Peer-to-Peer Networks

04: Chord

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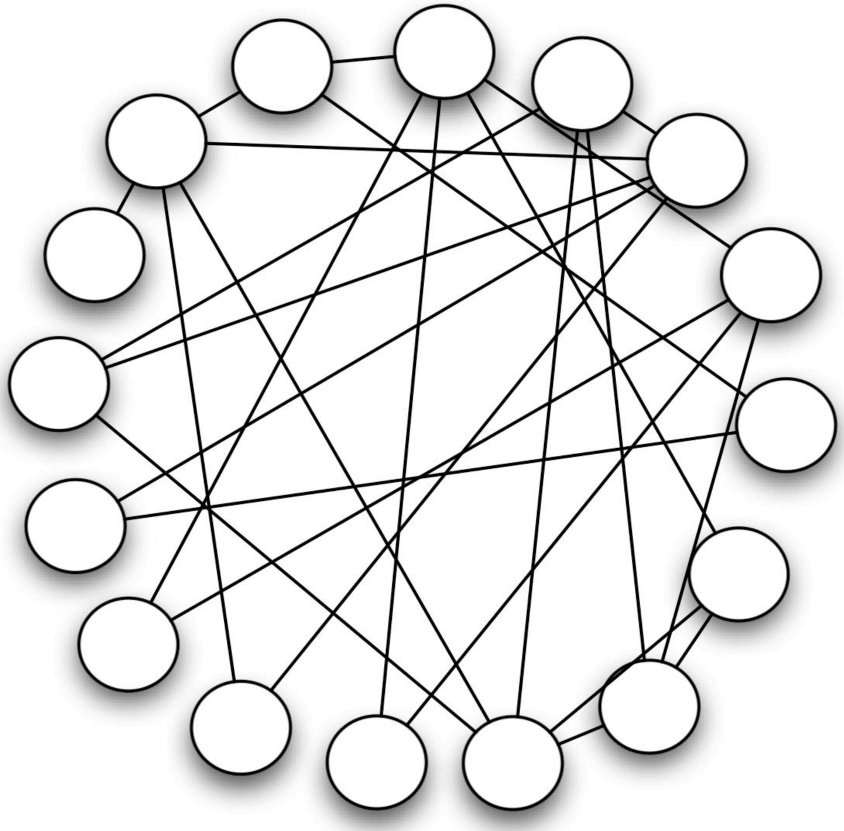
Why Gnutella Does Not Really Scale

- Gnutella
  - graph structure is random
  - degree of nodes is small
  - small diameter
  - strong connectivity
- Lookup is expensive
  - for finding an item the whole network must be searched
- Gnutella's lookup does not scale
  - reason: no structure within the index storage



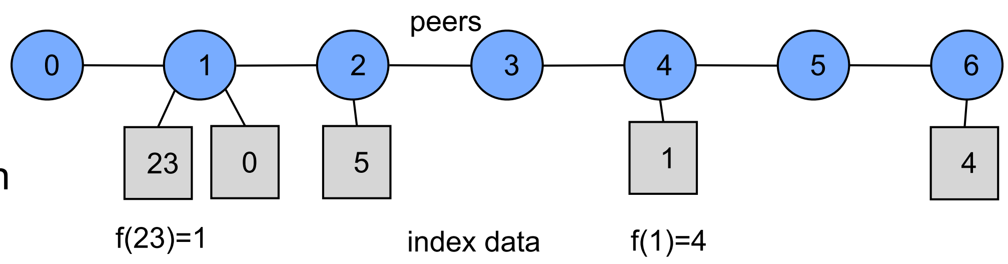
Two Key Issues for Lookup

- Where is it?
- How to get there?
- Napster:
  - Where? on the server
  - How to get there? directly
- Gnutella
  - Where? don‘t know
  - How to get there? don‘t know
- Better:
- Where is x?
  - at f(x)
- How to get there?
  - all peers know the route

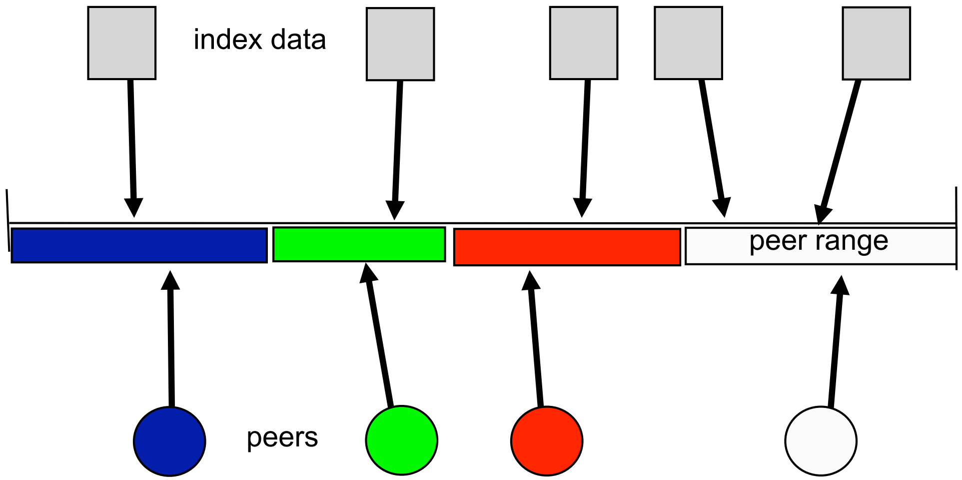
Distributed Hash-Table (DHT)

- Hash table
  - does not work efficiently for inserting and deleting
- Distributed Hash-Table
  - peers are „hashed“ to a position in an continuos set (e.g. line)
  - index data is also „hashed“ to this set
- Mapping of index data to peers
  - peers are given their own areas depending on the position of the direct neighbors
  - all index data in this area is mapped to the corresponding peer
- Literature
  - “Consistent Hashing and Random Trees: Distributed Caching Protocols for Relieving Hot Spots on the World Wide Web”, David Karger, Eric Lehman, Tom Leighton, Mathhew Levine, Daniel Lewin, Rina Panigrahy, STOC 1997

