# *Introduction to Kyoto Products*

# Kyoto Cabinet

*- lightweight database library -*

# Features

- straightforward implementation of DBM
  - process-embedded database
  - persistent associative array = key-value storage
  - successor of QDBM, and sibling of Tokyo Cabinet
    - e.g.) DBM, NDBM, GDBM, TDB, CDB, Berkeley DB
  - C++03 (with TR1) and C++0x porable
    - supports Linux, FreeBSD, Mac OS X, Solaris, Windows
- high performance
  - insert 1M records / 0.8 sec = 1,250,000 QPS
  - search 1M records / 0.7 sec = 1,428,571 QPS

- high concurrency
  - multi-thread safe
  - read/write locking by records, user-land locking by CAS
- high scalability
  - hash and B+tree structure = O(1) and O(log N)
  - no actual limit size of a database file (up to 8 exa bytes)
- transaction
  - write ahead logging, shadow paging
  - ACID properties
- various database types
  - storage selection: on-memory, single file, multiple files in a directory
  - algorithm selection: hash table, B+ tree
- other language bindings
  - C, Java, Python, Ruby, Perl, Lua, and so on

# Database Types

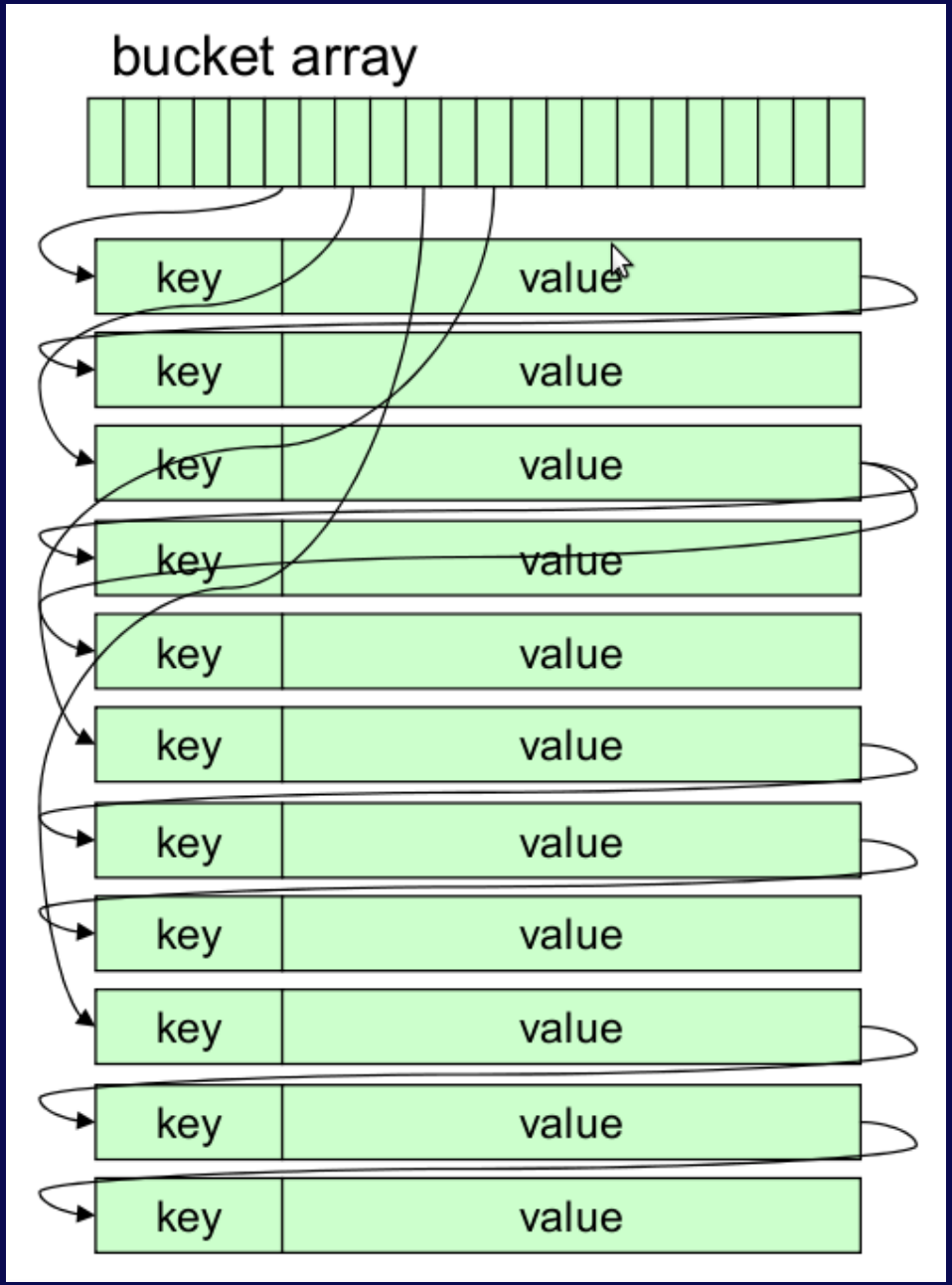
- ProtoHashDB: prototype hash database
  - on-memory database implemented with std::unorderd_map
- ProtoTreeDB: prototype tree database
  - on-memory database implemented with std::map
- CacheDB: cache hash database
  - on-memory database featuring LRU deletion = typical cache
- GrassDB: cache tree database
  - on-memory database of B+ tree =  cache with order
- HashDB: file hash database
  - file database of hash table = typical DBM
- TreeDB: file tree database
  - file database of B+ tree = DBM with order
- DirDB: directory hash database
  - respective files in a directory of the file system = for large records
- ForestDB: directory tree database
  - directory database of B+ tree = huge DBM with order

