



it's about time



Technical Whitepaper

Query Routing – a kdb+ framework for a scalable, load balanced system

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Query Routing: A kdb+ framework for a scalable, load balanced system

Due to the large scale that kdb+ systems commonly grow to, it is important to build solid foundations so that as the number of users and size of databases increase, the system is able to easily absorb the extra capacity.

Distributed kdb+ systems have been covered in a number of Kx Technical Whitepapers. The primary objective of this paper is to expand on routing, query tagging and connectivity management of a large distributing kdb+ system. The basic architecture used in this paper is based heavily on the ideas discussed in another whitepaper: “[Common design principles for kdb+ gateways](https://code.kx.com/q/wp/common_design_principles_for_kdb_gateways.pdf)”¹.

It is recommended the reader understand these concepts before progressing with this paper.

This paper focuses on the design principle of the Connection Manager Load Balancer schematic whilst providing an asynchronous-only method of communication between processes. In this paper, our Load Balancer will also act as a Connection Manager with distributing access to all services whilst minimizing the waiting time for gateways.

Traditional load-balancing techniques such as a straightforward round-robin approach to resource allocation is an acceptable approach for many systems, however it can result in several queries becoming queued up behind a long-running query whilst other service resources are idle. In this paper, the method used aims to be more efficient by tagging user queries that enter a gateway, identifying free services, and allocating queries on this basis.

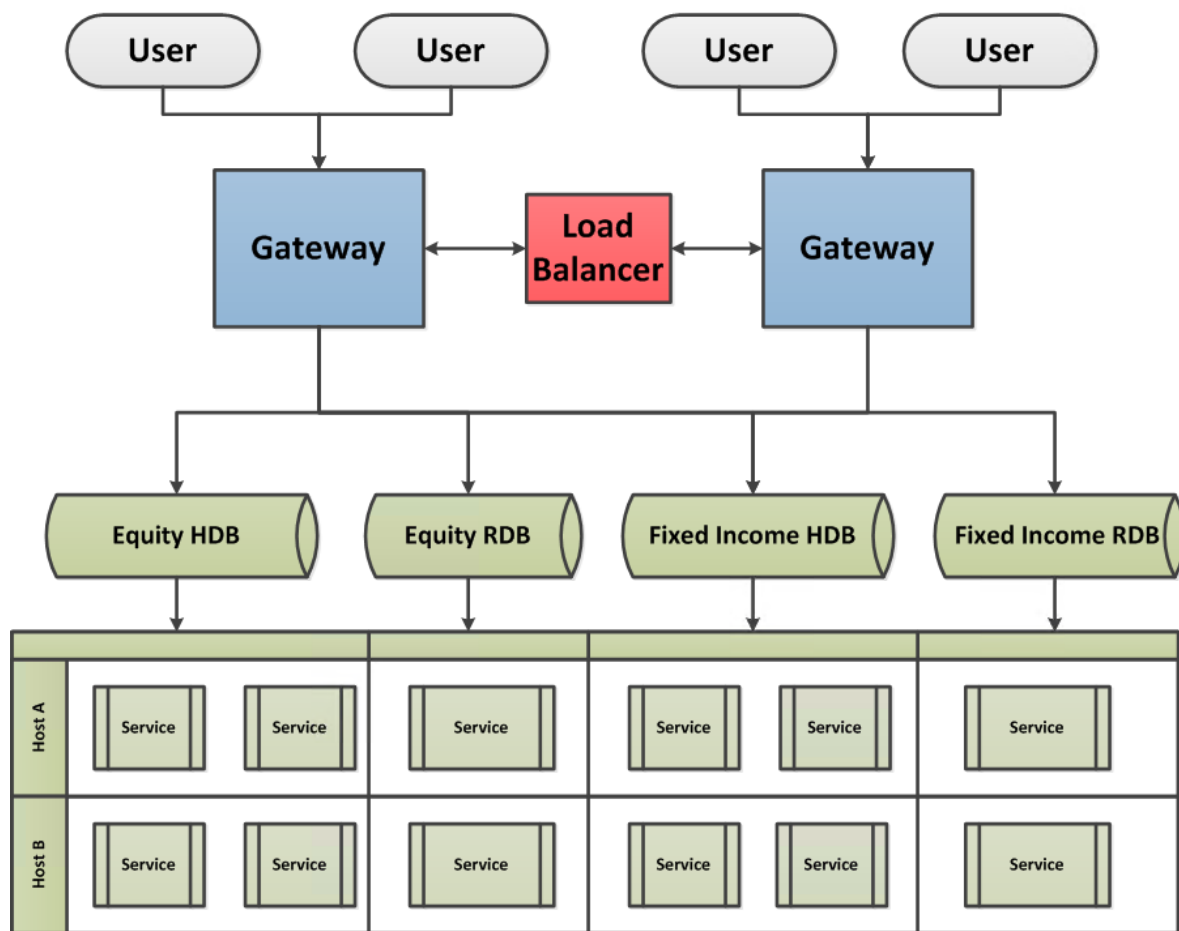
There are many other potential solutions to building a kdb+ framework for load balancing and query routing. Rather than presenting a golden solution, this paper explores one method of implementation.

