OST
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Blockchain (BlCh)

Algorithms for DHT/P2P Systems

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Algorithms for DHT Systems

Mechanisms based on Hashing in KV storage

- Search in DHTs / consistent hashing
  - DHT.get(h(«Institut für Software»))
  - In order to find it: DHT.put(h(«Institut für Software»), value)
- Keywords
  - DHT.get(h(«Institut»))
  - Find it: DHT.put(h(«Institut»), value), DHT.put(h(«für»), value), DHT.put(h(«Software»), value)
  - value points to h(«Institut für Software»)
- Keywords drawbacks
  - Find good keywords → “the”, “a” are not good keywords
  - Exact matches only

Mechanisms based on Hashing in KV storage

- Find “Institut” or “Software” - OR Systems
  - DHT.get(h(«Institut»)) or DHT.get(h(«Software»)), combine results
- Find “Institut” and “Software” - AND Systems
  1) DHT.get(h(«Institut»)) and DHT.get(h(«Software»)), intersect results
  2) DHT.get(h(«Institut») xor h(«Software»))
  - In order to find it:
    - DHT.put(h(«Institut») xor h(«Software»), value),
    - DHT.put(h(«Institut») xor h(«für»), value)
    - DHT.put(h(«für») xor h(«Software»), value)
  - Combination needs to be known in advance

3) Use Bloom Filters
   - bf = DHT.getBF(h(«Institut»)) and DHT.get(h(«Software», bf))
   - Sequential (less network, slower) vs. parallel (more network, faster)

Mechanisms based on Hashing in KV storage

- Similarity Search in DHT
  - https://fastss.csg.uzh.ch
- Project that brings similarity search to HT / DHT
  - Problem: Search for “netwrk” fails for DHTs
- Similarity: Edit distance / Levenshtein distance
  - Min operations to transform one string into another, operations: insert, delete, replace
  - Calculated in matrix size O(m x n)

$$d[i,0] = i,\ d[0,j] = j,$$
$$d[i,j] = min\ (d[i-1,j]+1,\ d[i,j-1]+1,$$
$$d[i-1,j-1]+(if\ s1[i]=s2[j]\ then\ 0\ else\ 1))$$

Mechanisms based on Hashing in KV storage

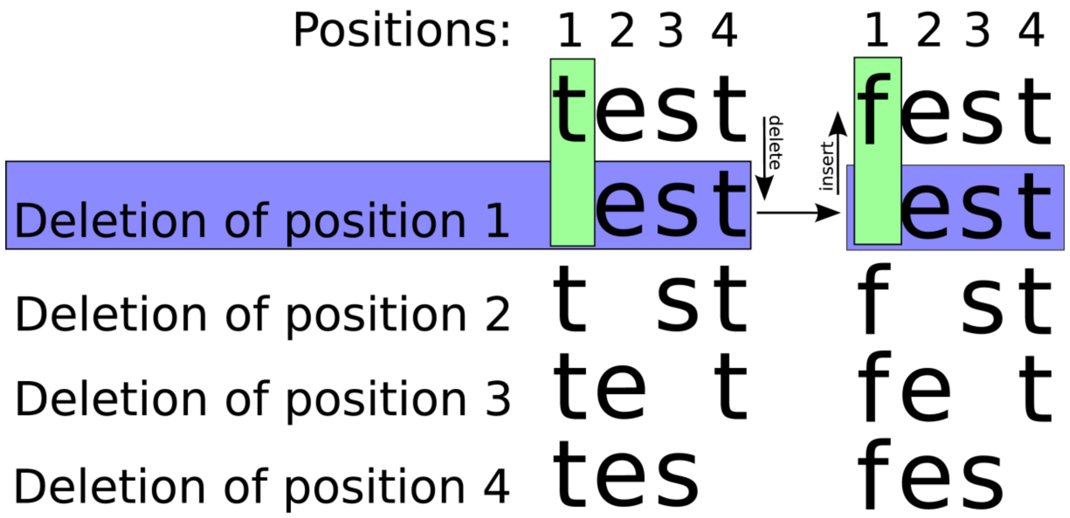
- Example d(test,east) = 2 (remove a, insert t)
- Expensive operation if all words need testing
- Main idea: pre-calculate errors
  - All possible errors? Neighbors for test with ed 2: test, testa, testaa, testab, ... , tea, teb, tec, ..., teaa, teab, ... → 23883 more of those!

