Chord: A Scalable Peer-to-peer Lookup Protocol for Internet Applications

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1 Introduction

This work aims at illustrating an implementation of Chord, a scalable distributed lookup protocol described in [1]. Basically, Chord provides a primitive, i.e. *lookup*, that allows to determine the responsible for a key in an efficient way. Hence, it represents a great solution to the data location problem: each data item needs just to be associated with a key and stored in the node to which the key is mapped.
In practice, the nodes are logically arranged in a ring topology and each of them is responsible for the ids belonging to the interval $(predecessorId, nodeId]$ [1]. The key-data pairs are assigned to the nodes depending on the hash value of the key and consistent hashing is used in order to keep the load balanced. Moreover, each node is required to maintain information about only a few other nodes: the predecessor, some successors and the elements of the finger table[2]. Therefore, Chord scales well to large numbers of nodes without affecting performance. Actually, it adapts effectively also in dynamic environments with frequent joins and leaves thanks to a simple stabilization algorithm.
Finally, it is worth mentioning that the iterative version of Chord has been implemented. Hence, a node resolving a lookup initiates all the communications needed to reach the target.
Starting from this, Section 2 will describe in detail the implementation, Section 3 will present the graphical simulator that has been developed to show the protocol's functioning and Section 4 will describe the simulations that have been performed and the results obtained.

2 Implementation

This section presents the methods and the behaviour of the five classes that have been used to implement the protocol. In particular, these classes can be subdivided into three groups:

- the control class (`TopologyBuilder`) that instantiates the nodes, initialises the ring, manages joins/leaves and initiates the lookups;

[1] The ids are integers in $[0, 2^m)$, where m is the number of bits of the identifiers. All the arithmetic is modulo 2^m.

[2] The finger table is a routing table: the i^{th} entry points at the responsible for the identifier $nodeId + 2^{i-1}$, with $1 \leq i \leq$ m.

- the class (`Node`) that defines the behaviour of the agents in the simulation, i.e. the nodes;
- the support classes (`FingerTable`, `Lookup` and `Utils`).

Before going into details, it is worth mentioning that the correspondence between simulation ticks and seconds has been assumed in both implementation and simulations.

2.1 TopologyBuilder

2.2 Node

The `Node` class, which defines the behaviour of the agents in the simulations, consists of several methods that can be grouped into six categories:

- initialization;
- lookup;
- stabilization;
- data management;
- crash and recovery;
- leave.

Each of them will be examined in a specific Section.
As regards the main fields, every node maintains: a finger table (the implementation will be presented in Section 2.3.1), a list of successors, a reference to the predecessor and a key-value map for data.
Basically, the finger table - as a routing table - allows to perform efficient and scalable lookups. In fact, the finger table is not needed for correctness[3] but avoids lookups characterised by a number of messages linear in the number of nodes.
Instead, the list of successors improves the robustness to failures and departures w.r.t. just a reference to the immediate successor. In fact, all successors would have to fail simultaneously in order to destroy the ring. It is worth mentioning that the first elements of the finger table and the successor list coincide.
As regards the reference to the predecessor, it is exploited by the stabilization algorithm to maintain the consistency of the successors and is used to transfer part of the data to the new responsible in presence of a join.

2.2.1 Initialization

As described in Section 2.1, two ring initialization modalities are supported: the insertion of one node at a time until the desired size has been reached; the creation of a ring of the desired size where each node knows the immediate successor.
The former is supported by the *create()* and *join()* methods: *create()* is called on the first node in order to build a new Chord ring, whereas *join()* performs all the operations required to join an existing ring. Hence, *join()* is used also after the initial phase of the simulation to insert new nodes in the ring.
Instead, the latter is supported by the *initSuccessor()* method, which initialises the successor list using the node provided.
As regards joining an existing ring, it implies asking a node already contained in the ring for the successor of the current node. This is done through the *find_successor_step()* method, which is presented in the following Section.