# performance characteristics

| class name | persistence | algorithm | time complexity | sequence | lock unit |
|---|---|---|---|---|---|
| ProtoHashDB | volatile | hash table | O(1) | undefined | whole (rwlock) |
| ProtoTreeDB | volatile | red black tree | O(log N) | lexical order | whole (rwlock) |
| CacheDB | volatile | hash table | O(1) | undefined | record (mutex) |
| GrassDB | volatile | B+ tree | O(log N) | custom order | page (rwlock) |
| HashDB | persistent | hash table | O(1) | undefined | record (rwlock) |
| TreeDB | persistent | B+ tree | O(log N) | custom order | page (rwlock) |
| DirDB | persistent | undefined | undefined | undefined | record (rwlock) |
| ForestDB | persistent | B+ tree | O(log N) | custom order | page (rwlock) |

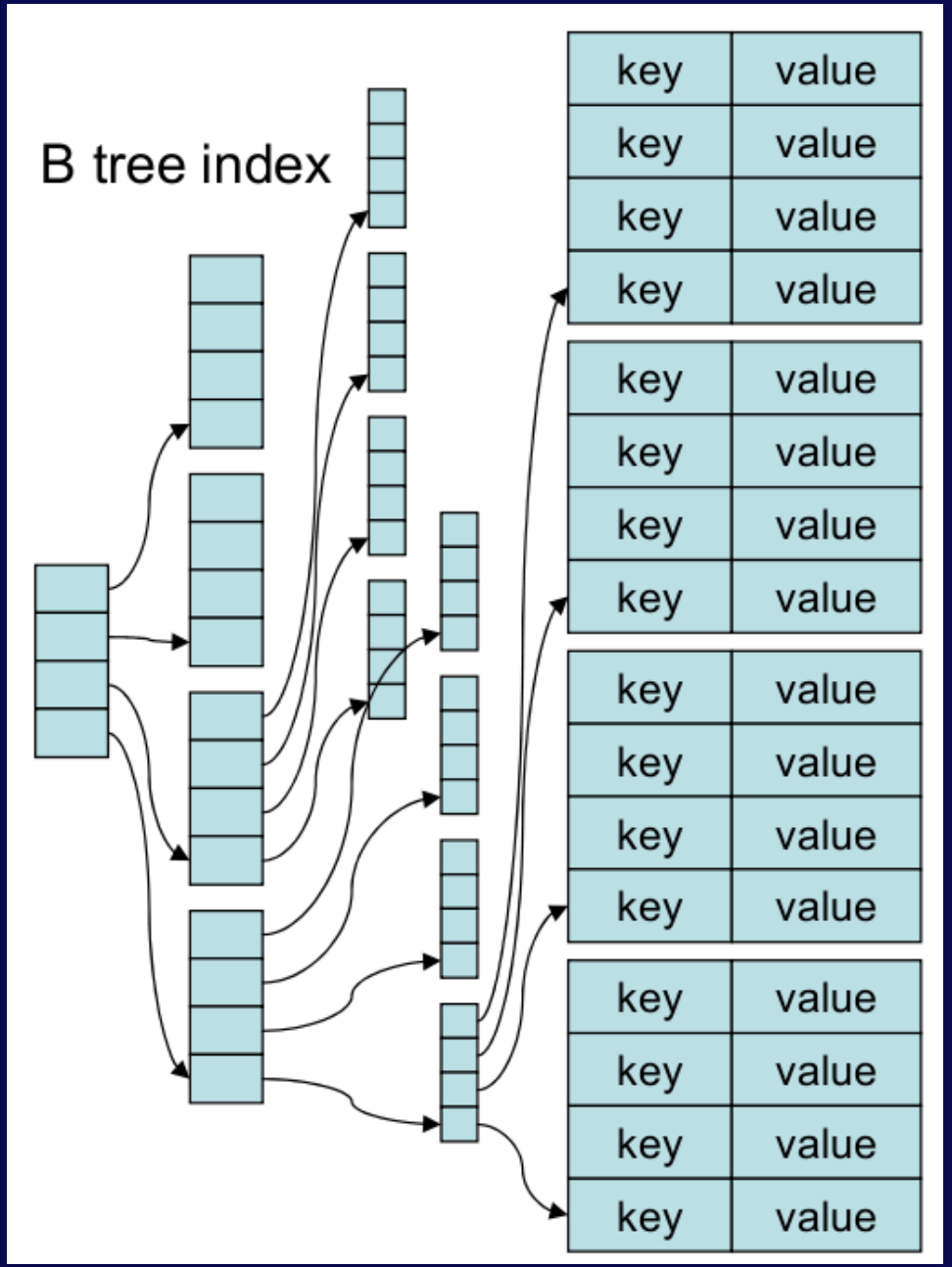
# HashDB: File Hash Database

- static hashing
  - O(1) time complexity
  - jilted dynamic hashing for simplicity and performance
- separate chaining
  - binary search tree
  - balances by the second hash
- free block pool
  - best fit allocation
  - dynamic defragmentation
- combines mmap and pread/pwrite
  - saves calling system calls
- tuning parameters
  - bucket number, alignment
  - compression



# TreeDB: File Tree Database

- B+ tree
  - O(log N) time complexity
  - custom comparison function
- page caching
  - separate LRU lists
  - mid-point insertion
- stands on HashDB
  - stores pages in HashDB
  - succeeds time and space efficiency
- cursor
  - jump, step, step_back
  - prefix/range matching



# HashDB vs. TreeDB

| | HashDB (hash table) | TreeDB (B+ tree) |
