

Apache Ignite: analisi di una piattaforma distribuita di elaborazione in-memory

Corso di Laurea Magistrale in Ingegneria e Scienze Informatiche
Progetto di Sistemi Distribuiti - A.A. 2019/2020

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Cos'è Apache Ignite

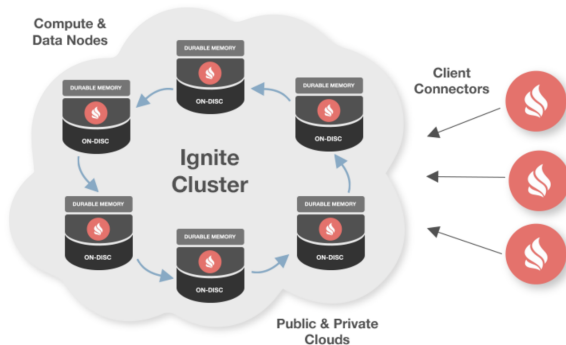
Apache Ignite è un framework che funge congiuntamente da:

- piattaforma distribuita di elaborazione
- DBMS distribuito



che sfrutta un **cluster** di nodi in grado di operare completamente **in-memory**.

Architettura fisica



Ignite adotta un'architettura di tipo **shared-nothing**, caratterizzata dall'assenza di un coordinatore che guidi gli altri componenti, che sono invece tutti considerati come entità di pari livello.

I nodi che compongono la topologia ad anello del cluster, in grado di trovarsi e collegarsi tra di loro autonomamente grazie al **meccanismo di discovery**, possono essere di due tipi:

- **server**: gestisce la memorizzazione dei dati in cache e partecipa alle computazioni
- **client**: consente di collegarsi da remoto ai nodi server e di interrogarli

Architettura di memoria

Esistono 3 diverse modalità con cui Ignite può operare:

- **Modalità memory-only:** viene usata unicamente la memoria RAM sia per le computazioni sia per la persistenza dei dati che vengono memorizzati in **cache**
- **Modalità native persistence:** viene utilizzato anche il disco, interno al nodo Ignite, per memorizzare una copia dei dati delle cache
- **Modalità external storage:** in questo caso Ignite viene utilizzato come layer di caching al di sopra di un database esistente

Data modeling

Livello fisico

A livello fisico, i dati vengono memorizzati (in cache e su disco) in formato binario.

Livello logico

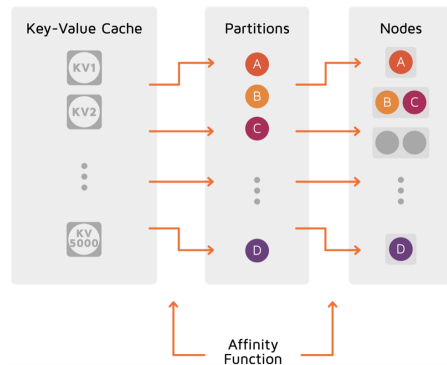
A livello logico, è possibile scegliere tra 2 diverse rappresentazioni:

- **Key-Value:** i dati vengono rappresentati sotto forma di coppie chiave-valore. Supporta operazioni di *get*, *put* e *delete*
- **SQL Table:** i dati vengono rappresentati mediante tabelle simili alla corrispondente nozione degli RDBMS

Data partitioning

I dati memorizzati in cache vengono partizionati e distribuiti tra i nodi del cluster tramite un'apposita **affinity function** che si occupa da un lato di suddividere i dati in partizioni, dall'altro di distribuire tali partizioni tra i nodi server. È possibile scegliere tra 2 diverse topologie di caching:

- **Partitioned:** le partizioni vengono uniformemente suddivise tra i nodi server, ciascuno dei quali può opzionalmente memorizzare una o più copie di backup
- **Replicated:** le partizioni vengono interamente replicate su ogni nodo server del cluster



Proprietà distribuite

Apache Ignite può essere inquadrato attraverso le seguenti proprietà distribuite:

- **Elasticità:** possibilità di scalare orizzontalmente in maniera illimitata
- **High Availability:** possibilità di impostare copie di backup dei dati
- **Fault Tolerance:** grazie ai backup e alla (opzionale) persistenza su disco
- **Safety:** capacità di gestire in maniera trasparente le failure momentanee
- **Strong Persistence:** grazie alla persistenza (nativa o esterna)
- **Teorema CAP:** possibilità di comportarsi da sistema AP (in modalità atomica) o da sistema CP (in modalità transazionale)

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 - Caching - Scenario 1.5: data rebalancing + Scenario 1.6: partition loss

● Native Persistence

- Native Persistence - Scenario 2.1 + Scenario 2.2: modalità WAL

● Distributed SQL

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● Distributed Computing

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● Continuous Query

● Messaging

4 Conclusioni

Feature di Ignite

- Multi-Tier Storage: **Caching, Native Persistence, External Storage**
- **Distributed SQL**
- **Distributed Transactions**
- **Distributed Computing**
- Servizi
- Machine Learning
- **Continuous Query**
- **Real-Time Data Streaming**
- **Messaging**
- **Apache Hadoop Performance Acceleration**
- **Apache Spark Performance Acceleration**

