KTH ROYAL INSTITUTE
OF TECHNOLOGY

# Distributed Hash Tables

Vladimir Vlassov

## Distributed Hash Tables

- Large scale data bases
  - hundreds of servers
- High churn rate
  - servers will come and go
- Benefits
  - fault tolerant
  - high performance
  - self administrating



## A key-value store

Associative array to store key-value pairs, a data structure known as a hash table (array of buckets) that maps keys to values.

Operations:
**`put (key, object)`** – store a given object with a given key
**`object: = get (key)`** – read a object given key.

Design issues:

- Identify : how to uniquely identify an object
- Store: how to distribute objects among servers
- Route: how to find an object



## Unique identifiers

We need ***unique identifiers*** to identify objects, i.e. to find a bucket to get/put an object with a given key

```
identifier = f(key, size_of_hash_table)
```

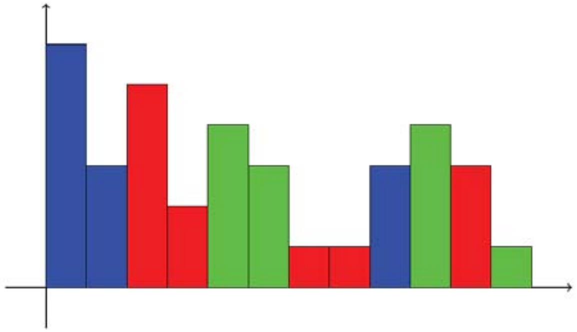
How to select identifiers:

- use a key (a name)
- a cryptographic hash of the key
- a cryptographic hash of the object

*why hash?*

## Key distribution – direct map

Direct map of keys to identifiers (buckets) gives a non-uniform (uneven) distribution of keys among buckets

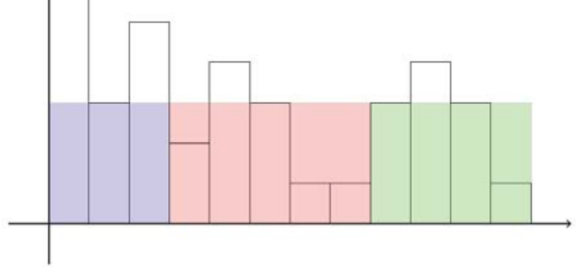




## Key distribution – hashing keys

***A cryptographic hash function*** gives a uniform (even) distribution of the keys among buckets

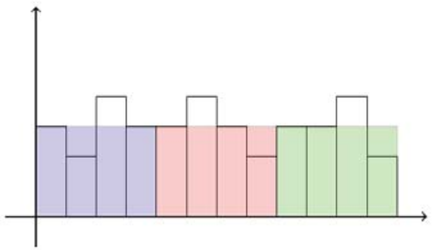
```
hash = hashfunc(key)
identifier = hash % table_size
```