Pure (Poor) Hashing

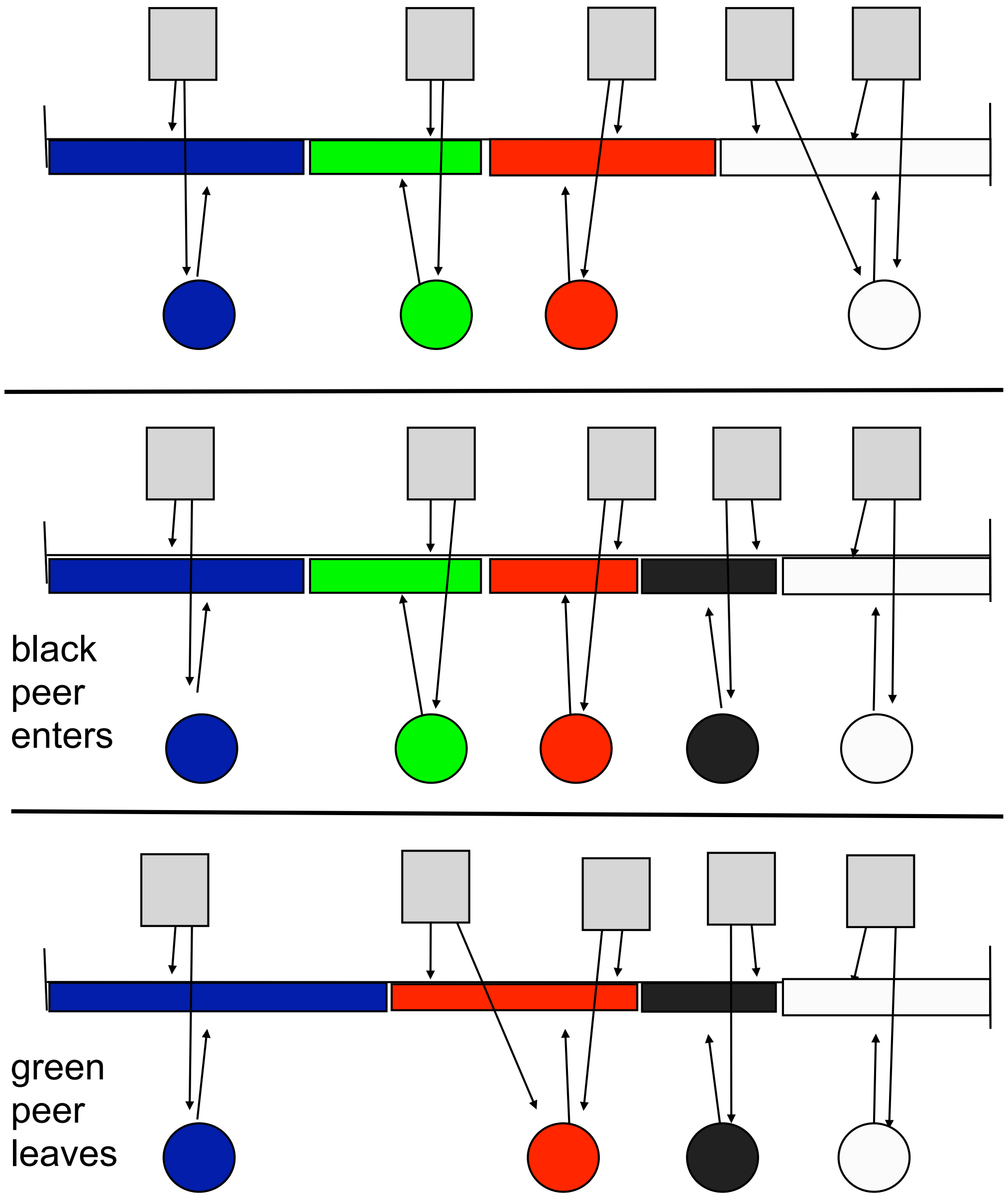


DHT



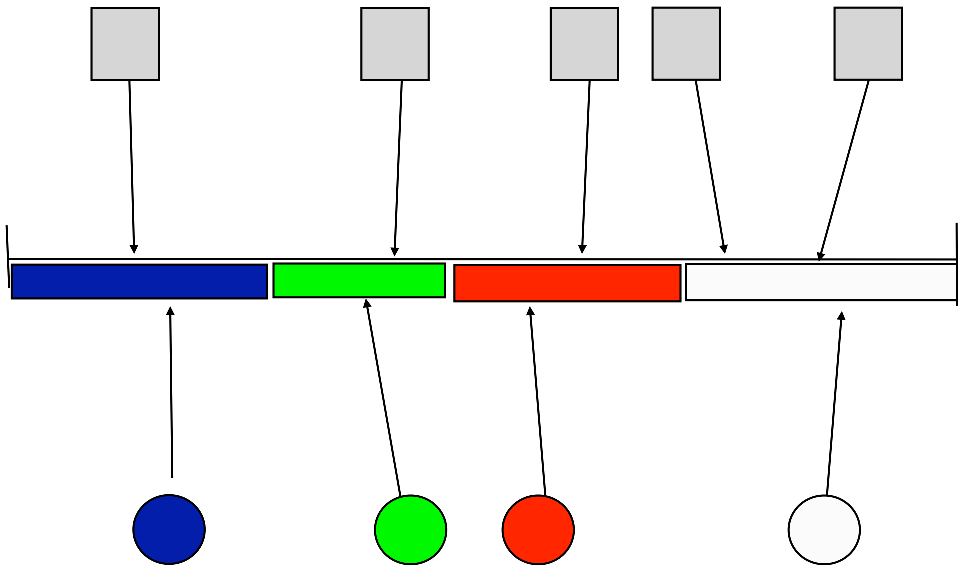
Entering and Leaving a DHT

- Distributed Hash Table
  - peers are hashed to to position
  - index files are hashed according to the search key
  - peers store index data in their areas
- When a peer enters
  - neighbored peers share their areas with the new peer
- When a peer leaves
  - the neighbors inherit the responsibilities for the index data



Features of DHT

- Advantages
  - Each index entries is assigned to a specific peer
  - Entering and leaving peers cause only local changes
- DHT is the dominant data struction in efficient P2P networks
- To do:
  - network structure



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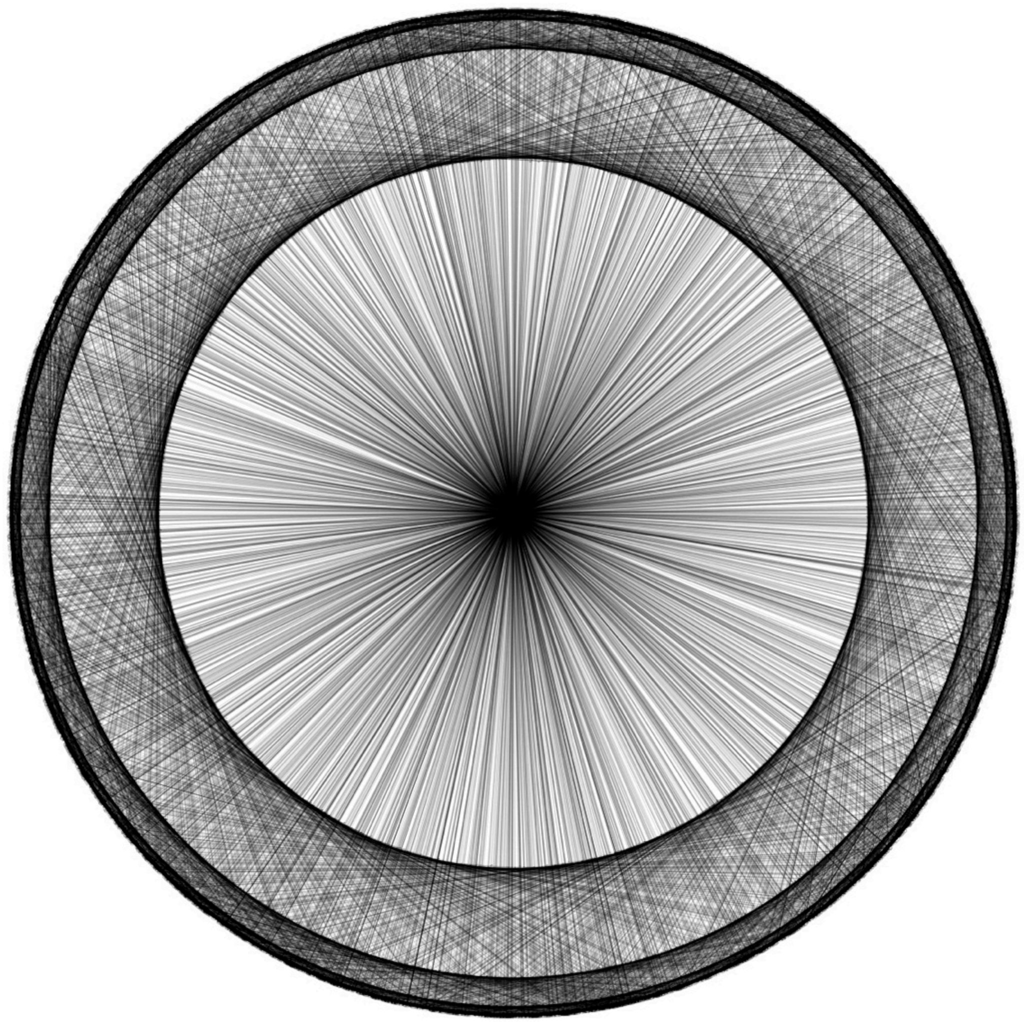
Chord

- Ion Stoica, Robert Morris, David Karger, M. Frans Kaashoek and Hari Balakrishnan (2001)
- Distributed Hash Table
  - range $\{0,..,2^m-1\}$
  - for sufficient large m
- Network
  - ring-wise connections
  - shortcuts with exponential increasing distance