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Caching - Scenario 1.1: partitioned vs. replicated

```
ignite_test_scenarios-ignite_server-1 | MODE: partitioned
ignite_test_scenarios-ignite_server-1 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-2 | MODE: partitioned
ignite_test_scenarios-ignite_server-2 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-3 | MODE: partitioned
ignite_test_scenarios-ignite_server-3 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-4 | MODE: partitioned
ignite_test_scenarios-ignite_server-4 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_client-1 | Inserting time: 78763 ms
ignite_test_scenarios-ignite_client-1 | Reading time (bulk): 4467 ms
ignite_test_scenarios-ignite_client-1 | Reading time: 117712 ms
ignite_test_scenarios-ignite_client-1 | Updating time: 71759 ms
```

```
visor> cache -s
cache -s
Time of the snapshot: 2023-03-16 15:48:45
```

Name(s)	Mode	Nodes	Total entries (Heap / Off-heap)	Primary entries (Heap / Off-heap)	Hits	Misses	Reads	Writes
cache(c0c)	PARTITIONED	4	50000 (0 / 50000)	min: 12211 (0 / 12211) avg: 12500.00 (0.00 / 12500.00) max: 12836 (0 / 12836)	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0

Cache 'cache(c0c)':

Name(s)	Mode	Nodes	Total entries (Heap / Off-heap)	Primary entries (Heap / Off-heap)	Hits	Misses	Reads	Writes
cache(c0c)	PARTITIONED	4	50000 (0 / 50000)	min: 12211 (0 / 12211) avg: 12500.00 (0.00 / 12500.00) max: 12836 (0 / 12836)	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0

Nodes for: cache(c0c)

Node ID(s), IP	CPUs	Heap Used	CPU Load	Up Time	Size (Primary / Backup)	Hi/Li/Rd/Wr
380615A5(9n1), 172.24.0.2	4	0.24 %	0.90 %	00:06:03.464	Total: 12836 (12836 / 0) Heap: 0 (0 / <n/a>) Off-Heap: 12836 (12836 / 0) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
94EFBCD1(8n0), 172.24.0.5	4	0.48 %	1.00 %	00:06:03.710	Total: 12383 (12383 / 0) Heap: 0 (0 / <n/a>) Off-Heap: 12383 (12383 / 0) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
F8ED9F25(8n5), 172.24.0.3	4	0.63 %	0.90 %	00:06:04.469	Total: 12650 (12650 / 0) Heap: 0 (0 / <n/a>) Off-Heap: 12650 (12650 / 0) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
61E9B1B0(8n2), 172.24.0.4	4	0.45 %	1.23 %	00:06:04.462	Total: 12211 (12211 / 0) Heap: 0 (0 / <n/a>) Off-Heap: 12211 (12211 / 0) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0

```
ignite_test_scenarios-ignite_server-1 | MODE: replicated
ignite_test_scenarios-ignite_server-1 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-2 | MODE: replicated
ignite_test_scenarios-ignite_server-2 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-3 | MODE: replicated
ignite_test_scenarios-ignite_server-3 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_server-4 | MODE: replicated
ignite_test_scenarios-ignite_server-4 | >>> Server node IP address successfully stored in the volume.
ignite_test_scenarios-ignite_client-1 | Inserting time: 97008 ms
ignite_test_scenarios-ignite_client-1 | Reading time (bulk): 604 ms
ignite_test_scenarios-ignite_client-1 | Reading time: 30452 ms
ignite_test_scenarios-ignite_client-1 | Updating time: 66336 ms
```

```
visor> cache -s
cache -s
Time of the snapshot: 2023-03-16 15:50:29
```

Name(s)	Mode	Nodes	Total entries (Heap / Off-heap)	Primary entries (Heap / Off-heap)	Hits	Misses	Reads	Writes
cache(c0c)	REPLICATED	4	50000 (0 / 50000)	min: 10455 (0 / 10455) avg: 12500.00 (0.00 / 12500.00) max: 14061 (0 / 14061)	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0

Cache 'cache(c0c)':

