# Lecture 4

# P2P with TomP2P

## http://tomp2p.net/doc

Universität Zürich[UZH]


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# 0. Lecture Overview

1. **Introduction**
   1. What is TomP2P
   2. History and project information
2. **Example**
3. **Fundamental concepts**
   1. XOR-based iterative routing
   2. Futures
   3. API Overview
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   2. Tracker / PEX with examples
5. **Advanced Topics in TomP2P**
   1. Bloom Filters
6. **References**

# P2P in the news

- **5.3.2015 - Newest version of uTorrent has Bitcoin mining offer during install**
  - Silently installs EpicScale
  - EpicScale is a bitcoin miner
  - Not easy to uninstall, many angry users
- **6.3.2015 - BTCPoint Creates 10,000 Bitcoin-Enabled ATMs Using Spanish Bank Network**
  - Bitcoin-to-cash withdrawals at 10,000 additional bank ATMs
  - 0% commission → they build ATMs
- **3.3.2015 - Evolution of the Internet: from Decentralized to Centralized**
  - **Choosing convenience over decentralization**
  - **Try to make your CT prototype convenient to use!**

# P2P in the news

- **3.3.2015 - Sync 2.0: Skip The Cloud, Share Direct**
  - New features compared to 1.x
  - Pro version for business workgroups
  - Available on NAS devices
- **18.2.2015 - MegaNET – New Decentralized, Non-IP Based and Encrypted Network**
  - Kim Dotcom wants to start own Internet using the blockchain
    - convicted of several crimes
      - suspended prison sentence in 1994 for computer fraud and data espionage / suspended prison sentence in 2003 for insider trading
      - 2012: Megaupload
  - Series of tweets…
  - MaidSafe – decentralized data storage

# 1. Introduction

What is TomP2P

History and project information

# Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **TomP2P is a P2P framework/library**
  - Implements DHT (structured), broadcasts (unstructured), direct messages (can implement super-peers)
  - NAT handling: UPNP, NATPMP, new addition: relays, hole punching
  - Direct / indirect (tracker / mesh) storage
  - Direct / indirect replication (churn prediction and ~rsync)
  - Modes: key,value / multi-key (versioned) value
  - Java 6, Maven, Github, Netty, TCP/UDP, MapDB, (Android)

# Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **TomP2P extends DHT**
  - Distributed hash table concept → put(key,value) / get(key)
  - Extended DHT operations →
    - put(key1,key2,value)
    - put prepare / put confirm
    - add(key, value)
    - digest(key) / bloomfilters / versions
    - get(key) / bloomfilters / versions

# Introduction

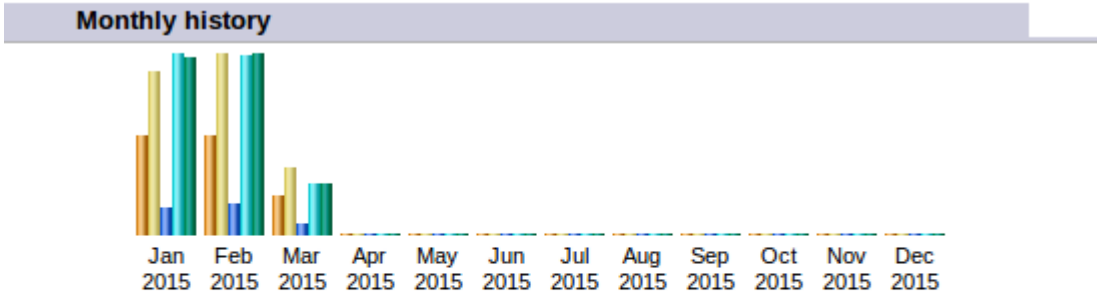
TomP2P
A P2P-based high performance key-value pair storage library

- **TomP2P history**
  - TomP2P v1: Created in 2004 and used for a distributed DNS project
    - This version used blocking IO operations (1 thread / socket)
  - TomP2P v2: Apache MINA (java.nio framework) / 6K LoC
    - Not well designed for non-blocking operations (event-driven)
  - TomP2P v3: Redesigned for non-blocking operations
    - Switched to Netty / 14K LoC, 6K LoC JUnits
  - TomP2P v4: API refinements, new features
    - Current release (preview) 4.1
    - Latest feature (work in progress) MapReduce
    - 22K LoC, 8K LoC Junits
  - TomP2P v5 (core 18K LoC): modularization, relays, API refinements

# Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **TomP2P started in 24.05.2004 and still going strong**
  - Github: watch 30 / star 131 / fork 53 (not sure if good/bad)
  - TomP2P website (although documentation is outdated)
  - 72 users on the mailinglist
  - 9 contributors on github
  - Don't buy the book!




| Month | Unique visitors | Number of visits | Pages | Hits | Bandwidth |
|---|---|---|---|---|---|
| Jan 2015 | 1,785 | 2,943 | 10,859 | 71,716 | 606.09 MB |
| Feb 2015 | 1,802 | 3,254 | 12,423 | 71,149 | 617.73 MB |
| Mar 2015 | 721 | 1,218 | 4,350 | 20,055 | 176.03 MB |
| Apr 2015 | 0 | 0 | 0 | 0 | 0 |
| May 2015 | 0 | 0 | 0 | 0 | 0 |

# Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **Academic background (CSG - UZH):**
  - Used in EU projects: EC-GIN, Emanics, SmoothIT, SmartenIT, Flamingo
  - Used in research projects: LiveShift, DRFS, Radiommender, Box2Box, Hive2Hive, B-Tracker, PiCsMu, peerwasp, (and non-academic)
- **http://tomp2p.net**
  - For questions: mailinglist (http://lists.tomp2p.net/cgi-bin/mailman/listinfo)
  - Specific questions: bocek -at- ifi.uzh.ch or tom -at- tomp2p.net
  - Documentation: http://tomp2p.net/doc/ (TomP2P v4.4)
    Overview: http://en.wikipedia.org/wiki/TomP2P
    - If something is missing, ask! – **Documentation for v5 is missing!**
  - Development: https://github.com/tomp2p
    - Feature request possible if good reasons provided
- **(Demo: how to setup TomP2P with Intellij/git/maven)**

# Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- A Declarative Interface for Smart-phone Based Sensor Network Systems, Asanka Sayakkara and Kasun De Zoysa, IWMS 2012, Bejing, China
- Hybrid Peer-to-Peer DNS, Ricardo Sancho and Ricardo Lopes Pereira, Instituto Superior Tecnico, Porto, Portugal
- A Semantic Publish-Subscribe Coordination Framework for IHE based Cross-Community Health Record Exchange, Visara Urovi, Alex C. Olivieri, Stefano Bromuri, Nicoletta Fornara, Michael Schumacher, ACM SIGAPP Applied Computing Review, 2013 (slides)

# Introduction

TomP2P
A P2P-based high performance key-value pair storage library

- Adding Cryptographically Enforced Permissions to Fully Decentralized File Systems – TUM, Bernhard Amann, Thomas Fuhrmann, April 2011
- Optimis FP7 IP project: Optimized Infrastructure Services, D1.2.1.3, Architecture Design document, ended May 2013
- Distributed Name-based Entity Search, Fausto Giunchiglia and Alethia Hume, ISWC 2012, Boston
- A Distributed Directory System, Fausto Giunchiglia and Alethia Hume, SSWS 2013, Sydney

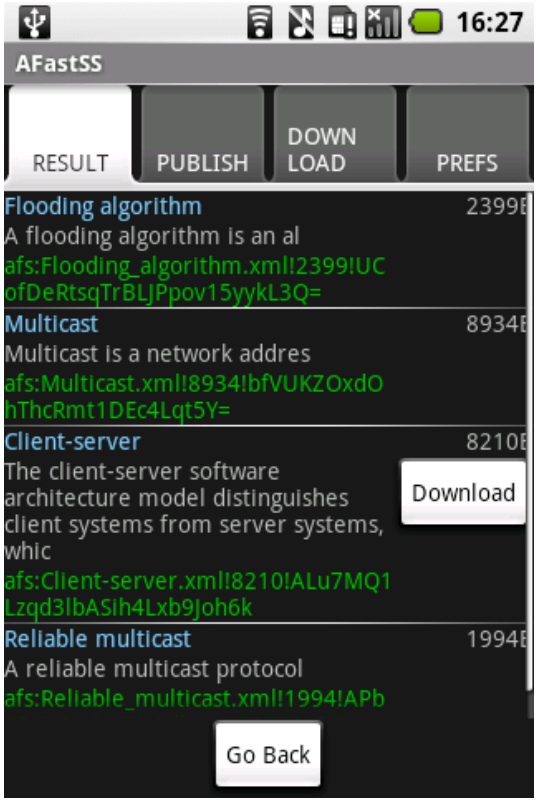
# Introduction

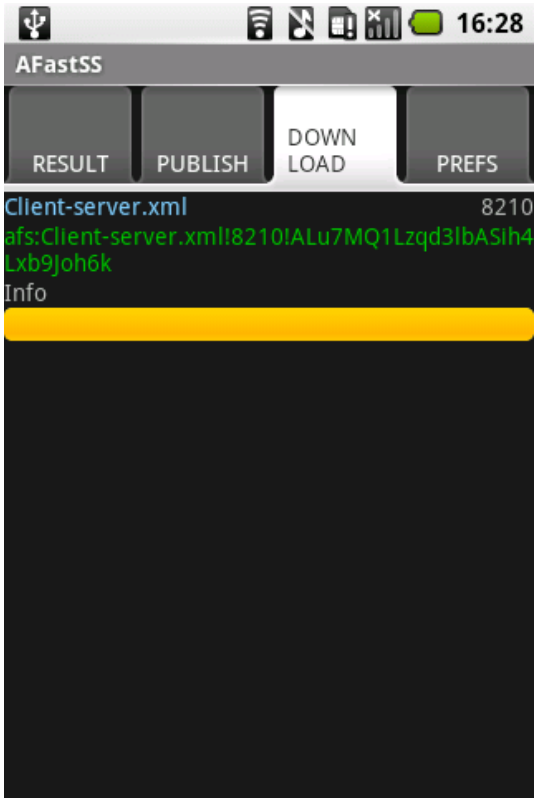
TomP2P
A P2P-based high performance key-value pair storage library