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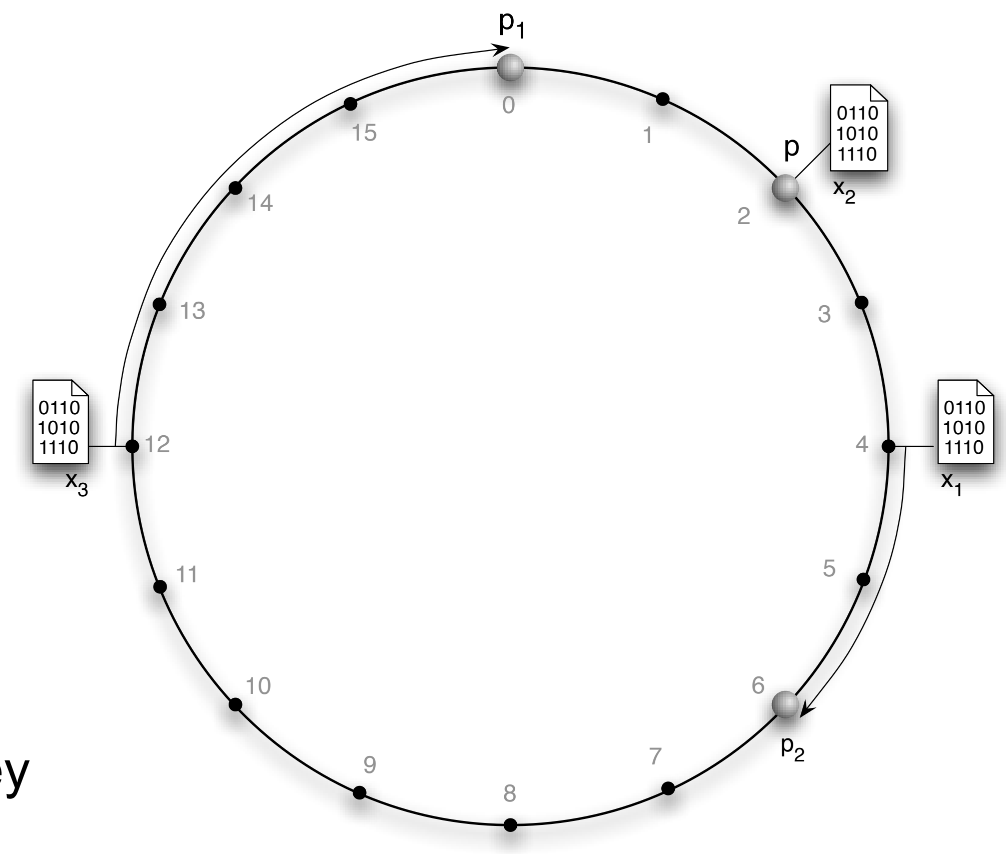
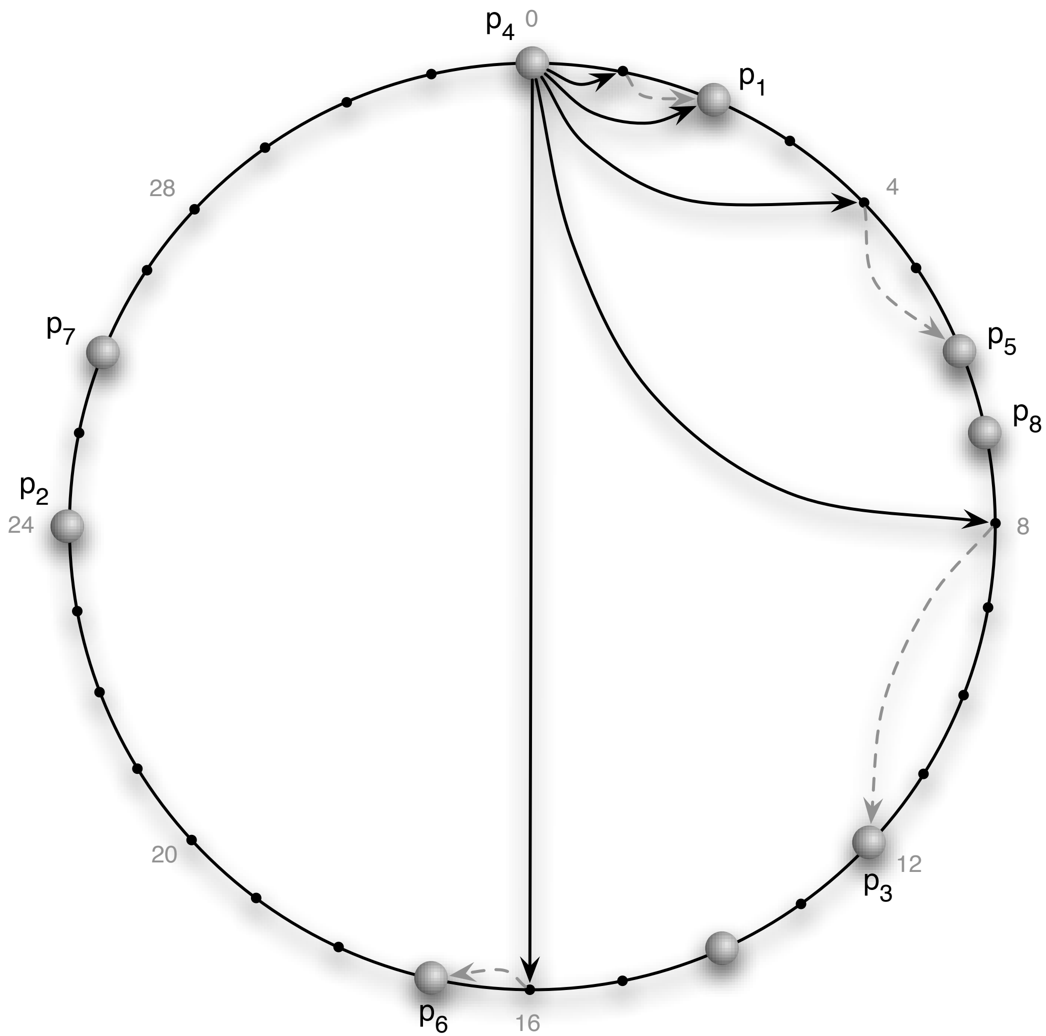
Chord as DHT

- n number of peers
- V set of peers
- k number of data stored
- K set of stored data
- m: hash value length
  - $m \geq 2 \log \max\{K,N\}$
- Two hash functions mapping to $\{0,..,2^{m-1}\}$
  - $r_V(b)$: maps peer to $\{0,..,2^{m-1}\}$
  - $r_K(i)$: maps index according to key i to $\{0,..,2^{m-1}\}$
- Index i maps to peer $b = f_V(i)$
  - $f_V(i) :=$ $\arg\min_{b \in V}\{(r_V(b)-r_K(i)) \bmod 2^m\}$



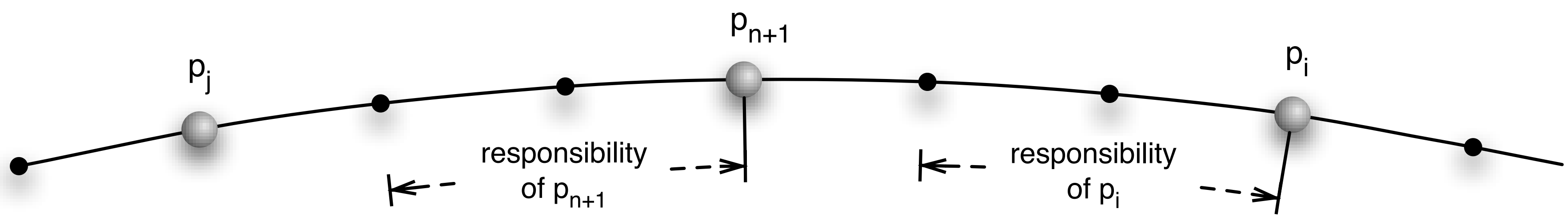
Pointer Structure of Chord

- For each peer
  - successor link on the ring
  - predecessor link on the ring
  - for all i ∈ {0,..,m-1}
    - Finger[i] := the peer following the value $r_V(b+2^i)$
- For small i the finger entries are the same
  - store only different entries
- Lemma
  - The number of different finger entries is O(log n) with high probability, i.e. $1-n^{-c}$.