All tests were run using kdb+ version 3.3 (2015.11.03)

1. https://code.kx.com/q/wp/common_design_principles_for_kdb_gateways.pdf

Technical overview

Interaction between the user and a gateway occurs through deferred synchronous communication, allowing multiple users to interact with a single gateway at the same time. With exception to the interaction between the user and the gateway, all processes in our system communicate via asynchronous messaging.



Overview of system framework

Gateway

The gateway is designed to accommodate multiple user requests, storing each query in an internal table and assigning a unique sequence number to each while keeping record of the handle to the user's process. The gateway requests a service from the load balancer

and sends the user's query to the allocated service. The results are then returned to the user via the handle associated with the query sequence number.

Load Balancer

The Load Balancer has the following purposes:

- A service provider informing gateways of all services within the system
- Service allocator assigning gateways and their unique query sequence number to the next available service
- Connectivity manager appropriately amending requests based on whether services/gateways are connected/disconnected to the system.

Service

A *service* is a broad term that can denote a typical HDB/RDB kdb+ database, or more complex report/function processes custom-designed to perform any range of aggregations. By starting duplicate instances of a service (e.g. HDBs pointing at the same data, RDBs subscribing to the same Tickerplant), we provide a pool of resources per service that can be deployed to different servers. This allows the potential for a hot-hot set up in which our framework will not only efficiently allocate between resources, but also automatically divert user queries in the event of a service/host failure.

