Types Don’t Know

Howard Hinnant
Ripple Labs
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Overview

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- This talk introduces a new way to hash types.

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- This technique is being considered for standardization.

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- This talk introduces a new way to hash types.
- This technique is being considered for standardization.
- Whether or not the committee standardizes this infrastructure, you can implement this in your own applications (free source code available to get you started).

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Scope

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- Details will be mentioned in passing, just to let you know the details exist, but will not be covered in depth.

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- This talk will concentrate only on the most important aspects of this new hashing technique.
- Details will be mentioned in passing, just to let you know the details exist, but will not be covered in depth.
- Details are more thoroughly covered in the standard proposal, and are fully fleshed out in the freely-available reference implementation.

Issues

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- How should one “combine” hash codes from your bases and data members to create a “good” hash function?

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- How does one know if you have a good hash function?

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- How should one “combine” hash codes from your bases and data members to create a “good” hash function?
- How does one know if you have a good hash function?
- If somehow you knew you had a bad hash function, how would you change it for a type built out of several bases and/or data members?

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Example Class

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...




};
```

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Example Class

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
```

How does one hash this class?

```
};
```

Example Class
Hash with std::hash<T>

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...




};
```

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Example Class
Hash with std::hash<T>

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
   std::size_t
   hash_code() const
   {
       std::size_t k1 = std::hash<std::string>{}(firstName_);
       std::size_t k2 = std::hash<std::string>{}(lastName_);
       std::size_t k3 = std::hash<int>{}(age_);


};
```

Here is one way…

Example Class
Hash with std::hash<T>

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        std::size_t k1 = std::hash<std::string>{}(firstName_);
        std::size_t k2 = std::hash<std::string>{}(lastName_);
        std::size_t k3 = std::hash<int>{}(age_);
        return hash_combine(k1, k2, k3);  // what algorithm is this?!
    }

};
```

Here is one way…

Is this a **good** hash algorithm?

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Example Class
Hash with std::hash<T>

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
   std::size_t
   hash_code() const
   {
       std::size_t k1 = std::hash<std::string>{}(firstName_);
       std::size_t k2 = std::hash<std::string>{}(lastName_);
       std::size_t k3 = std::hash<int>{}(age_);
       return hash_combine(k1, k2, k3);  // what algorithm is this?!
   }

};
```

What if we wanted to use another hash algorithm?

Is this a **good** hash algorithm?

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Example Hash Algorithm FNV-1A

Another hash algorithm:

```
std::size_t
fnv1a (void const* key, std::size_t len)
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...









};
```

Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        std::size_t k1 = fnv1a(firstName_.data(), firstName_.size());
        std::size_t k2 = fnv1a(lastName_.data(), lastName_.size());
        std::size_t k3 = fnv1a(&age_, sizeof(age_));



};
```

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Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        std::size_t k1 = fnv1a(firstName_.data(), firstName_.size());
        std::size_t k2 = fnv1a(lastName_.data(), lastName_.size());
        std::size_t k3 = fnv1a(&age_, sizeof(age_));
        return hash_combine(k1, k2, k3);  // what algorithm is this?!
    }
};
```

Ok, but our algorithm is still "polluted" by the combine step…

Anatomy Of A Hash Function

Anatomy Of A Hash Function

1. Initialize internal state.

Anatomy Of A Hash Function

1. Initialize internal state.
2. Consume bytes into internal state.

Anatomy Of A Hash Function

1. Initialize internal state.
2. Consume bytes into internal state.
3. Finalize internal state to result_type (often size_t).

Example Hash Algorithm FNV-1A

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

Example Hash Algorithm FNV-1A

Initialize internal state

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

Example Hash Algorithm FNV-1A

Initialize internal state

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
   std::size_t h = 14695981039346656037u;
   unsigned char const* p = static_cast<unsigned char const*>(key);
   unsigned char const* const e = p + len;
   for (; p < e; ++p)
       h = (h ^ *p) * 1099511628211u;
   return h;
}
```

Consume bytes into internal state

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Example Hash Algorithm FNV-1A

Initialize internal state

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

Consume bytes into internal state

Finalize internal state to size_t

Example Hash Algorithm FNV-1A

Consider repackaging this algorithm to make the three stages separately accessible…

Initialize internal state

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

Consume bytes into internal state

Finalize internal state to size_t

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Example Hash Algorithm FNV-1A

```
std::size_t
fnv1a(void const* key, std::size_t len) noexcept
{
    std::size_t h = 14695981039346656037u;
    unsigned char const* p = static_cast<unsigned char const*>(key);
    unsigned char const* const e = p + len;
    for (; p < e; ++p)
        h = (h ^ *p) * 1099511628211u;
    return h;
}
```

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Example Hash Algorithm FNV-1A

```
class fnv1a
{
    std::size_t h = 14695981039346656037u;
public:
    using result_type = std::size_t;

    void
    operator()(void const* key, std::size_t len) noexcept
    {
        unsigned char const* p = static_cast<unsigned char const*>(key);
        unsigned char const* const e = p + len;
        for (; p < e; ++p)
            h = (h ^ *p) * 1099511628211u;
    }

    explicit
    operator result_type() noexcept
    {
       return h;
    }
};
```

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Example Hash Algorithm FNV-1A

```
class fnv1a
{
    std::size_t h = 14695981039346656037u;
public:
    using result_type = std::size_t;

    void
    operator()(void const* key, std::size_t len) noexcept
    {
        unsigned char const* p = static_cast<unsigned char const*>(key);
        unsigned char const* const e = p + len;
        for (; p < e; ++p)
            h = (h ^ *p) * 1099511628211u;
    }

    explicit
    operator result_type() noexcept
    {
       return h;
    }
};
```

Initialize internal state

Consume bytes into internal state

Finalize internal state to size_t

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Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...









};
```

