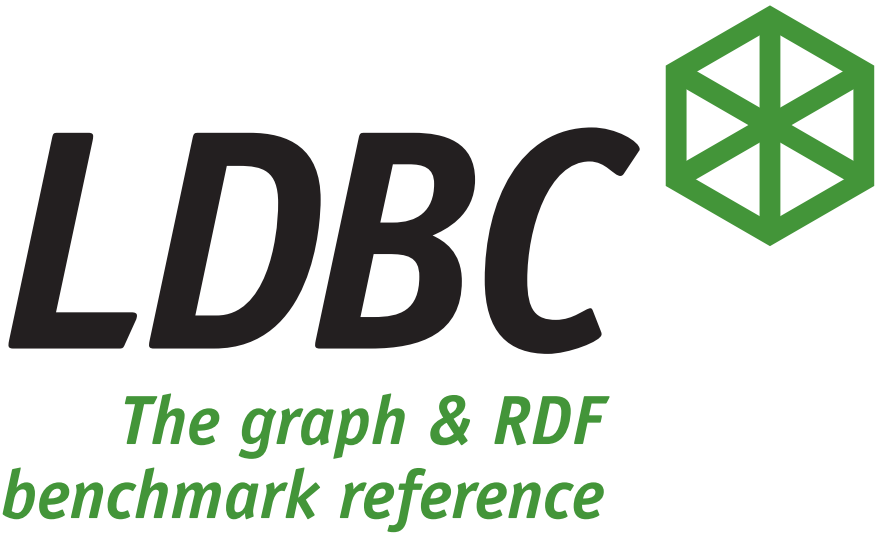

Full Disclosure Report of the LDBC Social Network Benchmark

An Implementation of the LDBC Social Network Benchmark's Interactive Workload over Graphscope Flex

July 13, 2023

General Terms

Executive Summary

This document describes an implementation of the LDBC Social Network Benchmark's Interactive workload on a graph database-like build of GraphScope Flex, a modular graph computing stack developed by Alibaba.

GraphScope Flex[1] is designed to accommodate the diverse and complex needs of real-world graph applications. These applications can involve a variety of graph workloads and can be deployed in different modes.

In the audited benchmark runs, the 'db_hiactor_cppsp_mcsr' build of GraphScope Flex 0.23.0 was used to execute scale factors SF30, SF100, and SF300 in a single-instance setting (plus another instance to run the driver). The instances were deployed on the Amazon Web Services infrastructure.

The queries are implemented imperatively using stored procedures written in C++17, which are then compiled and loaded into the database at runtime as shared libraries. The data schema follows the property graph model with indices only over vertex identifiers and neighbour sets. No additional indices nor precomputed properties are used. The system under test and the driver communicate using remote http.

Declaration of Audit Success

This report contains an audited LDBC benchmark run. The results have been gathered by an independent and impartial auditor who has validated the implementation of the queries, successfully run the ACID tests associated with the claimed isolation level (serializable), and verified the overall system's configuration conformance to the description of the benchmark and its strict requirements.

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[1] https://github.com/alibaba/GraphScope/tree/main/flex

Table of Contents

1 System Description and Pricing Summary

1.1 Details of machines driving and running the workload

1.1.1 Machine overview

The details below were obtained from Amazon Web Services dashboard (Instance Details page). The operating system was obtained from running `uname -a` command.

Table 1.1: Machine Type and Location

Cloud provider	Amazon Web Services
Machine region	US East(N.Virginia) us-east-1 Zone: us-east-1c
Common name of the item	r5d.12xlarge
Operating system	Ubuntu 20.04.1 SMP

Note that the system is configured with the following additional command, to allow for the required amount of asynchronous requests:

```
echo "fs.aio-max-nr = 1048576" » etcsysctl.conf && sysctl -p etcsysctl.conf
```

This benchmark used two `r5d.12xlarge` instances, one for the driver and one for the system under test (SUT). Both machines were assigned to the same VPC with the same subnetwork. This is shown in Figure 1.1.

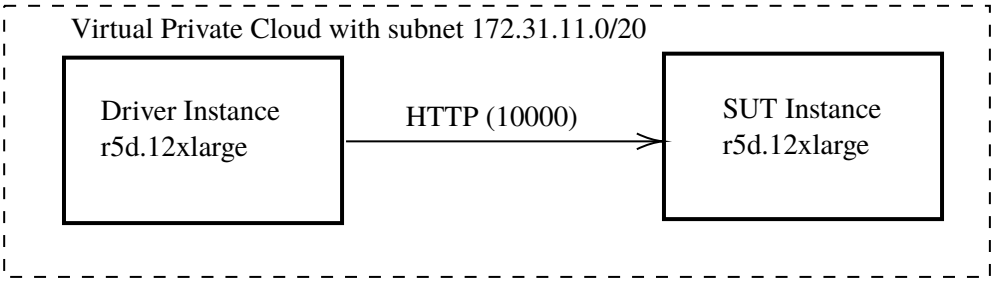

Figure 1.1: Overview of benchmark setup

1.1.2 CPU details

The details below were obtained using the command `lscpu` (Listing A.1) issued from the machine SUT and the datasheet of the used CPU type.

Table 1.2: CPU details summary

Type	Intel(R) Xeon(R) Platinum 8175M
Total number	1
Cores per CPU	24
Threads per CPU core	2
CPU clock frequency	2.50 GHz
Total cache size per CPU	L1 cache: 768KiB Data + 768KiB Instruction L2 cache: 24MiB L3 cache: 33MiB

1.1.3 Memory details

The total size of the memory installed is 384GiB and the type of memory is DDR4 2666 Mhz. This information was obtained using the `sudo lshw -c memory` command (Listing A.2) issued from the virtual machine instance.

1.1.4 Disk and storage details

The instance has multiple disks attached. Two 900GB NVMe SSD devices `/dev/nvme1n1` and `/dev/nvme1n2` (mounted at /disk1 and /disk2 respectively), used during the benchmarking: datasets (including update streams) were stored in `/dev/nvme1n1` while `/dev/nvme1n2` was used to run the driver and the database in their respective instances.

The file system type used for both drives was `xfs`. We tested the performance of `/disk2` of the SUT, where the database workspace lies with the `fio` command, using 4KB blocks and a queue depth of 1 (Listing A.5), obtaining an average of 18050 IOPS.

1.1.5 Network details

The benchmark was run using two `r5d.12xlarge` instances, both deployed in the same availability zone behind a Virtual Private Cloud (VPC) configured with subnetwork `172.31.11.0/20`. Only SUT had the following ports open:

- `10000`: HTTP port used by SUT

The `r5d.12xlarge` instances use a common Ethernet adapter. This information was obtained using the `lshw -class network` command (Listing A.3). Network throughput between the two instances was measured using the `iperf` tool on port 10000 using 48 threads and the output (Listing A.4) showed an average of 11.5 Gbit/sec from client to server and 17.5 Gbit/sec from server to client.

1.1.6 Machine pricing

The system pricing summary is included in the table below. The pricing of the AWS machine instance is the price for a 3-year Standard Reserved Instance (without upfront payment). The Graphscope Flex database software is freely available under the Apache Software License v2.0, hence its permanent license cost is 0.00 $. The maintenance service fee guarantees 24-hour availability, 7 days a week with a 4-hour response time. The service is provided by the open-source project's major contributors and maintainers.

Table 1.3: Pricing summary

Item	**Price**
r5d.12xlarge reserved instance machine in Amazon Web Services (standard 3-year term)	39 236.04 USD
Permanent Graphscope Flex license	0.00 USD
Maintenance service fee (3 years)	60 000.00 USD
Total cost of ownership	99 236.04 USD

1.1.7 System availability

The latest software version of Graphscope Flex (version 0.23.0) was made available on May 27th, 2023. This version was deployed to the machine described in this section. Graphscope Flex is an open-source software released under the Apache Software License 2.0, the used release is available online on GitHub[1].

[1] `https://github.com/alibaba/GraphScope/releases/download/v0.23.0/graphscope_flex_db_hiactor_cppsp_mcsr_0.23.0_amd64.deb`

2 Dataset Generation

2.1 General information

The data generation settings of the LDBC Datagen are described below.

Table 2.1: Datagen settings summary

Datagen version	v0.3.8
Output format	CsvComposite serializer
Scale factors	30, 100, and 300
Number of partitions	32

For validation, we used SF10. Validation parameters where downloaded from LDBC GitHub[1], which are generated using the Neo4j Implementation.

2.2 Datagen configurations

The Datagen configuration for SF10 is shown in Listing 2.1. The configurations for SF30, SF100 and SF300 are shown in Listings A.6–A.8.

Listing 2.1: Contents of `params-sf10.ini` used for scale factor 10

```
1 ldbc.snb.datagen.generator.scaleFactor:snb.interactive.10
2 ldbc.snb.datagen.serializer.dynamicActivitySerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.
      activity.CsvCompositeDynamicActivitySerializer
3 ldbc.snb.datagen.serializer.dynamicPersonSerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.person.
      CsvCompositeDynamicPersonSerializer
4 ldbc.snb.datagen.serializer.staticSerializer:ldbc.snb.datagen.serializer.snb.csv.staticserializer.
      CsvCompositeStaticSerializer
```

2.3 Data loading and data schema

The output produced by Datagen is loaded as-is into the system, without any kind of preprocessing. Two configuration files are used to specify what to load and the schema: `bulk_load_XXX.yaml` (see Listing 2.2) and `graph.yaml` (Listing A.9).

On the one hand, `bulk_load_XXX.yaml` is scale factor specific, and specifies the paths to the csv files with the data, along with the type of object being loaded (e.g. vertex or edge), the label (e.g. PERSON, KNOWS, etc.) and the format of the file. Properties are inferred from column names.

On the other hand, `graph.yaml` is shared between scale factors, and there we specify the schema (vertex and edge types, their properties, type of edge indexing, etc.) and the stored procedures paths.

[1] https://pub-383410a98aef4cb686f0c7601eddd25f.r2.dev/interactive-v1/validation_params-sf0.1-sf10.tar.zst

Listing 2.2: Excerpt from `bulk_load_sf100_32p.yaml`, describing the data loading process

```
{
  graph:
  vertex:
    - label_name: PLACE
      files:
        - path: /disk1/sf100_32p/social_network/static/place_0_0.csv
          format: standard_csv
    - label_name: PERSON
      files:
        - path: /disk1/sf100_32p/social_network/dynamic/person_0_0.csv
          format: standard_csv
    - label_name: COMMENT
      files:
        - path: /disk1/sf100_32p/social_network/dynamic/comment_0_0.csv
          format: standard_csv
    - label_name: POST
      files:
        - path: /disk1/sf100_32p/social_network/dynamic/post_0_0.csv
          format: standard_csv
    - label_name: FORUM
      files:
        - path: /disk1/sf100_32p/social_network/dynamic/forum_0_0.csv
          format: standard_csv
    - label_name: ORGANISATION
      files:
        - path: /disk1/sf100_32p/social_network/static/organisation_0_0.csv
          format: standard_csv
    - label_name: TAGCLASS
      files:
        - path: /disk1/sf100_32p/social_network/static/tagclass_0_0.csv
          format: standard_csv
    - label_name: TAG
      files:
        - path: /disk1/sf100_32p/social_network/static/tag_0_0.csv
          format: standard_csv
  edge:
    - src_label_name: COMMENT
      dst_label_name: PERSON
      edge_label_name: HASCREATOR
      files:
        - path: /disk1/sf100_32p/social_network/dynamic/comment_hasCreator_person_0_0.csv
          format: standard_csv
    ...
}
```

Data loading times are shown for each scale factor in the table below (second column). Loading times are reported by the SUT, and source code was inspected to audit its correctness. After loading, the database was shut down and started again. The third column shows the times to startup from an already loaded database.