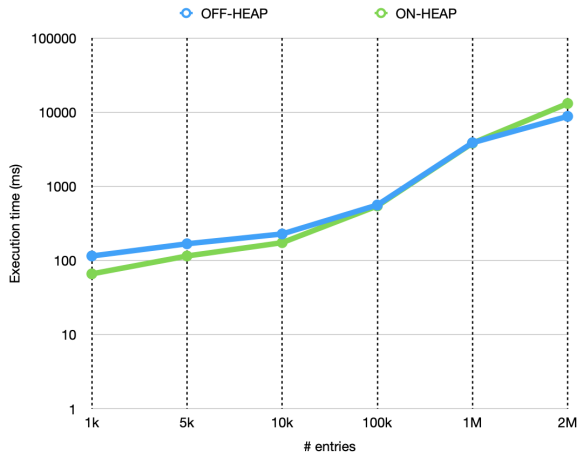
Name(s)	Mode	Nodes	Total entries (Heap / Off-heap)	Primary entries (Heap / Off-heap)	Hits	Misses	Reads	Writes
cache(c0c)	REPLICATED	4	50000 (0 / 50000)	min: 10455 (0 / 10455) avg: 12500.00 (0.00 / 12500.00) max: 14061 (0 / 14061)	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0	min: 0 avg: 0.00 max: 0

Nodes for: cache(c0c)

Node ID(s), IP	CPUs	Heap Used	CPU Load	Up Time	Size (Primary / Backup)	Hi/Li/Rd/Wr
D0152834(9n2), 172.23.0.4	4	0.42 %	1.00 %	00:19:04.306	Total: 50000 (13574 / 36426) Heap: 0 (0 / <n/a>) Off-Heap: 50000 (13574 / 36426) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
62E7A502(9n0), 172.23.0.2	4	0.52 %	0.10 %	00:19:08.014	Total: 50000 (10455 / 39545) Heap: 0 (0 / <n/a>) Off-Heap: 50000 (10455 / 39545) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
6C34D0A9(9n1), 172.23.0.3	4	0.61 %	1.00 %	00:19:06.288	Total: 50000 (14061 / 35939) Heap: 0 (0 / <n/a>) Off-Heap: 50000 (14061 / 35939) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0
27E3DEE8(9n3), 172.23.0.5	4	0.93 %	0.90 %	00:19:02.727	Total: 50000 (11910 / 38090) Heap: 0 (0 / <n/a>) Off-Heap: 50000 (11910 / 38090) Off-Heap Memory: <n/a>	Hi: 0 Li: 0 Rd: 0 Wr: 0

Caching - Scenario 1.2: on-heap vs. off-heap

# entries	cache operation	OFF-HEAP	ON-HEAP
1k	PUT	283	298
	GET	115	66
	UPDATE	99	116
5k	PUT	642	823
	GET	168	115
	UPDATE	108	158
10k	PUT	809	825
	GET	228	174
	UPDATE	169	194
100k	PUT	1750	1775
	GET	560	544
	UPDATE	402	720
1M	PUT	7321	10211
	GET	3879	3829
	UPDATE	3879	6151
2M	PUT	11593	22393
	GET	8801	13124
	UPDATE	8327	13509



Caching - Scenario 1.3: binary mode vs. no-binary mode

ignite_test_scenarios-ignite_client-1	Binary PUT operations time: 12783 ms
ignite_test_scenarios-ignite_client-1	Binary GET operations time: 8019 ms
ignite_test_scenarios-ignite_client-1	Binary UPDATE operations time: 13848 ms
ignite_test_scenarios-ignite_client-1	Non Binary PUT operations time: 6719 ms
ignite_test_scenarios-ignite_client-1	Non Binary GET operations time: 5221 ms
ignite_test_scenarios-ignite_client-1	Non Binary UPDATE operations time: 11199 ms
ignite_test_scenarios-ignite_client-1	Binary PUT operations time: 60879 ms
ignite_test_scenarios-ignite_client-1	Binary GET operations time: 43936 ms
ignite_test_scenarios-ignite_client-1	Binary UPDATE operations time: 90253 ms
ignite_test_scenarios-ignite_client-1	Non Binary PUT operations time: 44555 ms
ignite_test_scenarios-ignite_client-1	Non Binary GET operations time: 40393 ms
ignite_test_scenarios-ignite_client-1	Non Binary UPDATE operations time: 87937 ms
ignite_test_scenarios-ignite_client-1	Binary PUT operations time: 406156 ms
ignite_test_scenarios-ignite_client-1	Binary GET operations time: 367410 ms
ignite_test_scenarios-ignite_client-1	Binary UPDATE operations time: 809037 ms
ignite_test_scenarios-ignite_client-1	Non Binary PUT operations time: 410028 ms
ignite_test_scenarios-ignite_client-1	Non Binary GET operations time: 378006 ms
ignite_test_scenarios-ignite_client-1	Non Binary UPDATE operations time: 802644 ms