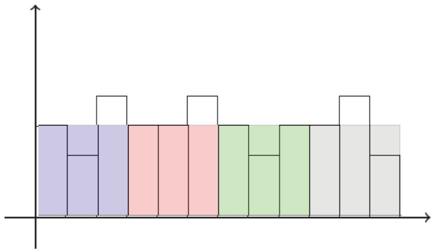




## Add a server

*at three-o'clock-in-the-morning do:*



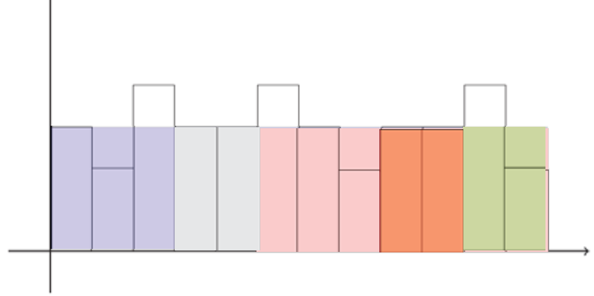




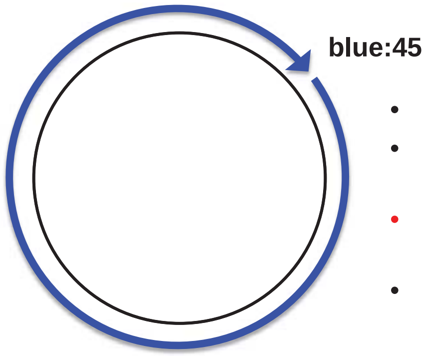
## Random distribution

Random distribution of key ranges among servers

*How to find a server responsible for a given key?*



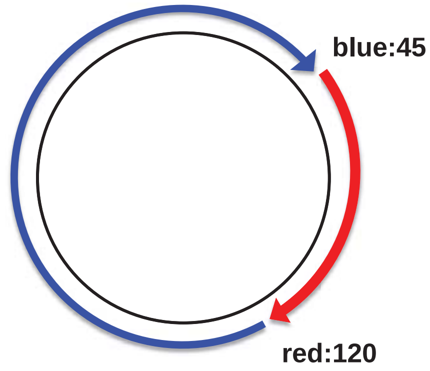
# Circular domain




- ID domain: `0,1,2,..., size-1`
- clockwise step along the ring
  `i = (i + 1)% size`
- ***responsibility***: from your predecessor to your number
- when inserted: take over responsibility



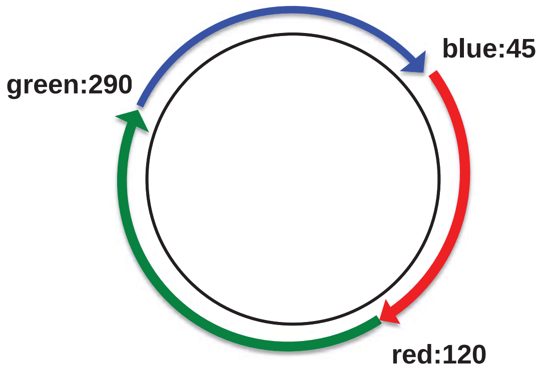
# Circular domain




- *responsibility*: from your predecessor to your number
- when inserted: take over responsibility



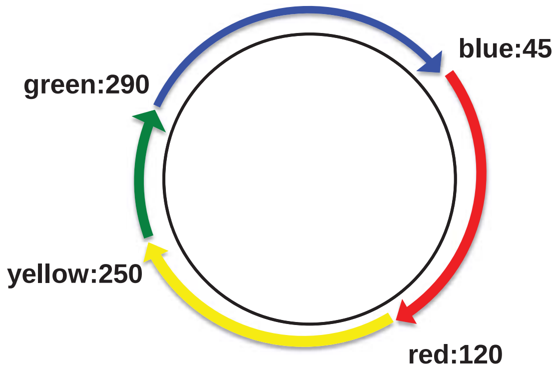
# Circular domain




- *responsibility*: from your predecessor to your number
- when inserted: take over responsibility

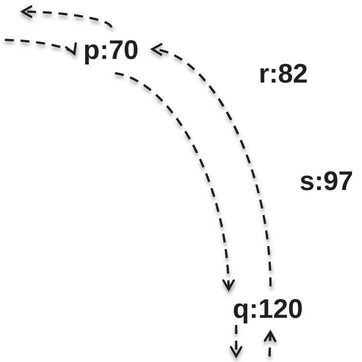


# Circular domain




- *responsibility*: from your predecessor to your number
- when inserted: take over responsibility
- talk to the node in front of you

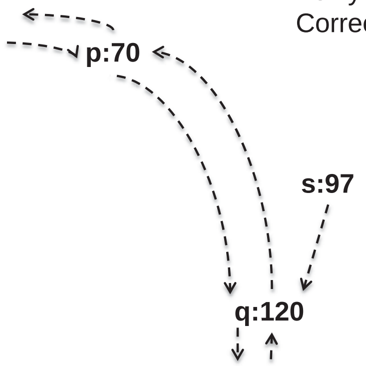
# Double linked circle




- predecessor
- successor
- how do we insert a new node
- concurrently



# Stabilization

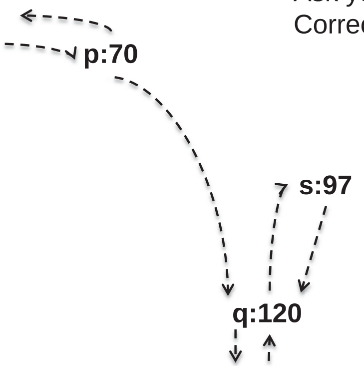



Ask your successor: ***Who is your predecessor?***
Correct a wrong link if any

s: - Who is your predecessor?
q: - It's p at 70.
s: - Why don't you point to me!



