Bioinformatics Resources - NoSQL -

Lecture & Exercises
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Evaluation

- Lectures are evaluated between June 5\textsuperscript{th} and 20\textsuperscript{th}
- Please bring a mobile device next week (June 15\textsuperscript{th})
- Please take 15 min to complete the survey
- The necessary information was sent to the students registered for the lecture
- This lecture is: 0000002112 Bioinformatische Ressourcen (IN2321) Lecturers: (Dr. Richter, M.Sc. Reeb)
Orga - Exam Date

- Exam scheduled for Friday, Jul 20\textsuperscript{th}
- Time: 13:00-15:00
- Room: Interimshörsaal 2 / 5620.01.102
- Registration is MANDATORY
- so far 27 students registered
Short SQL Recap

- schema
- typed data
- tables
- defined layout
- space consumption is computable
Short SQL Recap

- well defined theory
- relational algebra
- ACID principle
- standardized query language
- fast access with indices
- well supported by software vendors
No SQL

- in principle known for a long time
- Ken Thompson 1978: Key/Value system
- big push in 2000: Web 2.0
- Map/Reduce, BigTable databases
- data volume in the range of TB and PB
- growing relational databases more and more difficult on commodity hardware
- [http://www.w3resource.com/mongodb/nosql.php](http://www.w3resource.com/mongodb/nosql.php)
Definition

- non relational data model
- enables distributed and horizontal scalability
- open source
- no or simple schema
- support for simple data replication
- simple API
- different consistency model
Issues with Relational DB

- is the schema bad, the query also is
- based on strings, susceptible for typos
- errors are not detected at compile time
- cannot be refactored
Categories of No SQL Systems

- Wide Column Stores/Column Family Systems
- Document Stores
- Key/Values/Tuple Stores
- Graph Databases
Key/Value Systems

- at least very simple schema: key and value
- keys can be grouped in namespaces and databases
- values can be complex besides simple strings there are:
  - hashes
  - set
  - lists
- queries mostly limited to API
Column Family

- keys can point to an arbitrary number of key/value pairs
- nested key/value pairs
- nested columns
Document Stores

- works not on “actual” documents
- structured data like:
  - JSON
  - YAML
  - RDF
Graph Databases

- bases on graph or tree structures to connect elements
- property graph:
  - nodes to reflects items
  - edges to reflect relations
- very suitable for traversing
Theoretical Concepts

- Map/Reduce
- CAP-Theorem/ Eventually Consistent
- Consistent Hashing
- MVCC-Protocol
- Vector Clock
- Paxos
- REST
Map/Reduce

- require a (map/reduce) framework
- designed for efficient handling of data in the order of Tera or Peta bytes
- developed by Google
- patented since 2010
Map/Reduce Details

- originates from functional programming
- parallel processing
- no side effects
- no deadlocks
- no race conditions
- initial datastructure is not altered
- new copy with every level
Map/Reduce Details

- functions like in math:
  - a set of transformation definitions
  - no control structures
  - recursion
  - functions can be used as argument or return value: higher order functions
Map/Reduce Details

- two functions: map, reduce/fold
- used alternating (two phase approach)
- map (in parallel):
  - applied to all elements of list
  - returns a modified list
- reduce:
  - aggregate the return values from map into one result
Map/Reduce Details

- user has to provide:
  - map function
  - reduce function

- framework provides:
  - automatic parallelization and distribution
  - fault tolerance mechanisms for hard- and software failure
  - I/O scheduling
  - status and control information
Pseudocode Example

map(String key, String value):
    // key: document name
    // value: document contents
    for each word w in value:
        EmitIntermediate(w, "1");

reduce(String key, Iterator values):
    // key: a word
    // values: a list of counts
    int result = 0;
    for each v in values:
        result += ParseInt(v);
    Emit(AsString(result));
Characteristics of a Map/Reduce System

- commodity hardware
- Ethernet network
- large number of nodes (>100)
- distributed file system, data is stored in chunks and redundant
- data are local to processing node
CAP and Eventually Consistent

- horizontal scaling of relational databases insufficient
  - too much time to extend database to more computers
  - frequently modification of source code required
- mostly due to implementation of ACID principle
CAP Theorem

