Hashing

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Overview

- why hashing?
- hash functions
- hash values for user defined types
- variations in hashing containers

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Value Look-Up

key -> value

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Value Look-Up

k -> v

```
vector<pair<K, V>> c = …;
auto it = find_if(begin(c), end(c),
                  [=](auto&& p){ return v == p.first; });
if (it == end(c)) { not-found }
else { use it->second }
```


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Value Look-Up

k -> v

```
vector<pair<K, V>> c = …;
auto it = lower_bound(begin(c), end(c),
                      [=](auto&& p){ return k < p.first; });
if (it == end(c) || it->second != k) { not-found }
else { use it->second }
```

implications: k < x is defined and c is sorted accordingly

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Value Look-Up

k -> v

```
map<K, V> c = …;
auto it = c.find(k);

if (it == end(c)) { not-found }
else { use it->second }
```

implications: k < x is defined

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Value Look-Up

k -> v

```
unordered_map<K, V> c = …;
auto it = c.find(k);

if (it == end(c)) { not-found }
else { use it->second }
```

implications: hash(k) is defined

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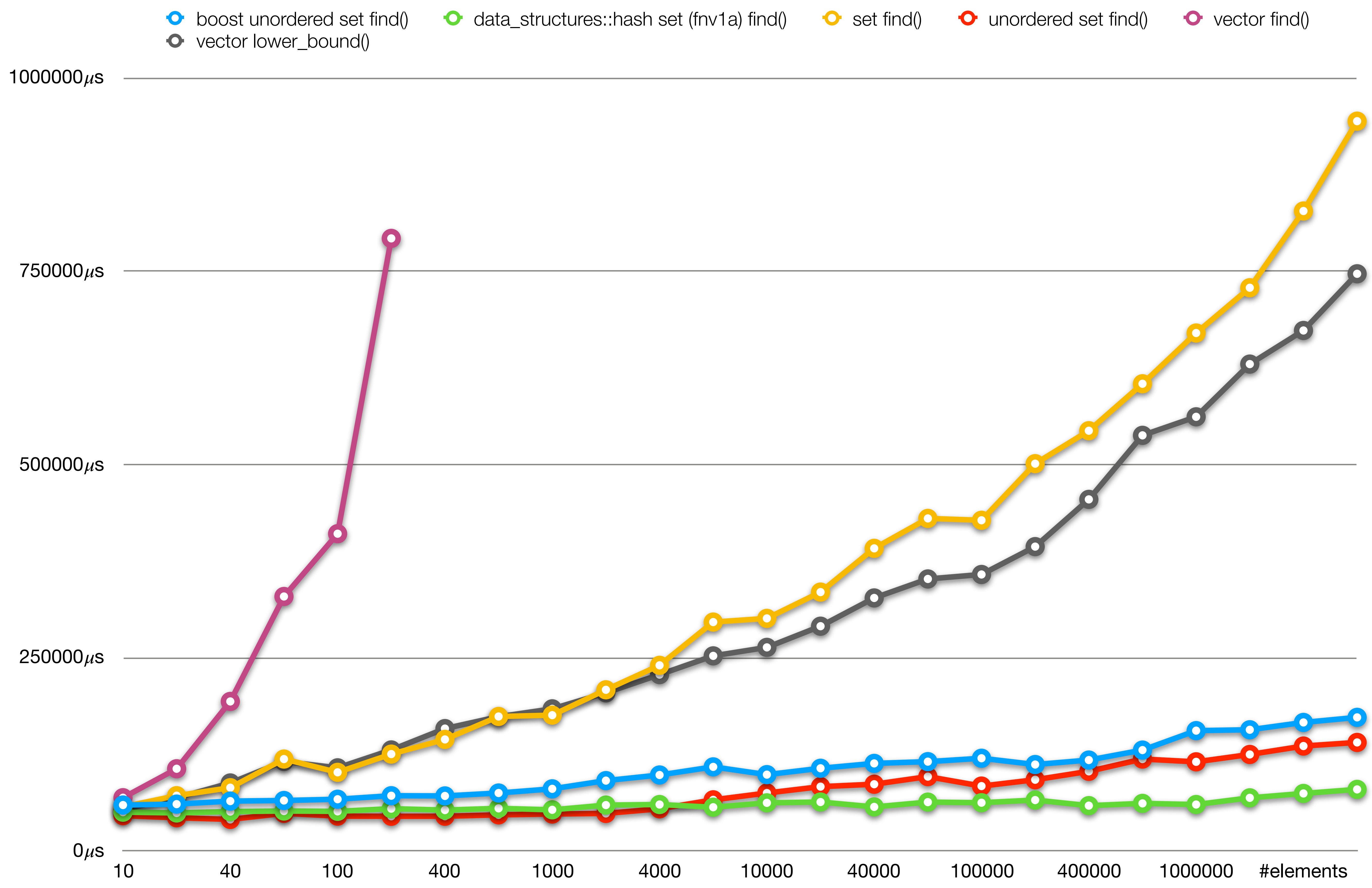
Comparing Algorithms



