Peer-to-Peer Systems

Nicole Hatt
Seminar of Distributed Computing
WS 03/04

Papers

- Pastry: Scalable, decentralized object location and routing for large-scale peer-to-peer systems

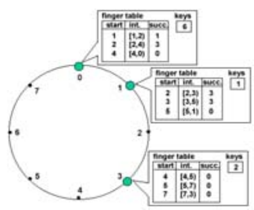
  Antony Rowstron and Peter Druschel
- Viceroy: A Scalable and Dynamic Emulation of the Butterfly

  Dahlia Malki, Moni Naor and David Ratajczak

Short reminder: Chord

- A distributed lookup protocol
- Key associated with each data item using consistent hashing
- Maps keys onto nodes
- Each of the N nodes needs routing information of O(log*N*) nodes
- Joins/ Leaves cost O(log²*N*) messages
- Each node maintains a finger table

- Example:
  net with nodes 0,1,3
  and keys 1, 2, 6



Pastry

Design: nodeID and key

- Unique 128 bit nodeID for each node assigned at random:
  - e.g. hash of node's IP address
  - indicates the position in a circular nodeID space from 0 to $2^{128} – 1$
  - nodes with adjacent nodeID's are not physically close to each other
- Every message is assigned a key
- nodeIDs and keys are sequences of digits with base 2^b
- Pastry routes a message with key k to the node having the nodeID numerically closest to k

Design: Proximity metric

- When routing messages, Pastry minimizes the distance the messages travel
- Each node has the possibility to determine its distance to any other node
- Distance is measured according to a scalar proximity metric:
  - Geographic distance

Design: Routing (1)

- Messages are routed to node with numerically closest nodeId to the given key
- In each routing step:
  - the message is routed to a node whose nodeId shares one digit more with the key than the nodeId of the present node
  - or to a node whose nodeId shares a prefix with the key as long as the current one but is numerically closer

  Repeat until numerically closest node is found
- Each node maintains a routing state to support the routing procedure

Design: Pastry node state

- **Routing table**
  - $\lceil log_{2^b} N \rceil$ rows with 2^b-1 entries
  - nodeIds of row n‘s entries share first n digits
  - Routing table entry is empty if no suitable node is known
- **Neighborhood set**
  Contains nodeIds of the closest nodes according to the proximity metric
- **Leaf set**
  A set of nodes with $|L|/2$ numerically closest larger and smaller nodeIds

NodeId 10233102

Leaf set

SMALLER		LARGER	
10233033	10233021	10233120	10233122
10233001	10233000	10233230	10233232

Routing table

-0-2212102	1	-2-2301203	-3-1203203
0	1-1-301233	1-2-230203	1-3-021022
10-0-31203	10-1-32102	2	10-3-23302
102-0-0230	102-1-1302	102-2-2302	3
1023-0-322	1023-1-000	1023-2-121	3
10233-0-01	1	10233-2-32	
0		102331-2-0	
		2	

Neighborhood set

13021022	10200230	11301233	31301233
02212102	22301203	31203203	33213321

Design: Routing (2)

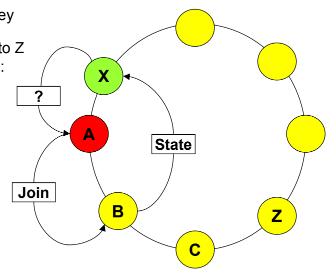
- Message with key D arrives at node with nodeId A
- **Leaf set**
  - Check whether D is in the range of the leaf set
  - In this case, directly forward message to corresponding node
- **Routing table**
  - if this is not the case, forward message to a node whose nodeId shares one more digit with D than the current node‘s nodeId

  - If entry is empty or not reachable, forward message to a node with nodeId that shares a prefix with the key as long as the present one and is numerically closer

  Repeat this step until searched node is found
- Routing procedure always converges
- **Routing Performance**
  The expected number of routing steps is $\lceil log_{2^b} N \rceil$