Balance in Chord

- Theorem
  - We observe in Chord for n peers and k data entries
    - Balance&Load: Every peer stores at most O(k/n log n) entries with high probability
    - Dynamics: If a peer enters the Chord then at most O(k/n log n) data entries need to be moved
- Proof
  - …



Properties of the DHT

- Lemma
  - For all peers b the distance $|r_V(b.succ) - r_V(b)|$ is
    - in the expectation $2^m/n$,
    - $O((2^m/n) \log n)$ with high probability (w.h.p.)
    - at least $2^m/n^{c+1}$ für a constant $c>0$ with high probability
  - In an interval of length $w\ 2^m/n$ we find
    - $\Theta(w)$ peers, if $w=\Omega(\log n)$, w.h.p.
    - at most $O(w \log n)$ peers, if $w=O(\log n)$, w.h.p.
- Lemma
  - The number of nodes who have a pointer to a peer b is $O(\log^2 n)$ w.h.p.

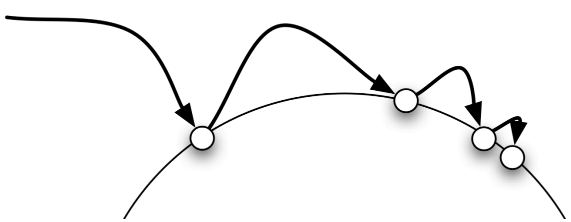
Lookup in Chord

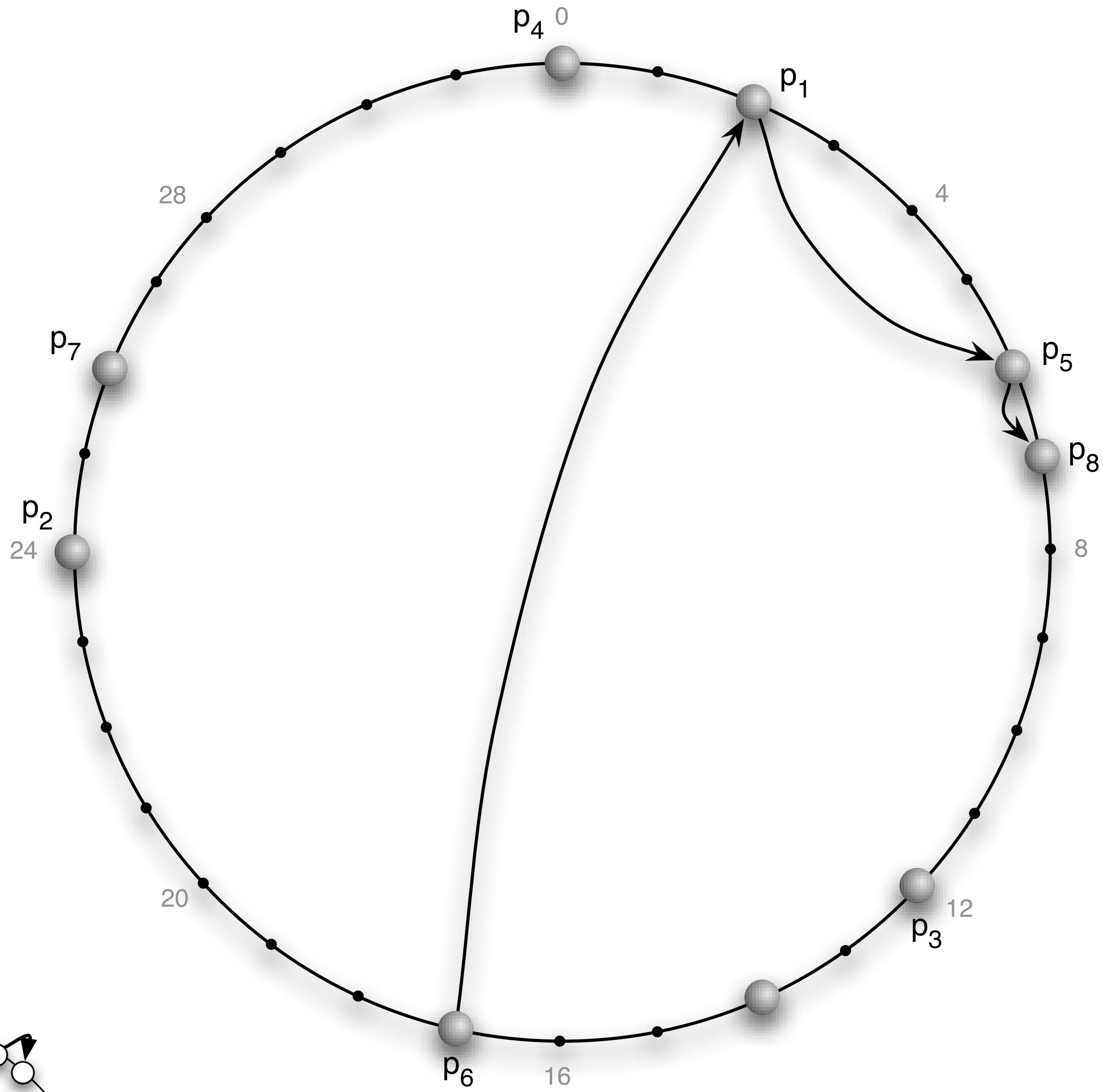
- Theorem
  - The Lookup in Chord needs O(log n) steps w.h.p.
- Lookup for element s
  - Termination(b,s):
    - if peer b,b'=b.succ is found with $r_K(s) \in [r_V(b),r_V(b'))$
  - Routing:
    Start with any peer b
    - while not Termination(b,s) do

```
for i=m downto 0 do
  if rK(s) ∈ [rV(b.finger[i]),rV(finger[i+1])] then
      b ← b.finger[i]
  fi
od
```

Lookup in Chord

- Theorem
  - The Lookup in Chord needs O(log n) steps w.h.p.
- Proof:
  - Every hops at least halves the distance to the target
  - At the beginning the distance is at most
  - The minimum distance between is $2^m/n^c$ w.h.p.
  - Hence, the runtime is bounded by c log n w.h.p.





How Many Fingers?

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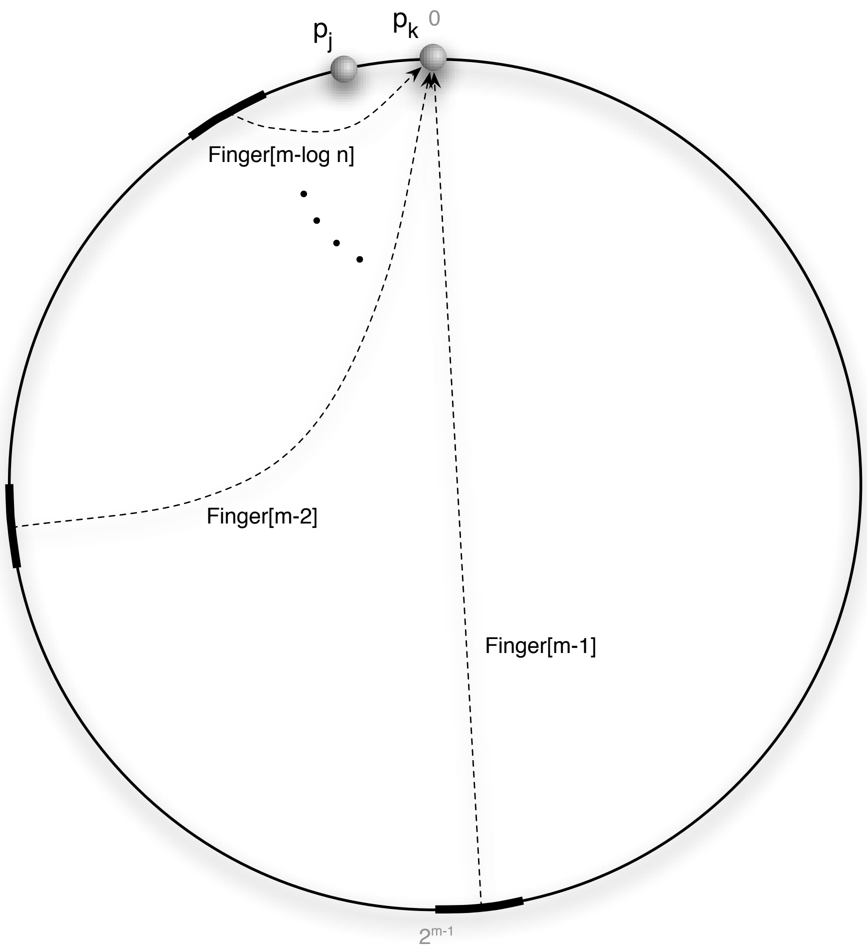
- Lemma
  - The out-degree in Chord is O(log n) w.h.p.
  - The in-degree in Chord is $O(\log_2 n)$ w.h.p.
- Proof
  - The minimum distance between peers is $2^m/n^c$ w.h.p.
    - this implies that that the out-degree is O(log n) w.h.p.
  - The maximum distance between peers is $O(\log n\ 2^m/n)$ w.h.p.
    - the overall length of all line segments where peers can point to a peer following a maximum distance is $O(\log^2 n\ 2^m/n)$
    - in an area of size $w=O(\log^2 n)$ there are at most $O(\log^2 n)$ w.h.p.



