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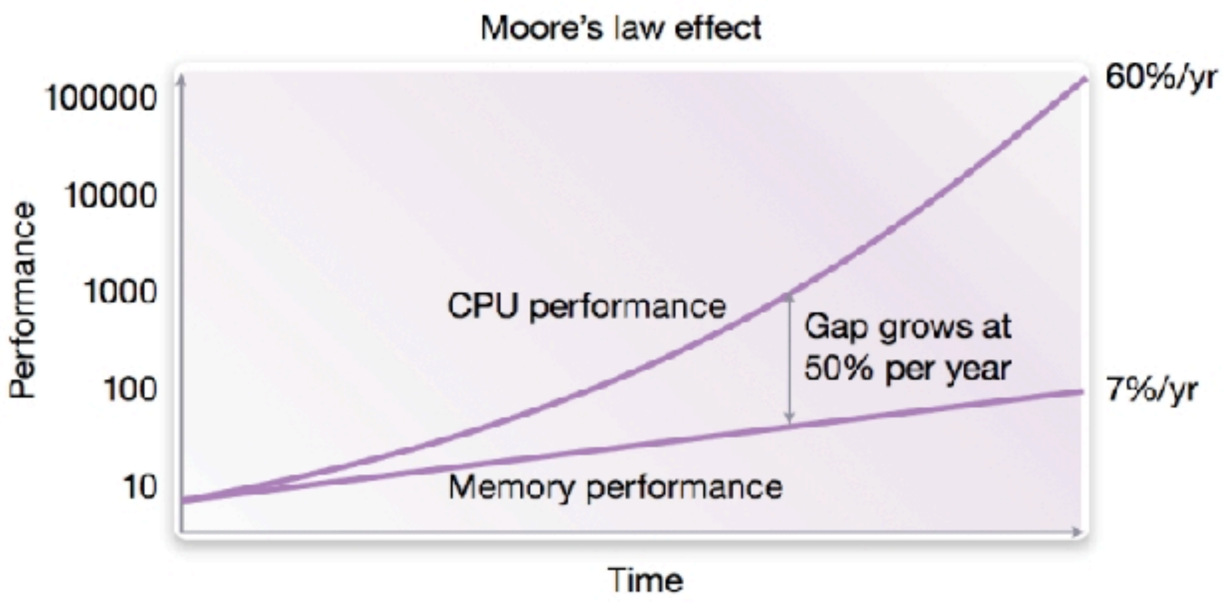
WEEK 3

BYOD

AGENDA

- Dictionary Encoding
- Organization
- Sprint 3

DICTIONARY ENCODING - MOTIVATION



- Memory access is the new bottleneck
- Decrease number of bits used for data representation

DICTIONARY ENCODING - MOTIVATION

- Dictionary encoding is an “easy-to-implement” fixed-width compression and basis for several other compression techniques
- Idea: encode every distinct value of a vector (large) with a distinct fixed-length *integer* value (small)

DICTIONARY ENCODING – EXAMPLE: SAMPLE DATA

- World population: 8 billion records

recID	fname	lname	gender	city	country	birthday
…	…	…	…	…	…	…
39	John	Smith	m	Chicago	USA	12.03.1964
40	Mary	Brown	f	London	UK	12.05.1964
41	Jane	Doe	f	Palo Alto	USA	23.04.1976
42	John	Doe	m	Palo Alto	USA	17.06.1952
43	Peter	Schmidt	m	Potsdam	GER	11.11.1975
…	…	…	…		…	…

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DICTIONARY ENCODING – EXAMPLE: ENCODE A COLUMN

recID	fname
…	…
39	John
40	Mary
41	Jane
42	John
43	Peter
…	…

Dictionary for "fname"

valueID	Value
…	…
23	John
24	Mary
25	Jane
26	Peter
…	…

Attribute Vector for "fname"

position	valueID
…	…
39	23
40	24
41	25
42	23
43	26
…	…

- Dictionary stores all distinct values with an implicit valueID
- Attribute vector stores valueIDs for all entries in the column (positions are stored implicitly)