2.2.2 Lookup

As introduced in Section 1, the lookups are performed in an iterative way. Hence, the node on which the *lookup()* method is called initiates all the communications needed to reach the responsible for the given key.
Basically, the node first checks if its successor is the

[3] It is sufficient that every node knows its successor to achieve correctness.

responsible for the key of interest: if it is, the lookup is finished; otherwise it asks the closest preceding node (w.r.t. the given key) among the ones contained in the finger table and in the successor list. Since the iterative version has been implemented, if the contacted node's successor is not the responsible, the contacted node provides the lookup initiator with a reference to the closest preceding node among the ones it knows. The procedure is repeated until the responsible is found.

Since the same steps are performed during the stabilization, the *lookup()* method just calls another function, i.e. *find_successor()*. In practice, *find_successor()* does the first check, whereas the *find_successor_step()* method implements the iterative step. As regards the communications between nodes, they are performed through the methods *processSuccRequest()* and *processSuccResponse()* using an exponentially distributed packet delay with mean of 50 milliseconds (0.05 ticks) as in [1].

Actually, the lookup initiator may not receive an answer due to a failure or an out-of-date reference (the target node has left the ring). In that case, after 500 milliseconds (0.5 ticks) it contacts the node from which it has learnt about that node in order to obtain another reference (*getPrevSuccessor()* method). If that node does not reply either, the lookup initiator iterates the procedure.

2.2.3 Stabilization

The stabilization protocol is run periodically to ensure that the various pointers (finger table, successors, predecessor) are up-to-date. The main method is *stabilization()*, which starts the various operations.

First of all, the node contacts sequentially its successors until it finds one alive (this is done in *stabilization()*). At that point, if the predecessor of the replying node belongs to the interval $(nodeId, successorId)$ the current node updates its immediate successor (*stabilization_step()* method) [4]. The next step consists in asking the immediate successor for its successor list, which is used to update the list of the current node. As regards the communication, it is managed through the methods *processStabRequest()* and *processStabResponse()*. In particular, the former method also verifies if the predecessor of the contacted node needs to be changed (*notifiedPredecessor()* method). In that case, the contacted node transfers the necessary data -if any- to the new predecessor and notifies the old predecessor that its successor should be changed (*setNewSuccessor()* method) accelerating the integration of a new node in the ring.

Once the response has been processed, the node moves on to the stabilization of the other pointers. This is done in the *fix_data_structures()* method: basically, the node stabilizes alternatively one entry of the finger table (*fix_fingers()* method) and one entry of the successor list (*fix_successors()* method) in addition to the predecessor. As regards the finger table, the node calls the *find_successor()* method in order to find the responsible for the id the entry points to. Instead, as for the successor list, the node calls the same method on the id of the last stabilized successor plus one. Once the responsible has been found, the corresponding data structure is updated by the method *setResult()*. In particular, since the first entry of the two data structures represent the immediate successor, they are never stabilized during this phase (it has already been done in the previous one). Finally, the node checks if the predecessor is still alive: if it is not, the pointer is set to `null`, which allows the node to accept a new predecessor in the next stabilization.

[4] This may happen in case a new node has recently joined the ring.

2.2.4 Data management

The data management category includes two methods: *transferDataUpToKey()* and *newData()*.
Basically, the former extracts the data with a hash value of the key up to a target value from the data owned by the current node, whereas the latter performs the acquisition of new data. In practice, these methods are exploited to transfer data: to the new predecessor; to the successor before leaving the ring (this operation is managed by the `TopologyBuilder`).

2.2.5 Crash and recovery

Nodes failures are simulated as follows: each node periodically crashes with a certain probability (*nodeCrash()* method) and schedules the recovery after a certain interval (*recovery()* method). While failed the node does not process any request or response. Instead, once it is up again, it performs immediately a stabilization using the references it had before crashing.

2.2.6 Leave

2.3 Support classes

2.3.1 Finger Table

2.3.2 Lookup

2.3.3 Utils

3 Simulator

4 Analyses and Results

References

[1] I. Stoica, R. Morris, D. Liben-Nowell, D. Karger, F. Kaashoek, F. Dabek and H. Balakrishnan, "Chord: A scalable peer-to-peer lookup protocol for internet applications", *IEEE Transactions on Networking*, vol. 11, Feb. 2003. DOI: `10.1109/TNET.2002.808407`.