		T	E	S	T
	0	1	2	3	4
E	1	1	1	2	3
A	2	2	2	2	3
S	3	3	3	2	3
T	4	3	4	3	2

$$d[i,0] = i,\ d[0,j] = j,$$
$$d[i,j] = min\,(d[i-1,j]+1,\ d[i,j-1]+1,$$
$$d[i-1,j-1] + (if\ s1[i] = s2[j]\ then\ 0\ else\ 1))$$

Mechanisms based on Hashing in KV storage

- FastSS pre-calculates with deletions only
  - Neighbors for test with ed 2: test, est, st, et, es, tst, tt, ts, tet, te, tes
  - Pre-calculation on query and index
  - 11 neighbors → 11 more queries, indexed enlarged by 11 entries



- Example d(test,fest)=1
  - test: indexed
  - fest: query

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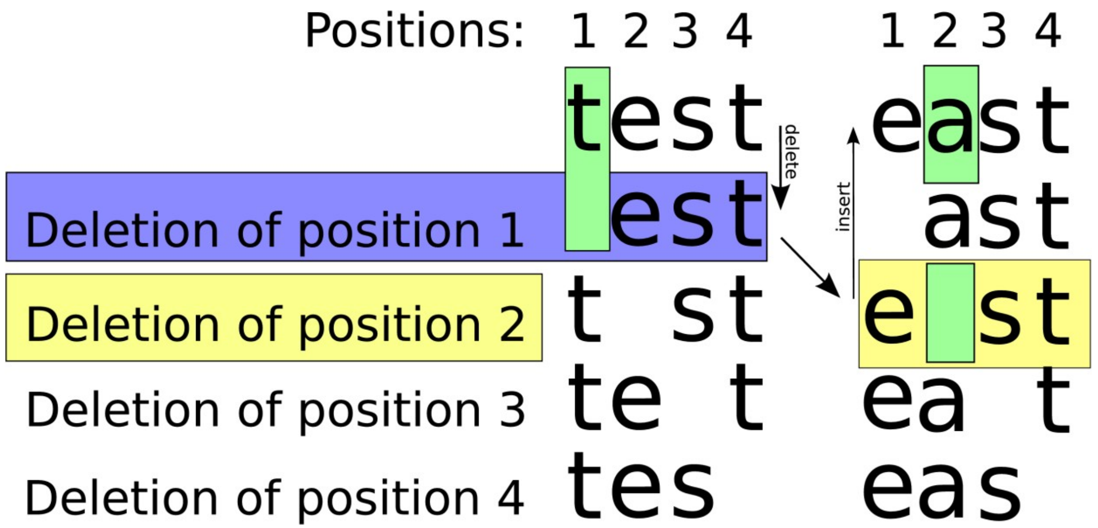
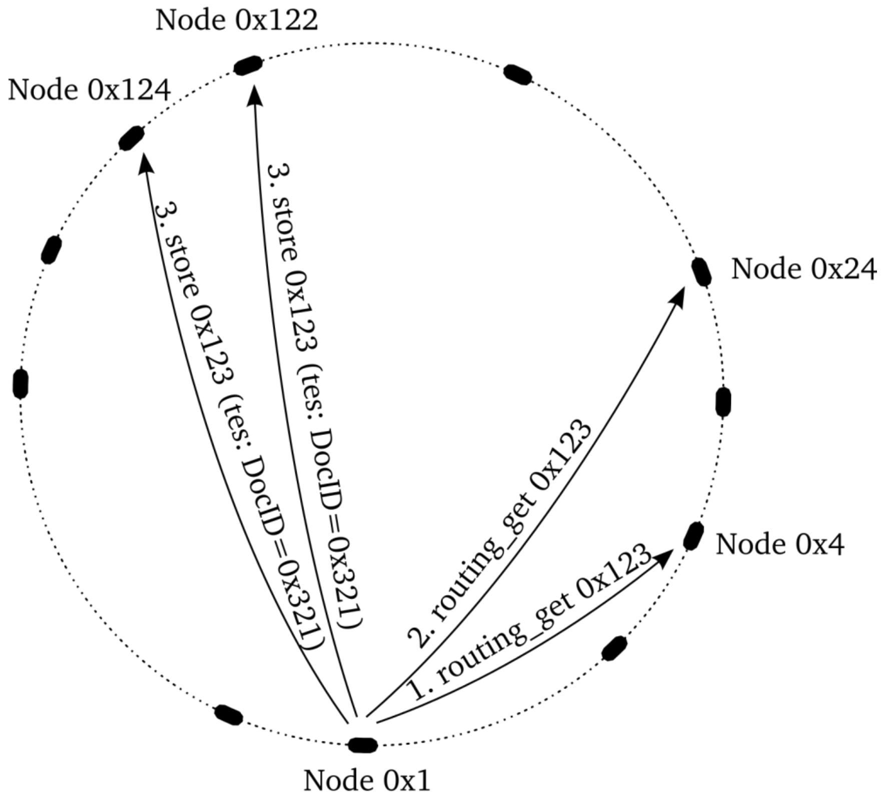
Mechanisms based on Hashing in KV storage

- Example d(test,east)=2
  - test: indexed
  - east: query
- FastSS with indexing Wikipedia documents in systems with consistent hashing