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DICTIONARY ENCODING - EXAMPLE: COMPRESSION RATE

- 5 million distinct values, all have a size of 50 B
  - Bits required per valueID: ceil($\log_2$(5,000,000)) b = 23
  - Dictionary size: 5 * 10^6 * 50 B = 250 * 10^6 B = 0.250 GB
  - Attribute vector size: 8 * 10^9 * 23b = 23 * 10^9 B = 23 GB
  - Uncompressed: 8 * 10^9 * 50 B = 400 * 10^9 B = 400 GB

  - compression rate = uncompressed size / compressed size
    = 400GB / (23 GB + 0.250 GB) ≈ 17

DICTIONARY ENCODING – QUERY DATA

recID	fname
…	…
39	John
40	Mary
41	Jane
42	John
43	Peter
…	…

Dictionary for "fname"

valueID	Value
…	…
23	John
24	Mary
25	Jane
26	Peter
…	…

Attribute Vector for "fname"

position	valueID
…	…
39	23
40	24
41	25
42	23
43	26
…	…

- Retrieve all persons (recIDs) with name "Mary"
  - 1. Search valueID for "Mary" (requested value)
  - 2. Scan Attribute vector for "24" (found valueID)

DICTIONARY ENCODING – SORTED DICTIONARY: ADVANTAGES

- Dictionary entries are sorted by their value
  - Dictionary search complexity: O(log(n)) instead O(n)
  - Speed up range queries
  - Dictionary entries can be further compressed

DICTIONARY ENCODING - DISADVANTAGES

- Dictionary entries are sorted by their value
  - Resorting for every new value that does not belong to the end of the sorted sequence (relatively cheap)
  - Updating the attribute vector (costly)
- Dictionary adds additional indirection for materialization
- Overhead for large number of data modifying operations

DICTIONARY ENCODING - IN OPOSSUM

- Dictionary encoding is applied to full chunk
- Sorted dictionaries are used
- valueIDs are the C99 fixed-width unsigned integer types (http://en.cppreference.com/w/c/types/integer)

QUESTIONS

ORGANIZATION

- First sprint was due **yesterday**
- Document and interfaces for 2nd sprint will be released today
- Use piazza for questions and discussions
- Have fun compressing the opossum

Build your own Database

Week 3

Outlook

1. Review Sprint 1
2. Move Constructors
3. std::move
4. (?:g?l|p?r|x)values

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Review Sprint 1

All groups submitted a (mostly) working implementation on time ☺

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Error Handling

- Some groups check for most edge cases, others do not
- We have no standard rules for error handling so far

```
void StorageManager::add_table(const std::string &name,
    std::shared_ptr<Table> table) { _tables[name] = table; }
```

- New policy: Always do checks when they are (almost) free, especially when they are in the control path (not the per-row data path)
- Use IS_DEBUG for expensive checks

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Error Handling

- Most STL-Containers can help us a lot at almost zero cost

```
std::map<std::string, Table> _tables;
```

A

```
_tables[name] = table;
```

B

```
if(_tables.find(name) != _tables.end()) {
  _tables[name] = table;
}
```

C

```
_tables.insert({name, table});
```

D

```
auto r = _tables.insert({name, table});
if(!r.second) throw std::runtime_error("...");
```

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Error Handling

```
std::vector<Chunk> _chunks;
```

A

```
Chunk &Table::get_chunk(ChunkID chunk_id) {
  return _chunks.at(chunk_id);
}
```

B

```
Chunk &Table::get_chunk(ChunkID chunk_id) {
  return _chunks[chunk_id];
}
```

C

```
Chunk &Table::get_chunk(ChunkID chunk_id) {
  if(chunk_id >= _chunks.size())
    throw std::runtime_error(...)
  return _chunks.at(chunk_id);
}
```

Error Handling

- What can we improve about this code?

```
std::map<std::string, Table> _tables;

if (_tables.find(name) != _tables.end()) {
  _tables.erase(name);
}
```

```
size_type erase( const key_type& key );                    (3)
```