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Hash Caveats

- *expected* O(1) access
  - O(1) access assumes at most few hash conflicts
- worst case access: O(n) (or O(log n) when using a tree to deal with conflicts)
- computing a better hash is often slower

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Hashes as DoS Target

- hash algorithms are exploited by denial of service attacks:
  - adversary feeds keys known to create conflicts
- counter measures:
  - use variation of hash algorithms
  - use strong hash algorithms creating few conflicts
  - *seed* the hash value with random values

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Scope of Hashes

- always the same hash value, e.g., for persistent storage
  ⇒ use a strong hash algorithm and large result to counter conflicts
- the same hash value within a process
  ⇒ use a fairly strong hash algorithm seeded per run
- the same hash value for the short-lived containers
  ⇒ different seed per container for a faster hash algorithm

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How To: Hash Algorithm

Do **not** design your own hash algorithm!

use a suitable existing one instead

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Considerations

- the hash computation should be fast
- hash values should be uniformly distributed
  - to allow hash tables use all bits for bucketing
  - flip 1 bit in the input ⇒ flip about 1/2 of result bits
- predictable hash ⇒ potential for denial of service attack

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General Layout of Hashing Algorithms

- some initial setup
- combining all bytes into an intermediate state
    - should change for each bit changed in the input
- reduce the intermediate state into one integer

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Jenkins

```
template <typename Range>
uint32_t jenkins(Range range) {
    Result result{};
    for (uint8_t c: range) {
        result += c;
        result += result << 10;
        result ^= result >> 6;
    }
    result += result << 3;
    result ^= result >> 11;
    return result += result << 15;
}
```


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FNV1

```
template <typename Range>
std::uint32_t fnv1(Range range) {
    std::uint32_t result{0x811c9dc5};
    for (unsigned char octet: range) {
        result *= std::uint32_t{16777619};
        result ^= octet;
    }
    return result;
}
```


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Pearson

```
template <typename FwdIt>
std::uint32_t pearson(FwdIt b, FwdIt e) {
    static uint8_t const (&table)[256] = { /*...*/ };
    uint32_t             result{};
    for (int s = 0; s != 32; s += 8) {
        unsigned byte = table[(*b + s / 8) % 256];
        for (uint8_t c: range{++FwdIt{b}, e})
            byte = table[byte ^ c];
        result |= Result{byte} << s;
    }
    return result;
}
```

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Pearson (unrolled)

```
template <typename InIt, std::size_t... I>
std::uint32 pearsonr(InIt b, InIt e,
                     std::index_sequence<I...>) {
    static uint8_t const (&table)[256] = { /*...*/ };
    uint8_t byte[] = { table[(*b + I) % 256]... };
    for (uint8_t c: range{++b, e}) {
        (void)((byte[I] = table[byte[I] ^ c]) |...);
    }
    return ((uint32_t{byte[I]} << (I * 8)) |...);
}
```


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Murmur

```
template <typename RndIt> std::uint32_t murmur(RndIt begin, RndIt end){
    std::uint32_t hash{seed}, len{end - begin};
    for (; 3 < end - begin; begin += 4) {
        std::uint32_t k{decode(begin)};
        k = rotate<15>(k * 0xcc9e2d51) * 0x1b873593;
        hash = rotate<13>(hash ^ k) * 5 + 0xe6546b64;
    }
    std::uint32_t remain{};
    for (; begin != end; ++begin)
        remain = (remain << 8) | std::uint8_t(*begin);
    remain = rotate<15>(remain * 0xcc9e2d51) * 0x1b873593;
    hash ^= remain; hash ^= len;
    hash ^= hash >> 16; hash *= 0x85ebca6b;
    hash ^= hash >> 13; hash *= 0xc2b2ae35;
    return hash ^= hash >> 16;
}
```

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User Defined Types

- a == b ⇒ hash(a) == hash(b)
- wanted: hash(a) == hash(b) ⇒ a == b with high probability
- just feed the bytes of the type to a hash algorithm?
  - **don't** hash pointers or non-salient attributes
  - there'll be dragons: -0.0 == 0.0
  - padding bits will haunt you

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Example

```
struct foo {
    std::unique_ptr<int> p;
    float                f;
    short                i;
    char                 c;
};

foo f0{ std::make_unique<int>(0x12345678), -0.0, 0x1234, 'A' };
foo f1{ std::make_unique<int>(0x12345678),  0.0, 0x1234, 'A' };
std::cout << "f0=" << f0 << "\n" << "f1=" << f1 << "\n";

f0=[ 70 03 c0 4f ea 7f 00 00 00 00 00 80 34 12 41 00 ]
f1=[ 20 29 c0 4f ea 7f 00 00 00 00 00 00 34 12 41 00 ]
```