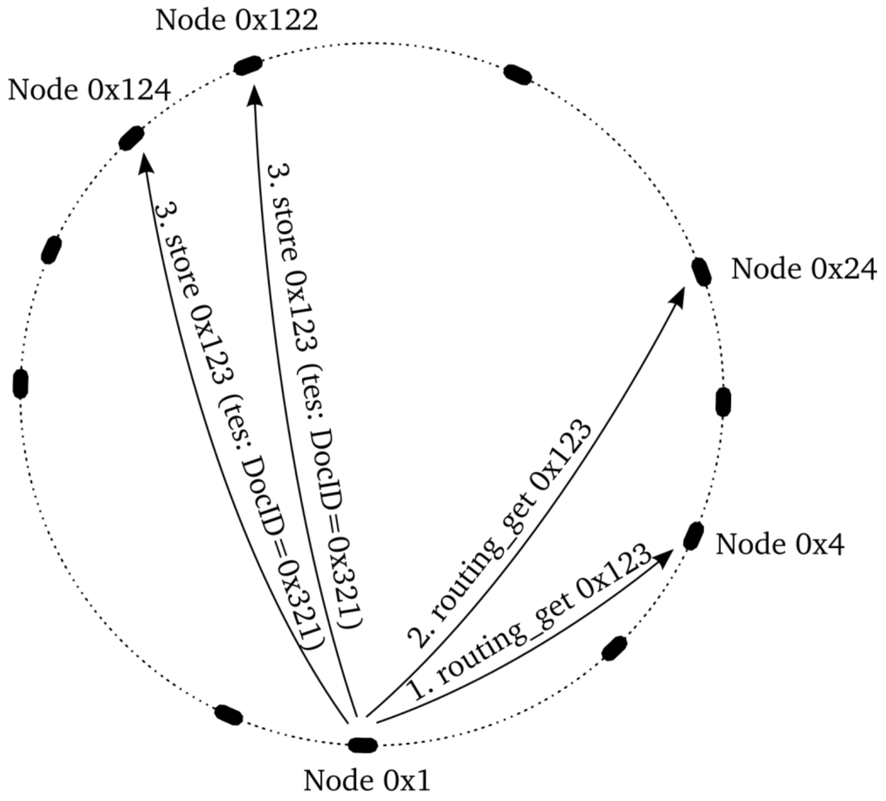
Mechanisms based on Hashing in KV storage

- Index documents using put(hash(document), document)
  - Document (0x321) contains word test
- Index all neighbors (test, tes, tst, tet, est) using put(hash(neighbor), point to document)
  - hash(“tes”) = 0x123



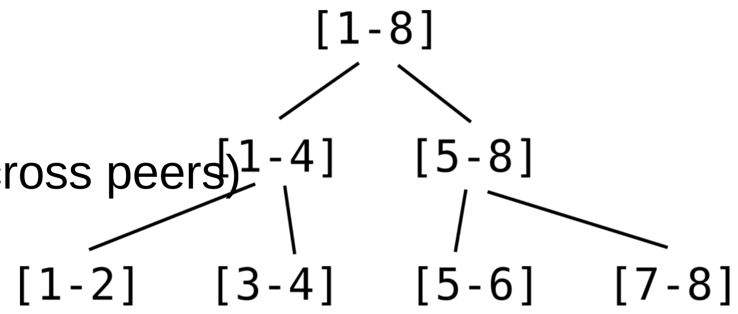
Mechanisms based on Hashing in KV storage

- User searches for “tesx”
- Neighbors are generated (tesx, esx, tsx, tex, tes)
  - get(hash(neighbor)) → 0x123
  - Find pointer to document (0x321)
  - document = get(0x321)
- Tests with edit distance 1, partially 2, ignoring delete pos.
  - Overhead (n choose k) for query and index
- Similarity search as series of put() and get()



Mechanisms based on Hashing in KV storage

- Range Queries
  - Problem: random insert vs. sequence insert
  - Sequence → [0..n-1] [n..2n-1] [2n..3n-1] […] → peer responsible for range, hash it, store it, done.
    - Insert 10 items: N = 5 → [0, 1, 2, 3, 4], [5, 6, 7, 8, 9] – sequential, 2 peers
    - Insert 10 items: N = 5 → [0], [5], [10], [15], [20], [25], [30], [35], [40], [45] – random, 10 peers
    - But random: worst case: 1 peers has 1 data item, range query for range [0..x] contacts x/n peers.
- Over-DHT
  - PHT: trie (prefix tree); DST: segment → tree on top of DHT
  - Main idea: hash of tree-node (resp. for range) → DHT
  - PHT: Peer stores n data items, if n reached, splits data (moves data across peers)
  - DST: stores data on each level (redundancy) up to a threshold
    - No data splitting