Node Join

Phase 1:
- A routes a join message with key equal to X
- X receives state tables from A to Z
- X initializes its state tables with:
  - A‘s neigborhood set
  - Z‘s leaf set
  - routing table:
    - row 0 = row 0 of A
    - row 1 = row 1 of B
    - row 2 = row 2 of C
- X send a copy of its state to all nodes
- Total cost: $O(log_{2^b} N)$
  N=number of nodes



Node Join (2)

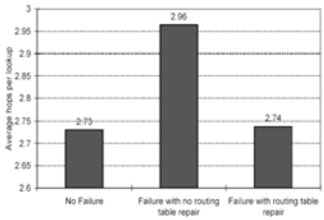
Phase 2:
- Proximity metric: Each node is able to determine the physical distance to any other node
- Improvement of X‘s routing table quality: X
  - requests state from each node in the routing and the neighborhood set
  - compares physical distances of the nodes in those tables
  - updates its state when closer nodes are found
  - informs other nodes about its state

Node departure

- **Failed/departed node:**
  Immediate neighbors can no longer communicate with it
- **Node replacement:**
  - To replace a node in its leaf set, a node n asks the next alive node m with largest index for its leaf table
  - M‘s leaf set partly overlaps with n‘s leaf set
  - A non common node among these leaf sets is selected to be the failed node‘s replacement
  - It is important to keep the neighborhood set up to date because it is important for testing if nearby nodes are still alive

Node failures: experimental results

- 5000 node Pastry network
- Quality of the network before and after 500 node failures (b=4)



Applications: PAST

- A storage utility on top of Pastry
- PAST replicates a file on its k numerically closest nodes
- PAST profits from the proximity metric:
  - When routing a message from a client to the numerically closest node, the message first reaches a physically close node among the numerically closest nodes
  - Minimize network load and client latency

Applications: SCRIBE

- Publish/subscribe system
- A node (rendez-vous point) with a nodeId numerically closest to a topicId of a given topic stores a list of subscribers
- Subscribers send messages using the topicId as key
- Each node along the path registers the message
- Publishers send data to the rendez-vous point using topicId as key
- Rendez-vous point forwards the data to all subscribers

Viceroy

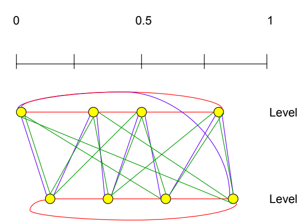
Viceroy: properties

- Completely distributed and scalable lookup service
- Key-value pairs are distributed across a changing set of servers
- Keys and servers have identifiers chosen in the same metric
- A key-value pair is on the server with the closest identifier to the key
- Viceroy is a combination of a ring and a butterfly network
- Each server in the network is entirely determined by:
  - Its identifier
  - Its level

The Viceroy network

The network consists of three sets of links:

- **a general ring**
  each node s is connected to
  - its successor (s.successor)
  - Its predecessor (s.predecessor)
- **level rings**
  all nodes of the same level are connected in a ring with these links:
  - s.nextonlevel
  - s.prevonlevel
- **butterfly**
  each node s points to two down nodes and one up level node:
  - s.right
  - s.left
  - s.up



System model: General ring

- Distribution of key-value pairs among servers:
  - each server is referred by an unique identifier
  - keys and server ID's are treated as dots in the same metric
  - keys and servers are mapped to the unit ring [0..1)
  - a key-value pair is on the server with the closest ID to the key
  - a server manages key-value pairs with keys between its counter-clockwise neighbor's ID and its own ID

System model: Level ring

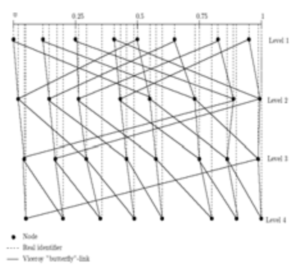
- Goal:
  - select levels that require as few level changes as possible when joins and leaves occur
  - Select levels so that a good dispersal of levels among servers is achieved

Distributed *SELECT-LEVEL* algorithm:

