
P-bucket=8KB	2.6717505	2.77006725
P-bucket=16KB	2.84456175	2.3266485