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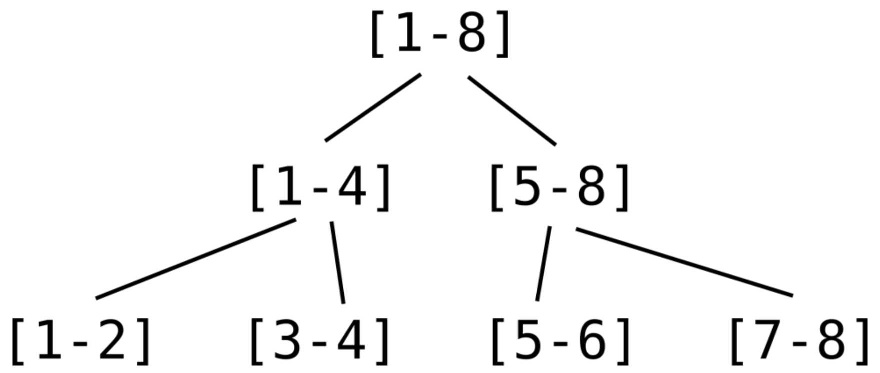
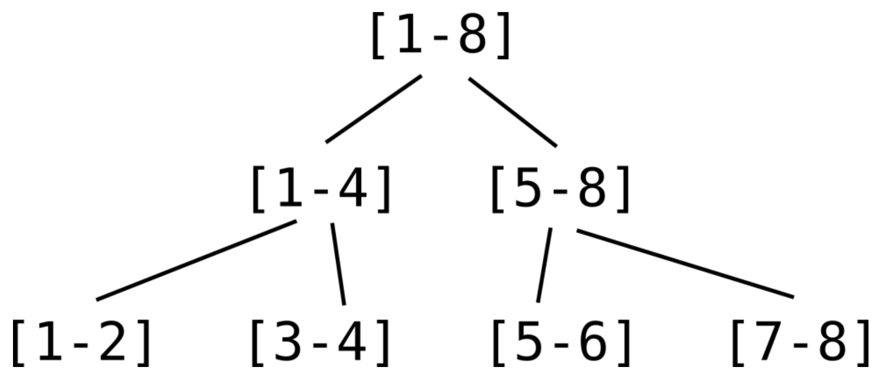
Mechanisms based on Hashing in KV storage

- Example:
  - Set n = 2, m=8
  - 1, “test”; 2, “hallo”;
    3, “world”; 5, “sys”; 6, “ost”; 7, “ifs”
- Tree: store value
  - Translate putDST(1, “test”) to
    - put(hash([1-8]),”test”) → may be stored (only if threshold not reached)
    - put(hash([1-4]),”test”) → may be stored
    - put(hash([1-2]),”test”) → will be stored
    - Store putDST(2, “hallo”), putDST(3, “world”), putDST(5, “sys”), …
- Query `getDST(1..5)` translates to
  - `get(hash[1-8])` → returns “1,test; 2,hallo”
  - `get(hash[1-4])` → returns “1,test; 2,hallo”
  - `get(hash[1-2])` → returns “1,test; 2,hallo”
  - `get(hash[3-4])` → returns “3,world”
  - `get(hash[5-8])` → returns “5,sys; 6,ost”
  - `get(hash[5-6])` → returns “5,sys; 6,ost”