3) Removes the element (if one exists) with the key equivalent to key.

```
std::map<std::string, Table> _tables;

_tables.erase(name);
```

Error Handling

- How can we further improve this?

```
std::map<std::string, Table> _tables;

_tables.erase(name);
```

Return value

3) Number of elements removed.

```
std::map<std::string, Table> _tables;

if(!_tables.erase(name)) {
  throw std::runtime_error(...)
};
```

Initializer Lists

- What is the problem with this code?

```
class Table {
  Table(const size_t chunk_size) {
    _chunk_size = chunk_size;
    _chunks.push_back(std::make_shared<Chunk>());
  }

protected:
  size_t _chunk_size;
  [...]
};
```

Initializer Lists

```cpp
class Table {
  Table(const size_t chunk_size) {
    _chunk_size = chunk_size;
    _chunks.push_back(std::make_shared<Chunk>());
  }

protected:
  const size_t _chunk_size;
  [...]
};
```

```
[:~/Desktop/tmp] 3s $ g++-6 test.cpp -std=c++17
test.cpp: In constructor 'Table::Table(size_t)':
test.cpp:5:3: error: uninitialized const member in 'const size_t {aka const long unsigned int}' [-fpermissive]
   Table(const size_t chunk_size) {
   ^~~~~
test.cpp:10:16: note: 'const size_t Table::_chunk_size' should be initialized
   const size_t _chunk_size;
                ^~~~~~~~~~~
test.cpp:6:19: error: assignment of read-only member 'Table::_chunk_size'
     _chunk_size = chunk_size;
                   ^~~~~~~~~~
```

Initializer Lists

- It is better to initialize members in the constructor`s initialization list

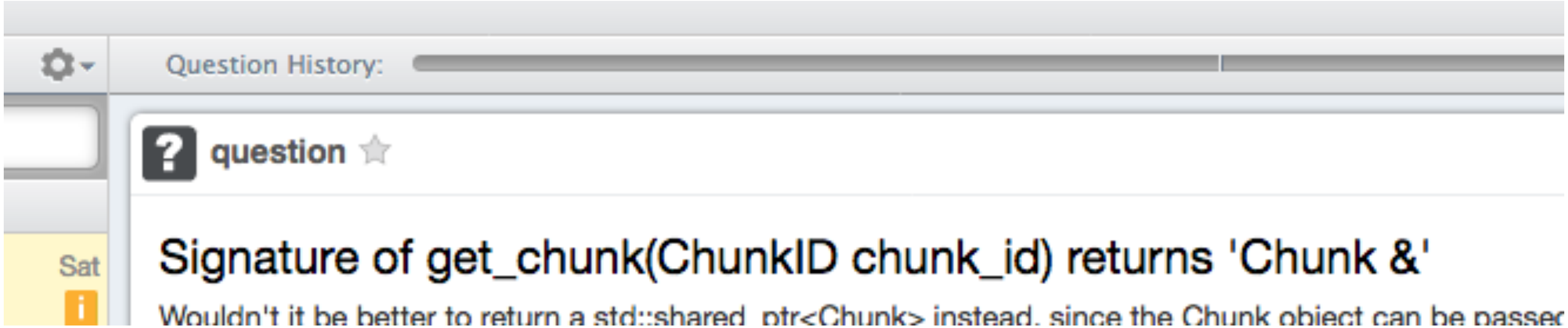
```
class Table {
  Table(const size_t chunk_size) : _chunk_size(chunk_size) {
    _chunks.push_back(std::make_shared<Chunk>());
  }

protected:
  const size_t _chunk_size;
  [...]
};
```