Table 2.2: Data loading times and startup times

Scale factor	Loading time (s)	Startup time (s)
30	394.493	14.23
100	1 311.83	44.90
300	3 992.51	128.743

3 Test Driver Details

The driver and implementations version used are described below as well as the amount of read and write threads used by the driver.

Table 3.1: Summary of test artifacts and main configuration parameters

Driver version	v1.2.0	`https://github.com/ldbc/ldbc_snb_interactive_driver/releases/tag/v1.2.0`
Implementations version	v1.0.0	`https://github.com/ldbc/ldbc_snb_interactive_impls/releases/tag/1.0.0`
LDBC SNB specification version	v0.3.6	`https://arxiv.org/pdf/2001.02299v3.pdf`
Driver read threads	48	
Driver write threads	64	

3.1 Driver implementation

A test driver adaptation for the SUT was provided by the test sponsor and is available as part of the attachment package. The SUT-specific test driver class `org.ldbcoucil.snb.impls.workloads.graphscope.interactive.GraphScopeInteractiveDb` extends the class `com.ldbc.driver.Db` provided in the LDBC SNB Interactive driver package. Internally, the `GraphScopeInteractiveDb` relies on an http connection to communicate with the SUT.

3.2 Benchmark configuration of driver

The driver applied time compression ratio values of

- TCR=0.00112 for scale factor 30,
- TCR=0.0039 for scale factor 100 and
- TCR=0.014 for scale factor 300.

The complete configuration files for the different scale factors are shown in Listings A.10–A.12, and are also included in the attached supplementary materials.

4 Performance Metrics

The performance metrics reported here show benchmark runs with scale factors 30, 100 and 300. In each case, the query on-time compliance is higher than the minimum required 95% [1]. The performance summary tables below highlight key performance characteristics.

Table 4.1: Summary of results for scale factor 30

Benchmark duration	Benchmark operations	Throughput	Query on-time compliance
02h 03m 03.184s	244 980 478	33 180.87 $\frac{\text{operations}}{\text{second}}$	100.00%

Table 4.2: Summary of results for scale factor 100

Benchmark duration	Benchmark operations	Throughput	Query on-time compliance
02h 01m 25.413s	244 974 654	33 625.36 $\frac{\text{operations}}{\text{second}}$	100.00%

Table 4.3: Summary of results for scale factor 300

Benchmark duration	Benchmark operations	Throughput	Query on-time compliance
02h 02m 44.435s	244 951 252	33 261.38 $\frac{\text{operations}}{\text{second}}$	100.00%

During the benchmark run, the query execution times shown in the tables below were observed using the different scale factors. Columns (except for Query and Total count) are showing duration values in microseconds (μs) precision. The notation $\mathbf{P_i}$ is used for the i^{th} percentile among all observed execution run times of a given query type.

[1] The total number of late operations for each run in the results in the attachment is referred to as `excessive_delay_count`.

Table 4.4: Detailed performance benchmark results for scale factor 30 in microseconds

Query	Total count	Min.	Max.	Mean	P_{50}	P_{90}	P_{95}	P_{99}
Query1	1 625 244	457	343 248	1 255.18	862	1 157	1 255	15 737
Query2	1 142 064	544	323 216	1 707.83	1 578	2 366	2 581	3 004
Query3	398 645	3 246	330 176	5 889.02	5 629	7 365	7 629	8 653
Query4	1 173 787	202	330 944	552.66	440	616	696	973
Query5	586 894	37 222	557 824	144 925.59	130 872	233 520	252 992	278 960
Query6	133 723	168	298 576	698.68	638	1 186	1 294	1 520
Query7	880 341	108	330 928	265.12	183	280	320	439
Query8	4 695 150	398	341 024	1 494.04	1 213	2 383	2 730	3 545
Query9	110 043	84 908	570 400	197 889.27	181 152	284 928	303 120	332 816
Query10	1 142 064	1 893	337 552	7 312.28	6 370	9 914	13 632	23 928
Query11	2 112 817	137	329 440	259.67	211	277	313	402
Query12	960 371	1 384	345 152	7 151.85	6 784	10 010	11 116	13 465
Query13	2 224 018	118	355 296	281.88	226	343	389	489
Query14	862 375	230	339 952	7 137.01	3 667	9 960	38 382	71 736
ShortQuery1PersonProfile	22 651 539	97	365 440	179.39	136	182	217	349
ShortQuery2PersonPosts	22 651 539	99	367 664	265.23	206	329	410	681
ShortQuery3PersonFriends	22 651 539	98	368 464	447.59	287	689	1 409	2 212
ShortQuery4MessageContent	22 653 918	96	365 216	186.46	137	188	227	352
ShortQuery5MessageCreator	22 653 918	95	391 392	170.14	131	172	205	306
ShortQuery6MessageForum	22 653 918	97	386 368	170.34	131	172	205	306
ShortQuery7MessageReplies	22 653 918	98	342 624	180.10	141	187	216	316
Update1AddPerson	12 946	178	215 648	390.59	311	560	631	885
Update2AddPostLike	9 844 761	139	383 328	315.54	203	283	332	557
Update3AddCommentLike	10 983 263	137	377 680	303.20	201	281	330	548
Update4AddForum	229 785	150	316 736	324.19	215	303	355	600
Update5AddForumMembership	34 908 158	136	375 776	317.98	203	284	332	559
Update6AddPost	2 967 525	149	344 192	328.69	224	334	396	647
Update7AddComment	8 503 041	150	369 776	335.55	223	330	391	657
Update8AddFriendship	913 174	142	337 584	308.38	203	283	331	557

Table 4.5: Detailed performance benchmark results for scale factor 100 in microseconds

Query	Total count	Min.	Max.	Mean	P_{50}	P_{90}	P_{95}	P_{99}
Query1	1 496 789	156	486 768	2 847.58	1 065	1 452	22 577	36 210
Query2	1 051 798	110	456 624	2 062.93	1 941	2 884	3 157	3 712
Query3	316 394	9 251	450 096	16 027.79	15 307	19 823	20 618	23 273
Query4	1 081 014	155	477 088	504.38	445	633	706	894
Query5	498 930	2 900	577 760	142 587.03	136 712	202 584	217 984	241 120
Query6	89 670	171	331 984	1 145.18	453	2 399	2 637	3 032
Query7	1 024 119	113	438 992	226.33	180	271	310	418
Query8	7 783 303	107	513 456	230.18	188	257	290	372
Query9	73 845	126	577 888	282 994.38	265 936	390 336	417 664	459 024
Query10	972 912	124	472 336	7 828.94	7 134	9 886	12 780	22 106
Query11	1 768 933	128	457 424	268.55	227	295	329	417
Query12	884 466	112	476 224	8 320.30	7 987	11 434	12 571	15 175
Query13	2 048 238	135	442 528	393.11	346	511	545	658
Query14	794 214	322	426 304	20 344.01	4 582	67 296	78 092	92 976
ShortQuery1PersonProfile	24 956 031	98	491 776	172.14	136	181	217	331
ShortQuery2PersonPosts	24 956 031	99	496 560	268.87	212	353	450	752
ShortQuery3PersonFriends	24 956 031	99	518 912	497.06	317	815	1 651	2 561
ShortQuery4MessageContent	24 959 042	97	489 712	179.43	137	190	228	335
ShortQuery5MessageCreator	24 959 042	95	513 392	163.02	132	172	205	299
ShortQuery6MessageForum	24 959 042	96	493 568	163.52	132	173	206	301
ShortQuery7MessageReplies	24 959 042	99	483 536	176.78	146	193	222	317
Update1AddPerson	9 945	192	235 624	447.20	321	569	627	838
Update2AddPostLike	7 066 490	141	478 496	303.90	208	291	339	554
Update3AddCommentLike	10 925 360	139	523 792	302.28	207	291	339	553
Update4AddForum	170 420	151	424 656	329.79	220	310	364	588
Update5AddForumMembership	21 709 074	138	505 040	301.65	207	291	339	555
Update6AddPost	2 325 968	152	495 248	364.33	235	354	420	691
Update7AddComment	7 400 652	153	524 112	340.41	231	341	405	660
Update8AddFriendship	777 859	143	476 864	307.31	210	296	345	565

Table 4.6: Detailed performance benchmark results for scale factor 300 in microseconds

Query	Total count	Min.	Max.	Mean	P_{50}	P_{90}	P_{95}	P_{99}
Query1	1 190 062	213	647 712	2 015.47	1 352	1 735	1 863	37 230
Query2	836 260	105	594 144	2 480.34	2 325	3 633	3 972	4 629
Query3	217 899	27 023	652 736	48 627.44	49 670	59 824	62 796	69 356
Query4	859 489	142	565 856	602.16	519	756	828	1 026
Query5	368 353	137	720 768	193 494.59	192 344	283 008	302 576	333 568
Query6	53 348	190	465 776	2 531.99	548	5 869	6 429	7 377
Query7	966 925	126	593 024	249.42	195	290	332	454
Query8	10 313 870	106	665 824	242.00	187	256	291	379
Query9	43 889	136	784 512	399 810.44	392 192	543 520	584 416	652 160
Query10	703 218	134	605 728	8 703.32	8 437	11 334	12 291	15 997
Query11	1 289 233	136	679 168	336.06	281	357	396	509
Query12	703 218	111	560 384	9 462.91	9 099	13 742	15 161	18 160
Query13	1 628 506	178	635 040	633.63	579	781	835	1 016
Query14	631 462	429	661 280	41 384.64	8 495	107 900	121 096	145 304
ShortQuery1PersonProfile	24 856 718	98	738 432	185.34	139	187	226	343
ShortQuery2PersonPosts	24 856 718	97	681 344	303.86	229	401	523	915
ShortQuery3PersonFriends	24 856 718	98	741 536	581.34	368	947	1 880	3 015
ShortQuery4MessageContent	24 854 797	95	712 096	197.08	140	198	240	348
ShortQuery5MessageCreator	24 854 797	95	752 384	175.56	134	177	213	316
ShortQuery6MessageForum	24 854 797	93	700 480	175.07	135	178	213	317
ShortQuery7MessageReplies	24 854 797	100	666 464	198.28	158	210	243	347
Update1AddPerson	6 980	192	376 976	605.42	361	607	692	946
Update2AddPostLike	6 967 271	140	746 688	345.45	214	304	356	640
Update3AddCommentLike	14 037 494	140	740 480	347.46	214	304	356	642
Update4AddForum	119 708	152	580 864	378.86	230	335	394	702
Update5AddForumMembership	16 380 979	137	771 968	346.38	214	304	356	641
Update6AddPost	2 172 529	153	673 088	630.40	255	410	500	1 904
Update7AddComment	10 848 212	150	709 408	367.55	238	359	425	760
Update8AddFriendship	623 005	143	608 768	355.58	224	332	385	682

5 Validation of the Results

The scale factor 10 data set was used for validating the correctness of the implementation over the SUT. The validation data set was created using the SNB Interactive reference implementation over Neo4j, which can be download from the LDBC GitHub repository[1]. The system with the driver configuration shown in Listing A.13 successfully returned the expected result sets for the queries of the benchmark.