- A P2P Semantic Query Framework for the Internet of Things, Richard Mietz, Sven Groppe, Oliver Kleine, Daniel Bimschas, Stefan Fischer, Kay Römer and Dennis Pfisterer, PIK, Volume 36, Issue 2 (May 2013)
- P2P Minecraft: "The mods described below are about adding peer-to-peer functionalities to Minecraft."
- Bitcoin Gateway - A Peer-to-peer Bitcoin Vault and Payment Network, Omar Syed & Aamir Syed, July 2011
- Bitsquare.io – The decentralized bitcoin exchange, ~ongoing

# Introduction

- **TomP2P with Android (early research)**
  - CSG: early adopter
  - TomP2P 5 and Android: work in progress

# 2. Example

Example and Demo

# Example

- **Demo: a simple put / get example**
- **Package net.tomp2p.examples. ExamplePutGet**

```
private static void examplePutGet(final PeerDHT[] peers, final Number160 nr)
        throws IOException, ClassNotFoundException {
    FuturePut futurePut = peers[PEER_NR_1].put(nr).data(new Data("hallo")).start();
    futurePut.awaitUninterruptibly();
    System.out.println("peer " + PEER_NR_1 + " stored [key: " + nr + ", value: \"hallo\"]");
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    futureGet.awaitUninterruptibly();
    System.out.println("peer " + PEER_NR_2 + " got: \"" + futureGet.data().object() + "\" for the key " + nr);
    // the output should look like this:
    // peer 30 stored [key: 0xba419d350dfe8af7aee7bbe10c45c0284f083ce4, value: "hallo"]
    // peer 77 got: "hallo" for the key 0xba419d350dfe8af7aee7bbe10c45c0284f083ce4
}
```

- **Defaults**
  - Replication factor 6, replication not enabled,
  - domain, content, version are zero if not specified