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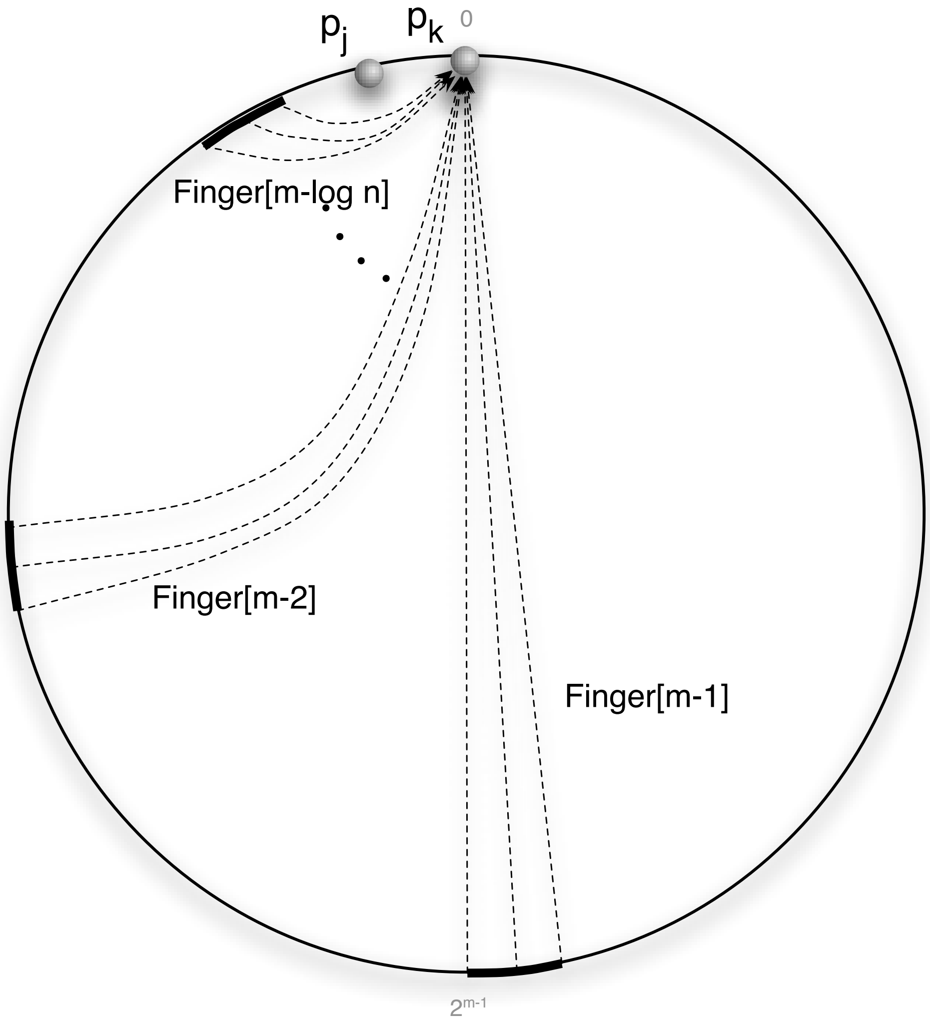
Inserting Peer

- Theorem
  - For integrating a new peer into Chord only $O(\log^2 n)$ messages are necessary.

Adding a Peer

- First find the target area in O(log n) steps
- The outgoing pointers are adopted from the predecessor and successor
  - the pointers of at most O(log n) neighbored peers must be adapted
- The in-degree of the new peer is O(log^{2}n) w.h.p.
  - Lookup time for each of them
  - There are O(log n) groups of neighb ored peers
  - Hence, only O(log n) lookup steps with at most costs O(log n) must be used
  - Each update of has constant cost



Data Structure of Chord

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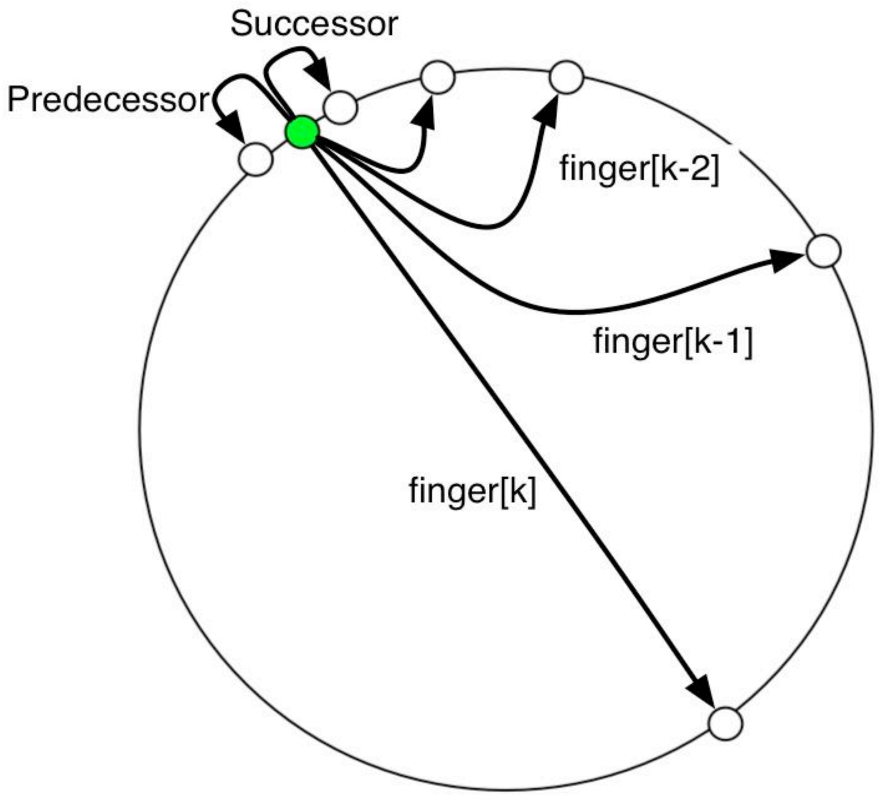
    - Finger[i] := the peer following the value $r_V(b+2^i)$
- For small i the finger entries are the same
  - store only different entries
- Chord
  - needs O(log n) hops for lookup
  - needs $O(\log^2 n)$ messages for inserting and erasing of peers



Routing-Techniques for CHORD: DHash++

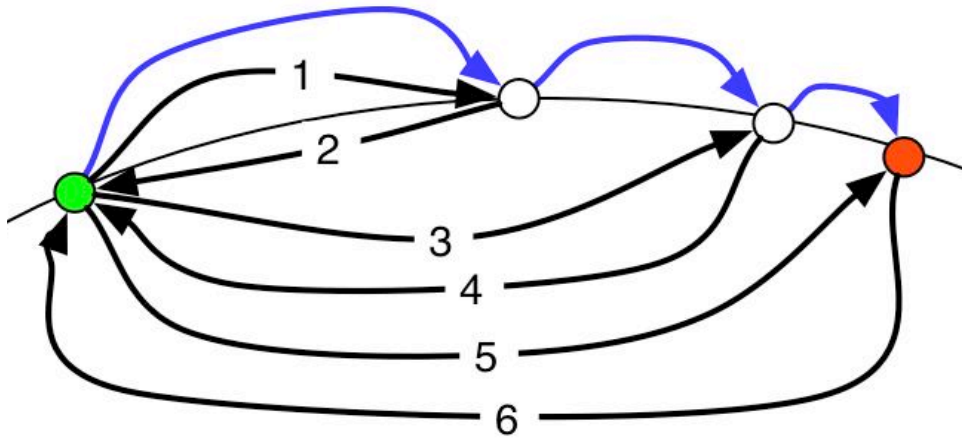
- Frank Dabek, Jinyang Li, Emil Sit, James Robertson, M. Frans Kaashoek, Robert Morris (MIT)
„Designing a DHT for low latency and high throughput“, 2003
- Idea
  - Take CHORD
- Improve Routing using
  - Data layout
  - Recursion (instead of Iteration)
  - Next Neighbor-Election
  - Replication versus Coding of Data
  - Error correcting optimized lookup
- Modify transport protocol