User interaction and logic flow

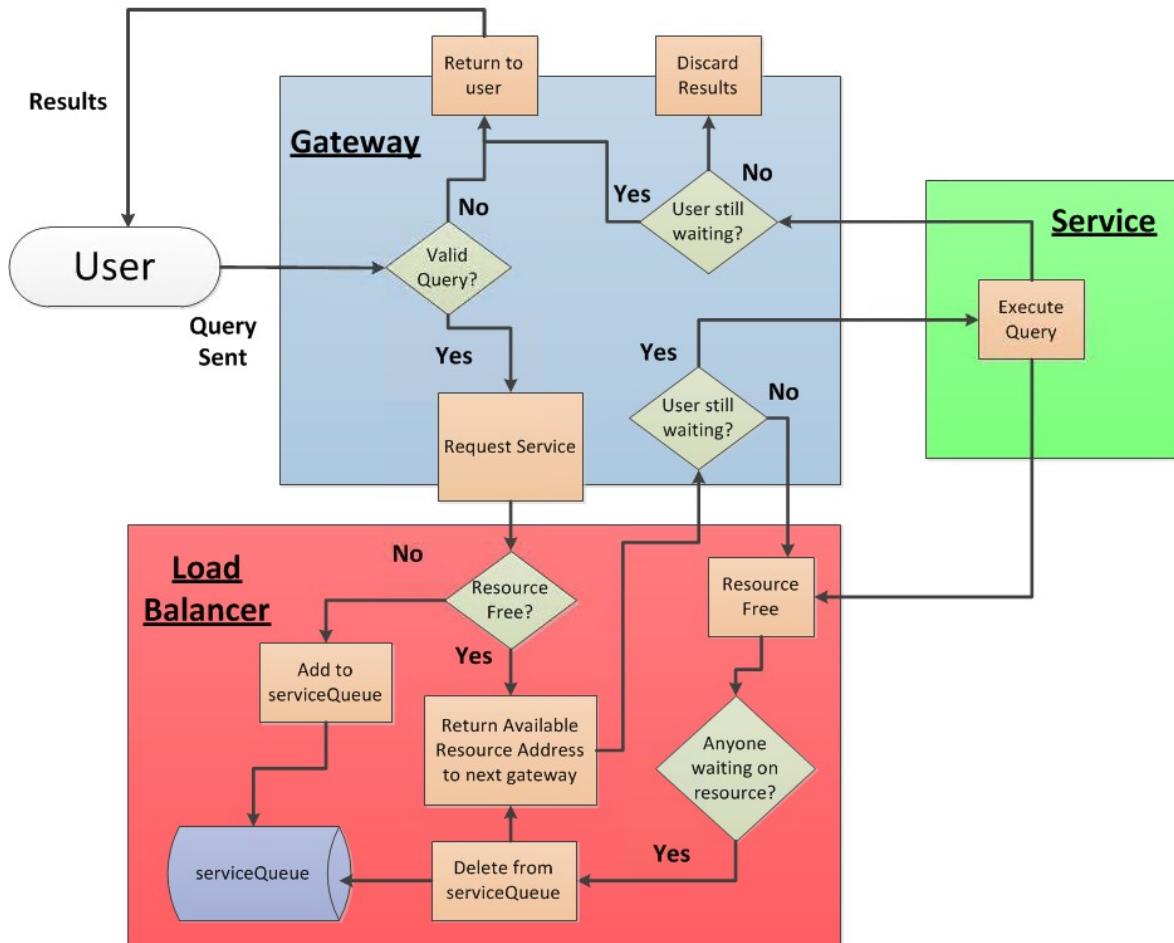
Services for any of the above databases can be distributed on separate servers, the quantity of which may be dependent on available hardware or user demand and be configured per database type. For the purpose of this paper, we minimize the complexity of the gateway query routing in order to emphasize the functionality of the Load Balancer. We will require the user to send her query to the gateway handle by calling the function `userQuery` with a two-item list parameter: the required service and the query to be executed. The user interacts with the gateway using deferred synchronous messaging.

Further information can be found at the Cookbook article on [load balancing](http://code.kx.com/q/cookbook/load-balancing/)².

```
gw:{h:hopen x;{(neg x)('userQuery;y);x[]}[h]}[':localhost:5555]
// ':localhost:5555 is an example gateway address
gw('EQUITY_MARKET_RDB;"select from trade where date=max date")
// Where EQUITY_MARKET_RDB is the name of the required service
```

2. <http://code.kx.com/q/cookbook/load-balancing/>

The diagram below outlines the logical steps taken when a user's query enters the system. Results are then returned to the user through the gateway. Errors can be returned to users due to an invalid service request from the gateway or an error from the service on evaluating a user query.



Flow diagram of system logic

Instead of taking a standard round-robin approach to load balancing as explained in “[Common design principles for kdb+ gateways](https://code.kx.com/q/wp/common_design_principles_for_kdb_gateways.pdf)”³, our Load Balancer will keep track of what resources are free and allocate queries to services only when they are available. After executing a query, the service provides a notification to the Load Balancer that it is available. The only exception to this occurs when a service gets allocated to a query but the user has since disconnected from the gateway. Here, the gateway notifies the Load Balancer that the service is no longer required.