[1] https://pub-383410a98aef4cb686f0c7601eddd25f.r2.dev/interactive-v1/validation_params-sf0.1-sf10.tar.zst

6 ACID Compliance

6.1 Transaction isolation level

The SUT supports the *serializable* isolation level, which is more strict than the *read committed* isolation level minimally required by the SNB Interactive specification.

6.2 SNB Interactive ACID test results

The ACID test implementation was reviewed to conform to the ACID test specifications, with all specified test cases implemented. The test was executed 200 times with a 100% rate of success: no atomicity or isolation tests failed. In particular, the following anomaly tests tested successfully:

- Dirty Writes (G0)
- Aborted Reads (G1A)
- Intermediate Reads (G1B)
- Circular Information Flow (G1C)
- Item-Many-Preceders (IMP)
- Predicate-Many-Preceders (PMP)
- Observed Transaction Vanishes (OTV)
- Fractured Reads (FR)
- Lost Updates (LU)
- Write Skews (WS)

6.3 Recovery and durability

Durability tests were conducted on all three audited scale factors: SF30, SF100 and SF300. After around two hours of execution time, the database process was killed with the `sudo pkill -9 rt_server` command. The following table shows the database restart times after the database server was killed.

Scale factor	Recovery startup time (s)
30	30.54
100	161.05
300	153.61

After killing and recovering from the crash, the driver log was inspected and, for each scale factor, the last 10 update operations were matched with their corresponding update queries from the dataset. Then, using the provided `rt_admin` tool, the presence of the contents on each update query was checked.

7 Supplementary Materials

The table below shows the list of supplementary materials. These materials are made available with this full disclosure report to allow reproducibility of results.

Table 7.1: Supplementary materials

File	Purpose
benchmark_sf{30_32p,100_32p,300_32p}.properties	Driver configuration properties per scale factor
validate.properties	Driver configuration properties used for validation
benchmark.sh	Script used to run the driver for sf30-300
validate.sh	Script used to run the driver for validation
validation_params-sf10.csv	CSV with sf10 validation params used
bulk_load_sf{10_1p,30_32p,100_32p,300_32p}.yaml	SUT loading process config file for different scale factors
graph.yaml	SUT schema file
params-sf{10,30,100,300}.ini	Datagen config params for different scale factors
graphscope_flex_db_hiactor_cppsp_mcsr_0.23.0_amd64.deb	Binary package with the SUT database
install_dependencies.sh	Script that installs required dependencies and configures machine parameters
build.sh	Build script
ic{1,2,3,4,5,6,7,8,9,10,11,12,13,14}.cc	Stored procedures implementing the benchmark Complex Reads
is{1,2,3,4,5,6,7}.cc	Stored procedures implementing the benchmark Short Reads
ins{1,2,3,4,5,6,7,8}.cc	Stored procedures implementing the benchmark Inserts
logs.tgz	Compressed archive of the logs folder
logs/driver/sf{10_1p,30_32p,100_32p,300_32p}	folder with driver logs of normal runs
logs/driver/sf{10_1p,30_32p,100_32p,300_32p}/recovery	folder with driver logs of recovery runs
logs/sut/sf{10_1p,30_32p,100_32p,300_32p}	folder with SUT logs of normal runs
logs/sut/sf{10_1p,30_32p,100_32p,300_32p}/recovery	folder with SUT logs of recovery runs

The supplementary folder directory structure is as follows:

```
supplementary_materials
├── driver
│   └── graphscope
│       ├── config
│       │   ├── benchmark_sf{30_32p,100_32p,300_32p}.properties
│       │   └── validate.properties
│       ├── scripts
│       │   ├── benchmark.sh
│       │   └── validate.sh
│       └── test-data
│           └── validation_params-sf10.csv
├── sut
│   ├── config
│   │   ├── bulk_load_sf{10_1p,30_32p,100_32p,300_32p}.yaml
│   │   ├── graph.yaml
│   │   └── params-sf{10,30,100,300}.ini
│   ├── graphscope_flex_db_hiactor_cppsp_mcsr_0.23.0_amd64.deb
│   ├── scripts
│   │   └── install_dependencies.sh
│   ├── stored_procedures
│   │   ├── build.sh
│   │   ├── utils.h
│   │   ├── ic{1,2,3,4,5,6,7,8,9,10,11,12,13,14}.cc
│   │   ├── is{1,2,3,4,5,6,7}.cc
│   │   └── ins{1,2,3,4,5,6,7,8}.cc
│   └── tests
│       ├── build.sh
│       └── test_acid.cc
└── logs
    ├── driver
    │   ├── sf10_1p
    │   │   └── recovery
    │   ├── sf30_32p
    │   │   └── recovery
    │   ├── sf100_32p
    │   │   └── recovery
    │   └── sf300_32p
    │       └── recovery
    ├── sut
    │   ├── sf10_1p
    │   │   └── recovery
    │   ├── sf30_32p
    │   │   └── recovery
    │   ├── sf100_32p
    │   │   └── recovery
    │   └── sf300_32p
    └── README.md
```

A Appendix

A.1 CPU details

Listing A.1: Output of the `lscpu` command for one core

```
Architecture:                    x86_64
CPU op-mode(s):                  32-bit, 64-bit
Byte Order:                      Little Endian
Address sizes:                   46 bits physical, 48 bits virtual
CPU(s):                          48
On-line CPU(s) list:             0-47
Thread(s) per core:              2
Core(s) per socket:              24
Socket(s):                       1
NUMA node(s):                    1
Vendor ID:                       GenuineIntel
CPU family:                      6
Model:                           85
Model name:                      Intel(R) Xeon(R) Platinum 8175M CPU @ 2.50GHz
Stepping:                        4
CPU MHz:                         2500.000
BogoMIPS:                        5000.00
Hypervisor vendor:               KVM
Virtualization type:             full
L1d cache:                       768 KiB
L1i cache:                       768 KiB
L2 cache:                        24 MiB
L3 cache:                        33 MiB
NUMA node0 CPU(s):               0-47
Vulnerability Itlb multihit:     KVM: Mitigation: VMX unsupported
Vulnerability L1tf:              Mitigation; PTE Inversion
Vulnerability Mds:               Vulnerable: Clear CPU buffers attempted, no microcode; SMT Host state unknown
Vulnerability Meltdown:          Mitigation; PTI
Vulnerability Mmio stale data:   Vulnerable: Clear CPU buffers attempted, no microcode; SMT Host state unknown
Vulnerability Retbleed:          Vulnerable
Vulnerability Spec store bypass: Vulnerable
Vulnerability Spectre v1:        Mitigation; usercopy/swapgs barriers and __user pointer sanitization
Vulnerability Spectre v2:        Mitigation; Retpolines, STIBP disabled, RSB filling
Vulnerability Srbds:             Not affected
Vulnerability Tsx async abort:   Not affected
Flags:                           fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush
     mmx fxsr sse sse2 ss ht syscall nx pdpe1gb rdtscp lm constant_tsc arch_perfmon rep_good nopl xtopo
                                 logy nonstop_tsc cpuid aperfmperf tsc_known_freq pni pclmulqdq monitor ssse3 fma
      cx16 pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave avx f16c rdrand hypervis
                                 or lahf_lm abm 3dnowprefetch invpcid_single pti fsgsbase tsc_adjust bmi1 avx2
     smep bmi2 erms invpcid mpx avx512f avx512dq rdseed adx smap clflushopt clwb avx512cd avx512bw avx512
                                 vl xsaveopt xsavec xgetbv1 xsaves ida arat pku ospke
```

A.2 Memory details

Listing A.2: Output of the `lshw -c memory` command

```
*-firmware
     description: BIOS
     vendor: Amazon EC2
     physical id: 0
     version: 1.0
     date: 10/16/2017
     size: 64KiB
     capacity: 64KiB
     capabilities: pci edd acpi virtualmachine
*-cache:0
     description: L1 cache
     physical id: 5
     slot: L1-Cache
     size: 1536KiB
     capacity: 1536KiB
     capabilities: synchronous internal write-back instruction
     configuration: level=1
*-cache:1
     description: L2 cache
     physical id: 6
     slot: L2-Cache
     size: 24MiB
     capacity: 24MiB
     capabilities: synchronous internal varies unified
     configuration: level=2
*-cache:2
     description: L3 cache
     physical id: 7
     slot: L3-Cache
     size: 33MiB
     capacity: 33MiB
     capabilities: synchronous internal varies unified
     configuration: level=3
*-memory
     description: System Memory
     physical id: 8
     slot: System board or motherboard
     size: 384GiB
   *-bank
        description: DIMM DDR4 Static column Pseudo-static Synchronous Window DRAM 2666 MHz (0.4 ns)
        physical id: 0
        size: 384GiB
        width: 64 bits
        clock: 2666MHz (0.4ns)
```

A.3 Network details

Listing A.3: Output of the `lshw -class network` command

```
  *-network
       description: Ethernet interface
       product: Elastic Network Adapter (ENA)
       vendor: Amazon.com, Inc.
       physical id: 5
       bus info: pci@0000:00:05.0
       logical name: ens5
       version: 00
       serial: 02:74:02:41:3a:81
       width: 32 bits
       clock: 33MHz
       capabilities: pciexpress msix bus_master cap_list ethernet physical
       configuration: broadcast=yes driver=ena driverversion=5.15.0-1019-aws ip=172.31.11.250 latency=0 link=yes
    multicast=yes
       resources: irq:0 memory:febf4000-febf7fff memory:fe800000-fe8fffff memory:febe0000-febeffff
```

A.4 Network performance

Some of the output has been omitted for briefness. First sum is from client to server, second sum from server to client.