# Stabilization

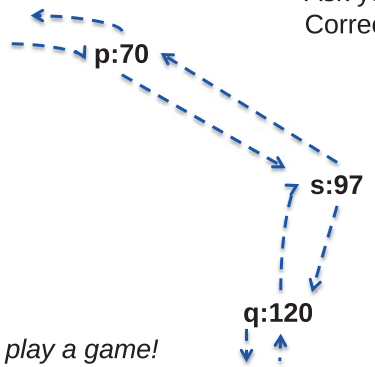



Ask your successor: ***Who is your predecessor?***
Correct a wrong link if any

s: - Who is your predecessor?
q: - It's p at 70.
s: - Why don't you point to me!
p: - Who is your predecessor?
q: - It's s at 97.
p: - Hmmm, that's a better successor.



# Stabilization




*Let's play a game!*

Ask your successor: ***Who is your predecessor?***
Correct a wrong link if any

s: - Who is your predecessor?
q: - It's p at 70.
s: - Why don't you point to me!
p: - Who is your predecessor?
q: - It's s at 97.
p: - Hmmm, that's a better successor.
p: - Who is your predecessor?
s: - I don't have one.
p: - Why don't you point to me!

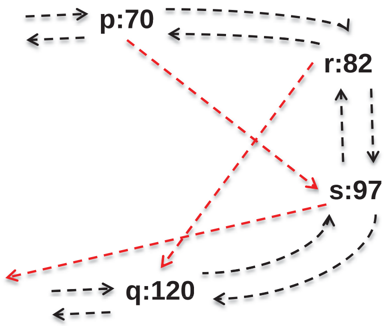
## Stabilization

Stabilization is run periodically: allow nodes to be inserted concurrently.

Inserted node will take over responsibility for part of a segment.



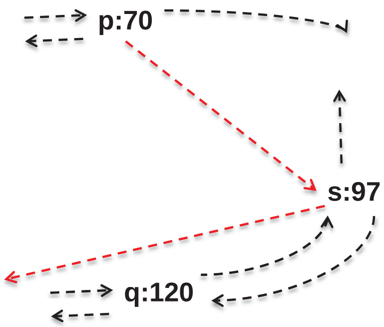
## Crashing nodes




- monitor neighbors
- safety pointer



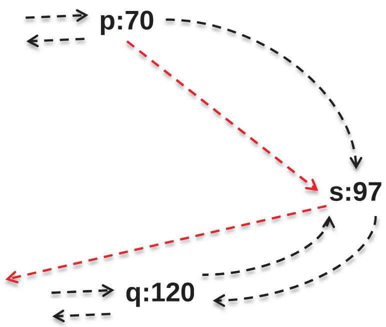
## Crashing nodes




- monitor neighbors
- safety pointer
- detect crash

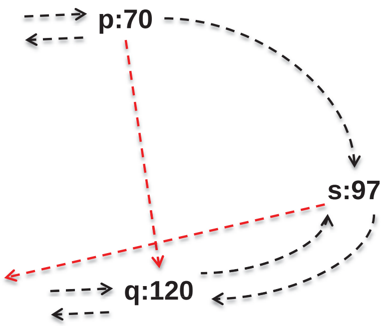


## Crashing nodes




- monitor neighbors
- safety pointer
- detect crash
- update forward pointer

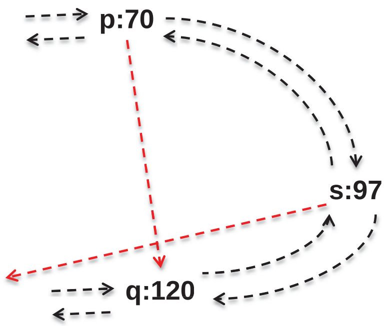
## Crashing nodes




- monitor neighbors
- safety pointer
- detect crash
- update forward pointer
- update safety pointer



## Crashing nodes




- monitor neighbors
- safety pointer
- detect crash
- update forward pointer
- update safety pointer
- stabilize



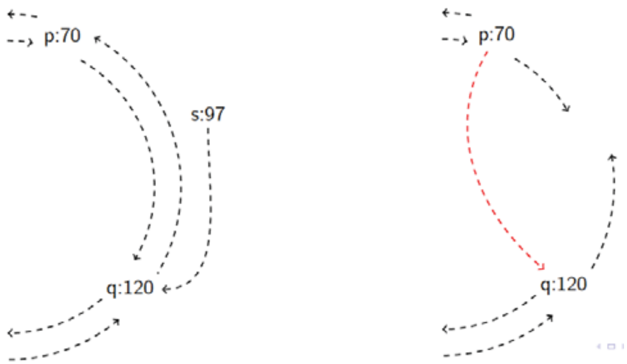
## Russian roulette

How many safety pointers do we need?



## Replication

Where should we store a replica of our data?