Initializer Lists

```cpp
struct A {
  A() { std::cout << "const A" << std::endl; }
  A(int x) { std::cout << "const A: " << x << std::endl; }
  ~A() { std::cout << "dest A" << std::endl; }
};

struct B {
  A a;
  B(int x) { a = A(x); }
};

struct C {
  A a;
  C(int x) : a(x) {}
};

int main() {
  B(1);
  C(2);
}
```

```
[:~/Desktop/tmp] $ ./a.out
const A
const A: 1
dest A
dest A
const A: 2
dest A
```

Chunk: Pointer vs Reference



„`std::vector<Chunk>` might re-locate the memory where a Chunk lives on, e.g. `push_back()`. So the memory location's persistance is NOT guaranteed and using the reference might be unsafe if further operations are performed on the Table, [...]“

Chunk: Pointer vs Reference

172

Use reference wherever you can, pointers wherever you must.

Avoid pointers until you can't.

The reason is that pointers make things harder to follow/read, less safe and far more dangerous manipulations than any other constructs.

So the rule of thumb is to use pointers only if there is no other choice.

1185

A smart pointer is a class that wraps a 'raw' (or 'bare') C++ pointer, to manage the lifetime of the object being pointed to. There is no single smart pointer type, but all of them try to abstract a raw pointer in a practical way.

Smart pointers should be preferred over raw pointers. If you feel you need to use pointers (first consider if you *really* do), you would normally want to use a smart pointer as this can alleviate many of the problems with raw pointers, mainly forgetting to delete the object and leaking memory.

Chunk: Pointer vs Reference

Iterator validity

If a reallocation happens, all iterators, pointers and references related to the container are invalidated.
Otherwise, only the end iterator is invalidated, and all iterators, pointers and references to elements are guaranteed to keep referring to the same elements they were referring to before the call.

- In this case:
  - Modifying a table while processing it as part of a query does not happen
  - In multi-threaded environments, modifications to std::vectors cause more problems anyway

Chunk: Pointer vs Reference

Miscellaneous

```
class Chunk {
 public:
  Chunk() {}
};
```

```
class Table {
 private:
    void addNewChunk();
}
```

```
void Table::append(std::initializer_list<AllTypeVariant> values) {
  if (_chunks.back()->size() == _chunk_size) append_new_chunk();

  _chunks.back()->append(values);
}
```

Miscellaneous

- Not a problem now, but might become in the future...

```
void Table::append(std::initializer_list<AllTypeVariant> values) {
  if (_chunk_size != 0 && _chunks.back().size() >= _chunk_size) {
    _chunks.push_back(Chunk());
    for (auto type_it = _column_types.begin(); type_it !=
         _column_types.end(); type_it++) {
      auto column = make_shared_by_column_type<BaseColumn,
                    ValueColumn>(*type_it);
      _chunks.back().add_column(column);
    }
  }
  _chunks.back().append(values);
}
```

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Miscellaneous

- Not a problem now, but might become in the future...

```
void Table::append(std::initializer_list<AllTypeVariant> values) {
  if (_chunk_size != 0 && _chunks.back().size() >= _chunk_size) {
    Chunk new_chunk;
    for (auto type_it = _column_types.begin(); type_it !=
          column_types.end(); type_it++) {
      auto column = make_shared_by_column_type<BaseColumn,
                     ValueColumn>(*type_it);
      new_chunk.add_column(column);
    }
    _chunks.emplace_back(std::move(new_chunk));
  }
  _chunks.back().append(values);
}
```