- Consistency, availability and partition tolerance cannot all completely satisfied at the same time.
- Only two of these criteria can be satisfied at the same time, here: availability and partition tolerance is the important combination.
- Consistency is reduced.
Consistency

- after a transaction the database is consistent, i.e.
  - all replicating nodes of database system have the same state after an transaction; changes are propagated to all nodes
  - read access to any node returns the same result
  - this require to wait for the completion of the propagation
Availability

- acceptable response time
- depends on the specific business case
- a certain response time is guaranteed up to a specified load level
Partition Tolerance

- if a node or a connection fails the system remains to be responsive
- in large computer centers those failures are frequent
BASE Consistency Model

- Basically available
- Soft state
- Eventually consistent
Characteristics

- focus on availability
- consistency is less important
- BASE is optimistic about consistency and defines it as a transition process and not as a defined state after a transaction
  -> Eventually Consistency
- consistent at some point in time
- interpretation different between systems
Levels of Consistency

- Causal Consistency
- Read-your-write Consistency
- Session Consistency
- Monotonic Read Consistency
- Monotonic Write Consistency
Consistent Hashing

- belongs to the family of hashing function
- maps elements of (potentially) very large source set to a hash value from a typically much smaller value set
- advantage: constant time
- applications:
  - check sums
  - securing against manipulations
  - fast search in data structures
Consistent Hashing

- here: find a constant place memory for an object
- minimize object movements on addition or removal of nodes
- minimize object movements upon insertions
- distribute equally among resources
- circular hash space
- servers and data object are integrated (clockwise)
- upon insertion or removal only neighbors are affected
Multiversion Concurrency Control (MVCC)

- data objects are versioned
- represents change timeline
- every write access creates a new version
- contains reference to the least recent version
- conflict resolution through explicit version comparison
Multiversion Concurrency Control (MVCC)

- disadvantage of conventional locks:
  - complete tables are locked
  - inefficient if communication time is high because of long cache pipeline or network traffic
  - not 100% guaranteed in distributed systems
  - parallel access are blocked
Multiversion Concurrency Control (MVCC)

- data objects are versioned
- represents change timeline
- every write access creates a new version
- contains reference to the least recent version
- conflict resolution through explicit version comparison
MVCC – No Conflict

transaction $T_{x_{Alice}}$

$v_{\text{latest}} = v_0$

Alice

$t_0$

read $v_0$

write $v_0 \rightarrow v_1$

$v_{\text{latest}} = v_1$

Bob

$t_1$

read $v_0$

read $v_1$
MVCC – Conflict Case

transaction $T_{x_{Alice}}$

$v_{latest} = v_0$

read $v_0$ write $v_0 \rightarrow v_{1a}$

$v_{latest} = v_{1a}$

read $v_0$ write $v_0 \rightarrow v_{1b}$

$t_0 \ t_1 \ t_2 \ t_3$

Conflict! $v_{latest} \neq v_0$

transaction $T_{x_{Bob}}$
Vector Clocks

- challenge:
  - many instances write data
  - they have to be synchronized and ordered afterwards

- solution: Vector Clocks
  - originated in the field of operating systems
  - Leslie Lamport (1978) describes Timestamps/Clocks
Lamport Timestamps/ Criteria

- **weak consistency criterion**: if event e1 causes event e2 then the timestamp of e1 has be smaller than the timestamp of e2

- **strong consistency criterion** (the opposite): if the timestamp of e1 is smaller than the one of e2 then event e1 has been the cause for event e2

- event can be sorted in a partial order
  - every event gets a timestamp which does not reflect real time
     - monotone increasing integer

- Timestamps fulfill only the weak criterion
Version Vector / Vector Clock

- Version Vector: Vector (Tuple) of values/timestamps of an object

- Vector Clock:
  - Each process/database has an counter which is incremented
  - every process remembers the sender and the timestamp
  - every message/version has a vector of id-timestamp pairs attached
Vector Clocks in NoSQL

- so the Vector Clock is a list of IDxTime tuples
- this enable the client to sort and figure out the different versions if multiple clients update and replicate records at the same time
- we demonstrate this with a simple example:
  - four people, denoted by their initial want to agree on a sports activity
Story to the Example

- Laura, Anna and Paul (replacing nodes) want to agree on sports (have consistent data)
  - nodes can request the current version of a record and they can update each other
  - simultaneous broadcast creates confusion
  - goal: consistent information (→ consensus protocols)
Story to the Example / Solution

- Laura starts, suggesting to go jogging: jogging, [L:1] (jogging is the data to store, L:1 the Vector Clock) and sends/replicates this to Anna and Paul.