# 3. Fundamental Concepts

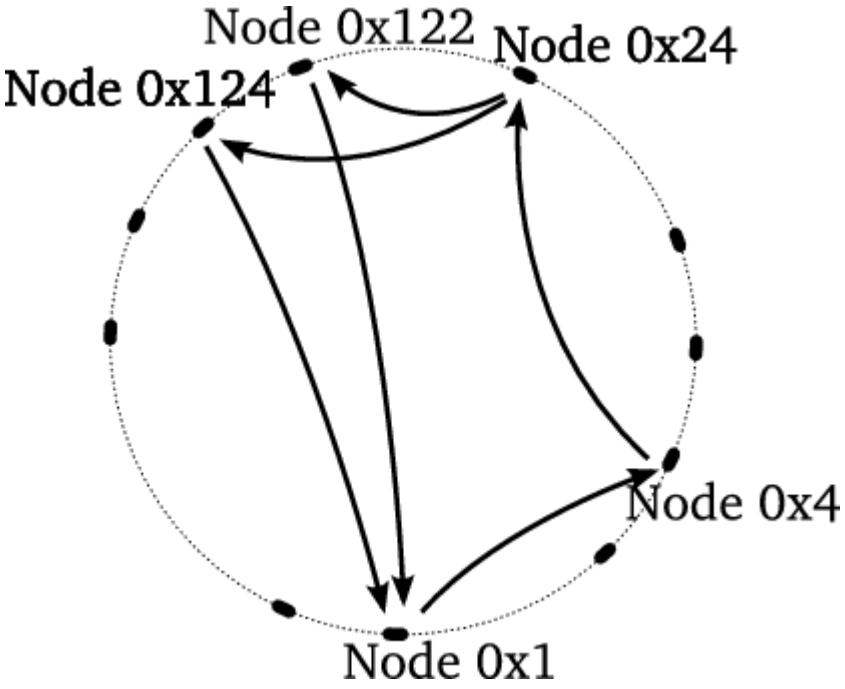
XOR-based iterative routing

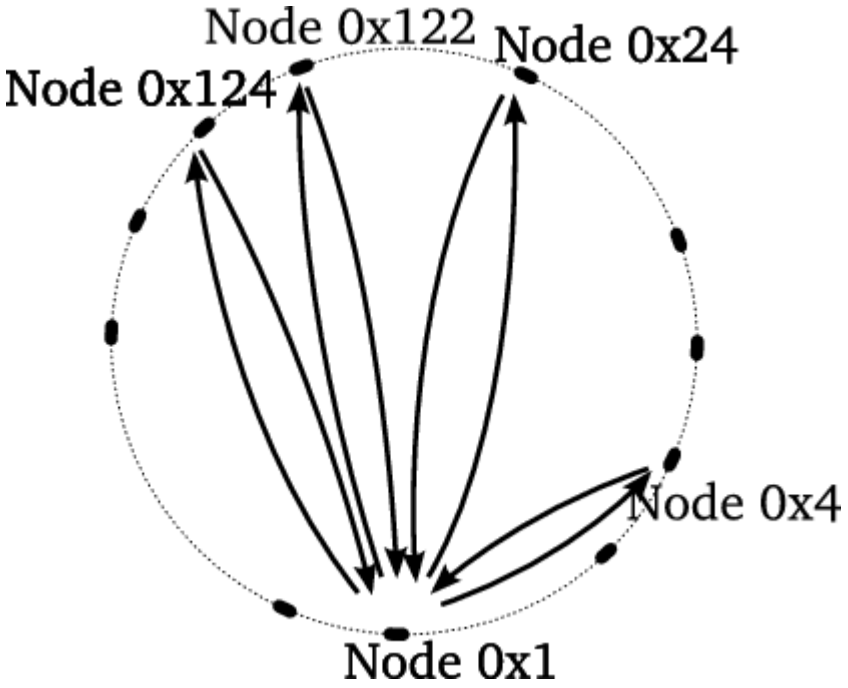
Futures

API Overview

# Fundamental Concepts (repetition)

- Recursive routing vs. iterative routing




+ online status update

- faulty peers cause delay

+ control

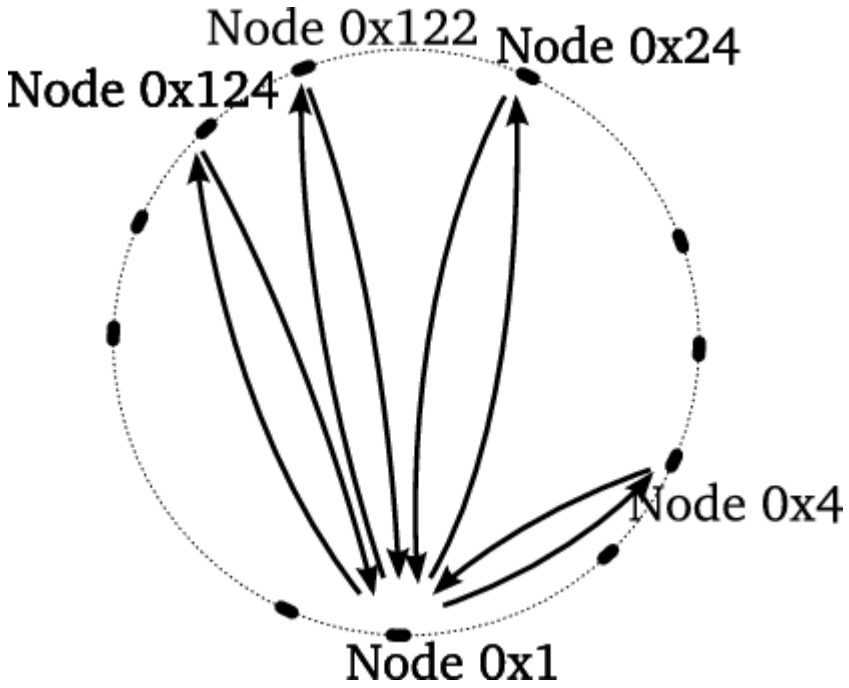
- neighbor maintenance

# Fundamental Concepts (repetition)

- **TomP2P: iterative XOR-based routing**
  - Node and data item unique 160bit identifier
  - Keys are located on the nodes whose node ID is closest to the key
  - Search for a key:
    - Lookup in neighbor table for closest peer (*e.g.* peers with ID: 0x1, 0x2, 0x3, 0x4)

| My ID | Neighbor ID | Distance (XOR) |
|---|---|---|
| 1 | 2 | 3 |
| 1 | 3 | 2 |
| 1 | 4 | 5 |

    - Difference to Pastry: one metric, no leaf set / routing table



# Fundamental Concepts

- **TomP2P iterative XOR-based routing**
  - Neighbors stored in 159 “bags”, bag has capacity c (Kademlia, c=20)
  - Routing takes O(log n) → M03, slides 11
  - By default UDP, message header 58 bytes
  - Routing Mechanism variables, can be tuned
    - directHits, potentialHits – routing sends digest
    - forceTCP – use TCP instead of UDP
    - maxDirectHits, maxNoNewInfo, maxSuccess, maxFailure – stop conditions
    - parallel – number of parallel connections
  - For the CT - don’t worry, default settings are fine ☺

# Fundamental Concepts

- **All distributed operations use futures**
- **Future objects**
  - Keeps track of future events, while the “normal” program flow continues → `addListener()` or `await()`
  - `await()`: Operations are executed in same thread
  - `addListener()`: Operations are executed in same or other thread
- **Demo: blocking operation (net.tomp2p.examples. ExamplePutGet)**

```
private static void exampleGetBlocking(final PeerDHT[] peers, final Number160 nr)
    throws ClassNotFoundException, IOException {
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    // blocking operation
    futureGet.awaitUninterruptibly();
    System.out.println("result blocking: " + futureGet.data().object());
    System.out.println("this may *not* happen before printing the result");
}
```