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hash_code/hash_expansion()

two dimensions of customization:

- hash_code for using different hashing algorithms
  - exposes functions to add a bit representations of objects
  - uses static [inline] member functions for its operations
  - few implementations created by hashing experts/library implementers
- hash_expansion() for users to expose the value representation of custom types

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hash_expansion()

- basic idea: recursively decompose objects and add bits:

```
hash_code hash_expansion(hash_code h, X const& value) {
    h = hash_code::combine(std::move(h), value.member1);
    h = hash_code::combine(std::move(h), value.member2);
    return h;
}
```

- using hash_expansion()/hash_code uses a default algorithm

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hash_expansion()

- basic idea: recursively decompose objects and add bits:

```
template <typename HashCode>
hash_code hash_expansion(HashCode h, X const& value) {
    return HashCode::combine(std::move(h), value.member1, value.member2);


}
```

- using a template argument allows customised algorithms

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hash_expansion()

- structs just append their respective members
- unions/variants append the active member and descriptor
- optional appends flag and, if present, the data
- sequences append values and the size
  - performance specialisation:
    contiguous sequences without padding directly added

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unordered_map<K, V, H>

- default hash: std::hash<K>
  - one to hash them all
- custom hash function: can still be used:

```
unordered_map<K, V, custom<K>> map;

unordered_map<K, V, stateful<K>> map(stateful<K>(seed));
```


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std::hash<T>

- needs to use hash_expansion(hash_code, T) if available:
  - using the default is what most users do
- hash needs to change between each run:
  - otherwise users will depend on hash values
  - ⇒ impossible to use an improved default algorithm

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unordered_map<K, V>

- a good starting point for an associative container
- not necessarily the best alternative, though:
  - element stability ⇒ more memory and memory access
  - iterator stability ⇒ can't even use "open addressing"

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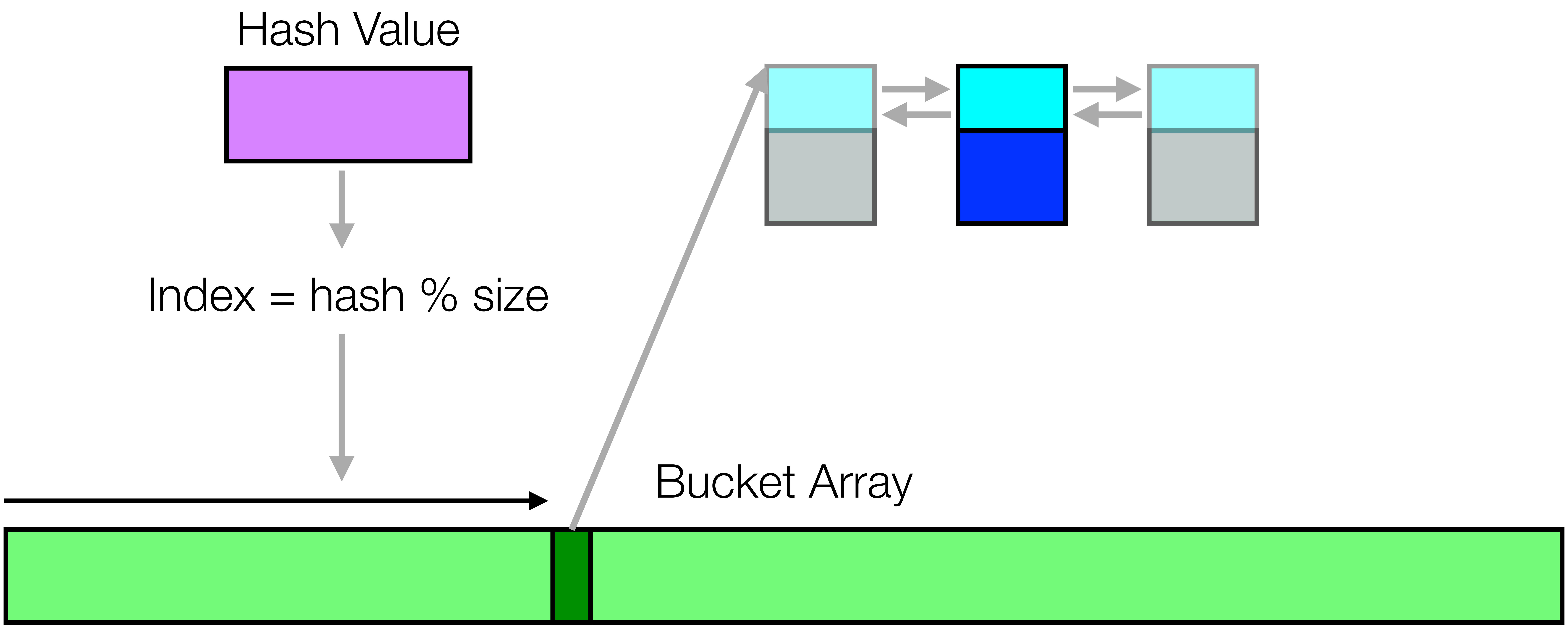
std::unordered_map