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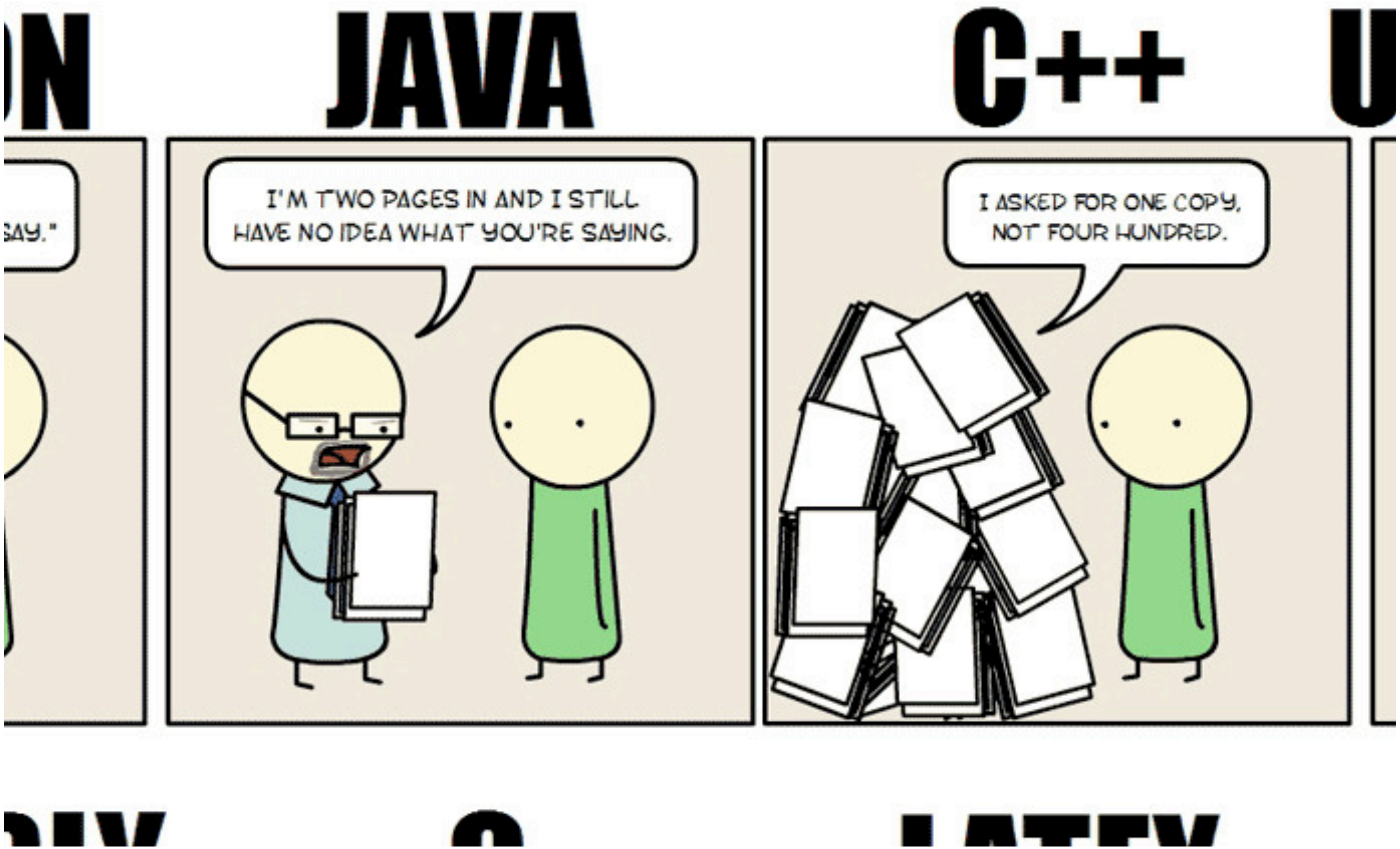
Miscellaneous

- Make the code shorter

```
void Table::append(std::initializer_list<AllTypeVariant> values) {
  if (_chunk_size != 0 && _chunks.back().size() >= _chunk_size) {
    Chunk new_chunk;
    for (auto&& type : _column_types) {
      auto column = make_shared_by_column_type<BaseColumn,
        ValueColumn>(type);
      new_chunk.add_column(column);
    }
    _chunks.emplace_back(std::move(new_chunk));
  }
  _chunks.back().append(values);
}
```

Deleting Copy Constructors



Deleting Copy Constructors

- Big classes in our database should not be copyable
- Deleted copy constructors should be default
- In this sprint: `base_column`

Avoiding Copies

- We want to avoid unnecessary copies as much as possible
- (Some copies make sense – most times, there is no point passing an integer by reference)
- How does the compiler know when to avoid copies and how can we help?