- Paul is becoming active and suggest to go surfing: surfing, [L:1,P:1] and sends this to Anna and Paul.

- Because of network problem Anna does not receive the message, Laura receives it.
Story to the Example / Solution

- Laura agrees to Paul and return the surfing suggestion, incrementing her counter: surfing, [P:1, L:2]

- Anna becomes concerned and agrees to jogging, based on Laura’s suggestion: jogging[L:1, A:1] and sends it to Paul

- Paul has to (and can) detect the conflict: jogging could had a majority (Laura & Anna), BUT Laura also already agreed on surfing (Laura & Paul)
Story to the Example / Solution

- surfing[A:0, P:1, L:2]
  jogging[P:0, L:1, A:1]
  not yet known counters are listed with 0

- Paul can detect that Anna’s message was not a response to his suggestion sind P:0. There are two possible resolutions:
  - jogging, because initially both girls wanted to
  - surfing, because Laura changed her mind
Story to the Example / Solution

- Paul decides to go on with surfing and communicates this to Anna and Laura: surfing,[L:2, A:1, P:2]
- the discussion could still go on now, but this way the Vector Clocks help to make reasonable decisions and to check causal dependencies
Paxos

- goal: ensures data integrity if nodes in cluster with replicated data fail
- belongs to Quorum-Consensus algorithms
- leads to an agreement between participating nodes
- superior to classical Two-Phase-Commit (2PC)
- tolerant for:
  - minority of the nodes fails
  - a transaction crashes
  - message loss

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Basic Paxos Consensus Algorithm

- based on voting:
  - one *client* suggests a values
  - the other *acceptors* (quorum) vote
  - each ballot has a *leader* (coordinator)
  - proposers support clients, convince acceptors and coordinate conflict resolutions
Basic Paxos – Execution

- Phase 1a (prepare): proposer/leader acquires the current (maximum) ballot number from phase 1 and sends it to the quorum

- Phase 1b (prepare): if the received number is larger than any number received before, a node sends its status to the leader including:
  - largest received number from phase 1a
  - largest number sent in phase 2b
  - no smaller or equal ballot numbers than the current will be accepted
Basic Paxos – Execution

- Phase 2a (accept): if the leader for a ballot received positive 1b messages from a quorum
  - free – no quorum has sent a number larger than 2b and has therefore voted for a value v (no completed ballot before)
  - forced – a quorum has sent a ballot larger phase 2b, i.e. it has selected an value v
  - if forced leader sends value v, if free leader can send any value
Basic Paxos – Execution

- Phase 2b (accepted): if an acceptor gets a 2a message for which he agreed before with a 1b message, the value is accepted and it sends a phase 2b message with v and ballot to the leader.

- Phase 3: If the leader get a phase 2b message for v and ballot from a quorum, it knows that v was accepted and communicates this to all interested processes.
Graph Databases

- graphs allow to represent connected information very intuitively by using vertices and edges
- useful for current problems like, a.o.:
  - internet routing
  - contacts in social networks
  - recommender systems
  - fraud detection
  - regulatory networks
  - semantic web
  - ...