Listing A.4: Output of the `iperf` command

```
# iperf -c 172.16.18.134 -r --parallel 48 -i 1 -t 2 -p 10000
------------------------------------------------------------
Server listening on TCP port 10000
TCP window size:  128 KByte (default)
------------------------------------------------------------
------------------------------------------------------------
Client connecting to 172.31.11.250, TCP port 10000
TCP window size:  455 KByte (default)
------------------------------------------------------------
[ 51] local 172.31.10.47 port 46782 connected with 172.31.11.250 port 10000
[ 50] local 172.31.10.47 port 46770 connected with 172.31.11.250 port 10000
[ 49] local 172.31.10.47 port 46762 connected with 172.31.11.250 port 10000
[  5] local 172.31.10.47 port 46332 connected with 172.31.11.250 port 10000
[  3] local 172.31.10.47 port 46346 connected with 172.31.11.250 port 10000
[  4] local 172.31.10.47 port 46320 connected with 172.31.11.250 port 10000
[  8] local 172.31.10.47 port 46360 connected with 172.31.11.250 port 10000
[  6] local 172.31.10.47 port 46356 connected with 172.31.11.250 port 10000
[  7] local 172.31.10.47 port 46374 connected with 172.31.11.250 port 10000
[ 10] local 172.31.10.47 port 46366 connected with 172.31.11.250 port 10000
[ 11] local 172.31.10.47 port 46400 connected with 172.31.11.250 port 10000
[ 13] local 172.31.10.47 port 46406 connected with 172.31.11.250 port 10000
[  9] local 172.31.10.47 port 46388 connected with 172.31.11.250 port 10000
[ 14] local 172.31.10.47 port 46442 connected with 172.31.11.250 port 10000
[ 18] local 172.31.10.47 port 46452 connected with 172.31.11.250 port 10000
[ 21] local 172.31.10.47 port 46462 connected with 172.31.11.250 port 10000
[ 16] local 172.31.10.47 port 46432 connected with 172.31.11.250 port 10000
[ 15] local 172.31.10.47 port 46418 connected with 172.31.11.250 port 10000
[ 17] local 172.31.10.47 port 46456 connected with 172.31.11.250 port 10000
[ 19] local 172.31.10.47 port 46464 connected with 172.31.11.250 port 10000
[ 24] local 172.31.10.47 port 46490 connected with 172.31.11.250 port 10000
```

```
[ 22] local 172.31.10.47 port 46498 connected with 172.31.11.250 port 10000
[ 12] local 172.31.10.47 port 46426 connected with 172.31.11.250 port 10000
[ 26] local 172.31.10.47 port 46530 connected with 172.31.11.250 port 10000
[ 23] local 172.31.10.47 port 46476 connected with 172.31.11.250 port 10000
[ 25] local 172.31.10.47 port 46514 connected with 172.31.11.250 port 10000
[ 27] local 172.31.10.47 port 46540 connected with 172.31.11.250 port 10000
[ 29] local 172.31.10.47 port 46550 connected with 172.31.11.250 port 10000
[ 30] local 172.31.10.47 port 46562 connected with 172.31.11.250 port 10000
[ 34] local 172.31.10.47 port 46572 connected with 172.31.11.250 port 10000
[ 20] local 172.31.10.47 port 46588 connected with 172.31.11.250 port 10000
[ 37] local 172.31.10.47 port 46602 connected with 172.31.11.250 port 10000
[ 31] local 172.31.10.47 port 46580 connected with 172.31.11.250 port 10000
[ 36] local 172.31.10.47 port 46630 connected with 172.31.11.250 port 10000
[ 33] local 172.31.10.47 port 46612 connected with 172.31.11.250 port 10000
[ 38] local 172.31.10.47 port 46626 connected with 172.31.11.250 port 10000
[ 39] local 172.31.10.47 port 46644 connected with 172.31.11.250 port 10000
[ 35] local 172.31.10.47 port 46656 connected with 172.31.11.250 port 10000
[ 43] local 172.31.10.47 port 46684 connected with 172.31.11.250 port 10000
[ 40] local 172.31.10.47 port 46706 connected with 172.31.11.250 port 10000
[ 41] local 172.31.10.47 port 46682 connected with 172.31.11.250 port 10000
[ 42] local 172.31.10.47 port 46668 connected with 172.31.11.250 port 10000
[ 45] local 172.31.10.47 port 46690 connected with 172.31.11.250 port 10000
[ 46] local 172.31.10.47 port 46712 connected with 172.31.11.250 port 10000
[ 44] local 172.31.10.47 port 46716 connected with 172.31.11.250 port 10000
[ 47] local 172.31.10.47 port 46746 connected with 172.31.11.250 port 10000
[ 48] local 172.31.10.47 port 46732 connected with 172.31.11.250 port 10000
[ 28] local 172.31.10.47 port 46534 connected with 172.31.11.250 port 10000
[ ID] Interval       Transfer     Bandwidth
[ 51]  0.0- 1.0 sec  40.5 MBytes   340 Mbits/sec
[ 49]  0.0- 1.0 sec  48.1 MBytes   404 Mbits/sec
[  5]  0.0- 1.0 sec  36.9 MBytes   309 Mbits/sec
[  3]  0.0- 1.0 sec  17.2 MBytes   145 Mbits/sec
[  4]  0.0- 1.0 sec  24.4 MBytes   204 Mbits/sec
[  8]  0.0- 1.0 sec  17.2 MBytes   145 Mbits/sec
[  6]  0.0- 1.0 sec  24.2 MBytes   203 Mbits/sec
[  7]  0.0- 1.0 sec  36.8 MBytes   308 Mbits/sec
[ 10]  0.0- 1.0 sec  24.0 MBytes   201 Mbits/sec
[ 11]  0.0- 1.0 sec  31.4 MBytes   263 Mbits/sec
[ 13]  0.0- 1.0 sec  41.1 MBytes   345 Mbits/sec
[  9]  0.0- 1.0 sec  17.4 MBytes   146 Mbits/sec
[ 14]  0.0- 1.0 sec  40.9 MBytes   343 Mbits/sec
[ 21]  0.0- 1.0 sec  17.5 MBytes   147 Mbits/sec
[ 16]  0.0- 1.0 sec  37.0 MBytes   310 Mbits/sec
[ 15]  0.0- 1.0 sec  41.4 MBytes   347 Mbits/sec
[ 17]  0.0- 1.0 sec  40.0 MBytes   336 Mbits/sec
[ 19]  0.0- 1.0 sec  24.4 MBytes   204 Mbits/sec
[ 24]  0.0- 1.0 sec  25.2 MBytes   212 Mbits/sec
[ 22]  0.0- 1.0 sec  25.4 MBytes   213 Mbits/sec
[ 12]  0.0- 1.0 sec  40.2 MBytes   338 Mbits/sec
[ 26]  0.0- 1.0 sec  17.5 MBytes   147 Mbits/sec
[ 23]  0.0- 1.0 sec  25.2 MBytes   212 Mbits/sec
[ 25]  0.0- 1.0 sec  24.0 MBytes   201 Mbits/sec
[ 27]  0.0- 1.0 sec  40.2 MBytes   338 Mbits/sec
[ 29]  0.0- 1.0 sec  36.9 MBytes   309 Mbits/sec
[ 30]  0.0- 1.0 sec  40.0 MBytes   336 Mbits/sec
[ 34]  0.0- 1.0 sec  24.2 MBytes   203 Mbits/sec
[ 20]  0.0- 1.0 sec  24.5 MBytes   206 Mbits/sec
[ 37]  0.0- 1.0 sec  36.9 MBytes   309 Mbits/sec
```

```
[ 31]  0.0- 1.0 sec  24.0 MBytes   201 Mbits/sec
[ 36]  0.0- 1.0 sec  31.4 MBytes   263 Mbits/sec
[ 33]  0.0- 1.0 sec  23.9 MBytes   200 Mbits/sec
[ 38]  0.0- 1.0 sec  25.1 MBytes   211 Mbits/sec
[ 39]  0.0- 1.0 sec  17.2 MBytes   145 Mbits/sec
[ 35]  0.0- 1.0 sec  24.4 MBytes   204 Mbits/sec
[ 43]  0.0- 1.0 sec  31.2 MBytes   262 Mbits/sec
[ 40]  0.0- 1.0 sec  24.1 MBytes   202 Mbits/sec
[ 41]  0.0- 1.0 sec  40.9 MBytes   343 Mbits/sec
[ 42]  0.0- 1.0 sec  40.0 MBytes   336 Mbits/sec
[ 45]  0.0- 1.0 sec  17.4 MBytes   146 Mbits/sec
[ 46]  0.0- 1.0 sec  17.2 MBytes   145 Mbits/sec
[ 44]  0.0- 1.0 sec  31.2 MBytes   262 Mbits/sec
[ 47]  0.0- 1.0 sec  40.0 MBytes   336 Mbits/sec
[ 48]  0.0- 1.0 sec  31.4 MBytes   263 Mbits/sec
[ 28]  0.0- 1.0 sec  41.1 MBytes   345 Mbits/sec
[ 50]  0.0- 1.0 sec  29.9 MBytes   251 Mbits/sec
[ 18]  0.0- 1.0 sec  27.6 MBytes   232 Mbits/sec
[SUM]  0.0- 1.0 sec  1.41 GBytes  12.1 Gbits/sec
[  4]  1.0- 2.0 sec  29.4 MBytes   246 Mbits/sec
[  4]  0.0- 2.0 sec  53.8 MBytes   225 Mbits/sec
[  8]  1.0- 2.0 sec  14.1 MBytes   118 Mbits/sec
[  8]  0.0- 2.0 sec  31.4 MBytes   132 Mbits/sec
[  6]  1.0- 2.0 sec  29.4 MBytes   246 Mbits/sec
[  6]  0.0- 2.0 sec  53.6 MBytes   225 Mbits/sec
[ 23]  1.0- 2.0 sec  25.9 MBytes   217 Mbits/sec
[ 23]  0.0- 2.0 sec  51.1 MBytes   214 Mbits/sec
[ 25]  1.0- 2.0 sec  29.5 MBytes   247 Mbits/sec
[ 25]  0.0- 2.0 sec  53.5 MBytes   224 Mbits/sec
[ 38]  1.0- 2.0 sec  25.8 MBytes   216 Mbits/sec
[ 38]  0.0- 2.0 sec  50.9 MBytes   213 Mbits/sec
[ 35]  1.0- 2.0 sec  29.4 MBytes   246 Mbits/sec
[ 35]  0.0- 2.0 sec  53.8 MBytes   225 Mbits/sec
[ 40]  1.0- 2.0 sec  29.4 MBytes   246 Mbits/sec
[ 40]  0.0- 2.0 sec  53.5 MBytes   224 Mbits/sec
[ 42]  1.0- 2.0 sec  34.1 MBytes   286 Mbits/sec
[ 42]  0.0- 2.0 sec  74.1 MBytes   311 Mbits/sec
[ 45]  1.0- 2.0 sec  14.0 MBytes   117 Mbits/sec
[ 45]  0.0- 2.0 sec  31.4 MBytes   132 Mbits/sec
[ 47]  1.0- 2.0 sec  34.0 MBytes   285 Mbits/sec
[ 47]  0.0- 2.0 sec  74.0 MBytes   310 Mbits/sec
[ 48]  1.0- 2.0 sec  39.1 MBytes   328 Mbits/sec
[ 48]  0.0- 2.0 sec  70.5 MBytes   296 Mbits/sec
[ 51]  1.0- 2.0 sec  39.2 MBytes   329 Mbits/sec
[ 51]  0.0- 2.0 sec  79.8 MBytes   333 Mbits/sec
[ 50]  1.0- 2.0 sec  29.6 MBytes   249 Mbits/sec
[ 50]  0.0- 2.0 sec  59.5 MBytes   247 Mbits/sec
[ 49]  1.0- 2.0 sec  34.4 MBytes   288 Mbits/sec
[ 49]  0.0- 2.0 sec  82.5 MBytes   342 Mbits/sec
[  5]  1.0- 2.0 sec  24.1 MBytes   202 Mbits/sec
[  5]  0.0- 2.0 sec  61.0 MBytes   254 Mbits/sec
[  3]  1.0- 2.0 sec  14.4 MBytes   121 Mbits/sec
[  3]  0.0- 2.0 sec  31.6 MBytes   132 Mbits/sec
[  7]  1.0- 2.0 sec  24.0 MBytes   201 Mbits/sec
[  7]  0.0- 2.0 sec  60.8 MBytes   254 Mbits/sec
[ 10]  1.0- 2.0 sec  29.8 MBytes   250 Mbits/sec
[ 10]  0.0- 2.0 sec  53.8 MBytes   224 Mbits/sec
[ 11]  1.0- 2.0 sec  39.6 MBytes   332 Mbits/sec
```

```
[ 11]  0.0- 2.0 sec  71.0 MBytes   297 Mbits/sec
[ 13]  1.0- 2.0 sec  45.4 MBytes   381 Mbits/sec
[ 13]  0.0- 2.0 sec  86.5 MBytes   362 Mbits/sec
[  9]  1.0- 2.0 sec  14.2 MBytes   120 Mbits/sec
[  9]  0.0- 2.0 sec  31.6 MBytes   132 Mbits/sec
[ 14]  1.0- 2.0 sec  45.6 MBytes   383 Mbits/sec
[ 14]  0.0- 2.0 sec  86.5 MBytes   362 Mbits/sec
[ 18]  1.0- 2.0 sec  25.8 MBytes   216 Mbits/sec
[ 18]  0.0- 2.0 sec  53.4 MBytes   221 Mbits/sec
[ 21]  1.0- 2.0 sec  14.2 MBytes   120 Mbits/sec
[ 21]  0.0- 2.0 sec  31.8 MBytes   132 Mbits/sec
[ 16]  1.0- 2.0 sec  24.0 MBytes   201 Mbits/sec
[ 16]  0.0- 2.0 sec  61.0 MBytes   254 Mbits/sec
[ 15]  1.0- 2.0 sec  45.4 MBytes   381 Mbits/sec
[ 15]  0.0- 2.0 sec  86.8 MBytes   363 Mbits/sec
[ 17]  1.0- 2.0 sec  34.4 MBytes   288 Mbits/sec
[ 17]  0.0- 2.0 sec  74.4 MBytes   311 Mbits/sec
[ 19]  1.0- 2.0 sec  29.4 MBytes   246 Mbits/sec
[ 19]  0.0- 2.0 sec  53.8 MBytes   225 Mbits/sec
[ 24]  1.0- 2.0 sec  25.8 MBytes   216 Mbits/sec
[ 24]  0.0- 2.0 sec  51.0 MBytes   213 Mbits/sec
[ 22]  1.0- 2.0 sec  25.8 MBytes   216 Mbits/sec
[ 22]  0.0- 2.0 sec  51.1 MBytes   214 Mbits/sec
[ 12]  1.0- 2.0 sec  34.0 MBytes   285 Mbits/sec
[ 12]  0.0- 2.0 sec  74.2 MBytes   310 Mbits/sec
[ 26]  1.0- 2.0 sec  14.4 MBytes   121 Mbits/sec
[ 26]  0.0- 2.0 sec  31.9 MBytes   132 Mbits/sec
[ 27]  1.0- 2.0 sec  34.0 MBytes   285 Mbits/sec
[ 27]  0.0- 2.0 sec  74.2 MBytes   310 Mbits/sec
[ 29]  1.0- 2.0 sec  24.1 MBytes   202 Mbits/sec
[ 29]  0.0- 2.0 sec  61.0 MBytes   254 Mbits/sec
[ 30]  1.0- 2.0 sec  34.4 MBytes   288 Mbits/sec
[ 30]  0.0- 2.0 sec  74.4 MBytes   310 Mbits/sec
[ 34]  1.0- 2.0 sec  29.8 MBytes   250 Mbits/sec
[ 34]  0.0- 2.0 sec  54.0 MBytes   225 Mbits/sec
[ 20]  1.0- 2.0 sec  29.6 MBytes   249 Mbits/sec
[ 20]  0.0- 2.0 sec  54.1 MBytes   226 Mbits/sec
[ 37]  1.0- 2.0 sec  24.1 MBytes   202 Mbits/sec
[ 37]  0.0- 2.0 sec  61.0 MBytes   254 Mbits/sec
[ 31]  1.0- 2.0 sec  29.9 MBytes   251 Mbits/sec
[ 31]  0.0- 2.0 sec  53.9 MBytes   225 Mbits/sec
[ 36]  1.0- 2.0 sec  39.2 MBytes   329 Mbits/sec
[ 36]  0.0- 2.0 sec  70.6 MBytes   296 Mbits/sec
[ 33]  1.0- 2.0 sec  29.8 MBytes   250 Mbits/sec
[ 33]  0.0- 2.0 sec  53.6 MBytes   224 Mbits/sec
[ 39]  1.0- 2.0 sec  14.4 MBytes   121 Mbits/sec
[ 39]  0.0- 2.0 sec  31.6 MBytes   132 Mbits/sec
[ 43]  1.0- 2.0 sec  39.4 MBytes   330 Mbits/sec