- **Demo: non - blocking operation (net.tomp2p.examples. ExamplePutGet)**
  - New utilities necessary (loops as recursions)
  - Advise: use `addListener(…)` as much as possible!
  - `operationComplete(…)` must be **always** called (problem if not)

```
private static void exampleGetNonBlocking(final PeerDHT[] peers, final Number160 nr) {
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    // non-blocking operation
    futureGet.addListener(new BaseFutureAdapter<FutureGet>() {
        @Override
        public void operationComplete(FutureGet future) throws Exception {
            System.out.println("result non-blocking: " + future.data().object());
        }

    });
    System.out.println("this may happen before printing the result");
}
```

# Fundamental Concepts

- **Future utilities**
  - `FutureForkJoin(int nr, boolean cancel, K... Forks)`
    - Joins already “forked” futures. Waits until all or `nr` future finished. If nr reached, futures may be cancelled (e.g. abort download)
  - `FutureLateJoin(int nrMaxFutures, int minSuccess)`
    `FutureLaterJoin()`
    - No need to add the futures in the constructor, can be added later
  - `FutureDone()`
    - A generic future used in many places, can be placeholder
- **ForkJoin in Java7**
  - Fork and join framework – future utilities in TomP2P focus on join, forking is done “manually”
- **Needs face-liftting, add Futures.waitAny / waitAll etc.**

# Fundamental Concepts

- **Fun with futures: loops**

```
Future loop() {
            Future future = new Future();
            recLoop(future);
            return future;
}

void recLoop(Future future) {
            int active = 0;
            for (int i = 0; i < parallel; i++) {
                        //if future finished, it will be set to null
                        if (futureResponses[i] == null) {
                                    active++;
                                    futureResponses[i] = doSomething();
                        }
                        else if (futureResponses[i] != null) active++;
            }
            if (active == 0) future.weAreDone();
            FutureForkJoin<FutureResponse> fp = new FutureForkJoin<FutureResponse>(1, futureResponses);
            fp.addListener(new BaseFutureAdapter<FutureForkJoin<FutureResponse>>() {
                        @Override
                        public void operationComplete(FutureForkJoin<FutureResponse> future)
                        throws Exception {
                                    boolean finished = evaluate(future);
                                    if(finished) future.weAreDone();
                                    else recLoop(future);
                        }
            });
}
```

# Fundamental Concepts

- Java 8 lambda expressions not used
- .NET and other languages have better support for async
  - Example (tbd)

# Fundamental Concepts

- **API Overview: Peer.java**
  - Core methods, network related
    - `sendDirect()`
    - `bootstrap()`
    - `announceShutdown()`
    - `ping()`
    - `discover()`
    - `broadcast()`
  - Methods for DHTs (PeerDHT.java)
    - `put(key, value),`
    - `get(key)`
    - `add()`
    - `digest()`
    - `remove()`
    - `send()`
    - `parallelRequest() // mostly used internally`

# Fundamental Concepts

- **Extensions**
  - TomP2P can store multiple values for a key
    - `put() (location_key, content_key, value)` → content_key specified in Builder
    - `get().setAll()`
      → returns a map with [`content_key, value`]
    - `add() (location_key, value)` → is translated to
      `put() (location_key, hash(value), value)`
  - TomP2P support domains
    - Avoid collision for same keys
    - Domains are used for protection (more details later)
    - Domains specified in Builder
    - `put() (key, domain, value)` → `get() (key,domain)`

- **Configurations Example**
  - Configuration with builder pattern

```
RoutingConfiguration rc = new RoutingConfiguration(0, 0, 1);
RequestP2PConfiguration pc = new RequestP2PConfiguration(1, 0, 0);
FuturePut fdht = peers[444].put(peers[30].peerID()).data(new Number160(5), data)
        .domainKey(Number160.createHash("test")).routingConfiguration(rc)
        .requestP2PConfiguration(pc).start();
```

  - System-wide configuration when creating Peer

```
Number160 peerId = new Number160(rnd);
PeerMap peerMap = new PeerMap(new PeerMapConfiguration(peerId));
master = new PeerBuilder(peerId)
        .ports(port).enableMaintenance(maintenance)
        .bindings(bindings).peerMap(peerMap).start().addAutomaticFuture(automaticFuture);
peers[0] = new PeerBuilderDHT(master).start();
```