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Graph Lingo

- graphs are represented by a pair (tuple) of two sets, $V$ (vertices) and $E$ (edges)
- vertices are nodes, representing a kind of fact
- edges are the connections/relations between vertices and can be directed or undirected
- $G = (V,E)$, $V = \{1,2\}$, $E = V \times V = \{(1,2)\}$
Property Graph Model

- directed, multi-relational graph
- labeled/(typed) edges
- vertices and labels have properties
- properties are key/value pairs of type <String, Object> like:
  Name: Alice or Age: 30
Property Graph Model

- strong typing of vertices and edges possible ('Type'/'_Type', depends on the support of the system)
  - useful to a semantic meaning
  - support of automatic handling
  - allows for definition of consistency criteria and indices
  - make partition of graphs easier
- bidirectional edges are realized by two unidirectional edges
Property Graph Model

- multi-edges require different labels
- vertices and edges have an unique identity: ‘Id’, ‘_Id’
- used for ids: integers, string, URIs
- extension: multi value property, which allow lists or sets of values
- special case for edge label values: edge weights
- another extension: higher order relations with hyper edges and hyper vertices
Property Graph Model / Extensions

- higher order relations with hyper edges and hyper nodes
  - hyper edge: connects more than two nodes
  - hyper vertex: combination of a set of vertices/nodes, keeps internal edges
- paths: sequence of edges
- subgraphs: a defined combination of nodes and edges into a single node
- version information allows to represent the graph evolution and/or concurrency
Graph Representations

- different representations available for persistence and memory
- difficult to match a good performance in persistence and a good support for a variety of graph algorithms at the same time
Adjacency Matrix

- square matrix/table
- all $n$ nodes are listed horizontally and vertically
- if an edge exists between nodes $u$ and $v$, there is an entry in the table at position $[u,v]$
- test for the connection of two nodes $u$ and $v$ can be done very quickly
Adjacency Matrix / Problems

- disadvantage: huge space consumption even with sparse matrices, i.e. graphs with many nodes but only a few edges
- it is difficult to identify the connecting edges for a given node
- to identify neighbors you always have to read a complete row or column
- hypergraphs can not be represented
Incidency Matrix

- a matrix with nodes on one axis and edges on the other axis
- much more space efficient for very weakly connected edges than the adjacency matrix
- in more connected graphs it needs more space than the adjacency matrix
- can represent hypergraphs
Edge List

- nodes and edges are stored separately
- insertion and deletion of single edges is very efficient
- identification of connecting edges given a node is inefficient, since the whole edge list has to be searched
Adjacency List

- extension of edge list
- edges are sorted according to their start node
- for every node the connecting edges are stored
- time consumption depends only to connectivity of the node, not on the complete graph size
Example Graph

\[
\begin{array}{cccc}
  v1 & v2 & v3 & v4 \\
  v1 & 0 & 0 & 0 & 0 \\
  v2 & 1 & 1 & 1 & 0 \\
  v3 & 2 & 1 & 0 & 0 \\
  v4 & 0 & 1 & 0 & 0 \\
\end{array}
\]

\[
\begin{array}{cccc}
  e1 & e2 & e3 & e4 & e5 & e6 \\
  v1 & 1 & 1 & 1 & 0 & 0 & 0 \\
  v2 & 0 & 0 & -1 & 2 & 1 & 1 \\
  v3 & -1 & -1 & 0 & 0 & 0 & 1 \\
  v4 & 0 & 0 & 0 & 0 & -1 & 0 \\
\end{array}
\]

V1 → v2 → v3 → v3
V2 → v2 → v3 → v4
V3 → v2
V3
Graph Traversal

- either partial or complete visit of the nodes
- three strategies:
  - breadth-first/depth-first
  - algorithmic traversals
  - random based
Graph Indexing and Partitioning

- Graph indexes are first-class citizens
- can inserted as sub-graphs and attached to specific nodes as specific information
- If Graph gets to big it can be split into partial graphs
- Optimal Partitioning is highly domain and semantics-dependent-> no good standard solution
Tinkerpop Graph Processing Step

- attempt to provide uniform interfaces for Property-Graph based systems
- covers the backend database from the application developer
- consists of several sub-projects:
  - Blueprints: Java interface for Property-Graph models
    - no own persistence yet
  - supports transactions
Graph Creation