Caching - Scenario 1.4: cache group

```
ignite_test_scenarios-ignite_server-1 [20:51:49] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-1 [20:51:49] ^-- Off-heap memory [used=862MB, free=73.02%, allocated=2998MB]
ignite_test_scenarios-ignite_server-1 [20:51:49] ^-- Page memory [pages=218359]
ignite_test_scenarios-ignite_server-1 [20:51:49] ^-- Ignite persistence [used=852MB]
ignite_test_scenarios-ignite_server-2 [20:51:48] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-2 [20:51:48] ^-- Off-heap memory [used=808MB, free=74.73%, allocated=2998MB]
ignite_test_scenarios-ignite_server-2 [20:51:48] ^-- Page memory [pages=204499]
ignite_test_scenarios-ignite_server-2 [20:51:48] ^-- Ignite persistence [used=798MB]
ignite_test_scenarios-ignite_server-3 [20:51:49] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-3 [20:51:49] ^-- Off-heap memory [used=823MB, free=74.27%, allocated=2998MB]
ignite_test_scenarios-ignite_server-3 [20:51:49] ^-- Page memory [pages=208279]
ignite_test_scenarios-ignite_server-3 [20:51:49] ^-- Ignite persistence [used=813MB]

ignite_test_scenarios-ignite_server-1 [20:57:36] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-1 [20:57:36] ^-- Off-heap memory [used=0MB, free=100%, allocated=2998MB]
ignite_test_scenarios-ignite_server-1 [20:57:36] ^-- Page memory [pages=25]
ignite_test_scenarios-ignite_server-1 [20:57:36] ^-- Ignite persistence [used=0MB]
ignite_test_scenarios-ignite_server-2 [20:57:32] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-2 [20:57:32] ^-- Off-heap memory [used=35MB, free=98.88%, allocated=2998MB]
ignite_test_scenarios-ignite_server-2 [20:57:32] ^-- Page memory [pages=9025]
ignite_test_scenarios-ignite_server-2 [20:57:32] ^-- Ignite persistence [used=35MB]
ignite_test_scenarios-ignite_server-3 [20:57:37] Data storage metrics for local node (to disable set 'metricsLogFrequency' to 0)
ignite_test_scenarios-ignite_server-3 [20:57:37] ^-- Off-heap memory [used=0MB, free=100%, allocated=2998MB]
ignite_test_scenarios-ignite_server-3 [20:57:37] ^-- Page memory [pages=25]
ignite_test_scenarios-ignite_server-3 [20:57:37] ^-- Ignite persistence [used=0MB]
```

Caching - Scenario 1.5: data rebalancing + Scenario 1.6: partition loss

Node ID ↓	Cache Size	Node ID ↓	Cache Size
D489D65D	0	D489D65D	0
AD62B935	0	AD62B935	504
74E9B418	0	74E9B418	484
332C1FEA	974	332C1FEA	508
131235E4	1026	131235E4	504

Node ID ↓	Cache Size	Node ID ↓	Cache Size	Node ID ↓	Cache Size
D489D65D	0	N/A	25198	N/A	25198
AD62B935	24997	N/A	25579	N/A	25579
74E9B418	24226	D489D65D	0	D489D65D	0
332C1FEA	25579	AD62B935	24997	AD62B935	51749
131235E4	25198	74E9B418	75003	74E9B418	48251

```
ignite_test_scenarios-ignite_client-1 | Before node close.
ignite_test_scenarios-ignite_client-1 | 0
ignite_test_scenarios-ignite_client-1 | 1
ignite_test_scenarios-ignite_client-1 | 2
ignite_test_scenarios-ignite_client-1 | 3
ignite_test_scenarios-ignite_client-1 | 4
ignite_test_scenarios-ignite_client-1 | 5
ignite_test_scenarios-ignite_client-1 | 6
ignite_test_scenarios-ignite_client-1 | 7
ignite_test_scenarios-ignite_client-1 | 8
ignite_test_scenarios-ignite_client-1 | 9
ignite_test_scenarios-ignite_client-1 | Closing..
```

```
ignite_test_scenarios-ignite_client-1 | After node close.
ignite_test_scenarios-ignite_client-1 | 0
ignite_test_scenarios-ignite_client-1 | 1
ignite_test_scenarios-ignite_client-1 | 2
ignite_test_scenarios-ignite_client-1 | null
ignite_test_scenarios-ignite_client-1 | null
ignite_test_scenarios-ignite_client-1 | 5
ignite_test_scenarios-ignite_client-1 | 6
ignite_test_scenarios-ignite_client-1 | 7
ignite_test_scenarios-ignite_client-1 | 8
ignite_test_scenarios-ignite_client-1 | 9
```

```
ignite_test_scenarios-ignite_client-1 | After node close.
ignite_test_scenarios-ignite_client-1 | 0
ignite_test_scenarios-ignite_client-1 | 1
ignite_test_scenarios-ignite_client-1 | 2
ignite_test_scenarios-ignite_client-1 | class org.apache.ignite.internal.processors.cache.CacheInvalidStateException: Failed to execute the cache operation (all partition owners have left the grid, partition data has been lost) [cacheName=myCache, partition=3, key=UserKeyCacheObjectImpl [part=3, val=3, hasValBytes=true]]
ignite_test_scenarios-ignite_client-1 | class org.apache.ignite.internal.processors.cache.CacheInvalidStateException: Failed to execute the cache operation (all partition owners have left the grid, partition data has been lost) [cacheName=myCache, partition=4, key=UserKeyCacheObjectImpl [part=4, val=4, hasValBytes=false]]
ignite_test_scenarios-ignite_client-1 | 5
ignite_test_scenarios-ignite_client-1 | 6
ignite_test_scenarios-ignite_client-1 | 7
ignite_test_scenarios-ignite_client-1 | 8
ignite_test_scenarios-ignite_client-1 | 9
```