[ 43]  0.0- 2.0 sec  70.6 MBytes   295 Mbits/sec
[ 41]  1.0- 2.0 sec  45.5 MBytes   382 Mbits/sec
[ 41]  0.0- 2.0 sec  86.4 MBytes   361 Mbits/sec
[ 46]  1.0- 2.0 sec  14.4 MBytes   121 Mbits/sec
[ 46]  0.0- 2.0 sec  31.6 MBytes   132 Mbits/sec
[ 44]  1.0- 2.0 sec  39.4 MBytes   330 Mbits/sec
[ 44]  0.0- 2.0 sec  70.6 MBytes   295 Mbits/sec
[ 28]  1.0- 2.0 sec  45.6 MBytes   383 Mbits/sec
[SUM]  1.0- 2.0 sec  1.39 GBytes  11.9 Gbits/sec
[ 28]  0.0- 2.0 sec  86.8 MBytes   362 Mbits/sec
```

```
[SUM]  0.0- 2.0 sec  2.79 GBytes  11.9 Gbits/sec
[  3] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45152
[  6] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45168
[  4] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45164
[  7] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45176
[ 10] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45200
[  9] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45188
[  5] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45212
[  8] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45216
[ 11] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45228
[ 12] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45222
[ 13] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45266
[ 16] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45236
[ 15] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45274
[ 14] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45252
[ 19] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45304
[ 17] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45290
[ 18] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45298
[ 21] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45308
[ 20] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45318
[ 22] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45328
[ 23] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45366
[ 24] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45330
[ 27] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45360
[ 28] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45344
[ 25] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45338
[ 31] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45376
[ 26] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45374
[ 29] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45384
[ 30] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45396
[ 33] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45444
[ 34] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45428
[ 35] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45474
[ 37] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45468
[ 36] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45562
[ 38] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45478
[ 40] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45504
[ 39] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45558
[ 41] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45490
[ 43] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45416
[ 42] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45540
[ 46] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45528
[ 44] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45402
[ 48] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45590
[ 45] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45512
[ 47] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45578
[ 50] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45552
[ 51] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45456
[ 49] local 172.31.10.47 port 10000 connected with 172.31.11.250 port 45452
[  3]  0.0- 1.0 sec  37.0 MBytes   310 Mbits/sec
[  6]  0.0- 1.0 sec  30.6 MBytes   257 Mbits/sec
[  4]  0.0- 1.0 sec  54.5 MBytes   457 Mbits/sec
[  7]  0.0- 1.0 sec  44.1 MBytes   370 Mbits/sec
[ 10]  0.0- 1.0 sec  19.3 MBytes   162 Mbits/sec
[  9]  0.0- 1.0 sec  19.7 MBytes   165 Mbits/sec
[  5]  0.0- 1.0 sec  36.9 MBytes   310 Mbits/sec
[  8]  0.0- 1.0 sec  36.8 MBytes   309 Mbits/sec
[ 11]  0.0- 1.0 sec  54.3 MBytes   456 Mbits/sec
```

```
[ 12]  0.0- 1.0 sec  18.7 MBytes   157 Mbits/sec
[ 13]  0.0- 1.0 sec  36.8 MBytes   309 Mbits/sec
[ 16]  0.0- 1.0 sec  18.6 MBytes   156 Mbits/sec
[ 15]  0.0- 1.0 sec  42.2 MBytes   354 Mbits/sec
[ 14]  0.0- 1.0 sec  19.2 MBytes   161 Mbits/sec
[ 19]  0.0- 1.0 sec  11.8 MBytes  99.3 Mbits/sec
[ 17]  0.0- 1.0 sec  14.7 MBytes   124 Mbits/sec
[ 18]  0.0- 1.0 sec  11.8 MBytes  98.9 Mbits/sec
[ 21]  0.0- 1.0 sec  19.2 MBytes   161 Mbits/sec
[ 20]  0.0- 1.0 sec  11.8 MBytes  99.0 Mbits/sec
[ 22]  0.0- 1.0 sec  44.1 MBytes   370 Mbits/sec
[ 23]  0.0- 1.0 sec  19.1 MBytes   160 Mbits/sec
[ 24]  0.0- 1.0 sec  11.8 MBytes  99.0 Mbits/sec
[ 27]  0.0- 1.0 sec  44.1 MBytes   370 Mbits/sec
[ 28]  0.0- 1.0 sec  44.1 MBytes   370 Mbits/sec
[ 25]  0.0- 1.0 sec  54.2 MBytes   454 Mbits/sec
[ 31]  0.0- 1.0 sec  19.2 MBytes   161 Mbits/sec
[ 26]  0.0- 1.0 sec  12.8 MBytes   108 Mbits/sec
[ 29]  0.0- 1.0 sec  36.7 MBytes   308 Mbits/sec
[ 30]  0.0- 1.0 sec  42.2 MBytes   354 Mbits/sec
[ 33]  0.0- 1.0 sec  42.2 MBytes   354 Mbits/sec
[ 34]  0.0- 1.0 sec  18.5 MBytes   156 Mbits/sec
[ 35]  0.0- 1.0 sec  30.1 MBytes   252 Mbits/sec
[ 37]  0.0- 1.0 sec  44.1 MBytes   370 Mbits/sec
[ 36]  0.0- 1.0 sec  44.0 MBytes   369 Mbits/sec
[ 38]  0.0- 1.0 sec  42.1 MBytes   353 Mbits/sec
[ 40]  0.0- 1.0 sec  42.1 MBytes   353 Mbits/sec
[ 39]  0.0- 1.0 sec  36.6 MBytes   307 Mbits/sec
[ 41]  0.0- 1.0 sec  44.0 MBytes   369 Mbits/sec
[ 43]  0.0- 1.0 sec  18.5 MBytes   156 Mbits/sec
[ 42]  0.0- 1.0 sec  19.1 MBytes   160 Mbits/sec
[ 46]  0.0- 1.0 sec  17.3 MBytes   145 Mbits/sec
[ 44]  0.0- 1.0 sec  42.1 MBytes   353 Mbits/sec
[ 48]  0.0- 1.0 sec  30.0 MBytes   252 Mbits/sec
[ 45]  0.0- 1.0 sec  18.5 MBytes   156 Mbits/sec
[ 47]  0.0- 1.0 sec  30.1 MBytes   252 Mbits/sec
[ 50]  0.0- 1.0 sec  11.8 MBytes  98.6 Mbits/sec
[ 51]  0.0- 1.0 sec  11.8 MBytes  98.6 Mbits/sec
[ 49]  0.0- 1.0 sec  11.8 MBytes  98.6 Mbits/sec
[  3]  1.0- 2.0 sec  26.8 MBytes   225 Mbits/sec
[  6]  1.0- 2.0 sec  29.5 MBytes   248 Mbits/sec
[  4]  1.0- 2.0 sec  54.1 MBytes   454 Mbits/sec
[  7]  1.0- 2.0 sec  33.8 MBytes   283 Mbits/sec
[ 10]  1.0- 2.0 sec  23.7 MBytes   198 Mbits/sec
[  9]  1.0- 2.0 sec  23.7 MBytes   198 Mbits/sec
[  5]  1.0- 2.0 sec  26.7 MBytes   224 Mbits/sec
[  8]  1.0- 2.0 sec  26.8 MBytes   225 Mbits/sec
[ 11]  1.0- 2.0 sec  54.1 MBytes   454 Mbits/sec
[ 12]  1.0- 2.0 sec  23.5 MBytes   197 Mbits/sec
[ 13]  1.0- 2.0 sec  26.7 MBytes   224 Mbits/sec
[ 16]  1.0- 2.0 sec  23.4 MBytes   197 Mbits/sec
[ 15]  1.0- 2.0 sec  33.8 MBytes   284 Mbits/sec
[ 14]  1.0- 2.0 sec  23.7 MBytes   198 Mbits/sec
[ 19]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[ 17]  1.0- 2.0 sec  14.7 MBytes   124 Mbits/sec
[ 18]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[ 21]  1.0- 2.0 sec  23.7 MBytes   199 Mbits/sec
[ 20]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
```

```
[ 22]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 23]  1.0- 2.0 sec  23.7 MBytes   199 Mbits/sec
[ 24]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[ 27]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 28]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 25]  1.0- 2.0 sec  54.1 MBytes   454 Mbits/sec
[ 31]  1.0- 2.0 sec  23.7 MBytes   199 Mbits/sec
[ 26]  1.0- 2.0 sec  13.0 MBytes   109 Mbits/sec
[ 29]  1.0- 2.0 sec  26.7 MBytes   224 Mbits/sec
[ 30]  1.0- 2.0 sec  33.8 MBytes   283 Mbits/sec
[ 33]  1.0- 2.0 sec  33.8 MBytes   284 Mbits/sec
[ 34]  1.0- 2.0 sec  23.5 MBytes   197 Mbits/sec
[ 35]  1.0- 2.0 sec  37.7 MBytes   316 Mbits/sec
[ 37]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 36]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 38]  1.0- 2.0 sec  33.8 MBytes   284 Mbits/sec
[ 40]  1.0- 2.0 sec  33.8 MBytes   284 Mbits/sec
[ 39]  1.0- 2.0 sec  26.8 MBytes   225 Mbits/sec
[ 41]  1.0- 2.0 sec  44.3 MBytes   371 Mbits/sec
[ 43]  1.0- 2.0 sec  23.5 MBytes   197 Mbits/sec
[ 42]  1.0- 2.0 sec  23.7 MBytes   199 Mbits/sec
[ 46]  1.0- 2.0 sec  24.7 MBytes   207 Mbits/sec
[ 44]  1.0- 2.0 sec  33.8 MBytes   283 Mbits/sec
[ 48]  1.0- 2.0 sec  37.7 MBytes   316 Mbits/sec
[ 45]  1.0- 2.0 sec  23.5 MBytes   197 Mbits/sec
[ 47]  1.0- 2.0 sec  37.7 MBytes   316 Mbits/sec
[ 50]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[ 51]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[ 49]  1.0- 2.0 sec  16.7 MBytes   140 Mbits/sec
[  3]  0.0- 2.0 sec  64.5 MBytes   267 Mbits/sec
[  6]  0.0- 2.0 sec  60.8 MBytes   252 Mbits/sec
[  4]  0.0- 2.0 sec   110 MBytes   456 Mbits/sec
[  7]  0.0- 2.0 sec  79.0 MBytes   326 Mbits/sec
[ 10]  0.0- 2.0 sec  44.0 MBytes   182 Mbits/sec
[  9]  0.0- 2.0 sec  44.4 MBytes   183 Mbits/sec
[  5]  0.0- 2.0 sec  64.8 MBytes   268 Mbits/sec
[  8]  0.0- 2.0 sec  64.4 MBytes   266 Mbits/sec
[ 11]  0.0- 2.0 sec   110 MBytes   456 Mbits/sec
[ 12]  0.0- 2.0 sec  43.2 MBytes   179 Mbits/sec
[ 13]  0.0- 2.0 sec  64.4 MBytes   266 Mbits/sec
[ 16]  0.0- 2.0 sec  42.9 MBytes   178 Mbits/sec
[ 15]  0.0- 2.0 sec  76.9 MBytes   318 Mbits/sec
[ 14]  0.0- 2.0 sec  43.8 MBytes   181 Mbits/sec
[ 19]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 18]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 21]  0.0- 2.0 sec  43.8 MBytes   181 Mbits/sec
[ 20]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 22]  0.0- 2.0 sec  89.5 MBytes   371 Mbits/sec
[ 23]  0.0- 2.0 sec  43.6 MBytes   180 Mbits/sec
[ 24]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 27]  0.0- 2.0 sec  89.2 MBytes   371 Mbits/sec
[ 28]  0.0- 2.0 sec  89.4 MBytes   371 Mbits/sec
[ 25]  0.0- 2.0 sec   109 MBytes   455 Mbits/sec
[ 31]  0.0- 2.0 sec  43.9 MBytes   181 Mbits/sec
[ 26]  0.0- 2.0 sec  26.4 MBytes   109 Mbits/sec
[ 29]  0.0- 2.0 sec  64.5 MBytes   267 Mbits/sec
[ 30]  0.0- 2.0 sec  77.0 MBytes   318 Mbits/sec
[ 33]  0.0- 2.0 sec  77.0 MBytes   318 Mbits/sec
```

```
[ 34]  0.0- 2.0 sec  43.0 MBytes   178 Mbits/sec
[ 35]  0.0- 2.0 sec  68.9 MBytes   285 Mbits/sec
[ 37]  0.0- 2.0 sec  89.4 MBytes   371 Mbits/sec
[ 36]  0.0- 2.0 sec  89.2 MBytes   370 Mbits/sec
[ 40]  0.0- 2.0 sec  76.8 MBytes   318 Mbits/sec
[ 39]  0.0- 2.0 sec  64.1 MBytes   265 Mbits/sec
[ 41]  0.0- 2.0 sec  89.2 MBytes   370 Mbits/sec
[ 43]  0.0- 2.0 sec  42.8 MBytes   177 Mbits/sec
[ 42]  0.0- 2.0 sec  43.8 MBytes   181 Mbits/sec
[ 44]  0.0- 2.0 sec  76.9 MBytes   318 Mbits/sec
[ 48]  0.0- 2.0 sec  68.8 MBytes   285 Mbits/sec
[ 45]  0.0- 2.0 sec  42.5 MBytes   177 Mbits/sec
[ 47]  0.0- 2.0 sec  68.9 MBytes   285 Mbits/sec
[ 50]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 51]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 49]  0.0- 2.0 sec  29.2 MBytes   121 Mbits/sec
[ 17]  0.0- 2.0 sec  30.2 MBytes   124 Mbits/sec
[ 38]  0.0- 2.1 sec  77.0 MBytes   313 Mbits/sec
[ 46]  0.0- 2.1 sec  43.1 MBytes   175 Mbits/sec
[SUM]  0.0- 2.1 sec  4.21 GBytes  17.5 Gbits/sec
```