Listing 6.2.1 zeigt ein einfaches Beispiel für die Erzeugung eines mithilfe von Neo4j
per-
sistenten Blueprints-Property-Graphen, bestehend aus drei Knoten und drei Kanten.

```java
// Erzeuge einen neuen Graphen mit Neo4j-Persistenz
Graph graph = new Neo4jGraph("/tmp/my_graph");

// Erzeuge Knoten mit Id "Alice", "Bob" und "Carol"
Vertex alice = graph.addVertex("Alice");
Vertex bob   = graph.addVertex("Bob");
Vertex carol = graph.addVertex("Carol");

// Füge die Namen und das Alter als Properties hinzu
alice.setProperty("Name", "Alice");
alice.setProperty("Alter", 18);
bob .setProperty("Name", "Bob");
bob .setProperty("Alter", 22);
carol.setProperty("Name", "Carol");
carol.setProperty("Alter", 20);

// Erstelle die dazugehörigen Kanten...
Edge e1 = graph.addEdge("e1", alice, bob, "kennt");
Edge e2 = graph.addEdge("e2", alice, carol, "kennt");
Edge e3 = graph.addEdge("e3", carol, bob, "kennt");

// ...und setzte das Kanten-Property "seit"
e1.setProperty("seit", "2001/10/03");
e2.setProperty("seit", "2003/12/04");
e3.setProperty("seit", "2001/07/12");

graph.shutdown();
```

Anders als bei relationalen Datenbanken erfolgt der Datenzugri
ff
bei Graphdatenbanken
in der Regel nicht primär über Indexanfragen, sondern über die Traversierung des Gra-
phpen selbst. Die einfachste Traversierungsmethode ist dabei die Iteration über alle Knoten
graph.getVertices()
or Kanten
graph.getEdges()
des Graphen, wobei für jeden
Knoten bzw. jede Kante eine bestimmte Methode ausgeführt werden soll. In Listing 6.2.2
wird dementsprechend für jeden Knoten des Graphen der Iterator
getOutEdges()
auer-
-...und setzte das Kanten-Property "seit"
graph.shutdown();
System.out.println(edge);
}

Listing 6.2.3

Set<String> indexKeys = new HashSet<String>();
indexKeys.add("Name");

// Indiziere die angegebenen Property-Schlüssel aller Knoten
AutomaticIndex index = graph.createAutomaticIndex(
    "IndexOfName", Vertex.class, indexKeys);

// Bereits vorhandene Knoten müssen neu indiziert werden
AutomaticIndexHelper.reIndexElements(index, graph.getVertices());

// Iteriere über die Ergebnisse der Indexanfrage
for (Vertex vertex : index.get("Name", "Alice")) {
    System.out.println("Vertex: " + vertex);
}
Graph Query Languages

- no common standard yet
- pattern-based: SPARQL, RDF Query language
- navigation-base: Gremlin, sones GQL
- logic-bases: OWL, GraphLog
Neo4j

- one of the oldest NoSQL graph databases (2003)
- full ACID support
- uses own format to store graphs on disc
- Apache Lucene used for indexing
- can run as server as well as embedded
Integration with Java

- easiest integration using Maven (adding to the xml file), then:

```java
GraphDatabaseService graphdb = new EmbeddedGraphDatabase("/var/graphdb");
```
Graph Creation

class Relationships

enum Relationships implements Rel { knows }

Transaction tx = graphdb.beginTx();
try {
    Node Alice = graphdb.createNode();
    Node Bob = graphdb.createNode();
    Node Carol = graphdb.createNode();
    Alice.setProperty("Name", "Alice");
    Bob.setProperty("Name", "Bob");
    Carol.setProperty("Name", "Carol");
    Alice.setProperty("Age", 18);
    Bob.setProperty("Age", 20);
    Carol.setProperty("Age", 22);
    Relationship Alice_Bob = Alice.createRelationshipTo(Bob, Rel.knows);
    Relationship Alice_Carol = Alice.createRelationshipTo(Carol, Rel.knows);
    Relationship Carol_Bob = Carol.createRelationshipTo(Bob, Rel.knows);
}
Graph Creation

Alice_Bob.setProperty("since", );
Alice_Carol.setProperty("since", );
Carol_Bob.setProperty("since", );
    tx.success();
} catch (Exception e) {
    tx.failure();
} finally {
    tx.finish();
}
Manual Indexing