Native Persistence - Scenario 2.1 + Scenario 2.2: modalità WAL

```

ignite_test_scenarios-ignite_client-1 | WAL MODE: fsync
ignite_test_scenarios-ignite_client-1 | Inserting time: 850962 ms
ignite_test_scenarios-ignite_client-1 | [12:48:23] Ignite node stopped OK [name=s1, uptime=00:14:22.133]
ignite_test_scenarios-ignite_client-1 | [12:48:23] Ignite node stopped OK [name=s2, uptime=00:14:18.269]
ignite_test_scenarios-ignite_client-1 | >>> Servers gracefully closed
ignite_test_scenarios-ignite_client-1 | >>> Servers restarted
ignite_test_scenarios-ignite_client-1 | Re-connection of server nodes succeeded. All cache entries have been restored.

ignite_test_scenarios-ignite_client-1 | WAL MODE: fsync (with WAL optimization)
ignite_test_scenarios-ignite_client-1 | Inserting time: 403283 ms
ignite_test_scenarios-ignite_client-1 | [13:30:09] Ignite node stopped OK [name=s1, uptime=00:07:02.549]
ignite_test_scenarios-ignite_client-1 | [13:30:10] Ignite node stopped OK [name=s2, uptime=00:06:59.500]
ignite_test_scenarios-ignite_client-1 | >>> Servers gracefully closed
ignite_test_scenarios-ignite_client-1 | >>> Servers restarted
ignite_test_scenarios-ignite_client-1 | Re-connection of server nodes succeeded. All cache entries have been restored.

ignite_test_scenarios-ignite_server-1 | MODE: fsync
ignite_test_scenarios-ignite_server-2 | MODE: fsync
ignite_test_scenarios-ignite_client-1 | Inserting time: 48896 ms
ignite_test_scenarios-ignite_client-1 | >>> Server nodes (simulated) crash is going to happen...
ignite_test_scenarios-ignite_client-1 | Disk copies of all cache entries are up-to-date. No data loss occurred following the simulated crash of the nodes.

ignite_test_scenarios-ignite_server-1 | MODE: background
ignite_test_scenarios-ignite_server-2 | MODE: background
ignite_test_scenarios-ignite_client-1 | Inserting time: 31256 ms
ignite_test_scenarios-ignite_client-1 | >>> Server nodes (simulated) crash is going to happen...
ignite_test_scenarios-ignite_client-1 | Disk copies of all cache entries are up-to-date. No data loss occurred following the simulated crash of the nodes.

ignite_test_scenarios-ignite_server-1 | MODE: none
ignite_test_scenarios-ignite_server-2 | MODE: none
ignite_test_scenarios-ignite_client-1 | Inserting time: 18535 ms
ignite_test_scenarios-ignite_client-1 | >>> Server nodes (simulated) crash is going to happen...
ignite_test_scenarios-ignite_client-1 | Disk copies of the cache entries have not been set because of the simulated crash of the nodes. Data loss occurred.

ignite_test_scenarios-ignite_server-1 | MODE: none
ignite_test_scenarios-ignite_server-2 | MODE: none
ignite_test_scenarios-ignite_client-1 | Inserting time: 17519 ms
ignite_test_scenarios-ignite_client-1 | >>> Gracefully deactivation of the cluster is going to happen...
ignite_test_scenarios-ignite_client-1 | Disk copies of all cache entries are up-to-date. No data loss occurred following the simulated crash of the nodes.

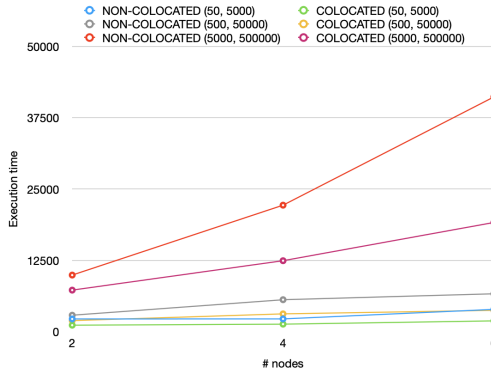
```

Distributed SQL - Scenario 3.2: colocated vs. non-colocated

[illegible]

Distributed SQL - Scenario 3.2: colocated vs. non-colocated

# nodes	NON-COLOCATED (50, 5000)	COLOCATED (50, 5000)	NON-COLOCATED (500, 50000)	COLOCATED (500, 50000)	NON-COLOCATED (5000, 500000)	COLOCATED (5000, 500000)
2	2231	1135	2882	1941	9920	7284
4	2237	1319	5603	3120	22177	12440
6	3911	1897	6645	3749	41157	19143