|---|---|---|
| time efficiency | faster, O(1) | slower, O(log N) |
| space efficiency | larger, 16 bytes/record footprint | smaller, 3 bytes/record footprint |
| concurrency | higher, locked by the record | lower, locked by the page |
| cursor | undefined order<br>jump by full matching, able to step back | ordered by application logic<br>jump by range matching, unable to step back |
| fragmentation | more incident | less incident |
| random access | faster | slower |
| sequential access | slower | faster |
| transaction | faster | slower |
| memory usage | smaller | larger |
| compression | less efficient | more efficient |
| tuning points | number of buckets, size of mapped memory | size of each page, capacity of the page cache |
| typical use cases | session management of web service<br>user account database<br>document database<br>access counter<br>cache of content management system<br>graph/text mining | job/message queue<br>sub index of relational database<br>dictionary of words<br>inverted index of full-text search<br>temporary storage of map-reduce<br>archive of many small files |

# Directory Databases

- DirDB: directory hash database
  - respective files in a directory of the file system
  - suitable for large records
  - strongly depends on the file system performance
    - ReiserFS > EXT3 > EXT4 > EXT2 > XFS > NTFS
- ForestDB: directory tree database
  - B+ tree stands on DirDB
  - reduce the number of files and alleviates the load
  - most scalable approach among all database types