Mechanisms based on Hashing in KV storage

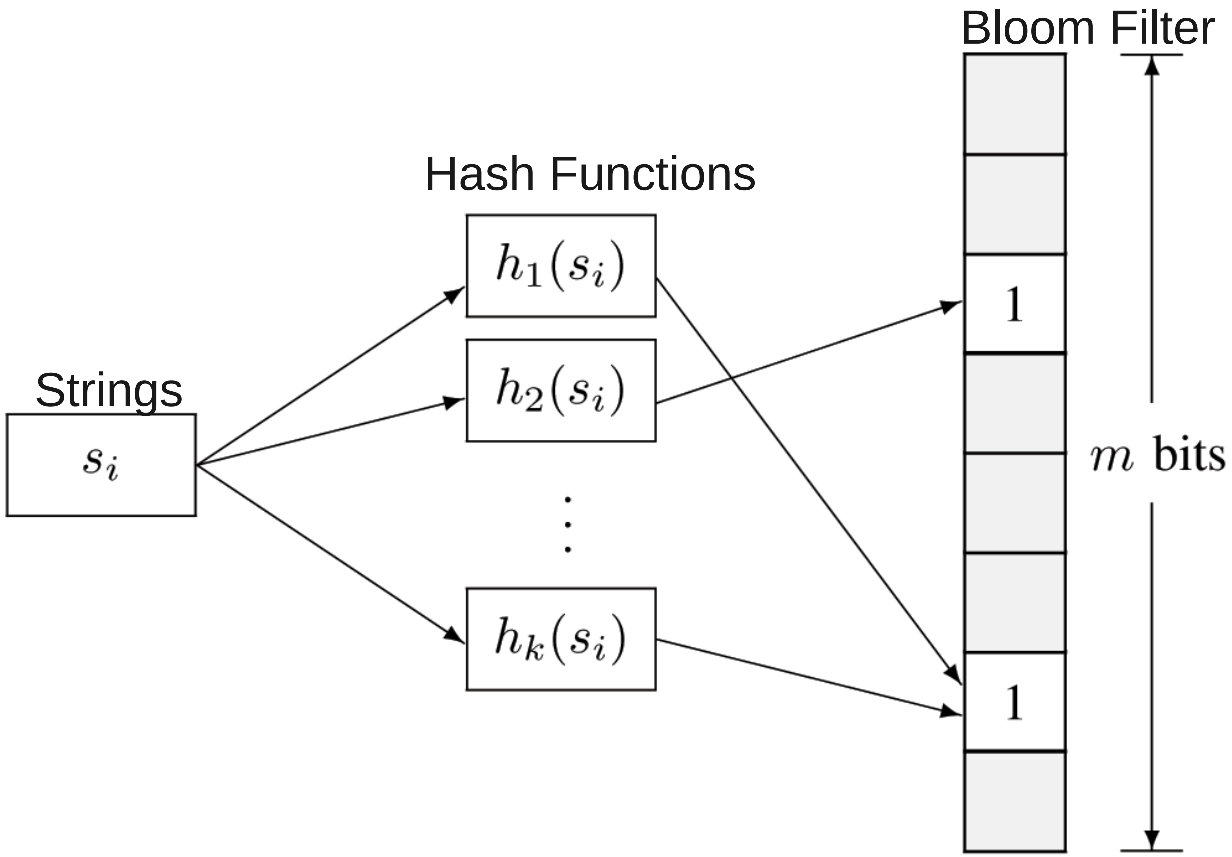
- Example:
  - Set n = 2, m=8
  - 1, “test”; 7, “ifs”
- Tree: store value
  - Translate putDST(1, “test”) to
    - put(hash([1-8]),”test”) → may be stored (only if threshold not reached)
    - put(hash([1-4]),”test”) → may be stored
    - put(hash([1-2]),”test”) → will be stored
    - Store putDST(7, “ifs”)
- Query `getDST(1..5)` translates to
  - `get(hash[1-8])` → returns “1,test; 7,ifs”
  - `get(hash[1-4])` → returns “1,test;”
  - `get(hash[5-8])` → returns “7,ifs”
- Range query as series of `put()` and `get()`



Algorithms for P2P Systems

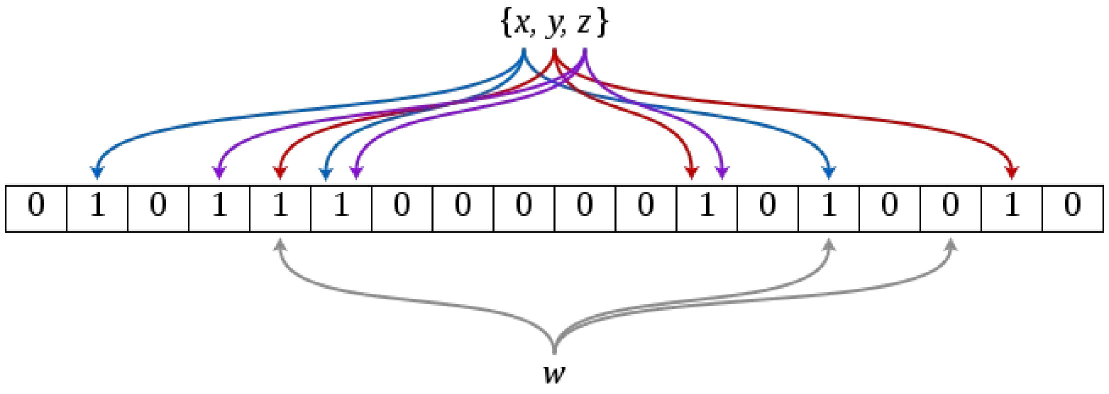
Bloom Filter

- An array of m bits, initially all bits set to 0
- A bloom filter uses k independent hash functions
  - h1, h2, …, hk with range {1, …, m}
- Each input is hashed with every hash functic
  - Set the corresponding bits in the vector
- Operations
  - Insertion
    - The bit A[hi(x)] for 1 < i < k are set to 1
  - Query
    - Yes if all of the bits A[hi(x)] are 1, no otherwise
  - Deletion
    - Removing an element from this simple Bloom filter is impossible