Avoiding Copies for a String

```
class string {
    char *buf;

public:
    string(const char *str) {
        size_t size = strlen(str) + 1;
        buf = (char*)malloc(size
        memcpy(buf, str, size);
    }
    void print() { std::cout <
};
```

Rule of Three

Destructor

Copy Const

Copy Assign

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Avoiding Copies for a String

```
class string {
    char *buf;
public:
    string(const char *str) {
        size_t size = strlen(str) + 1;
        buf = (char*)malloc(size);
        memcpy(buf, str, size);
    }
    ~string() { free(buf); }
    string(const string& that) {
        size_t size = strlen(that.buf) + 1;
        buf = (char*)malloc(size);
        memcpy(buf, that.buf, size);
    }
    string& operator=(const string & that) {[...]}
    void print() { std::cout << buf << std::endl; }
};
```

Avoiding Copies for a String

```
class string {
    char *buf;
public:
    string(const char *str) {
        size_t size = strlen(str) + 1;
        buf = (char*)malloc(size);
        memcpy(buf, str, size);
        std::cout << "allocated " << size << " bytes" << std::endl;
    }
    ~string() { free(buf); }
    string(const string& that) {
        size_t size = strlen(that.buf) + 1;
        buf = (char*)malloc(size);
        memcpy(buf, that.buf, size);
        std::cout << "allocated " << size << " bytes" << std::endl;
    }
    string& operator=(const string & that) {[...]}
    void print() { std::cout << buf << std::endl; }
};
```

Avoiding Copies for a String

```
int main() {
    string a("test");
    a.print();

    string b(a);
    b.print();

    string c = a;
    c.print();
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++03 -Wall -Wextra && ./a.out
allocated 5 bytes
test
allocated 5 bytes
test
allocated 5 bytes
test
```

Avoiding Copies for a String

```
// I also modifi… tements to print the string

int main() {
    std::vector<string> v;
    v.push_back("test");
}
```

implicit constructor

```
⌂36% [:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 5 bytes for "test"
allocated 5 bytes for "test"
```

Avoiding Copies for a String

```
// I also modified the print statements to print the string

int main() {
    std::vector<string> v;
    v.push_back("foo");
    v.push_back("bar");
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 4 bytes for "foo" (constructor)
allocated 4 bytes for "foo" (copy constructor)
allocated 4 bytes for "bar" (constructor)
allocated 4 bytes for "bar" (copy constructor)
allocated 4 bytes for "foo" (copy constructor)
```

Avoiding Copies for a String

„The purpose of a move constructor is to steal as many resources as it can from the original object, as fast as possible, because the original does not need to have a meaningful value any more, because it is going to be destroyed (or sometimes assigned to) in a moment anyway."

https://akrzemi1.wordpress.com/2011/08/11/move-constructor/

Avoiding Copies for a String

```
class string {
    [...]
    string(string&& that) : buf(that.buf) {
        that.buf = nullptr;
        std::cout << "moved " << buf << std::endl;
    }
};
```

Rule of Five

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Avoiding Copies for a String

```
class string {
    [...]
    string(string&& that) : buf(that.buf) {
        that.buf = nullptr;
        std::cout << "moved " << buf << std::endl;
    }
    string& operator=(string&& that) {
        free(buf);
        buf = that.buf;
        that.buf = nullptr;
        std::cout << "moved " << buf << std::endl;
        return *this;
    }
};
```

Avoiding Copies for a String

```
string get_test() {
    return string("test");
}

int main() {
    std::vector<string> v;
    v.push_back("foo");
    v.push_back(get_test());
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 4 bytes for "foo" (constructor)
moved foo
allocated 5 bytes for "test" (constructor)
moved test
allocated 4 bytes for "foo" (copy constructor)
```

Avoiding Copies for a String

```
class string {
    [...]
    string(string&& that) noexcept : buf(that.buf) {
        that.buf = nullptr;
        std::cout << "moved " << buf << std::endl;
    }
    string& operator=(string&& that) noexcept {
        free(buf);
```