A.5 IO performance

Listing A.5: Output of the `fio` command

```
$ fio --rw=write --ioengine=sync --fdatasync=1 --direct=1 --directory=io-test-data --size=2g --bs=4k --name=iotest
iotest: (g=0): rw=write, bs=(R) 4096B-4096B, (W) 4096B-4096B, (T) 4096B-4096B, ioengine=sync, iodepth=1
fio-3.16
Starting 1 process
iotest: Laying out IO file (1 file / 2048MiB)
Jobs: 1 (f=1): [W(1)][100.0%][w=70.5MiB/s][w=18.1k IOPS][eta 00m:00s]
iotest: (groupid=0, jobs=1): err= 0: pid=371625: Thu Jun 15 16:05:45 2023
  write: IOPS=18.1k, BW=70.5MiB/s (73.9MB/s)(2048MiB/29043msec); 0 zone resets
    clat (usec): min=21, max=614, avg=23.74, stdev= 2.60
     lat (usec): min=21, max=614, avg=23.81, stdev= 2.62
    clat percentiles (nsec):
     |  1.00th=[22144],  5.00th=[22400], 10.00th=[22400], 20.00th=[22656],
     | 30.00th=[22912], 40.00th=[23168], 50.00th=[23168], 60.00th=[23424],
     | 70.00th=[23680], 80.00th=[23936], 90.00th=[24448], 95.00th=[25728],
     | 99.00th=[35584], 99.50th=[39168], 99.90th=[46336], 99.95th=[50944],
     | 99.99th=[69120]
   bw (  KiB/s): min=67784, max=72968, per=99.99%, avg=72201.86, stdev=688.73, samples=58
   iops        : min=16946, max=18242, avg=18050.45, stdev=172.17, samples=58
  lat (usec)   : 50=99.95%, 100=0.05%, 250=0.01%, 750=0.01%
  fsync/fdatasync/sync_file_range:
    sync (usec): min=27, max=3659, avg=30.78, stdev=12.40
    sync percentiles (nsec):
     |  1.00th=[28544],  5.00th=[28800], 10.00th=[29056], 20.00th=[29312],
     | 30.00th=[29568], 40.00th=[29568], 50.00th=[29824], 60.00th=[30336],
     | 70.00th=[30592], 80.00th=[30848], 90.00th=[31616], 95.00th=[35584],
     | 99.00th=[47872], 99.50th=[51456], 99.90th=[61184], 99.95th=[67072],
     | 99.99th=[90624]
  cpu          : usr=4.24%, sys=21.50%, ctx=1572866, majf=0, minf=13
  IO depths    : 1=200.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
     submit    : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
     complete  : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
     issued rwts: total=0,524288,0,0 short=524287,0,0,0 dropped=0,0,0,0
     latency   : target=0, window=0, percentile=100.00%, depth=1

Run status group 0 (all jobs):
  WRITE: bw=70.5MiB/s (73.9MB/s), 70.5MiB/s-70.5MiB/s (73.9MB/s-73.9MB/s), io=2048MiB (2147MB), run=29043-29043msec

Disk stats (read/write):
  nvme2n1: ios=0/1047263, merge=0/4, ticks=0/19506, in_queue=19506, util=99.74%
```