IndexManager index = graphdb.index();
Index<Node> UserIdx = index.forNodes("User");
RelationshipIndex KnowsIdx = index.forRelationships("knows");
UserIdx.add(Alice, "Name", Alice.getProperty("Name"));
UserIdx.add(Alice, "Age", Alice.getProperty("Age"));
[...]
Traversal Configuration

- besides simple traversals and wildcard searches there are number of sophisticated tweaks:
  - Order: Determines the branching order (DFS/BFS)
  - Uniqueness: how to handle multiple hits of the same nodes
  - Pruning: which branches not to follow
  - Filtering: which hits are considered for the result
  - Relationship expanding: dedicated edge handling
Example Traversal

TraversalDescription td = new TraversalDescriptionImpl();
  td = td.prune(Traversal.pruneAfterDepth(2)).
    filter(Traversal.returnAllButStartNode()).
  relationships(KNOWS);
Traverser tr = td.traverse(startNode);
for ( Path path : tr ) {
  System.out.println( "End Node: " +
    path.endNode().getProperty( NodeProperty.NAME ) );
}
Cypher

- own graph query language since version 1.4
  - developed for pattern recognition
  - declarative
  - implemented in Scala -> parallel enabled
- query structure:
  - starts with a set of nodes
  - match statement (node in (), edges ->)
  - return statement with optional where or sort
Examples

// start nodes via Ids
start Person = (1, 2)
match (Person)-[:knows]->(Friend)
where Friend.Age > 18
return Friend.Name, Friend.Age, Friend.City?
sort by Friend.Name

// starts nods via index query
start Person = (Person-index, Name, "Alice")
match (Person)-[:knows]->()-[[:knows]->(FriendofFriend)
where not(FriendofFriend.Age < 17)
return FriendofFriend.Name
Interfacing NoSql

- specific APIs vary heavily
- most support RESTful interface:
  - REpresentational State Transfer
  - architecture for web applications
  - predominantly implemented using HTTP protocol
CRUD

- minimum set of access functions:
  - Create, Read, Update, Delete

<table>
<thead>
<tr>
<th>CRUD</th>
<th>SQL</th>
<th>HTTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create</td>
<td>insert</td>
<td>POST</td>
</tr>
<tr>
<td>Read</td>
<td>select</td>
<td>GET</td>
</tr>
<tr>
<td>Update</td>
<td>update</td>
<td>PUT</td>
</tr>
<tr>
<td>Delete</td>
<td>delete</td>
<td>DELETE</td>
</tr>
</tbody>
</table>
Components

- Resources, Operations, Links
- Each request is independent, i.e. it has no state
  -> no need for synchronization
- Abstract view of HTTP protocol: nouns and verbs.
  - Each request is defined by the application of a verb to noun and an optional response
- A request is composed of a header with a method and meta data in key/value format and an optional body
- A response is like a request but without a method
Resources

- addressable end-point to the system
  - e.g. HTML document, video, a process
- a resource is abstract and can have more than one representation
- the user always interacts with a representation (HTML, a graphics format, XML,...) and may choose the desired one
Operations

- HTTP defines a set of operations with known semantics:
  - GET
  - HEAD
  - PUT
  - POST
  - DELETE
Characteristics for Operations

- operations can be classified according to the criteria safe and idempotent which are important for the system’s integrity and caching performance
- safe: no side effects, no responsibility for the user
- idempotent: side effect, but only the first time – upon multiple execution the server state does not change anymore
GET/HEAD

- safe and idempotent
- HEAD: returns only meta information about the resource
- GET: contains in addition to the meta information also a representation of the resource
- a non conforming example: “http://www.example.com/api?action=delete”
PUT

- idempotent
- the referenced resource representation is transmitted to the server (side effect -> not safe)
- only the first execution changes the state of the server
- this can be achieved if a server maintains version numbers for a document which has to be match by the request
PUT – Simple Example

- Q (request): GET doc
- R (response): return doc v=1, doc content
- Q: Put doc v=1, doc content modified
- R: Request v=1 matches server v=1; doc content modified stored; update version v=2
- Q (a second time): Put doc v=1, doc content modified (maybe again)
- R: Request v=1 does not match server v=2; doc content not stored;
DELETE