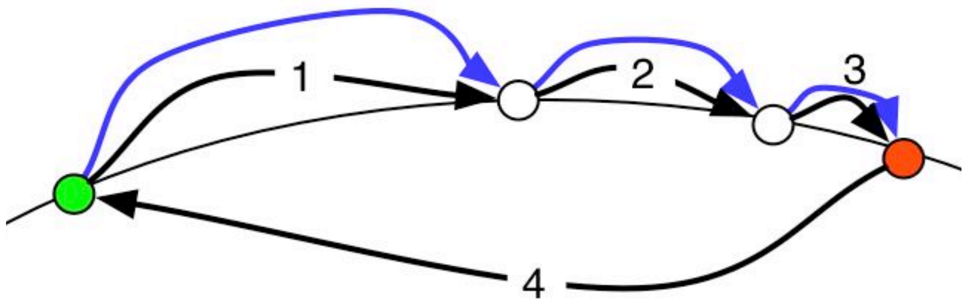
Data Layout

- Distribute Data?
- Alternatives
  - Key location service
    - store only reference information
  - Distributed data storage
    - distribute files on peers
  - Distributed block-wise storage
    - either caching of data blacks
    - or block-wise storage of all data over the network

Recursive Versus Iterative Lookup

- Iterative lookup
  - Lookup peer performs search on his own
- Recursive lookup
  - Every peer forwards the lookup request
  - The target peer answers the lookup-initiator directly
- DHash++ choses recursive lookup
  - speedup by factor of 2





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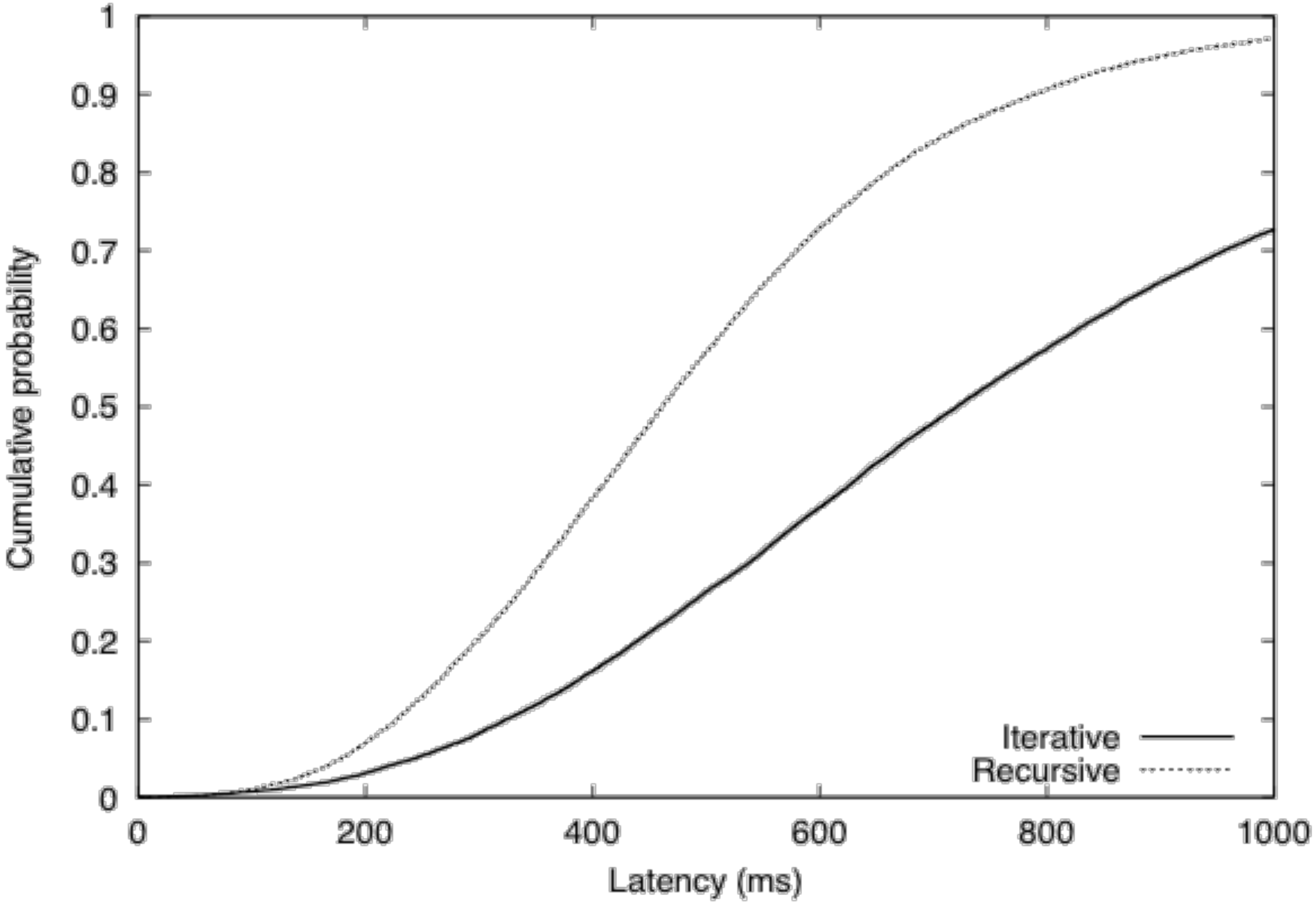
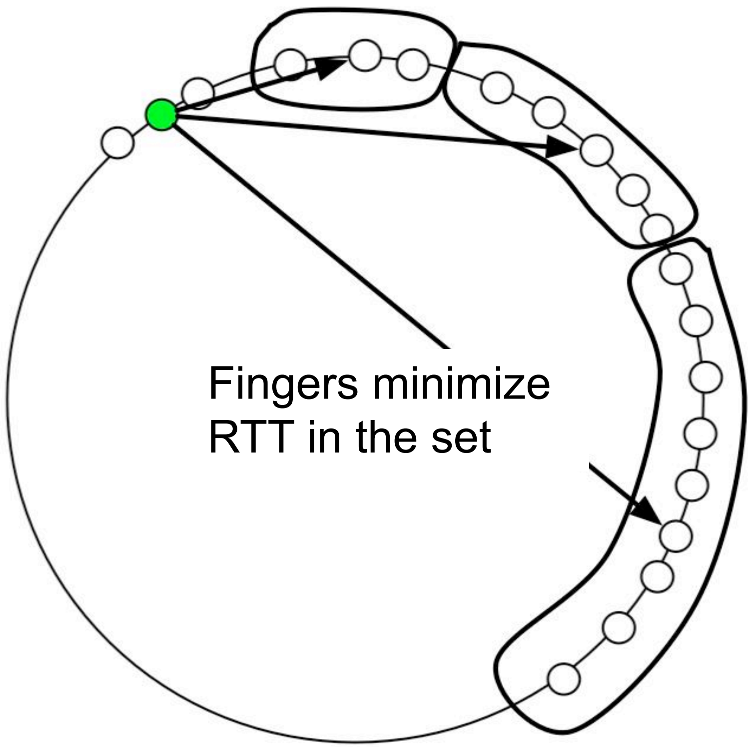


Next Neighbor Selection

- RTT: Round Trip Time
  - time to send a message and receive the acknowledgment
- Method of Gummadi, Gummadi, Grippe, Ratnasamy, Shenker, Stoica, 2003, „The impact of DHT routing geometry on resilience and proximity“
  - Proximity Neighbor Selection (PNS)
    - Optimize routing table (finger set) with respect to (RTT)
    - method of choice for DHASH++
  - Proximity Route Selection(PRS)
    - Do not optimize routing table choose nearest neighbor from routing table