Query of an Element, m=18, k=3

- Insert x, y, z
- Query w



http://en.wikipedia.org/wiki/Bloom_filter

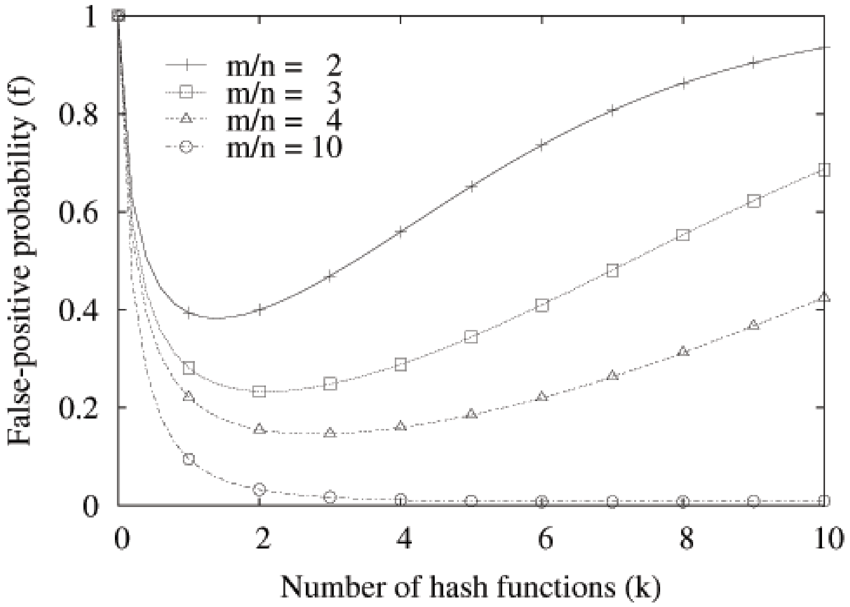
- Example for False-positives
  - Insertions
    - Hash („color printer“) => (1,4,6)
    - Hash („digital camera“) => (3,4,5)
    - Bloom filter (1,3,4,5,6)
  - Query
    - Hash („heat sensor“) => (3,4,6)
    - Matches since bits 3,4,6 are all set to 1
  - Online
- False-negative
  - Query
    - Hash (“color printer”) => (1,4,6) , matches (1,3,4,5,6) → no false-negative

Properties

- Space Efficiency
  - Any Bloom filter can represent the entire universe of elements
    - In this case, all bits are 1
- No Space Constraints
  - Add never fails
  - But false positive rate increases steadily as elements are added
- Simple Operations
  - Union of Bloom filters: bitwise OR
  - Intersection of Bloom filters: bitwise AND

- No false negative, but false positive
- False-positive probability:
  - *n* number of strings; *k* hash functions; *m*-bit vector

$$f = (1 - e^{-\frac{nk}{m}})^k$$



=> Given m/n, there is an optimal number of hash functions (opt. k = m/n ln 2) (when 50% of the bits are set)

Bloom Filter Variants

- Compressed Bloom Filters
  - When the filter is intended to be passed as a message
  - False-positive rate is optimized for the compressed bloom filter (uncompressed bit vector m will be larger but sparser)
  - However, compression/decompression, more memory
- Generalized Bloom Filter
  - Two type of hash functions gi (reset bits to 0) and hj (set bits to 1)
  - Start with an arbitrary vector (bits can be either 0 or 1)
  - In case of collisions between gi and hj, bit is reset to 0
  - Store more info with low false positive
  - Produces either false positives or false negatives
- Counting Bloom Filters
  - Entry in the filter not be a single bit but a counter
  - Delete operation possible (decrementing counter)
  - Variable-Increment Counting Bloom Filter
- Scalable Bloom Filter
  - Adapt dynamically to number of elements, consist of regular Bloom filters
  - “A SBF is made up of a series of one or more (plain) Bloom Filters; when filters get full due to the limit on the fill ratio, a new one is added; querying is made by testing for the presence in each filter”
- Others, e.g., Cuckoo filter
- Usage: e.g., fast search at LinkedIn