Distributed Computing - Scenario 4.3 + Scenario 4.2: checkpointing

```
ignite_test_scenarios-ignite_server-2 | >>> Job will be failed over to another server node
ignite_test_scenarios-ignite_server-1 | >>> Computation restarted from checkpoint
ignite_test_scenarios-ignite_client-1 | +++ COMPUTATION WITH CHECKPOINT +++
ignite_test_scenarios-ignite_client-1 | Primes numbers smaller than 500000 are 41538
ignite_test_scenarios-ignite_client-1 | Sample output: [2, 3, 5, 7, 11, 13, 17, 19, 23, 29]
ignite_test_scenarios-ignite_client-1 | Execution time: 211372 ms
```

```
ignite_test_scenarios-ignite_server-1 | >>> Job will be failed over to another server node
ignite_test_scenarios-ignite_client-1 | +++ COMPUTATION WITHOUT CHECKPOINT +++
ignite_test_scenarios-ignite_client-1 | Primes numbers smaller than 500000 are 41538
ignite_test_scenarios-ignite_client-1 | Sample output: [2, 3, 5, 7, 11, 13, 17, 19, 23, 29]
ignite_test_scenarios-ignite_client-1 | Execution time: 344640 ms
```

```
ignite_test_scenarios-ignite_server-1 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 131 ms
ignite_test_scenarios-ignite_server-1 | JOB 4 (with simulated failure and checkpointing) - MAP - Compute time: 60 ms
ignite_test_scenarios-ignite_server-1 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint save time: 616 ms
ignite_test_scenarios-ignite_server-1 | >>> A (simulated) node crash happened. Map job will be failed over to another node.
ignite_test_scenarios-ignite_server-1 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 197 ms
ignite_test_scenarios-ignite_server-1 | JOB 4 (with simulated failure and checkpointing) - MAP - Execute from checkpoint
ignite_test_scenarios-ignite_server-2 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 73 ms
ignite_test_scenarios-ignite_server-2 | JOB 4 (with simulated failure and checkpointing) - MAP - Compute time: 14 ms
ignite_test_scenarios-ignite_server-2 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint save time: 250 ms
ignite_test_scenarios-ignite_server-2 | >>> A (simulated) node crash happened. Map job will be failed over to another node.
ignite_test_scenarios-ignite_server-2 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 141 ms
ignite_test_scenarios-ignite_server-2 | JOB 4 (with simulated failure and checkpointing) - MAP - Execute from checkpoint
ignite_test_scenarios-ignite_server-3 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 254 ms
ignite_test_scenarios-ignite_server-3 | JOB 4 (with simulated failure and checkpointing) - MAP - Compute time: 39 ms
ignite_test_scenarios-ignite_server-3 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint save time: 415 ms
ignite_test_scenarios-ignite_server-3 | >>> A (simulated) node crash happened. Map job will be failed over to another node.
ignite_test_scenarios-ignite_server-3 | JOB 4 (with simulated failure and checkpointing) - MAP - Checkpoint load time: 354 ms
ignite_test_scenarios-ignite_server-3 | JOB 4 (with simulated failure and checkpointing) - MAP - Execute from checkpoint
```

```
ignite_test_scenarios-ignite_client-1 | >>> JOB 1 - MAP INPUT SIZE: 14747 - GRID SIZE: 3
ignite_test_scenarios-ignite_client-1 | JOB 1 - split
ignite_test_scenarios-ignite_client-1 | JOB 1 - split
ignite_test_scenarios-ignite_client-1 | JOB 1 - split
ignite_test_scenarios-ignite_client-1 | >>> JOB 2 - MAP INPUT SIZE: 20265 - GRID SIZE: 3
ignite_test_scenarios-ignite_client-1 | JOB 2 - split
ignite_test_scenarios-ignite_client-1 | JOB 2 - split
ignite_test_scenarios-ignite_client-1 | JOB 2 - split
ignite_test_scenarios-ignite_client-1 | >>> JOB 3 - MAP INPUT SIZE: 20265 - GRID SIZE: 3
ignite_test_scenarios-ignite_client-1 | JOB 3 - split
ignite_test_scenarios-ignite_client-1 | JOB 3 - split
ignite_test_scenarios-ignite_client-1 | JOB 3 - split
ignite_test_scenarios-ignite_client-1 | >>> JOB 4 - MAP INPUT SIZE: 20265 - GRID SIZE: 3
ignite_test_scenarios-ignite_client-1 | JOB 4 (with simulated failure and checkpointing) - split
ignite_test_scenarios-ignite_client-1 | JOB 4 (with simulated failure and checkpointing) - split
ignite_test_scenarios-ignite_client-1 | JOB 4 (with simulated failure and checkpointing) - split
ignite_test_scenarios-ignite_client-1 | Sample output:
ignite_test_scenarios-ignite_client-1 | (doc, word): tf-idf
ignite_test_scenarios-ignite_client-1 | (purgatorio, dificio): 5.156707832250241E-6
ignite_test_scenarios-ignite_client-1 | (paradiso, occaso): 5.250186614659548E-6
ignite_test_scenarios-ignite_client-1 | (paradiso, voci): 0.0
ignite_test_scenarios-ignite_client-1 | (paradiso, deuropal): 1.4225439914122315E-5
ignite_test_scenarios-ignite_client-1 | (purgatorio, veggondomi): 1.3972158097682513E-5
ignite_test_scenarios-ignite_client-1 | (purgatorio, manco): 0.0
ignite_test_scenarios-ignite_client-1 | (purgatorio, inver): 0.0
ignite_test_scenarios-ignite_client-1 | (paradiso, cerchi): 0.0
ignite_test_scenarios-ignite_client-1 | (purgatorio, ovio): 0.0
ignite_test_scenarios-ignite_client-1 | (inferno, offensione): 5.163058085254244E-6
ignite_test_scenarios-ignite_client-1 | Execution time: 16442 ms
```