Next Neighbor Selection

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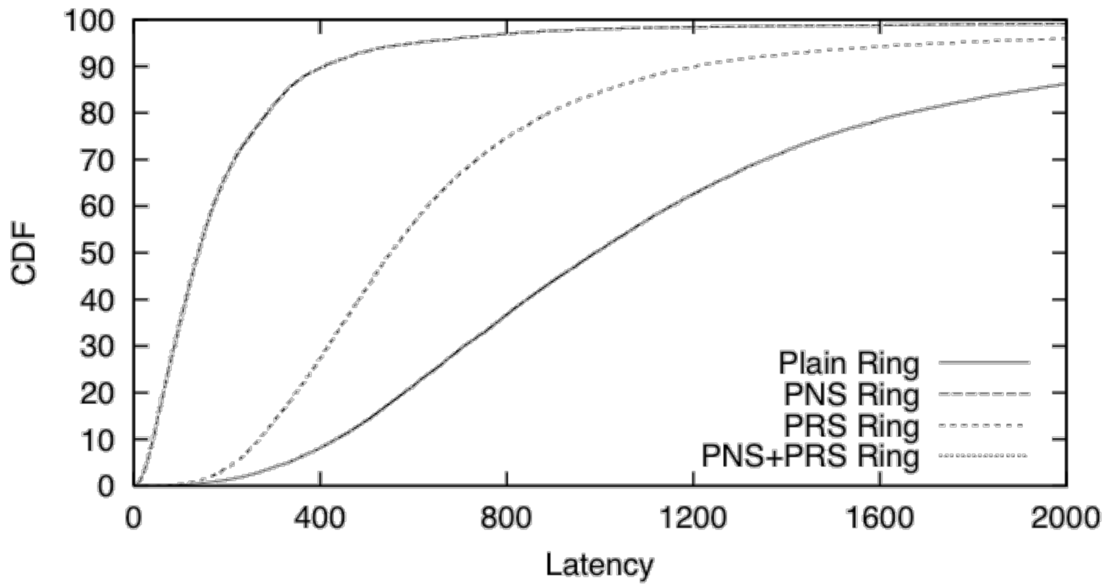
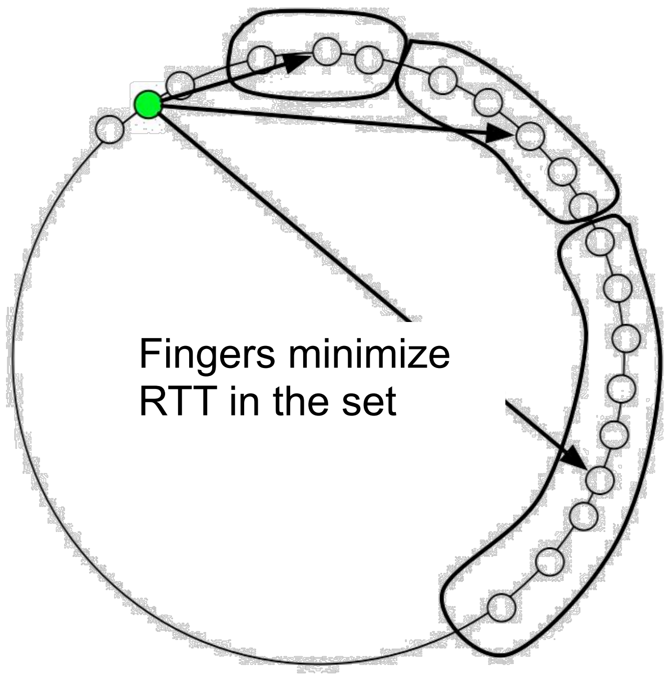
  - Proximity Neighbor Selection (PNS)
    - Optimize routing table (finger set) with respect to (RTT)
    - method of choice for DHASH++
  - Proximity Route Selection(PRS)
    - Do not optimize routing table choose nearest neighbor from routing table
- Simulation of PNS, PRS, and both
  - PNS as good as PNS+PRS
  - PNS outperforms PRS



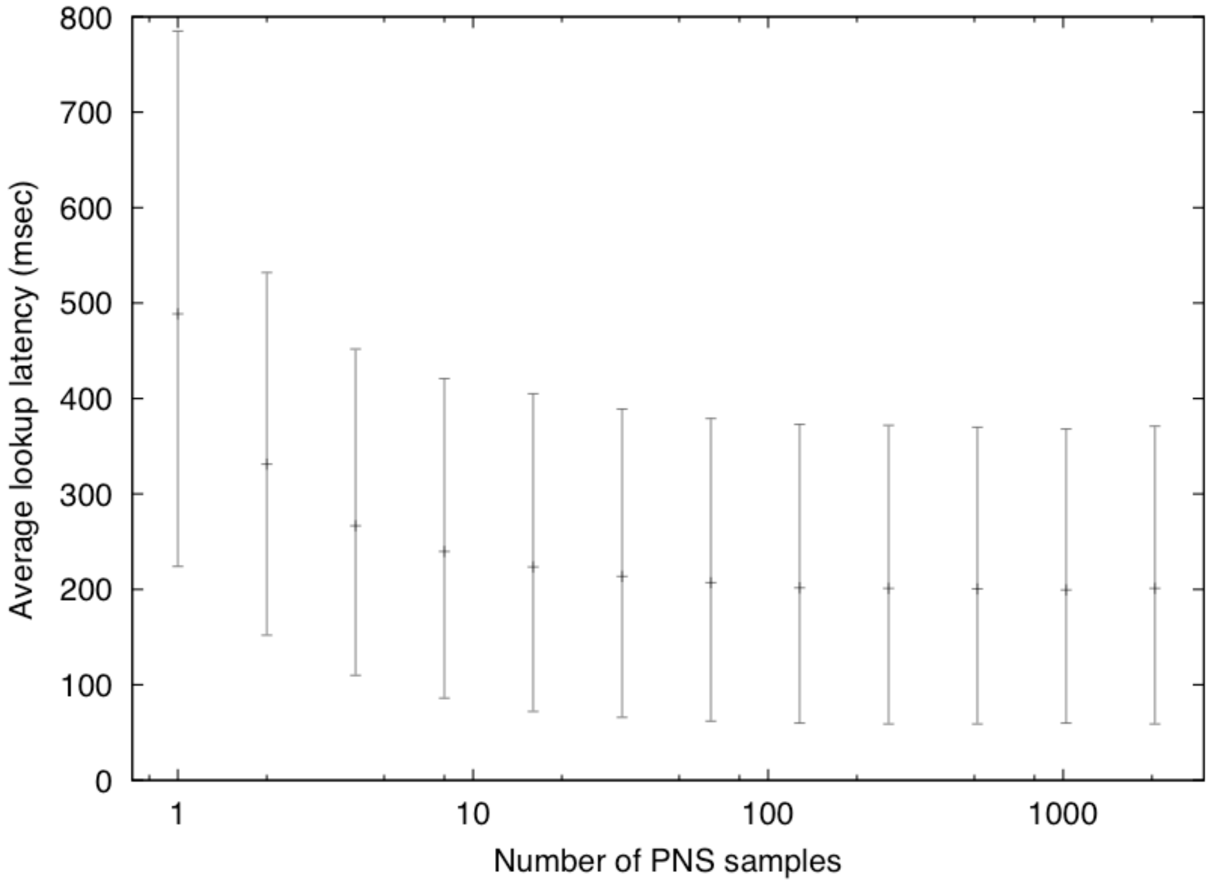
Next Neighbor Selection

- DHash++ uses (only) PNS
  - Proximity Neighbor Selection
- It does not search the whole interval for the best candidate
  - DHash++ chooses the best of 16 random samples (PNS-Sample)