## Routing overlay

- The problem of finding an object in our distributed table:
  - nodes can join and crash
  - trade-off between routing overhead and update overhead

*In the worst case we can always forward a request to our successor.*



## Leaf set

Assume that each node holds a leaf set of its closest ($\pm l$) neighbors (a.k.a. a finder table).

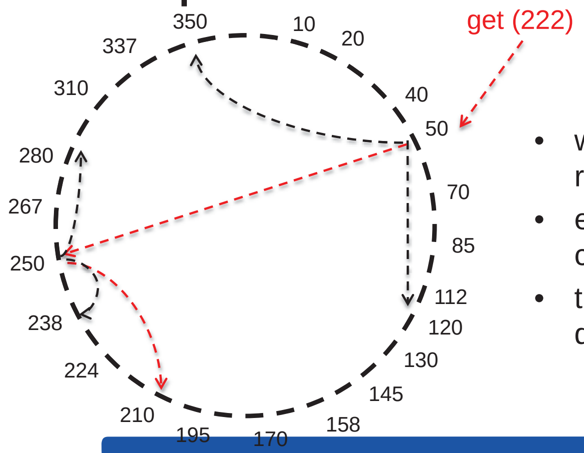
We can jump $l$ nodes in each routing step but we still have complexity of $O(n)$.

Leaf set is updated in $O(l)$.

*The leaf set could be as small as only the immediate neighbors but is often chosen to be a handful.*



## Improvement




- we're looking for the responsible node of an object
- each router hop brings us closer to the responsible node
- the *leaf set* gives us the final destination

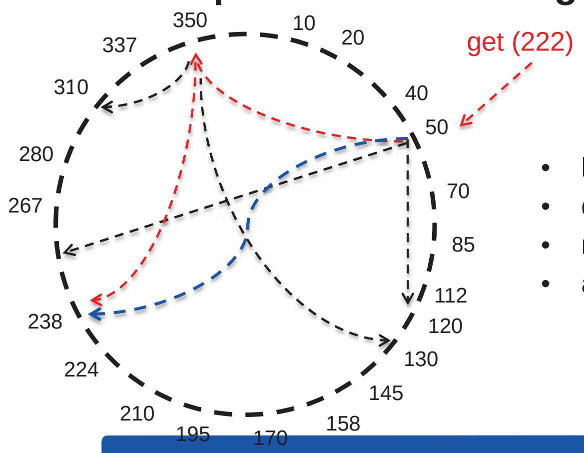


## Pastry

A routing table, each row represents one level of routing.

- 32 rows
- 16 entries per row
- any node found in 32 hops
- maximal number of nodes $16^{32}$ or $2^{128}$ (more than enough)
- search is $O(lg(n))$ where $n$ is number of nodes

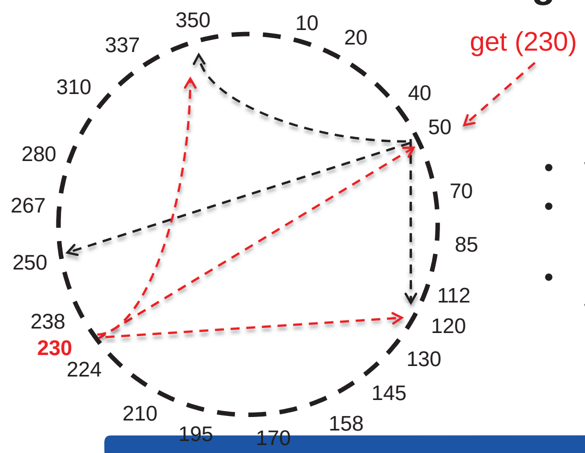
# The price of fast routing




- be lazy
- detect failed nodes when used
- route in alternative direction
- ask neighbors of alternative node



# Network aware routing




- when inserting new node
- attach to the network-wise closest node
- adopt the routing entries on the way down



# Overlay networks

Structured

- a well-defined structure
- takes time to add or delete nodes
- takes time to add objects
- easy to find objects

Unstructured

- a random structure
- easy to add or delete nodes
- easy to add objects
- takes time to find objects



# DHT usage

Large scale key-value store.

- fault tolerant system in high churn rate environment
- high availability low maintenance

## The Pirate Bay

- replaces the tracker by a DHT
- clients connects as part in the DHT
- DHT keeps track of peers that share content



## Riak

- large scale key-value store
- inspired by Amazon Dynamo
- implemented in Erlang



## Summary DHT

- why hashing?
- distribute storage in ring
- replication
- routing