  - … and per module

# 5. Components with Examples

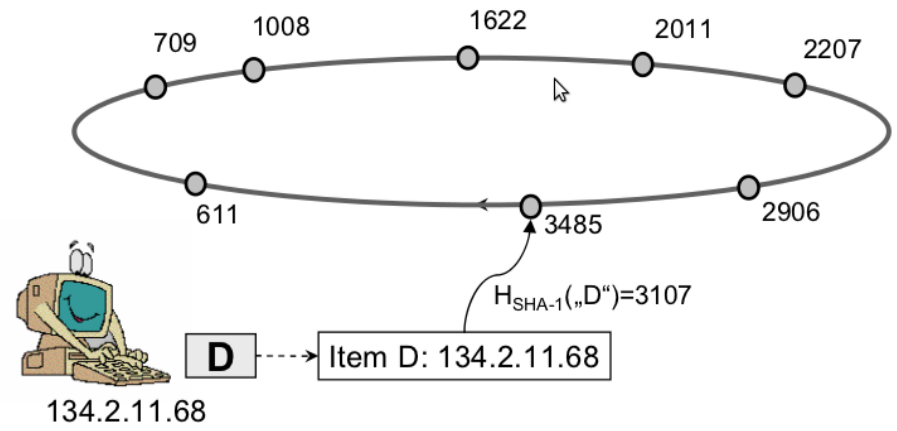
DHT

Tracker

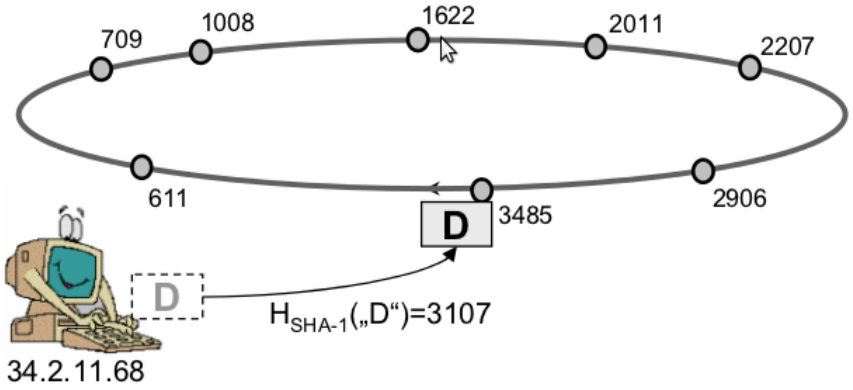
# Components with Examples (repetition)

- **DHT vs. Tracker**
  - M03, slide 23: DHT “stored by value” – direct storage
  - M03, slide 24: Tracker “stored by reference” – indirect storage

**indirect (Tracker)**




**direct (DHT)**



# Components with Examples

- **B-Tracker**
  - Centralized tracker – one peer gets traffic
  - DHT: store reference on 20 peers – 20 peers gets traffic
  - PEX: exchange information every minute (push)
  - B-Tracker, every downloading peer becomes a tracker → forms mesh
    - Better balance of load
    - To avoid duplicates send compressed list of known peers
  - B-Tracker in TomP2P enabled by default

# Components with Examples

- **Demo: Tracker (net.tomp2p.examples.ExampleTracker)**
  - Create 100 peers,
  - Add to tracker, get from tracker
  - Stored on 3 peers: TrackerBuilder.java (can be configured)
  - Attachment of data is possible (attachement(Data))

```
private static void example(final PeerTracker[] peers) throws IOException, ClassNotFoundException {

    FutureTracker futureTracker = peers[12].addTracker(Number160.createHash("song1")).start().awaitUninterruptibly();
    System.out.println("added myself to the tracker with location [song1]: "+futureTracker.isSuccess()+" I'm: "+peers[12].peerAddress());

    FutureTracker futureTracker2 = peers[24].getTracker(Number160.createHash("song1")).start().awaitUninterruptibly();

    System.out.println("peer24 got this: "+futureTracker2.trackers());
    System.out.println("currently stored on: "+futureTracker2.trackerPeers());
}
```

# Components with Examples

- **Demo: Tracker**
  - Although demo uses `await()`, try not to use it
  - Tracker vs. DHT what is better for the CT? You decide!

- **Further interesting aspects for the challenge task:**
  - To be discussed on Thursday
  - Reminder: Thursday starts the challenge task
  - Task presentation and Scrum introduction