1. A server s estimates n_0, the total number of servers in the configuration
   Let n_0 = 1/distance(s, SUCC(s))
2. Based on this estimate n_0, select a level l between $[1 \ldots \lfloor \log n_0 \rfloor]$ uniformly at random and return l

System model: butterfly

- Each server s at level l points to:
  - **A right down link to level l+1**
    clockwise closest node to s $+1/2^l$ *($NLEVEL_{l+1}(s+1/2^l)$)*
  - **A left down link to level l+1**
    clockwise-closest node to s *($NLEVEL_{l+1}(s)$)*
  - **An up link (if l>1) to level l-1**
    clockwise closest node to s *($NLEVEL_{l-1}(s)$)*



Simple *LOOKUP* subroutine

- Only global ring and butterfly links are used
- *LOOKUP(x,y)* finds the clockwise closest to the value x starting at server y
- It consists of 3 routing phases:
  - **Proceed to root**
    find root server by following level up links
  - **Traverse tree**
    lookup down from the root, if down link does not exist, go directly to traverse ring
    - if distance d(current, x) < $1/2^{current..level}$ then
      current = current.left
    - else current = current.right
  - **Traverse ring**
    select closer server to x between current.successor and current.predecessor, repeat until closest server is found and return result

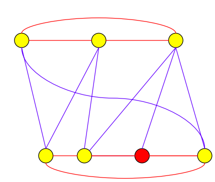
Viceroy construction: Join

A joining server s performs the steps:

1. Select an identifier
2. Find its successor using the *LOOKUP* function, insert s in the ring and update the pointers
3. Transfer all key-value pairs from successor with key between s.predecessor and s
4. Select a level l, update level ring pointers
5. Find s.left, s.right and s.up

Viceroy construction: Leave

- Outbound connections have to be removed
- Inbound connections must find a replacement
  - Using the LOOKUP subroutine
  - By pointing to the successor



- Transfer resources to its successor

Improved *LOOKUP* subroutine

- **Problem of the simple *LOOKUP*:**
  In the third phase the current and target node might be at a distance of $O(\log^2 n)$ when the ring is traversed.

- **Improvement to achieve an O(logn) dilation:**
  Third phase is a combination of level and global rings:

  if current.nextonlevel $\in$ stretch(current,x)
  then current = current.nextonlevel
  elsif current.prevonlevel $\in$ stretch(current,x)
  then current = current.prevonlevel
  else current = current.successor or predecessor
  repeat until clockwise closest node to x found

  Stretch (x, y) = clockwise region between server x and y

Simple Viceroy Analysis

If n servers are present:

- The first two phases take $O(\log n)$ steps
- The last phase takes $O(\log n)$ steps in expectation and $O(\log^2 n)$ at worst w.h.p. with the simple lookup and $O(\log n)$ with the improved
- For any server the expected load is $O((\log n)/n)$ and w.h.p. the maximum load on all servers is $O((\log^2 n)/n)$
- The outdegree of each node is 7 (in simple version only 5), the expected indegree is O(1) and the largest indegree is $O(\log n)$ w.h.p.

The Bucket solution

- Largest indegree in the number can be as large as the log of the number of servers
- „Buckets“ are added:
  - Sets of $O(\log n)$ servers
    In case of a size drop, two buckets are merged
    If the size exceeds $c \log n$,the bucket is split in two
  - One set does not overlap with any other set
  - Inside a bucket a ring is maintained
  - In one bucket is at least one server of each level and no more than c

Comparison: Pastry/Viceroy

- **Implementation**
  - Pastry:
    - Implemented in java
    - Report on experimental results
    - Applications running on top of it

- **Assumptions**
  - Viceroy: multiple join/leave operations can fail

Comparison: Pastry/Viceroy (2)

- **Routing table**
  Each Pastry node provides routing information in a state table

- **Locality**
  Pastry has the additional ability to root messages along the shortest distance according to the proximity metric

- **Network**
  - Viceroy: butterfly/ ring combination
  - Pastry: ring