- idempotent
  - once the resource is removed all subsequent requests fail -> server state remains the same
- not safe
- the referred resource is remove from the server/access blocked
POST

- no guarantees at all
- transmits data for processing
- the processing result can be used to create a new resource, modify an existing one or not at all
- can be used for very complex queries because all parameters can be included in the body – GET had to include it in the URI
LINKS

- HTTP does not represent links
- links are modeled in URIs
- encoding depends on the type of representation
- can contain meta data to support appropriate resource by the user
2.7.3 Entwurf von REST-Applikationen


Die Plattform bietet zu diesem Zweck eine maschinenorientierte Schnittstelle auf Basis von HTTP und JSON. Die Nutzergemeinde kann Wertungen für einzelne Cocktails einreichen, um monatlich den besten Cocktail zu kürren.

Für die grundlegenden CRUD-Operationen des Systems bietet HTTP mit den vorgestellten Operationen umfassende Unterstützung. Um einen Eintrag für einen neuen Cocktail anlegen, wird einfach dessen Repräsentation mittels POST an die URI geschickt:

```
POST /api/ HTTP/1.1
Host: cocktails.example.com
Content-Type: application/json
...
{
  "name": "Ipanema",
  "description": "Eine alkoholfreie Variante für den Caipirinha-Abend",
  "ingredients": {
    "Limette": {"amount": 1, "preparation": "Achteln"},
    "Brauner Zucker": {"amount": 2, "unit": "TL"},
    ...
  },
  "preparation": "Limetten und Zucker in einem Glas mörsern, mit crushed ice bedecken und den Flüssigkeiten auffüllen. Mit einem Strohhalm servieren"
}
```

Wenn die Anfrage problemlos bearbeitet werden kann, antwortet der Server mit einem Status-Code "201 Created" und der URI des neu angelegten Cocktails.
<table>
<thead>
<tr>
<th>HTTP/1.1 201 Created</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content-Type: application/json</td>
</tr>
<tr>
<td>Location: <a href="http://cocktails.example.com/cocktails/1">http://cocktails.example.com/cocktails/1</a></td>
</tr>
</tbody>
</table>

```
...
{
  "id": "1",
  "name": "Ipanema",
  "description": "Eine alkoholfreie Variante für den Caipirinha-Abend",
  "ingredients": {
    "Limette": { "amount": 1, "preparation": "Achteln" },
    "Brauner Zucker": { "amount": 2, "unit": "TL" },
    ...
  },
  "preparation": "Limetten und Zucker in einem Glas mörsern, mit crushed ice bedecken und den Flüssigkeiten auffüllen. Mit einem Strohhalm servieren",
  "links": {
    "linktypes/publish": "http://cocktails.example.com/publish/1",
    "linktypes/edit": "http://cocktails.example.com/cocktails/1",
    "linktypes/delete": "http://cocktails.example.com/cocktails/1"
  }
}
```
Außerdem enthält die Repräsentation des Cocktails nun einen veränderten Linkblock:

```plaintext
DELETE /cocktails/1 HTTP/1.1
Host: cocktails.example.com

{ ... 
  "tags" : [ "alkoholfrei", "Eis" ],
  ... 
}
```

```plaintext
DELETE /cocktails/1 HTTP/1.1
Host: cocktails.example.com
```

```plaintext
POST /publish/1 HTTP/1.1
Host: cocktails.example.com
Content-Type: application/json

{ ... 
  "publish" : true 
}
```

```plaintext
{ "id" : "1",
  ...
  "links" : {
    "linktypes/delete" : "http://cocktails.example.com/cocktails/1",
    "linktypes/ratings" : "http://cocktails.example.com/ratings/1"
  }
}
```
Document Stores

- originates to Damien Katz and Lotus Notes, CouchDB

- the responsibility for the schema is moved from the database towards the application:
  - loss of enforcement of normalization and referential integrity
  - gain of flexibility and schema modifications at run-time for the application

- data mostly stored as JSON
MongoDB

- Document Store
- try to close the gap between classic RDBMS and Key/Value stores
- supported by a number of successful internet companies (10gen, ...)
- good integration with programming languages: C++, C#, Java, JavaScript, PHP, Ruby, Perl, Python