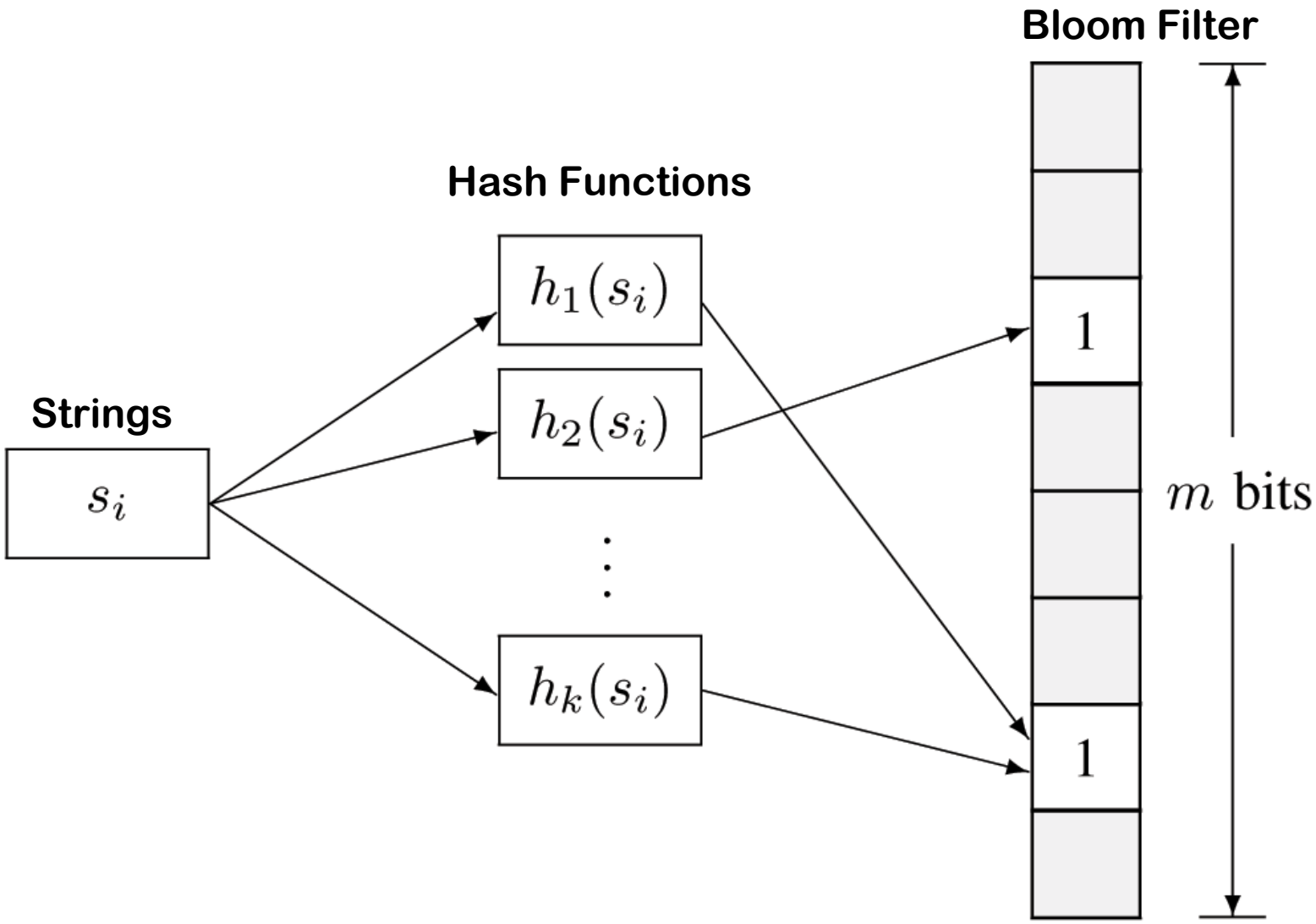
# 5. Bloom Filters

Traditional Bloom Filter, Attenuated Bloom Filter

# Traditional Bloom Filter

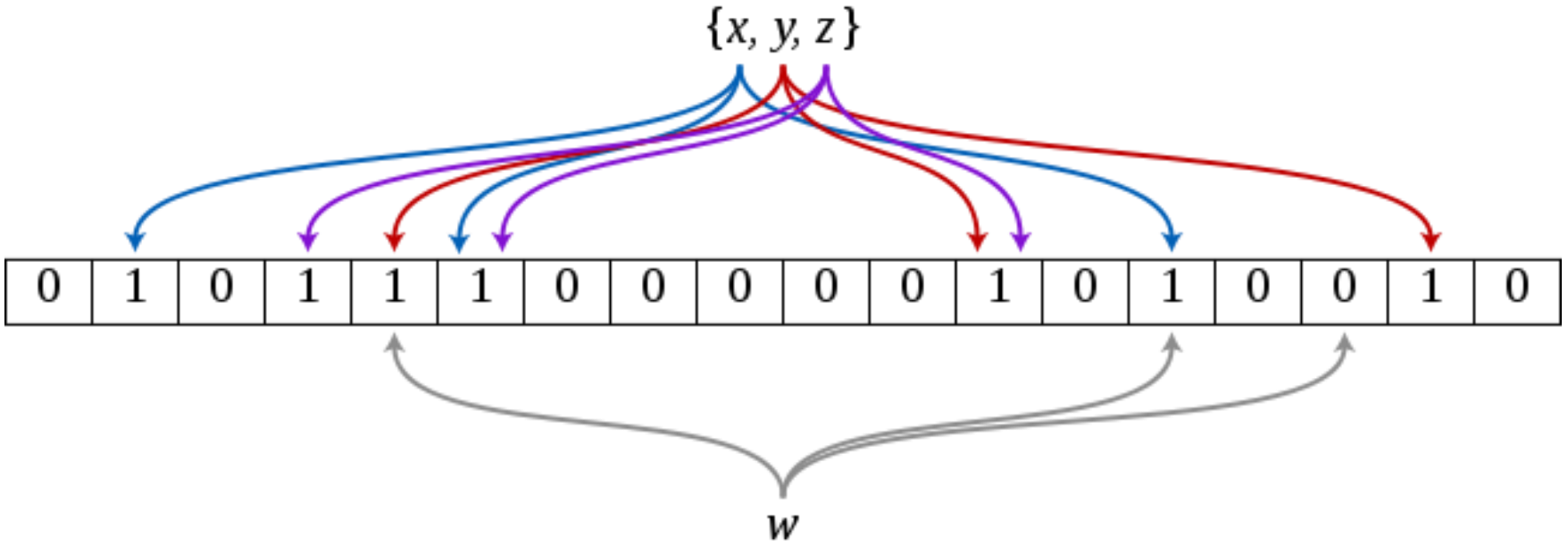
- **An array of *m* bits, initially all bits set to 0**
- **A bloom filter uses *k* independent hash functions**
  - *h1, h2, …, hk* with range {1, …, m}
- **Each key is hashed with every hash function**
  - Set the corresponding bits in the vector
- **Operations**
  - Insertion
    - The bit A[hi(x)] 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