3. https://code.kx.com/q/wp/common_design_principles_for_kdb_gateways.pdf

Gateways

When a connection is opened to the Load Balancer, the handle is set to the variable `LB`, which will be referenced throughout this paper. As asynchronous messages are used throughout this framework, we also create the variable `NLB`, which is assigned with the negative handle to the load balancer.

```
\p 5555
manageConn:{@[{NLB::neg LB::hopen x};`:localhost:1234;{show x}]];
registerGWFunc:{addResource LB(`registerGW;`)};
```

The gateway connects to the Load Balancer and retrieves the addresses of all service resources, establishing a connection to each. This is the only time the gateway uses synchronous IPC communication to ensure it has all of the details it requires before accepting user queries. After the gateway registers itself as a subscriber for any new resources that come available, all future communication is sent via asynchronous messages.

```
resources:([address:()] source:();sh:());
addResource:{`resources upsert `address xkey update sh:{hopen first x}'[address] from x};
```

The gateway process creates and maintains an empty query table. The complexity of this table is at the developer's discretion. In this example we'll record:

- Unique sequence number per query (`sq`)
- Handle from user process (`uh`)
- Timestamps for when the query was received, when the query got sent to an available resource, and when the query results are sent back to the user (`rec`, `snt`, `ret` respectively)
- The user ID (`user`)
- The service handle (`sh`)
- The service requested by user (`serv`)
- The user's query

```

queryTable:([sq:`int$()];
uh:`int$();
rec:`timestamp$();
snt:`timestamp$();
ret:`timestamp$();
user:`$();
sh:`int$();
serv:`$();
query:());

```

This table could be extended to include more information by making small changes to the code in this paper. These fields could include the status of a query, error messages received from service or the total time a query took from start to end.

As mentioned previously, users make requests by calling the `userQuery` function on the gateway. This function takes a two-item list argument: `(Service;Query)`. The gateway will validate the existence of a service matching the name passed to `userQuery` and send an error if no such resource exists. We are setting outside the scope of this paper any further request validation, including access permissioning.

For further details on access control, please refer to the Technical Whitepaper “[Permissions with kdb+](http://code.kx.com/q/wp/permissions_with_kdb+)”⁴.

When a user sends her query via the `userQuery` function, we assign the query a unique sequence number and publish an asynchronous request to the Load Balancer to be assigned an available resource.

```

userQuery:{
  $[(serv:x 0) in exec distinct source from resources; // Check if valid service
  [queryTable,:(SEQ+:1;.z.w;.z.p;0Np;0Np;.z.u;0N;serv;x 1);
  NLB(`requestService;SEQ;serv)];
  (neg .z.w)('$"Service Unavailable")]];

```

The `addResource` function defined earlier is used to add new service instances to the plant, while the `serviceAlloc` function is used to pass back an allocated resource for a given query sequence number. The query is retrieved by its sequence number from `queryTable` and sent to the allocated service resource. If the user has since disconnected from the gateway before a resource could be provided, the gateway informs the Load Balancer to make this resource free again by executing the `returnService` function in the Load Balancer. After each event, the timestamp fields are updated within the `queryTable`.

4. http://code.kx.com/q/wp/permissions_with_kdb.pdf


```

serviceAlloc:{[sq;addr]
  $[null queryTable[sq;`uh];
    // Check if user is still waiting on results
    NLB(`returnService;sq);
    // Service no longer required
    [(neg sh:resources[addr;`sh]) (`queryService;(sq;queryTable[sq;`query]));
    // Send query to allocated resource, update queryTable
    queryTable[sq;`snt`sh]:(.z.p;sh)]];

```

When a service returns results to the gateway, the results arrive tagged with the same sequence number sent in the original query. This incoming message packet executes the `returnRes` function, which uses the sequence number to identify the user handle and return the results. If the user has disconnected before the results can be returned then the user handle field `uh` will be set to null (through the `.z.pc` trigger) causing nothing further to be done.

```

returnRes:{[res]
  uh:first exec uh from queryTable where sq=(res 0);
  // (res 0) is the sequence number
  if[not null uh;(neg uh)(res 1)];
  // (res 1) is the result
  queryTable[(res 0);`ret]:.z.p
};

```

In the situation where a process disconnects from the gateway, `.z.pc` establishes what actions to take. As mentioned, a disconnected user will cause `queryTable` to be updated with a null user handle. If the user currently has no outstanding queries, the gateway has nothing to do. If a service disconnects from the gateway whilst processing an outstanding user request, then all users that have outstanding requests to this database are informed and the database is purged from the available resources table.