If a search for a matching exception handler leaves a function marked `noexcept` or `noexcept(true)`, `std::terminate` is called immediately.

```
    }
};
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 4 bytes for "foo" (constructor)
moved foo
allocated 5 bytes for "test" (constructor)
moved test
moved foo
```

Avoiding Copies for a String

```
int main() {
    string a("baz");
    std::vector<string> v;

    v.push_back(a);

    // we'll never use a again...
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 4 bytes for "baz" (constructor)
allocated 4 bytes for "baz" (copy constructor)
```

Avoiding Copies for a String

```
int main() {
    string a("baz");
    std::vector<string> v;

    v.push_back(std::move(a));

    // we'll never use a again...
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra && ./a.out
allocated 4 bytes for "baz" (constructor)
moved baz
```

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Avoiding Copies for a String

```
int main() {
    string a("baz");
    std::vector<string> v;

    v.push_back(std::move(a));

    // we'll never use a again...

    string b(a);
    // but you promised :(
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra -O3 && ./a.out
allocated 4 bytes for "baz" (constructor)
moved baz
Segmentation fault: 11
```

```
string(string&& that) : buf(that.buf) {
    that.buf = nullptr;
}
```

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What is std::move?

- What does std::move do?
- From an instruction POV: Nothing
- „std::move is used to *indicate* that an object t may be "moved from", i.e. allowing the efficient transfer of resources from t to another object.
- „In particular, std::move produces an xvalue expression that identifies its argument t. It is exactly equivalent to a static_cast to an rvalue reference type.“

```
template <typename T>
typename remove_reference<T>::type&& move(T&& arg) {
  return static_cast<typename remove_reference<T>::type&&>(arg);
}
```

Deep Dive: l,r,gl,pr,x,wtfvalues

```
[:~/Desktop/tmp] 1 $ g++-6 test.cpp -std=c++1z -Wall -Wextra -O3 && ./a.out
test.cpp: In function 'int main()':
test.cpp:61:11: error: lvalue required as left operand of assignment
  zwei() = 3;
           ^
```

```
[:~/Desktop/tmp] 1 $ g++-6 test.cpp -std=c++1z -Wall -Wextra -O3 && ./a.out
test.cpp: In function 'int& zwei()':
test.cpp:58:22: error: invalid initialization of non-const reference of type 'int&' from an rvalue of type 'int'
 int &zwei() { return 2;}
                      ^
```

Deep Dive: l,r,gl,pr,x,wtfvalues

~~Good~~, old, simpler C++03 times...