A.6 Datagen configuration

Listing A.6: Contents of `params-sf30.ini` used for scale factor 30

```
ldbc.snb.datagen.generator.scaleFactor:snb.interactive.30
ldbc.snb.datagen.serializer.numUpdatePartitions:32

ldbc.snb.datagen.serializer.dynamicActivitySerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.activity.CsvCompositeDynamicActivitySerializer
ldbc.snb.datagen.serializer.dynamicPersonSerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.person.CsvCompositeDynamicPersonSerializer
ldbc.snb.datagen.serializer.staticSerializer:ldbc.snb.datagen.serializer.snb.csv.staticserializer.CsvCompositeStaticSerializer
```

Listing A.7: Contents of `params-sf100.ini` used for scale factor 100

```
ldbc.snb.datagen.generator.scaleFactor:snb.interactive.100
ldbc.snb.datagen.serializer.numUpdatePartitions:32

ldbc.snb.datagen.serializer.dynamicActivitySerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.activity.CsvCompositeDynamicActivitySerializer
ldbc.snb.datagen.serializer.dynamicPersonSerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.person.CsvCompositeDynamicPersonSerializer
ldbc.snb.datagen.serializer.staticSerializer:ldbc.snb.datagen.serializer.snb.csv.staticserializer.CsvCompositeStaticSerializer
```

Listing A.8: Contents of `params-sf300.ini` used for scale factor 300

```
ldbc.snb.datagen.generator.scaleFactor:snb.interactive.300
ldbc.snb.datagen.serializer.numUpdatePartitions:32

ldbc.snb.datagen.serializer.dynamicActivitySerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.activity.CsvCompositeDynamicActivitySerializer
ldbc.snb.datagen.serializer.dynamicPersonSerializer:ldbc.snb.datagen.serializer.snb.csv.dynamicserializer.person.CsvCompositeDynamicPersonSerializer
ldbc.snb.datagen.serializer.staticSerializer:ldbc.snb.datagen.serializer.snb.csv.staticserializer.CsvCompositeStaticSerializer
```

A.7 Import configuration

Listing A.9: Content of `import.conf` describing the data schema

```
graph:
  graph_store: mutable_csr
  vertex:
    - label_name: PLACE
      properties:
        - name: _ID
          type: int64
        - name: name
          type: String
        - name: url
          type: String
        - name: type
          type: String
      max_vertex_num: 1460
```

```
    - label_name: PERSON
      properties:
        - name: _ID
          type: int64
        - name: firstName
          type: String
        - name: lastName
          type: String
        - name: gender
          type: String
        - name: birthday
          type: Date
        - name: creationDate
          type: Date
        - name: locationIP
          type: String
        - name: browserUsed
          type: String
        - name: language
          type: String
        - name: email
          type: String
      max_vertex_num: 1254000
    - label_name: COMMENT
      properties:
        - name: _ID
          type: int64
        - name: creationDate
          type: Date
        - name: locationIP
          type: String
        - name: browserUsed
          type: String
        - name: content
          type: String
        - name: length
          type: int32
      max_vertex_num: 762949871
    - label_name: POST
      properties:
        - name: _ID
          type: int64
        - name: imageFile
          type: String
        - name: creationDate
          type: Date
        - name: locationIP
          type: String
        - name: browserUsed
          type: String
        - name: language
          type: String
        - name: content
          type: String
        - name: length
          type: int32
      max_vertex_num: 187893047
    - label_name: FORUM
```

```
      properties:
        - name: _ID
          type: int64
        - name: title
          type: String
        - name: creationDate
          type: Date
      max_vertex_num: 12549398
    - label_name: ORGANISATION
      properties:
        - name: _ID
          type: int64
        - name: type
          type: String
        - name: name
          type: String
        - name: url
          type: String
      max_vertex_num: 7955
    - label_name: TAGCLASS
      properties:
        - name: _ID
          type: int64
        - name: name
          type: String
        - name: url
          type: String
      max_vertex_num: 71
    - label_name: TAG
      properties:
        - name: _ID
          type: int64
        - name: name
          type: String
        - name: url
          type: String
      max_vertex_num: 16080
  edge:
    - src_label_name: COMMENT
      dst_label_name: PERSON
      edge_label_name: HASCREATOR
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: POST
      dst_label_name: PERSON
      edge_label_name: HASCREATOR
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: POST
      dst_label_name: TAG
```

```
      edge_label_name: HASTAG
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
    - src_label_name: COMMENT
      dst_label_name: COMMENT
      edge_label_name: REPLYOF
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: COMMENT
      dst_label_name: POST
      edge_label_name: REPLYOF
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: FORUM
      dst_label_name: POST
      edge_label_name: CONTAINEROF
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: None
      incoming_edge_strategy: Single
    - src_label_name: FORUM
      dst_label_name: PERSON
      edge_label_name: HASMEMBER
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
        - name: joinDate
          type: Date
      outgoing_edge_strategy: None
    - src_label_name: FORUM
      dst_label_name: PERSON
      edge_label_name: HASMODERATOR
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
      incoming_edge_strategy: None
    - src_label_name: PERSON
      dst_label_name: TAG
      edge_label_name: HASINTEREST
```

```
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      incoming_edge_strategy: None
    - src_label_name: COMMENT
      dst_label_name: PLACE
      edge_label_name: ISLOCATEDIN
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: None
    - src_label_name: PERSON
      dst_label_name: PLACE
      edge_label_name: ISLOCATEDIN
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: POST
      dst_label_name: PLACE
      edge_label_name: ISLOCATEDIN
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: None
    - src_label_name: ORGANISATION
      dst_label_name: PLACE
      edge_label_name: ISLOCATEDIN
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: PERSON
      dst_label_name: PERSON
      edge_label_name: KNOWS
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
        - name: creationDate
          type: Date
    - src_label_name: PERSON
      dst_label_name: COMMENT
      edge_label_name: LIKES
      properties:
        - name: _SRC
          type: int64
```

```
        - name: _DST
          type: int64
        - name: creationDate
          type: Date
      outgoing_edge_strategy: None
    - src_label_name: PERSON
      dst_label_name: POST
      edge_label_name: LIKES
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
        - name: creationDate
          type: Date
      outgoing_edge_strategy: None
    - src_label_name: PERSON
      dst_label_name: ORGANISATION
      edge_label_name: WORKAT
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
        - name: workFrom
          type: int32
    - src_label_name: PLACE
      dst_label_name: PLACE
      edge_label_name: ISPARTOF
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: TAG
      dst_label_name: TAGCLASS
      edge_label_name: HASTYPE
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: TAGCLASS
      dst_label_name: TAGCLASS
      edge_label_name: ISSUBCLASSOF
      properties:
        - name: _SRC
          type: int64
        - name: _DST
          type: int64
      outgoing_edge_strategy: Single
    - src_label_name: PERSON
      dst_label_name: ORGANISATION
      edge_label_name: STUDYAT
      properties:
        - name: _SRC
```

```
          type: int64
        - name: _DST
          type: int64
        - name: studyFrom
          type: int32
      incoming_edge_strategy: None

stored_procedures:
  - /disk2/ldbc_snb_audit/stored_procedures/libic1.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic2.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic3.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic4.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic5.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic6.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic7.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic8.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic9.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic10.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic11.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic12.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic13.so
  - /disk2/ldbc_snb_audit/stored_procedures/libic14.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis1.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis2.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis3.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis4.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis5.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis6.so
  - /disk2/ldbc_snb_audit/stored_procedures/libis7.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins1.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins2.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins3.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins4.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins5.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins6.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins7.so
  - /disk2/ldbc_snb_audit/stored_procedures/libins8.so
```

A.8 Benchmark configuration

Listing A.10: Contents of `benchmark_sf30_32p.properties` used for scale factor 30

```
url=http://172.31.11.250:10000

printQueryNames=false
printQueryStrings=false
printQueryResults=false

status=1
thread_count=48
name=LDBC-SNB
mode=execute_benchmark
results_log=true
status=1
time_unit=MICROSECONDS
time_compression_ratio=0.00112
peer_identifiers=
workload_statistics=false
spinner_wait_duration=1
help=false
ignore_scheduled_start_times=false

workload=org.ldbcouncil.snb.driver.workloads.interactive.LdbcSnbInteractiveWorkload
db=org.ldbcoucil.snb.impls.workloads.graphscope.interactive.GraphScopeInteractiveDb


ldbc.snb.interactive.updates_dir=/disk1/sf30_32p/social_network/
ldbc.snb.interactive.parameters_dir=/disk1/sf30_32p/substitution_parameters/
ldbc.snb.interactive.short_read_dissipation=0.2
# Supported scale factors are 0.1, 0.3, 1, 3, 10, 30, 100, 300, 1000
ldbc.snb.interactive.scale_factor=30

operation_count=245000000
warmup=58000000

ldbc.snb.interactive.LdbcQuery1_enable=true
ldbc.snb.interactive.LdbcQuery2_enable=true
ldbc.snb.interactive.LdbcQuery3_enable=true
ldbc.snb.interactive.LdbcQuery4_enable=true
ldbc.snb.interactive.LdbcQuery5_enable=true
ldbc.snb.interactive.LdbcQuery6_enable=true
ldbc.snb.interactive.LdbcQuery7_enable=true
ldbc.snb.interactive.LdbcQuery8_enable=true
ldbc.snb.interactive.LdbcQuery9_enable=true
ldbc.snb.interactive.LdbcQuery10_enable=true
ldbc.snb.interactive.LdbcQuery11_enable=true
ldbc.snb.interactive.LdbcQuery12_enable=true
ldbc.snb.interactive.LdbcQuery13_enable=true
ldbc.snb.interactive.LdbcQuery14_enable=true

ldbc.snb.interactive.LdbcShortQuery1PersonProfile_enable=true
ldbc.snb.interactive.LdbcShortQuery2PersonPosts_enable=true
ldbc.snb.interactive.LdbcShortQuery3PersonFriends_enable=true
ldbc.snb.interactive.LdbcShortQuery4MessageContent_enable=true
ldbc.snb.interactive.LdbcShortQuery5MessageCreator_enable=true
ldbc.snb.interactive.LdbcShortQuery6MessageForum_enable=true
```

```
ldbc.snb.interactive.LdbcShortQuery7MessageReplies_enable=true

ldbc.snb.interactive.LdbcUpdate1AddPerson_enable=true
ldbc.snb.interactive.LdbcUpdate2AddPostLike_enable=true
ldbc.snb.interactive.LdbcUpdate3AddCommentLike_enable=true
ldbc.snb.interactive.LdbcUpdate4AddForum_enable=true
ldbc.snb.interactive.LdbcUpdate5AddForumMembership_enable=true
ldbc.snb.interactive.LdbcUpdate6AddPost_enable=true
ldbc.snb.interactive.LdbcUpdate7AddComment_enable=true
ldbc.snb.interactive.LdbcUpdate8AddFriendship_enable=true
```