If our Load Balancer connection has dropped, all users with queued queries will be informed. All connections are disconnected and purged from the `resources` table. This ensures that all new queries will be returned directly to users as the Load Balancer is unavailable to respond to their request. A timer is set to attempt to reconnect to the Load Balancer. On reconnection, the gateway will re-register itself, pull all available resources and establish new connections. The `.z.ts` trigger is executed once, on script startup, to initialize and register the process.

```

.z.pc:{[handle]
  // if handle is for a user process, set the query handle (uh) as null
  update uh:0N from `queryTable where uh=handle;
  // if handle is for a resource process, remove from resources
  delete from `resources where sh=handle;
  // if any user query is currently being processed on the service which
  // disconnected, send message to user
  if[count sq:exec distinct sq from queryTable where sh=handle,null ret;
    returnRes'[sq cross `"$Service Disconnect""]];
  if[handle~LB; // if handle is Load Balancer
    // Send message to each connected user, which has not received results
    (neg exec uh from queryTable where not null uh,null snt)@\: `"$Service Unavailable";
    // Close handle to all resources and clear resources table
    hclose each (0!resources)`sh;
    delete from `resources;
    // update queryTable to close outstanding user queries
    update snt:.z.p,ret:.z.p from `queryTable where not null uh,null snt;
    // reset LB handle and set timer of 10 seconds
    // to try and reconnect to Load Balancer process
    LB::0; NLB::0; value"\t 10000""]];

.z.ts:{
  manageConn[]; if[0<LB;@[registerGWFunc;`;{show x}];value"\t 0"]
  };

.z.ts[];

```

Load Balancer

Within our Load Balancer there are two tables and a list:

```
\p 1234
services:([handle:`int$()]
  address:`$();
  source:`$();
  gwHandle:`int$();
  sq:`in t$();
  udt:`timestamp$());

serviceQueue:([gwHandle:`int$();sq:`int$()]
  source:`$();
  time:`timestamp$());

gateways:();
```

The **service** table maintains all available instances/resources of services registered and the gateways currently using each service resource. The **serviceQueue** maintains a list of requests waiting on resources. A list is also maintained, called **gateways**, which contains all gateway handles.

Gateways connecting to the Load Balancer add their handle to the **gateways** list. New service resources add their connection details to the **services** table. When a service resource registers itself using the **registerResource** function, the Load Balancer informs all registered gateways of the newly available resource. The next outstanding query within the **serviceQueue** table is allocated immediately to this new resource.

```
registerGW:{gateways,::z.w ; select source, address from services};
registerResource:{[name;addr]
  `services upsert (.z.w;addr;name;0N;0N;.z.p);
  (neg gateways)@\:(`addResource;enlist`source`address!(name;addr));
  // Sends resource information to all registered gateway handles
  serviceAvailable[.z.w;name]};
```

Incoming requests for service allocation arrive with a corresponding sequence number. The combination of gateway handle and sequence number will always be unique. The **requestService** function either provides a service to the gateway or adds the request to the **serviceQueue**. When a resource is allocated to a user query, the resource address is returned to the gateway along with the query sequence number that made the initial request.

```

sendService:{[gw;h]neg[gw]raze(`serviceAlloc;services[h;`sq`address])};
// Returns query sequence number and resource address to gateway handle

requestService:{[seq;serv]
  res:exec first handle from services where source=serv,null gwHandle;
  // Check if any idle service resources are available
  ${null res;
    addRequestToQueue[seq;serv;.z.w];
    [services[res;`gwHandle`squdt]:(.z.w;seq;.z.p);
    sendService[.z.w;res]]];};