lvalue („left value“)

```
a = 3;
b[4] = 'x';
…
```

rvalue („right value“)

```
a = 3;
b[4] = foo();
…
```

Deep Dive: l,r,gl,pr,x,wtfvalues

Now we need something to identify values that can be moved from

lvalue („left value“)

```
a = 3;
b[4] = 'x';
…
```

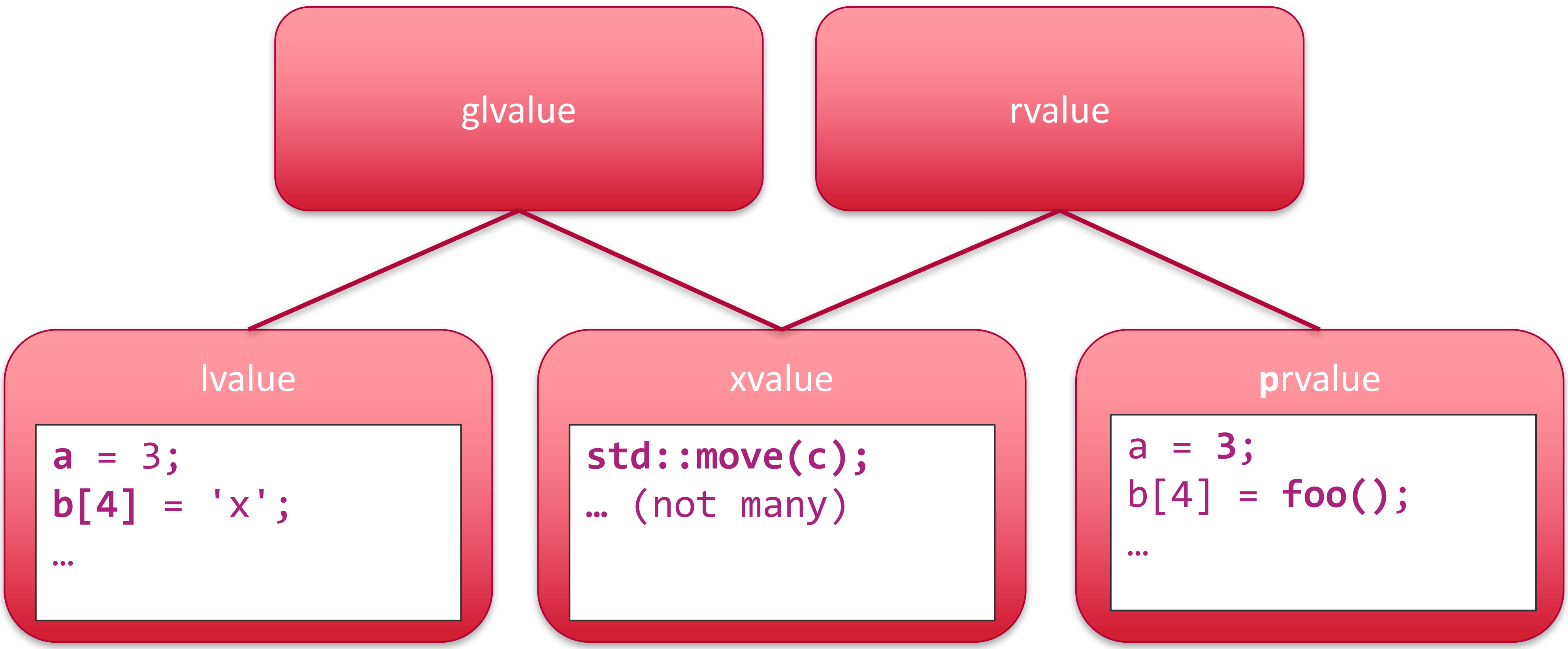
xvalue

```
std::move(c);
… (not many)
```

rvalue („right value“)

```
a = 3;
b[4] = foo();
…
```

Deep Dive: l,r,gl,pr,x,wtfvalues



Ensure Moves

```
string(const string& that) {
    size_t size = strlen(that.buf) + 1;
    buf = (char*)malloc(size);
    memcpy(buf, that.buf, size);
}
string(const string& that) = delete;
```

What does this mean for Opossum?

- You hopefully now have a better idea why we delete the copy constructors and how moves work

```
void Table::append(std::initializer_list<AllTypeVariant> values) {
  if (_chunk_size > 0 && _chunks.back().size() == _chunk_size) {
    Chunk newChunk;
    for (auto &&type : _column_types) {
      newChunk.add_column(make_shared_by_column_type<BaseColumn,
                                    ValueColumn>(type));
    }
    _chunks.push_back(std::move(newChunk));
  }

  _chunks.back().append(values);
}
```

Named Return Value Optimization

```
string get_foo() {
    return string("foo");
}

string get_baz() {
    return std::move(string("baz"));
}

int main() {
    get_foo();
    get_baz();
}
```

```
[:~/Desktop/tmp] $ g++-6 test.cpp -std=c++1z -Wall -Wextra -O3 && ./a.out
allocated 4 bytes for "foo" (constructor)
allocated 4 bytes for "baz" (constructor)
moved baz
```

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Next Steps

- Please remember to submit your code reviews for sprint 1
- Dictionary Compression by 16 Nov
- Any Questions about Sprint 2?

ILIW