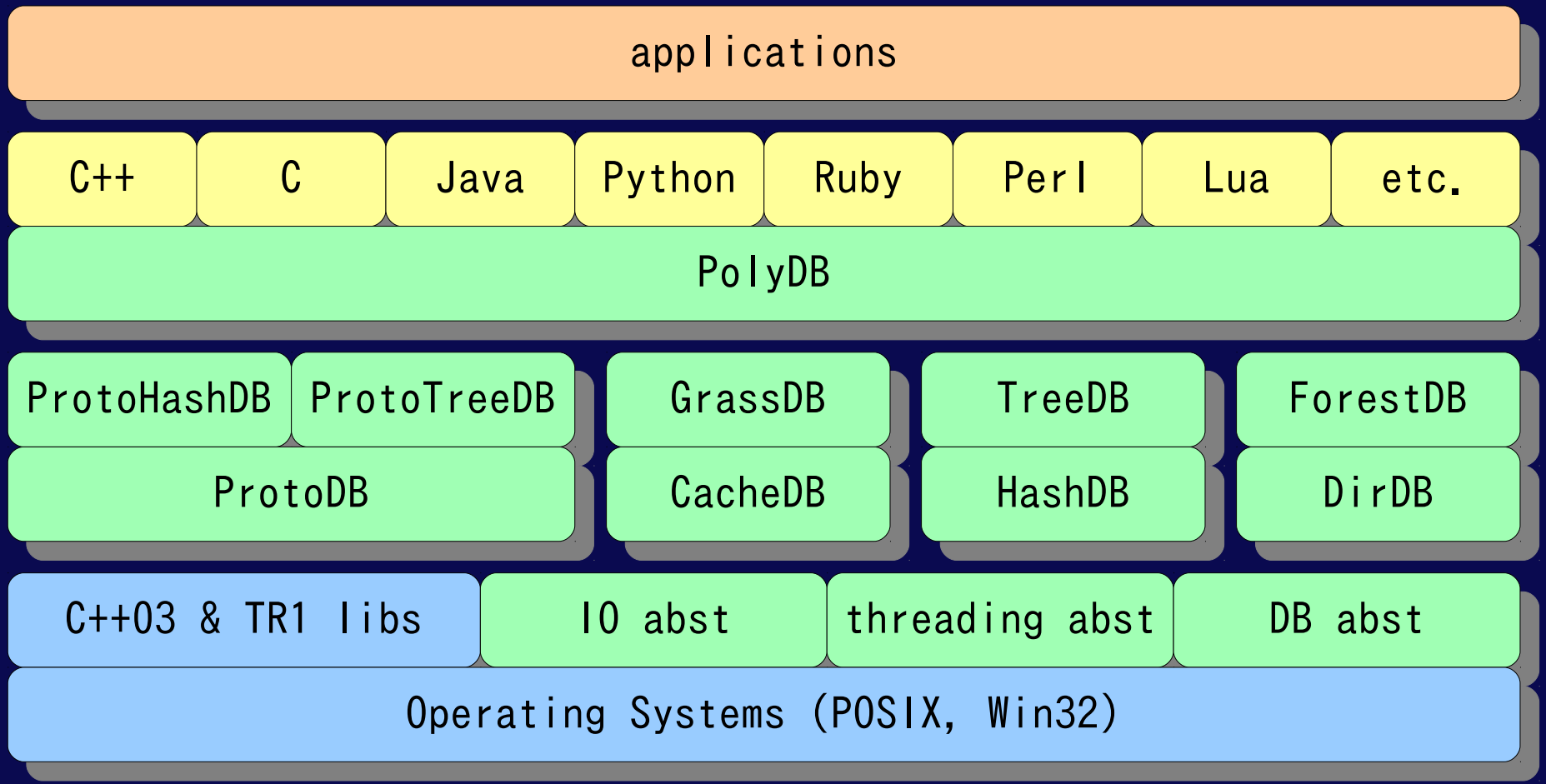
# On-memory Databases

- ProtoDB: prototype database template
  - DB wrapper for STL map
  - any data structure compatible std::map are available
  - ProtoHashDB: alias of ProtoDB<std::unordered_map>
  - ProtoTreeDB: alias of ProtoDB<std::map>
- CacheDB: cache hash database
  - hash table with double linked list
  - constant memory usage
  - LRU (least recent used) records are removed
  - much less memory usage than std::map and std::unordered_map
- GrassDB: cache tree database
  - B+ tree stands on CacheDB
  - much less memory usage than CacheDB