```

If all matching resources are busy, then the gateway handle + sequence number combination is appended to the `serviceQueue` table along with the service required.

```

addRequestToQueue:{[seq;serv;gw]`serviceQueue upsert (gw;seq;serv;.z.p)};

```

After a service resource has finished processing a request, it sends an asynchronous message to the Load Balancer, executing the `returnService` function. As mentioned previously, if the user disconnects from the gateway prior to being allocated a service resource, the gateway also calls this function. The incoming handle differentiates between these two situations.

```

returnService:{
  serviceAvailable . $[.z.w in (0!services)`handle;
  (.z.w;x);
  value first select handle,source from services where gwHandle=.z.w,sq=x]
}

```

On execution of the `serviceAvailable` function, the Load Balancer will either mark this resource as free, or allocate the resource to the next gateway + sequence number combination that has requested this service, updating the `services` and `serviceQueue` tables accordingly.

```

serviceAvailable:{[zw;serv]
  nxt:first n:select gwHandle,sq from serviceQueue where source=serv;
  serviceQueue::(1#n)_ serviceQueue;
  // Take first request for service and remove from queue
  services[zw;`gwHandle`squdt]:(nxt`gwHandle;nxt`squdt;.z.p);
  if[count n;sendService[nxt`gwHandle;zw]]];};

```

Any resource that disconnects from the Load Balancer is removed from the `services` table. If a gateway has disconnected, it is removed from the resource subscriber list `gateways` and all queued queries for any resources must also be removed, and the resource freed up for other gateways. Unlike other components in this framework, the Load Balancer does not attempt to reconnect to processes, as they may have permanently been

removed from the service pool of resources. In a dynamically adjustable system, service resources could be added and removed on demand based on the size of the serviceQueue table.

```
.z.pc:{[h]
  services _:h;
  gateways::gateways except h;
  delete from `serviceQueue where gwHandle=h;
  update gwHandle:0N from `services where gwHandle=h
};
```

If a gateway dies, data services will continue to run queries that have already been routed to them, which will not subsequently be returned to the client. It is also possible that the next query assigned to this resource may experience a delay as the previous query is still being evaluated. As mentioned later, all resources should begin with a timeout function to limit interruption of service.

Example service

The example below takes a simple in-memory database containing trade and quote data that users can query. An example timeout of ten seconds is assigned, to prevent queries running for too long.

```
\T 10
\p 2222
LB:0;

quote:([
  date:10#.z.D-1;
  sym:10#\FDP;
  time:09:30t+00:30t*til 10;
  bid:100.+0.01*til 10;
  ask:101.+0.01*til 10);

trade:([
  date:10#.z.D-1;
  sym:10#\FDP;
  time:09:30t+00:30t*til 10;
  price:100.+0.01*til 10;
  size:10#100);
```

Each instance of a service uses the same service name. Within this example, the service name is hard-coded, but this would ideally be set via a command line parameter. In our example below, our service name is set to `EQUITY_MARKET_RDB. In designing a user-friendly system, service names should be carefully set to clearly describe a service's purpose. Similar processes (with either a different port number or running on a different host) can be started up with this service name, increasing the pool of resources available to users.

The `serviceDetails` function is executed on connection to the Load Balancer to register each service address.

```
manageConn:{@[{NLB::neg LB::hopen x};`:localhost:1234;
  {show "Can't connect to Load Balancer-> ",x}}];

serviceName:`EQUITY_MARKET_RDB;

serviceDetails:(`registerResource;
  serviceName;
  `$": " sv string ();.z.h;system"p"));
```

When a gateway sends the service a request via the `queryService` function, a unique sequence number assigned by a given gateway arrives as the first component of the incoming asynchronous message. The second component, the query itself, is then evaluated. The results of this query is stamped with the same original sequence number and returned to the gateway handle.

As mentioned previously, query interpretation/validation on the gateway side is outside of the scope of this paper. Any errors that occur due to malformed queries will be returned via protected evaluation from database back to the user. In the situation where the process query times out, 'stop' will be returned to the user via the projection `errProj`.