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Google's Hash Idea

https://youtu.be/ncHmEUmJZf4

- use open addressing as collision handling
  - store the elements directly in the array
- use a descriptor array with one char per element
  - high bit to indicate empty and other bits deleted flag
  - other 7 bits used from the hash
  - ⇒ SIMD instructions to locate the likely cell

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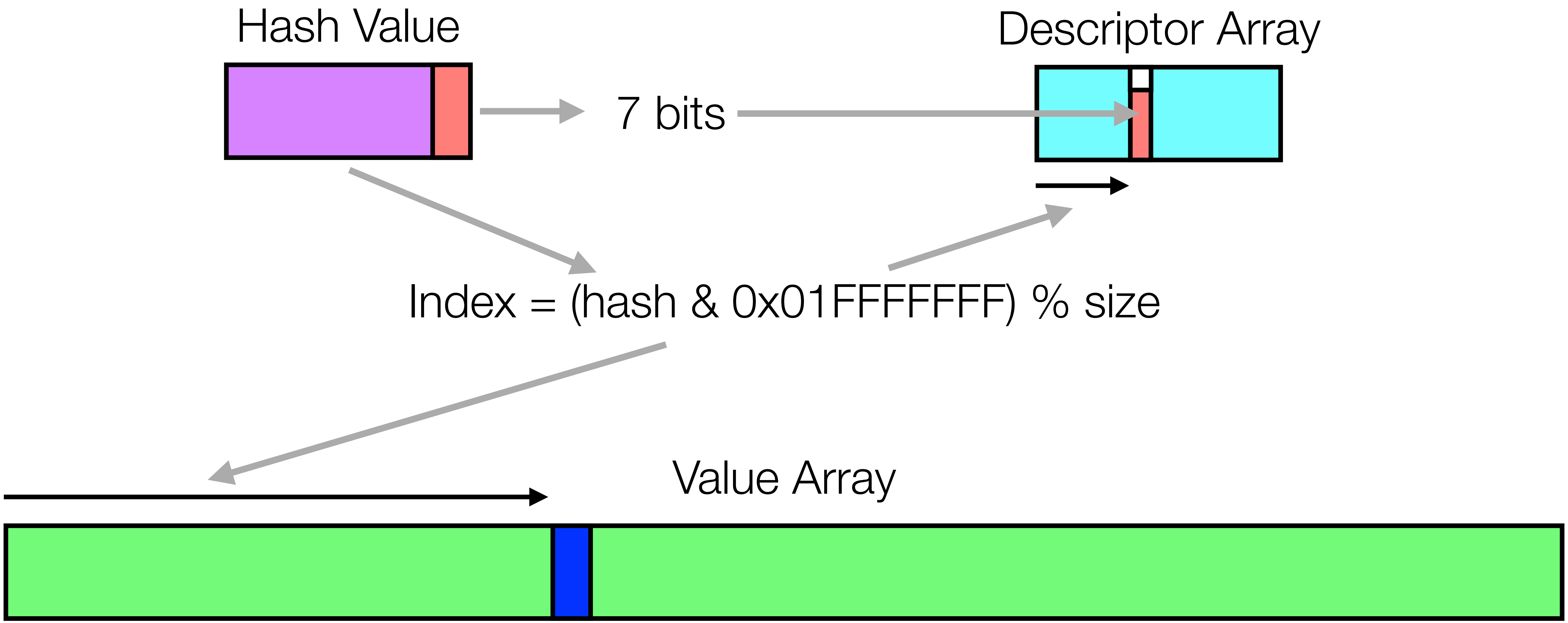

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Lock-Free Hash

http://preshing.com/20160201/new-concurrent-hash-maps-for-cpp/

- reasonably common use case:
  - one updating thread, multiple reading threads
- lock-free hash map is quite viable
  - an implementation ships, e.g., Thread Building Blocks

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Transparent Hash

- consider avoiding temporary objects:

```
unordered_map<string, T> map = …;

char buffer[100];
auto size = read(buffer);

auto it = map.find(string_view(buffer, buffer + size));
```

- string and string_view need to produce the same hash
- it needs to be detectable that hashes are compatible

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Summary

- hash maps are an important data structure of efficiency
- a good hashing function is needed for effective use
- hash_expansion() for hashes for user-defined types
- hash maps come in variations, e.g., for collision resolution

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Questions ?

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Thank You!

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