# Class Hierarchy

- DB = interface of record operations
  - BasicDB = interface of storage operations, mix-in of utilities
    - ProtoHashDB, ProtoTreeDB, CacheDB, HashDB, TreeDB, ...
    - PolyDB
- PolyDB: polymorphic database
  - dynamic binding to concrete DB types
    - "factory method" and "strategy" patterns
  - the concrete type is determined when opening
    - naming convention
      - ProtoHashDB: "-", ProtoTreeDB: "+", CacheDB: "*", GrassDB: "%"
      - HashDB: ".kch", TreeDB: ".kct", DirDB: ".kcd", ForestDB: ".kcf"

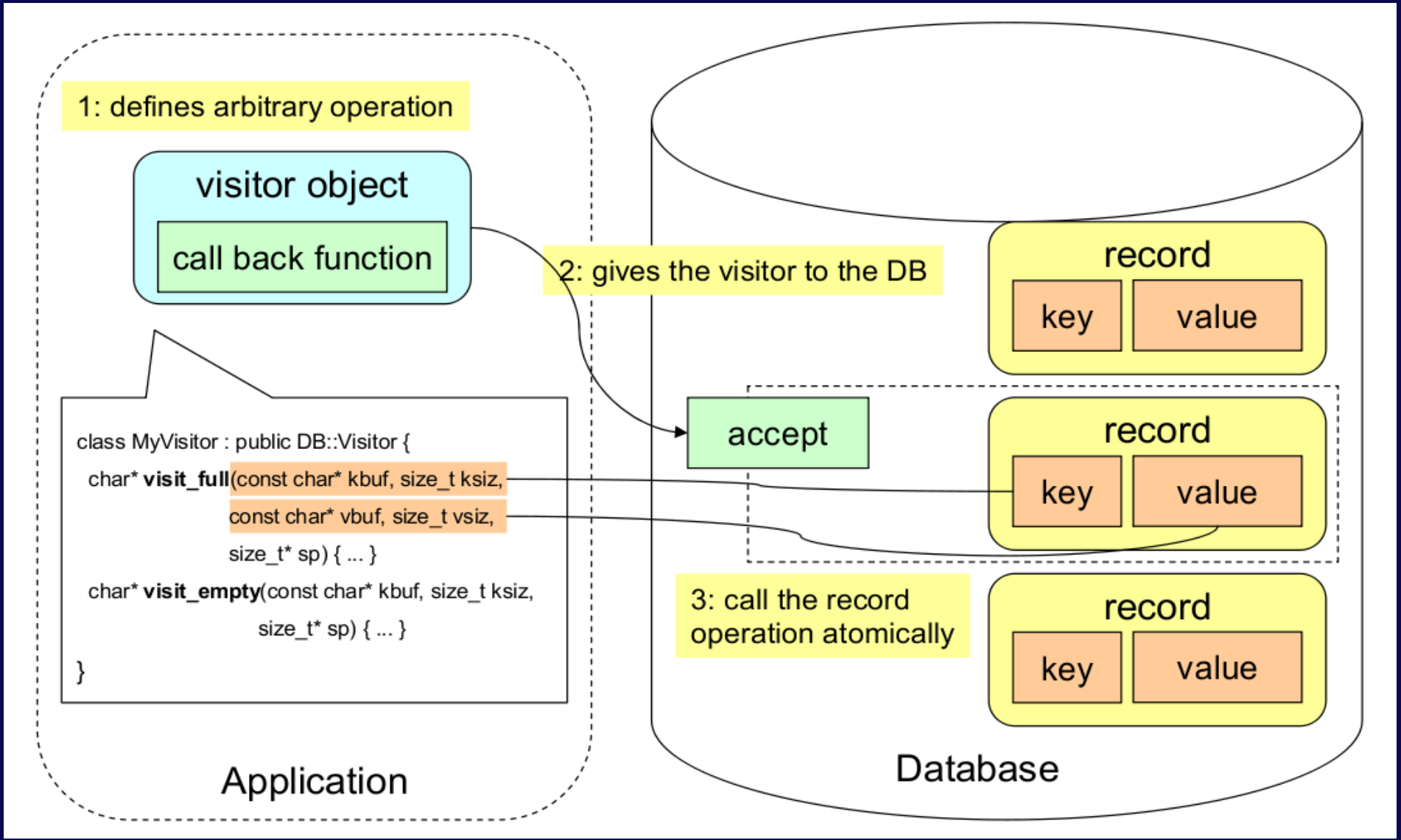
# Components


applications
C++
C
Java
Python
Ruby
Perl
Lua
etc.
PolyDB
ProtoHashDB
ProtoTreeDB
GrassDB
TreeDB
ForestDB
ProtoDB
CacheDB
HashDB
DirDB
C++03 & TR1 libs
IO abst
threading abst
DB abst
Operating Systems (POSIX, Win32)