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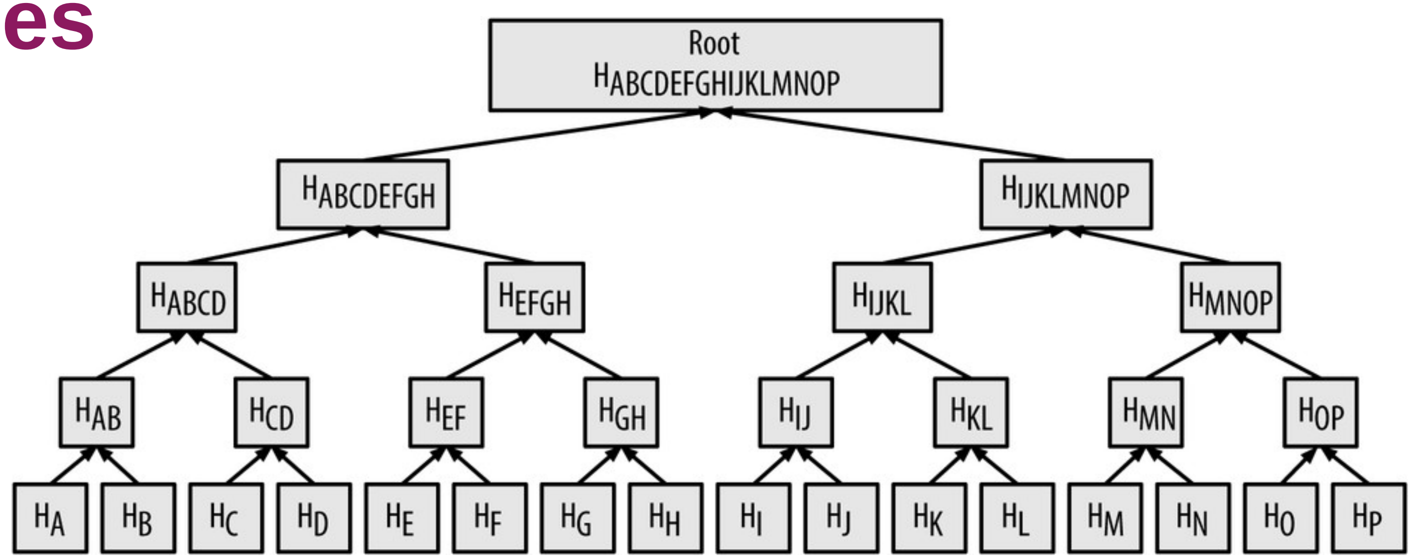
Merkle Trees



- A Merkle tree is a binary hash tree containing leaf nodes
- Constructed bottom-up, i.e.,
- Used to summarize all transactions in a block
- To prove that a specific transaction is included in a block, a node only needs to produce hashes, constituting a merkle path connecting the specific transaction to the root of the tree.

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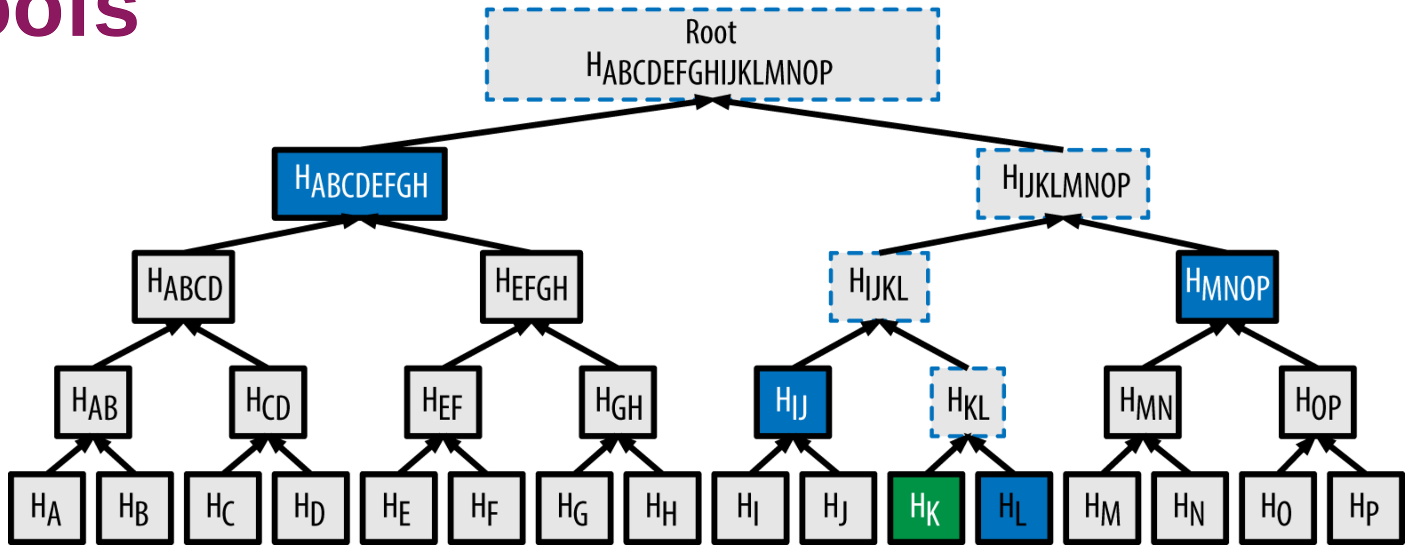
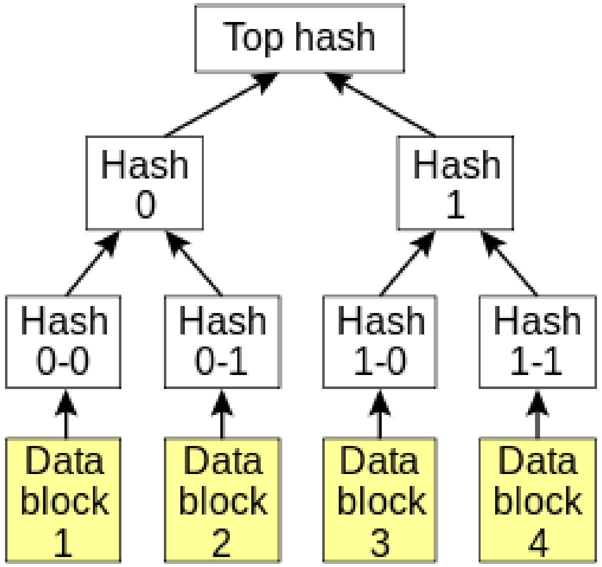
Merkle Proofs