Distributed Computing - Scenario 4.4: task-data colocation

```

ignite_test_scenarios-ignite_client-1 | TOTAL PARTITIONS USED: 500
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | +++ TASK-DATA COLOCATION VERSIONS +++
ignite_test_scenarios-ignite_client-1 | >>> KEY VERSION
ignite_test_scenarios-ignite_client-1 | Output size: 500
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 107421.40), (Concert1, 101940.98), (Concert10, 111694.13), (Concert100, 100823.30),
ignite_test_scenarios-ignite_client-1 | (Concert101, 111481.51), (Concert102, 106030.14), (Concert103, 106678.01), (Concert104, 104729.37), (Concert105, 103813.62), (Concert106, 101779.89)]
ignite_test_scenarios-ignite_client-1 | Execution time: 354209 ms
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | >>> NOT SCALABLE PARTITION VERSION (PARTITION DEPENDENT)
ignite_test_scenarios-ignite_client-1 | Output size: 500
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 107421.40), (Concert1, 101940.98), (Concert10, 111694.13), (Concert100, 100823.30),
ignite_test_scenarios-ignite_client-1 | (Concert101, 111481.51), (Concert102, 106030.14), (Concert103, 106678.01), (Concert104, 104729.37), (Concert105, 103813.62), (Concert106, 101779.89)]
ignite_test_scenarios-ignite_client-1 | Execution time: 300683 ms
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | >>> PARTITION VERSION
ignite_test_scenarios-ignite_client-1 | Output size: 500
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 107421.40), (Concert1, 101940.98), (Concert10, 111694.13), (Concert100, 100823.30),
ignite_test_scenarios-ignite_client-1 | (Concert101, 111481.51), (Concert102, 106030.14), (Concert103, 106678.01), (Concert104, 104729.37), (Concert105, 103813.62), (Concert106, 101779.89)]
ignite_test_scenarios-ignite_client-1 | Execution time: 341626 ms
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | +++ WITHOUT TASK-DATA COLOCATION VERSION +++
ignite_test_scenarios-ignite_client-1 | Computation is going to be performed on this node (node ID: 5fc331da-4483-421f-9bc6-ce500bf8f4bf)
ignite_test_scenarios-ignite_client-1 | Output size: 500
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 107421.40), (Concert1, 101940.98), (Concert10, 111694.13), (Concert100, 100823.30),
ignite_test_scenarios-ignite_client-1 | (Concert101, 111481.51), (Concert102, 106030.14), (Concert103, 106678.01), (Concert104, 104729.37), (Concert105, 103813.62), (Concert106, 101779.89)]
ignite_test_scenarios-ignite_client-1 | Execution time: 464640 ms

ignite_test_scenarios-ignite_client-1 | TOTAL PARTITIONS USED: 1024
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | +++ TASK-DATA COLOCATION VERSIONS +++
ignite_test_scenarios-ignite_client-1 | >>> KEY VERSION
ignite_test_scenarios-ignite_client-1 | Output size: 5000
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 159.98), (Concert1, 91.00), (Concert10, 107.48), (Concert100, 159.98), (Concert1000, 125.49),
ignite_test_scenarios-ignite_client-1 | (Concert1001, 270.96), (Concert1002, 0.00), (Concert1003, 156.48), (Concert1004, 30.99), (Concert1005, 110.98)]
ignite_test_scenarios-ignite_client-1 | Execution time: 57345 ms
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | >>> NOT SCALABLE PARTITION VERSION (PARTITION DEPENDENT)
ignite_test_scenarios-ignite_client-1 | Output size: 1024
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 2684.45), (Concert1, 2664.75), (Concert10, 3702.00), (Concert100, 2837.20), (Concert1000, 1505
ignite_test_scenarios-ignite_client-1 | .88), (Concert1001, 2001.72), (Concert1002, 1367.92), (Concert1003, 1433.84), (Concert1004, 677.84), (Concert1005, 1571.80)]
ignite_test_scenarios-ignite_client-1 | Execution time: 28020 ms
ignite_test_scenarios-ignite_client-1 |
ignite_test_scenarios-ignite_client-1 | >>> PARTITION VERSION
ignite_test_scenarios-ignite_client-1 | Output size: 5000
ignite_test_scenarios-ignite_client-1 | Sample output: [(Concert0, 159.98), (Concert1, 91.00), (Concert10, 107.48), (Concert100, 159.98), (Concert1000, 125.49),
ignite_test_scenarios-ignite_client-1 | (Concert1001, 270.96), (Concert1002, 0.00), (Concert1003, 156.48), (Concert1004, 30.99), (Concert1005, 110.98)]
ignite_test_scenarios-ignite_client-1 | Execution time: 23389 ms