# Insertion of an Element



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

- Insert x, y, z
- Query w




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

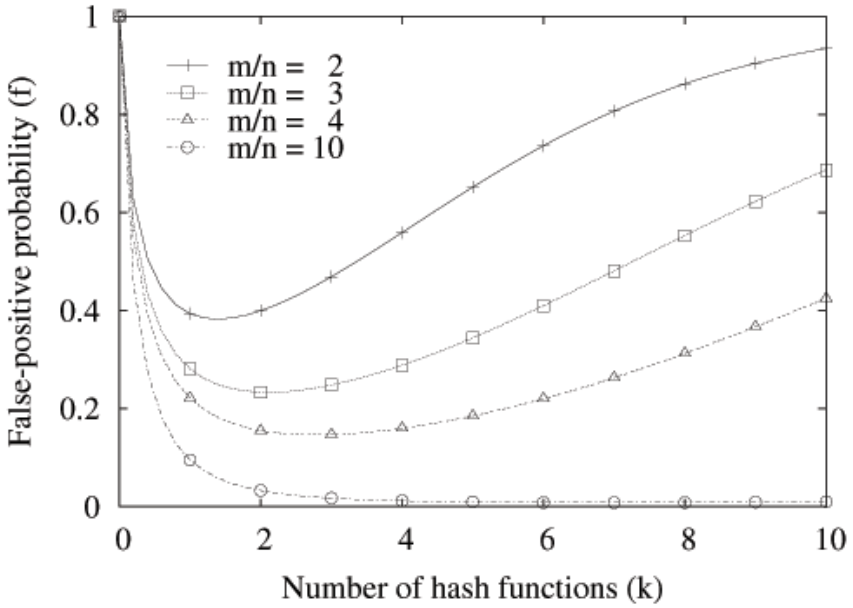
# Properties

- **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

# False-Positive Probability

- **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)**

# Examples

- **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

# Bloom Filter Variants (1)

- **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 bits with low false positive
  - Produces either false positives or false negatives

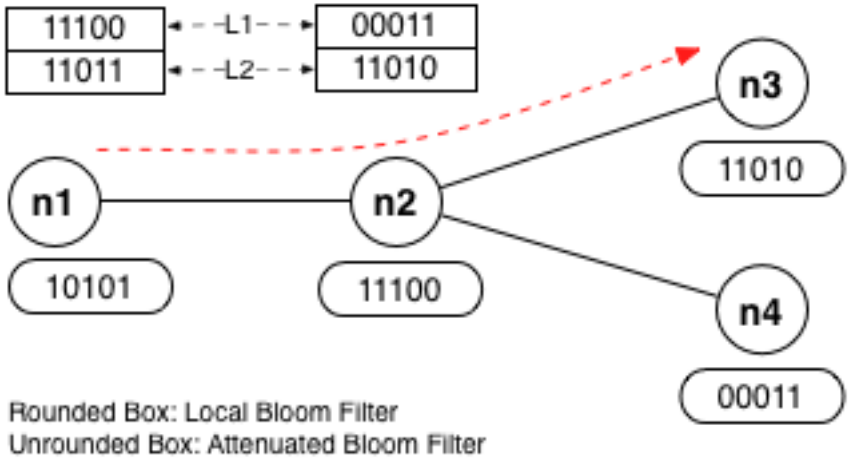
# Bloom Filter Variants (2)

- **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”

# Bloom Filter Variants (3)

- **Attenuated Bloom Filter**
  - Use arrays of Bloom filters to store shortest path distance information
  - Each neighbor link is associated with an attenuated Bloom filter
  - An attenuated Bloom filter consists of *d* normal Bloom filters

    → *d*th filter keeps track of resources reachable via *d* hops.
  - Finds fast only resources within *d* hops, false positive




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

# Example and Applications

- **Demo**
  - Setup: Bloom Filter of size 128 bits, 20 Number160 objects
- **Applications: Distributed Caching, Spell checking, Routing, (distributed) Databases**
- **B-Tracker uses Bloom Filters**
  - "To avoid duplicates send compressed list of known peers"
  - Idea: store peers in Bloom Filter and send it. Other peers only send us peer not in the Bloom Filter
    - Less traffic (request is larger, reply may be smaller)
    - False positive are possible
- **Demo: Bloom Filter for get() in TomP2P**