Listing A.11: Contents of `benchmark_sf100_32p.properties` used for scale factor 100

```
url=http://172.31.11.250:10000

printQueryNames=false
printQueryStrings=false
printQueryResults=false

status=1
thread_count=48
name=LDBC-SNB
mode=execute_benchmark
results_log=true
status=1
time_unit=MICROSECONDS
time_compression_ratio=0.0039
peer_identifiers=
workload_statistics=false
spinner_wait_duration=1
help=false
ignore_scheduled_start_times=false

workload=org.ldbcouncil.snb.driver.workloads.interactive.LdbcSnbInteractiveWorkload
db=org.ldbcoucil.snb.impls.workloads.graphscope.interactive.GraphScopeInteractiveDb


ldbc.snb.interactive.updates_dir=/disk1/sf100_32p/social_network/
ldbc.snb.interactive.parameters_dir=/disk1/sf100_32p/substitution_parameters/
ldbc.snb.interactive.short_read_dissipation=0.2
# Supported scale factors are 0.1, 0.3, 1, 3, 10, 30, 100, 300, 1000
ldbc.snb.interactive.scale_factor=100

operation_count=245000000
warmup=65000000

ldbc.snb.interactive.LdbcQuery1_enable=true
ldbc.snb.interactive.LdbcQuery2_enable=true
ldbc.snb.interactive.LdbcQuery3_enable=true
ldbc.snb.interactive.LdbcQuery4_enable=true
ldbc.snb.interactive.LdbcQuery5_enable=true
ldbc.snb.interactive.LdbcQuery6_enable=true
ldbc.snb.interactive.LdbcQuery7_enable=true
ldbc.snb.interactive.LdbcQuery8_enable=true
ldbc.snb.interactive.LdbcQuery9_enable=true
ldbc.snb.interactive.LdbcQuery10_enable=true
ldbc.snb.interactive.LdbcQuery11_enable=true
ldbc.snb.interactive.LdbcQuery12_enable=true
```

```
ldbc.snb.interactive.LdbcQuery13_enable=true
ldbc.snb.interactive.LdbcQuery14_enable=true

ldbc.snb.interactive.LdbcShortQuery1PersonProfile_enable=true
ldbc.snb.interactive.LdbcShortQuery2PersonPosts_enable=true
ldbc.snb.interactive.LdbcShortQuery3PersonFriends_enable=true
ldbc.snb.interactive.LdbcShortQuery4MessageContent_enable=true
ldbc.snb.interactive.LdbcShortQuery5MessageCreator_enable=true
ldbc.snb.interactive.LdbcShortQuery6MessageForum_enable=true
ldbc.snb.interactive.LdbcShortQuery7MessageReplies_enable=true

ldbc.snb.interactive.LdbcUpdate1AddPerson_enable=true
ldbc.snb.interactive.LdbcUpdate2AddPostLike_enable=true
ldbc.snb.interactive.LdbcUpdate3AddCommentLike_enable=true
ldbc.snb.interactive.LdbcUpdate4AddForum_enable=true
ldbc.snb.interactive.LdbcUpdate5AddForumMembership_enable=true
ldbc.snb.interactive.LdbcUpdate6AddPost_enable=true
ldbc.snb.interactive.LdbcUpdate7AddComment_enable=true
ldbc.snb.interactive.LdbcUpdate8AddFriendship_enable=true
```

Listing A.12: Contents of `benchmark_sf300_32p.properties` used for scale factor 300

```
url=http://172.31.11.250:10000

printQueryNames=false
printQueryStrings=false
printQueryResults=false

status=1
thread_count=48
name=LDBC-SNB
mode=execute_benchmark
results_log=true
status=1
time_unit=MICROSECONDS
time_compression_ratio=0.014
peer_identifiers=
workload_statistics=false
spinner_wait_duration=1
help=false
ignore_scheduled_start_times=false

workload=org.ldbcouncil.snb.driver.workloads.interactive.LdbcSnbInteractiveWorkload
db=org.ldbcoucil.snb.impls.workloads.graphscope.interactive.GraphScopeInteractiveDb


ldbc.snb.interactive.updates_dir=/disk1/sf300_32p/social_network/
ldbc.snb.interactive.parameters_dir=/disk1/sf300_32p/substitution_parameters/
ldbc.snb.interactive.short_read_dissipation=0.2
# Supported scale factors are 0.1, 0.3, 1, 3, 10, 30, 100, 300, 1000
ldbc.snb.interactive.scale_factor=300

operation_count=245000000
warmup=57000000

ldbc.snb.interactive.LdbcQuery1_enable=true
ldbc.snb.interactive.LdbcQuery2_enable=true
ldbc.snb.interactive.LdbcQuery3_enable=true
```

```
ldbc.snb.interactive.LdbcQuery4_enable=true
ldbc.snb.interactive.LdbcQuery5_enable=true
ldbc.snb.interactive.LdbcQuery6_enable=true
ldbc.snb.interactive.LdbcQuery7_enable=true
ldbc.snb.interactive.LdbcQuery8_enable=true
ldbc.snb.interactive.LdbcQuery9_enable=true
ldbc.snb.interactive.LdbcQuery10_enable=true
ldbc.snb.interactive.LdbcQuery11_enable=true
ldbc.snb.interactive.LdbcQuery12_enable=true
ldbc.snb.interactive.LdbcQuery13_enable=true
ldbc.snb.interactive.LdbcQuery14_enable=true

ldbc.snb.interactive.LdbcShortQuery1PersonProfile_enable=true
ldbc.snb.interactive.LdbcShortQuery2PersonPosts_enable=true
ldbc.snb.interactive.LdbcShortQuery3PersonFriends_enable=true
ldbc.snb.interactive.LdbcShortQuery4MessageContent_enable=true
ldbc.snb.interactive.LdbcShortQuery5MessageCreator_enable=true
ldbc.snb.interactive.LdbcShortQuery6MessageForum_enable=true
ldbc.snb.interactive.LdbcShortQuery7MessageReplies_enable=true

ldbc.snb.interactive.LdbcUpdate1AddPerson_enable=true
ldbc.snb.interactive.LdbcUpdate2AddPostLike_enable=true
ldbc.snb.interactive.LdbcUpdate3AddCommentLike_enable=true
ldbc.snb.interactive.LdbcUpdate4AddForum_enable=true
ldbc.snb.interactive.LdbcUpdate5AddForumMembership_enable=true
ldbc.snb.interactive.LdbcUpdate6AddPost_enable=true
ldbc.snb.interactive.LdbcUpdate7AddComment_enable=true
ldbc.snb.interactive.LdbcUpdate8AddFriendship_enable=true
```

A.9 Validation configuration

Listing A.13: The contents of `validate.properties`

```
url=http://172.31.11.250:10000
readTimeout=5000000
connectTimeout=5000000
connectPoolMaxIdle=10
keepAliveDuration=5000
maxRequestsPerHost=180
maxRequests=180

printQueryNames=false
printQueryStrings=false
printQueryResults=false

status=1
thread_count=1
mode=validate_database
name=LDBC-SNB
results_log=false
time_unit=MILLISECONDS
time_compression_ratio=0.001
peer_identifiers=
workload_statistics=false
spinner_wait_duration=0
help=false
```

```
ignore_scheduled_start_times=true

ldbc.snb.interactive.update_interleave=895969
workload=org.ldbcouncil.snb.driver.workloads.interactive.LdbcSnbInteractiveWorkload
db=org.ldbcoucil.snb.impls.workloads.graphscope.interactive.GraphScopeInteractiveDb

operation_count=10000

validate_database=/disk1/sf10_1p/validation_params.csv
ldbc.snb.interactive.parameters_dir=/disk1/sf10_1p/substitution_parameters/
ldbc.snb.interactive.short_read_dissipation=0.2
# Supported scale factors are 0.1, 0.3, 1, 3, 10, 30, 100, 300, 1000
ldbc.snb.interactive.scale_factor=10

ldbc.snb.interactive.LdbcQuery1_freq=1
ldbc.snb.interactive.LdbcQuery2_freq=1
ldbc.snb.interactive.LdbcQuery3_freq=1
ldbc.snb.interactive.LdbcQuery4_freq=1
ldbc.snb.interactive.LdbcQuery5_freq=1
ldbc.snb.interactive.LdbcQuery6_freq=1
ldbc.snb.interactive.LdbcQuery7_freq=1
ldbc.snb.interactive.LdbcQuery8_freq=1
ldbc.snb.interactive.LdbcQuery9_freq=1
ldbc.snb.interactive.LdbcQuery10_freq=1
ldbc.snb.interactive.LdbcQuery11_freq=1
ldbc.snb.interactive.LdbcQuery12_freq=1
ldbc.snb.interactive.LdbcQuery13_freq=1
ldbc.snb.interactive.LdbcQuery14_freq=1

ldbc.snb.interactive.LdbcQuery1_enable=true
ldbc.snb.interactive.LdbcQuery2_enable=true
ldbc.snb.interactive.LdbcQuery3_enable=true
ldbc.snb.interactive.LdbcQuery4_enable=true
ldbc.snb.interactive.LdbcQuery5_enable=true
ldbc.snb.interactive.LdbcQuery6_enable=true
ldbc.snb.interactive.LdbcQuery7_enable=true
ldbc.snb.interactive.LdbcQuery8_enable=true
ldbc.snb.interactive.LdbcQuery9_enable=true
ldbc.snb.interactive.LdbcQuery10_enable=true
ldbc.snb.interactive.LdbcQuery11_enable=true
ldbc.snb.interactive.LdbcQuery12_enable=true
ldbc.snb.interactive.LdbcQuery13_enable=true
ldbc.snb.interactive.LdbcQuery14_enable=true

ldbc.snb.interactive.LdbcShortQuery1PersonProfile_enable=true
ldbc.snb.interactive.LdbcShortQuery2PersonPosts_enable=true
ldbc.snb.interactive.LdbcShortQuery3PersonFriends_enable=true
ldbc.snb.interactive.LdbcShortQuery4MessageContent_enable=true
ldbc.snb.interactive.LdbcShortQuery5MessageCreator_enable=true
ldbc.snb.interactive.LdbcShortQuery6MessageForum_enable=true
ldbc.snb.interactive.LdbcShortQuery7MessageReplies_enable=true

ldbc.snb.interactive.LdbcUpdate1AddPerson_enable=true
ldbc.snb.interactive.LdbcUpdate2AddPostLike_enable=true
ldbc.snb.interactive.LdbcUpdate3AddCommentLike_enable=true
ldbc.snb.interactive.LdbcUpdate4AddForum_enable=true
ldbc.snb.interactive.LdbcUpdate5AddForumMembership_enable=true
ldbc.snb.interactive.LdbcUpdate6AddPost_enable=true
```

```
ldbc.snb.interactive.LdbcUpdate7AddComment_enable=true
ldbc.snb.interactive.LdbcUpdate8AddFriendship_enable=true
```