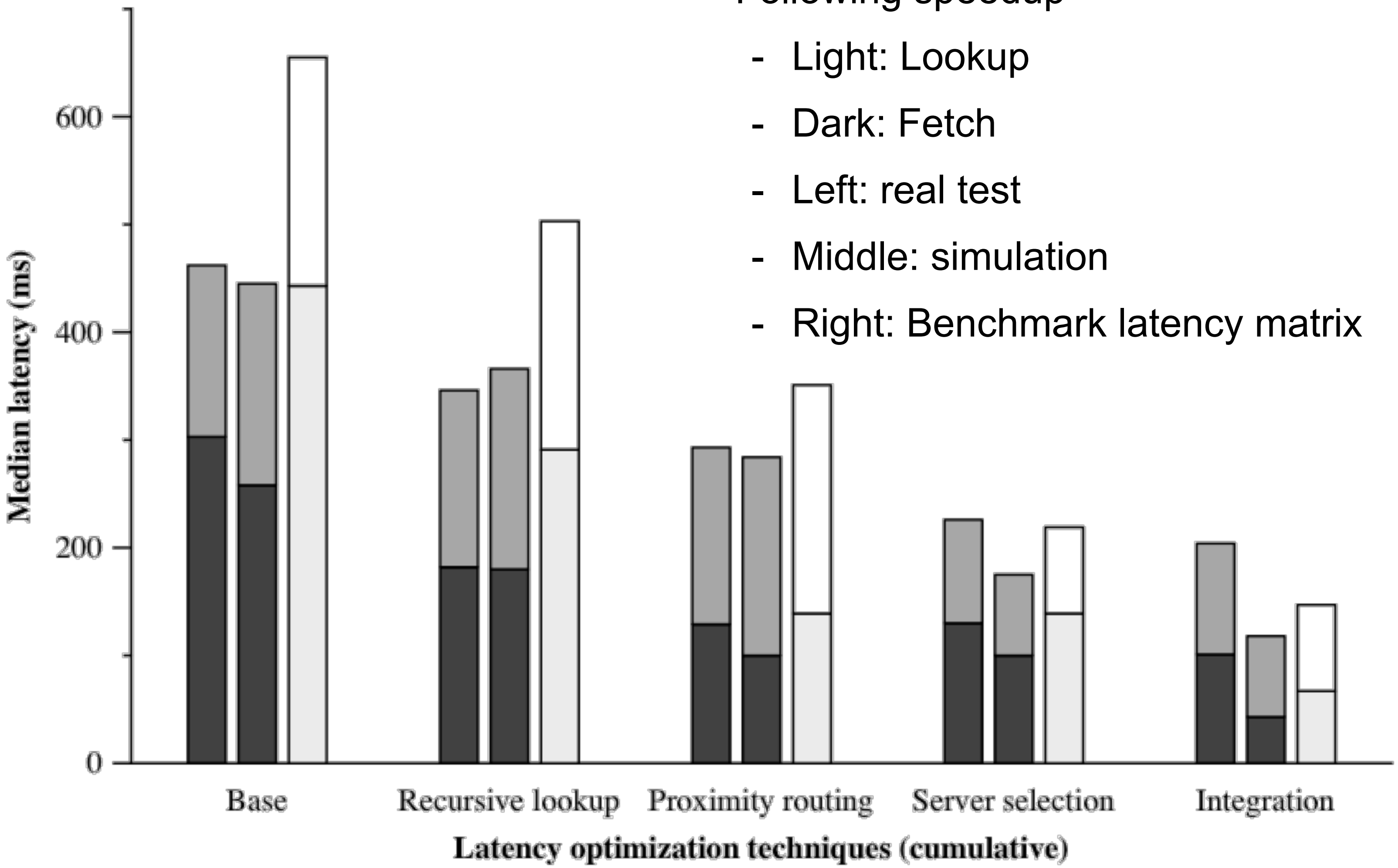


Next Neighbor Selection

- DHash++ uses (only) PNS
  - Proximity Neighbor Selection
- e (0.1,0.5,0.9)-percentile of such a PNS-Sampling

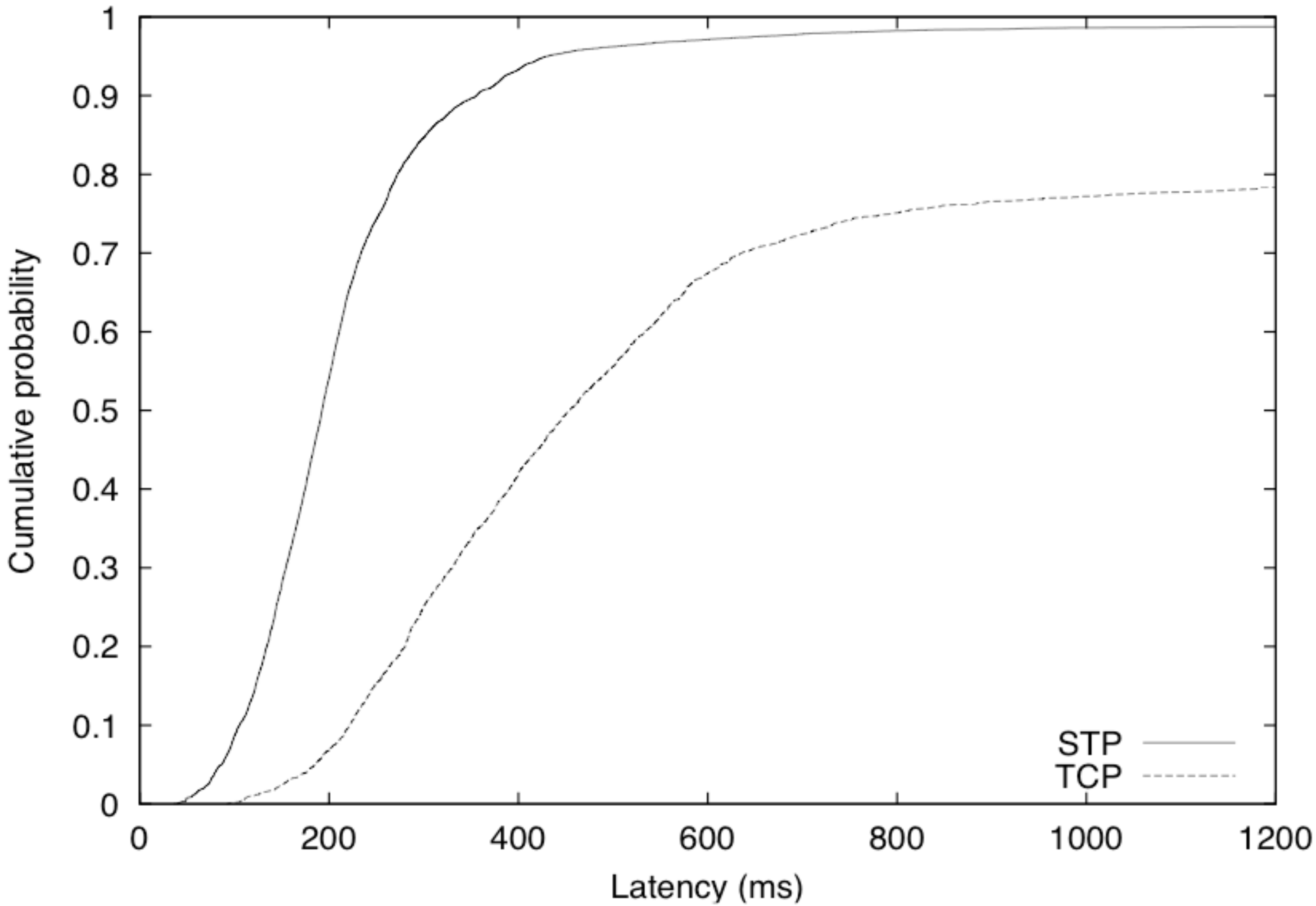


Cumulative Performance Win



- Following speedup
  - Light: Lookup
  - Dark: Fetch
  - Left: real test
  - Middle: simulation
  - Right: Benchmark latency matrix

Modified Transport Protocol



Discussion DHash++

- Combines a large quantity of techniques
  - for reducing the latecy of routing
  - for improving the reliability of data access
- Topics
  - latency optimized routing tables
  - redundant data encoding
  - improved lookup
  - transport layer
  - integration of components
- All these components can be applied to other networks
  - some of them were used before in others
  - e.g. data encoding in Oceanstore
- DHash++ is an example of one of the most advanced peer-to-peer networks

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