# Abstraction of KVS

- what is "key-value storage" ?
  - each record consists of one key and one value
  - atomicity is assured for only one record
  - records are stored in persistent storage
- so, what?
  - every operation can be abstracted by the "visitor" pattern
  - the database accepts one visitor for a record at the same time
    - lets it read/write the record arbitrary
    - saves the computed value
- flexible and useful interface
  - provides the "DB::accept" method realizing whatever operations
  - "DB::set", "DB::get", "DB::remove", "DB::increment", etc. are built-in as wrappers of the "DB::accept"

# Visitor Interface



# Comparison with Tokyo Cabinet

- pros
  - space efficiency: smaller size of DB file
    - footprint/record: TC=22B -> KC=16B
  - parallelism: higher performance in multi-thread environment
    - uses atomic operations such as CAS
  - portability: non-POSIX platform support
    - supports Win32
  - usability: object-oriented design
    - external cursor, generalization by the visitor pattern
    - new database types: GrassDB, ForestDB
  - robustness: auto transaction and auto recovery
- cons
  - time efficiency per thread: due to grained lock
  - discarded features: fixed-length database, table database
  - dependency on modern C++ implementation: jilted old environments

# Example Codes

```cpp
#include <kcpolydb.h>

using namespace std;
using namespace kyotocabinet;

// main routine
int main(int argc, char** argv) {
  // create the database object
  PolyDB db;
  // open the database
  if (!db.open("casket.kch", PolyDB::OWRITER | PolyDB::OCREATE)) {
    cerr << "open error: " << db.error().name() << endl;
  }
  // store records
  if (!db.set("foo", "hop") ||
      !db.set("bar", "step") ||
      !db.set("baz", "jump")) {
    cerr << "set error: " << db.error().name() << endl;
  }
  // retrieve a record
  string* value = db.get("foo");
  if (value) {
    cout << *value << endl;
    delete value;
  } else {
    cerr << "get error: " << db.error().name() << endl;
  }
  // traverse records
  DB::Cursor* cur = db.cursor();
  cur->jump();
  pair<string, string>* rec;
  while ((rec = cur->get_pair(true)) != NULL) {
    cout << rec->first << ":" << rec->second << endl;
    delete rec;
  }
  delete cur;
  // close the database
  if (!db.close()) {
    cerr << "close error: " << db.error().name() << endl;
  }
  return 0;
}
```

```cpp
#include <kcpolydb.h>

using namespace std;
using namespace kyotocabinet;

// main routine
int main(int argc, char** argv) {
  // create the database object
  PolyDB db;
  // open the database
  if (!db.open("casket.kch", PolyDB::OREADER)) {
    cerr << "open error: " << db.error().name() << endl;
  }
  // define the visitor
  class VisitorImpl : public DB::Visitor {
    // call back function for an existing record
    const char* visit_full(const char* kbuf, size_t ksiz,
                           const char* vbuf, size_t vsiz, size_t *sp) {
      cout << string(kbuf, ksiz) << ":" << string(vbuf, vsiz) << endl;
      return NOP;
    }
    // call back function for an empty record space
    const char* visit_empty(const char* kbuf, size_t ksiz, size_t *sp) {
      cerr << string(kbuf, ksiz) << " is missing" << endl;
      return NOP;
    }
  } visitor;
  // retrieve a record with visitor
  if (!db.accept("foo", 3, &visitor, false) ||
      !db.accept("dummy", 5, &visitor, false)) {
    cerr << "accept error: " << db.error().name() << endl;
  }
  // traverse records with visitor
  if (!db.iterate(&visitor, false)) {
    cerr << "iterate error: " << db.error().name() << endl;
  }
  // close the database
  if (!db.close()) {
    cerr << "close error: " << db.error().name() << endl;
  }
  return 0;
}
```

# Other Kyoto Products?

- now, planning...

- Kyoto Tycoon?
  - database server using Kyoto Cabinet
  - supports expiration and multiple databases
- Kyoto Diaspora?
  - inverted index using Kyoto Cabinet

maintainability is our paramount concern...

*FAL Labs* *http://fallabs.com/*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