On completion of a request, an asynchronous message is sent to the Load Balancer informing it that the service is now available for the next request.

```
execRequest:{[nh;rq]nh(`returnRes;(rq 0;@[value;rq 1;{x})));nh[]};

queryService:{
  errProj:{[nh;sq;er]nh(sq;`$er);nh[]};
  @[execRequest[neg .z.w];x;errProj[neg .z.w;x 0]];
  NLB(`returnService;serviceName));
```

Note that in the `execRequest` function, `nh` is the asynchronous handle to the gateway. Calling `nh[]` after sending the result causes the outgoing message queue for this handle to be flushed immediately. For more details, see the [Cookbook article on IPC](http://code.kx.com/q/cookbook/ipc/)⁵.

Like our gateway, the `.z.pc` handle is set to reconnect to the Load Balancer on disconnect. The `.z.ts` function retries to connect to the Load Balancer, and once successful the service registers its details. The `.z.ts` function is executed once on start-up – like the gateway – to initialize the first connection.

```
.z.ts:{manageConn[];if[0<LB;@[NLB;serviceDetails;{show x}];value"\t 0"]};
.z.pc:{[handle]if[handle~LB;LB::0;value"\t 10000"]};
.z.ts[];
```

5. <http://code.kx.com/q/cookbook/ipc/>

Example client

An example query from a user may look like the following:

```
q)gw:{h:hopen x;{(neg x)(`userQuery;y);x[]}[h]}[`:localhost:5555]
q)gw(`EQUITY_MARKET_RDB;"select from quote")
date      sym time      bid    ask
-----
2016.01.31 FDP 09:30:00.000 100    101
2016.01.31 FDP 10:00:00.000 100.01 101.01
2016.01.31 FDP 10:30:00.000 100.02 101.02
2016.01.31 FDP 11:00:00.000 100.03 101.03
..
q)gw(`EQUITY_MARKET_RDB;"select from trade")
date      sym time      price  size
-----
2016.01.31 FDP 09:30:00.000 100    100
2016.01.31 FDP 10:00:00.000 100.01 100
2016.01.31 FDP 10:30:00.000 100.02 100
2016.01.31 FDP 11:00:00.000 100.03 100
..
```

An example query from a user requesting an invalid service name will show the following:

```
q)gw(`MADE_UP_SERVICE;"select from quote")
`Service Unavailable
```

All queries for valid data services can then be viewed by looking at `queryTable` within the gateway:

```
sq| uh  rec                                     snt                                     ..
--|-----
1 | 244 2016.02.16D11:39:20.634490000 2016.02.16D11:39:20.634490000 ..
2 | 244 2016.02.16D11:39:22.994304000 2016.02.16D11:39:22.994304000 ..

ret                                     user  sh  serv                                     ..
-----
2016.02.16D11:39:20.634490000 Kevin 464 EQUITY_MARKET_RDB ..
2016.02.16D11:39:22.994304000 Kevin 464 EQUITY_MARKET_RDB ..

query
-----
"select from quote"
"select from trade"
```


Conclusion

This paper has presented an approach to building a kdb+ framework for query routing and load balancing. Within this example we've achieved the following:

- A minimal IPC hop architecture for users to retrieve results from a network distributed set of databases
- Service provision with an aim to reduce waiting time of gateways and users.
- Plant connection stability including smooth additions of new resources to help deal with query queue and methods for recovering due to a process drop within the plant.
- Error tracking through protected evaluation.
- Enforced asynchronous communication between processes to prevent blocking.

As an example framework focused on network routing, this paper covers much of the core functionality, but the scope of this paper does not encompass some desirable production features a system architect should consider, such as permissions, query validation and capacity management. Where topics haven't been covered previously, the Kx Technical Whitepaper series will continue to drill down on important components that provide the building blocks for a stable, scalable, protected and efficient kdb+ system.

All tests were run using kdb+ version 3.3 (2015.11.03)