- A node can prove that transaction K is included in the block by producing a merkle path
  - $\boldsymbol{log_2 16} = \boldsymbol{4\ hashes}$ long

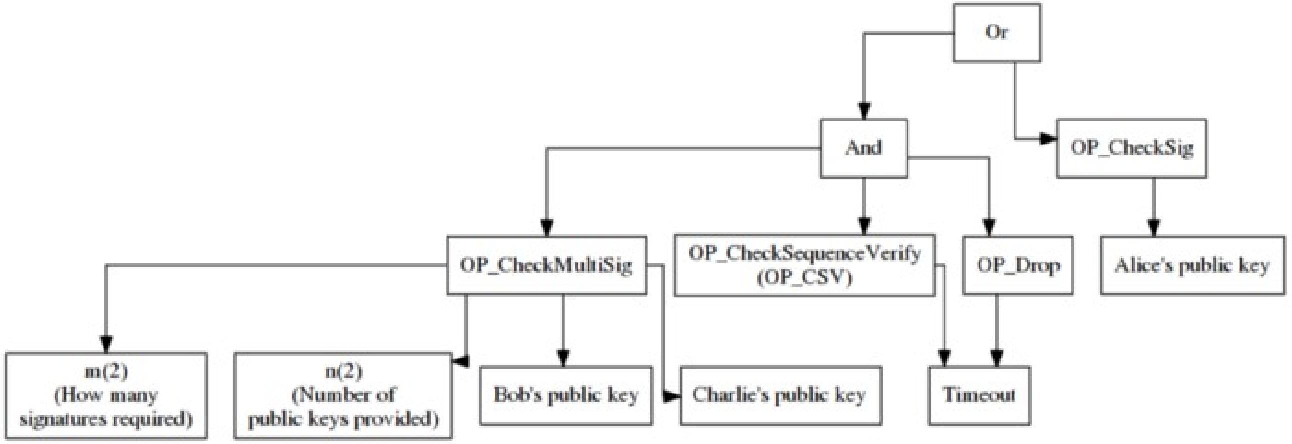
BitTorrent: Mechanisms

- Magnet links
  - Magnet is URI scheme, does not point to a centralized tracker
    - No centralized tracker: pointer to DHT
    - General purpose, not only for BT
    - magnet:?xl=1000&dn=song1.mp3&xt=urn:tree:tiger:2A3B…
  - tree:tiger → Hash Tree
    - Tree of hashes (|| → concatenation)
    - hash 0 = hash(hash 0-0 || hash 0-1)
    - hash 1 = hash(hash 1-0 || hash 1-1)
    - Top hash = hash(hash 0 || hash 1)



http://en.wikipedia.org/wiki/Hash_tree

- Merkle hash / hash tree also seen in Bitcoin blocks (transactions), MAST (Merk Abstract Syntax Tree)



https://medium.com/coinmonks/merkle-tree-a-simple-explanation-and-implementation-48903442bc08

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BitTorrent: Mechanisms

- Verification
  - Peer A has top hash (root hash)
  - Peer downloads C4 from peer B
    - create hash 8
  - Need hash 10, 13, 3 (uncle hash)
    - Can be from peer B
  - With 8,10,13,3 can create root hash

    → verify this root hash
- Usage: Blockchain, P2P filesharing, git, Amazons Dynamo, ZFS

```
                   7 = root hash
                  / \
                /     \
              /         \
            /             \
          3*                11
         / \               / \
        /   \             /   \
       /     \           /     \
      1       5         9       13* = uncle hash
     / \     / \       / \      / \
    0   2   4   6     8   10* 12   14

    C0  C1  C2  C3    C4  C5  C6   E
    =chunk index      ^^           = empty hash
```

The Merkle hash tree of an interval of width W=8

http://datatracker.ietf.org/doc/draft-ietf-ppsp-peer-protocol/ Section 5.2