```

Continuous Query - Scenario 6.1

```
ignite_test_scenarios-ignite_client-1 | >>> Test 1 Cache continuous query example started.
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=3, val=[ ID: 3 - Type: base - UserId: 17 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=12, val=[ ID: 12 - Type: vip - UserId: 19 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=0, val=[ ID: 0 - Type: base - UserId: 1 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=8, val=[ ID: 8 - Type: vip - UserId: 3 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=16, val=[ ID: 16 - Type: vip - UserId: 9 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Queried existing entry [key=18, val=[ ID: 18 - Type: base - UserId: 13 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=24, val=[ ID: 24 - Type: base - UserId: 20 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=25, val=[ ID: 25 - Type: base - UserId: 21 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=26, val=[ ID: 26 - Type: base - UserId: 22 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=27, val=[ ID: 27 - Type: base - UserId: 23 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=28, val=[ ID: 28 - Type: base - UserId: 24 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=29, val=[ ID: 29 - Type: base - UserId: 25 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=30, val=[ ID: 30 - Type: base - UserId: 26 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=31, val=[ ID: 31 - Type: base - UserId: 27 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=32, val=[ ID: 32 - Type: base - UserId: 28 - ConcertId: 1 ]]
ignite_test_scenarios-ignite_client-1 | Updated entry [key=33, val=[ ID: 33 - Type: base - UserId: 29 - ConcertId: 1 ]]
```

Messaging - Scenario 8.1

```
ignite_test_scenarios-ignite_client-1 | >>> Start sending unordered messages.
ignite_test_scenarios-ignite_client-1 | >>> Unordered messages sent.
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=1, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=0, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=5, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=7, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=3, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=2, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=4, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=6, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=9, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]
ignite_test_scenarios-ignite_server-1 | Received unordered message [msg=8, fromNodeId=7b4579fb-6d3c-4618-ba0e-517ab0f22139]

ignite_test_scenarios-ignite_client-1 | >>> Start sending ordered messages.
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=0, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=1, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=2, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=3, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=4, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=5, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=6, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=7, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=8, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | Received ordered message [msg=9, fromNodeId=e0bd8e3a-e4eb-4de6-a052-b1533633e993]

ignite_test_scenarios-ignite_client-1 | >>> Ordered messages sent.
ignite_test_scenarios-ignite_client-1 | >>> Check the remote nodes output to see the prints.
ignite_test_scenarios-ignite_client-1 | >>> Waiting for the acknowledgements of the remote nodes.
ignite_test_scenarios-ignite_client-1 | >>> Test 1 ordered-unordered messages completed.
```

```
ignite_test_scenarios-ignite_client-1 | >>> Test 2 ping-pong messages simulation.
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PONG, sender=6d53ad0a-bffd-48ab-b960-8707f153985f]
ignite_test_scenarios-ignite_client-1 | Received message [msg=PING, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_client-1 | Received message [msg=STOP, sender=e0bd8e3a-e4eb-4de6-a052-b1533633e993]
ignite_test_scenarios-ignite_server-1 | >>> Test 2 ping-pong messages simulation completed.
```

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4 Conclusioni

Pro

- architettura in-memory e shared-nothing con storage multi-tier
- ogni nodo funge contemporaneamente da compute node e da data node
- possibilità di scaling orizzontale illimitato
- discovery automatico dei nodi
- data rebalancing automatico al variare della topologia
- in modalità external storage, offre pieno supporto a SQL a DB che non lo prevedono, permettendo ad esempio di eseguire join distribuiti e co-locati
- automatic job failover

Contro

- topologia ad anello limitante all'aumentare del numero di nodi
- data model a chiave-valore limitante in certe situazioni
- modalità di caching on-heap non sempre più performante di quella off-heap
- in modalità external storage, è necessario pre-caricare in RAM tutti i dati che si vogliono utilizzare
- gestione più verbosa dei task di MapReduce rispetto ad Apache Hadoop
- meccanismo di checkpointing non sempre conveniente
- task-data colocation e cache colocation da abilitare e gestire esplicitamente