Example Class Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        fnv1a h;




};
```

Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        fnv1a h;
        h(firstName_.data(), firstName_.size());
        h(lastName_.data(), lastName_.size());
        h(&age_, sizeof(age_));


};
```

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Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        fnv1a h;
        h(firstName_.data(), firstName_.size());
        h(lastName_.data(), lastName_.size());
        h(&age_, sizeof(age_));
        return static_cast<std::size_t>(h); // No more hash_combine!
    }
};
```

Now we are using a “pure” FNV-1A algorithm for the **entire** data structure!

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Example Class
Hash with FNV-1A

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
    std::size_t
    hash_code() const
    {
        fnv1a h;
        h(firstName_.data(), firstName_.size());
        h(lastName_.data(), lastName_.size());
        h(&age_, sizeof(age_));
        return static_cast<std::size_t>(h); // No more hash_combine!
    }
};
```

Now we are using a “pure” FNV-1A algorithm for the **entire** data structure!

This same technique can be used with almost every existing hashing algorithm!

Combining Types

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:




};
```

Combining Types

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:
    std::size_t
    hash_code() const
    {
        std::size_t h1 = customer_.hash_code();
        std::size_t h2 = product_.hash_code();
        std::size_t h3 = date_.hash_code();



};
```

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Combining Types

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:
    std::size_t
    hash_code() const
    {
        std::size_t h1 = customer_.hash_code();
        std::size_t h2 = product_.hash_code();
        std::size_t h3 = date_.hash_code();
        // hash_combine is back!!!
        return hash_combine(h1, h2, h3);
    }
};
```

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Combining Types

How do we use FNV-1A for the **entire** Sale class?

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:
    std::size_t
    hash_code() const
    {
        std::size_t h1 = customer_.hash_code();
        std::size_t h2 = product_.hash_code();
        std::size_t h3 = date_.hash_code();
        // hash_combine is back!!!
        return hash_combine(h1, h2, h3);
    }
};
```

hash_append

Looking back at the Customer class, let's solve this problem!

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
     std::size_t
     hash_code() const
     {
         fnv1a h;
         h(c.firstName_.data(), c.firstName_.size());
         h(c.lastName_.data(), c.lastName_.size());
         h(&c.age_, sizeof(c.age_));
         return static_cast<std::size_t>(h);
     }
};
```

hash_append

Let some other piece of code construct and finalize fnv1a.

Customer only appends to the state of fnv1a.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    // ...
     friend
     void
     hash_append(fnv1a& h, const Customer& c)
     {
         h(c.firstName_.data(), c.firstName_.size());
         h(c.lastName_.data(), c.lastName_.size());
         h(&c.age_, sizeof(c.age_));
     }

};
```

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hash_append

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:









};
```

hash_append

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
public:
    friend
    void
    hash_append(fnv1a& h, const Sale&s)
    {
        hash_append(h, s.customer_);
        hash_append(h, s.product_);
        hash_append(h, s.date_);
    }
};
```

Now types can recursively build upon one another's hash_append to build up state in fnv1a.

hash_append

Primitive and std-defined types can be given hash_append overloads.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:

    friend
    void
    hash_append(fnv1a& h, const Customer& c)
    {
        h(c.firstName_.data(), c.firstName_.size());
        h(c.lastName_.data(), c.lastName_.size());
        h(&c.age_, sizeof(c.age_));
    }
};
```

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hash_append

Primitive and std-defined types can be given hash_append overloads.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:

    friend
    void
    hash_append(fnv1a& h, const Customer& c)
    {
        hash_append(h, c.firstName_);
        hash_append(h, c.lastName_);
        hash_append(h, c.age_);
    }
};
```

Simplify!

hash_append

If all Hash Algorithms follow the same interface as given for fnv1a, then hash_append can be templated on the algorithm.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    template <class HashAlgorithm>
    friend
    void
    hash_append(HashAlgorithm& h, const Customer& c)
    {
        hash_append(h, c.firstName_);
        hash_append(h, c.lastName_);
        hash_append(h, c.age_);
    }
};
```

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hash_append

If all Hash Algorithms follow the same interface as given for fnv1a, then hash_append can be templated on the algorithm.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    template <class HashAlgorithm>
    friend
    void
    hash_append(HashAlgorithm& h, const Customer& c)
    {
        hash_append(h, c.firstName_);
        hash_append(h, c.lastName_);
        hash_append(h, c.age_);
    }
};
```

Now Customer can be hashed using **any** HashAlgorithm!

hash_append

One can easily create a variadic version of hash_append.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    template <class HashAlgorithm>
    friend
    void
    hash_append(HashAlgorithm& h, const Customer& c)
    {
        hash_append(h, c.firstName_);
        hash_append(h, c.lastName_);
        hash_append(h, c.age_);
    }
};
```

hash_append

One can easily create a variadic version of hash_append.

```
class Customer
{
    std::string firstName_;
    std::string lastName_;
    int         age_;
public:
    template <class HashAlgorithm>
    friend
    void
    hash_append(HashAlgorithm& h, const Customer& c)
    {
        hash_append(h, c.firstName_ , c.lastName_ , c.age_);
    }


};
```

hash_append

For primitive types that are *contiguously hashable* one can just send their bytes to the hash algorithm in hash_append.

```
template <class HashAlgorithm>
void
hash_append(HashAlgorithm& h, int i)
{
    h(&i, sizeof(i));
}


template <class HashAlgorithm, class T>
void
hash_append(HashAlgorithm& h, T* p)
{
    h(&p, sizeof(p));
}
```

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FNV-1A

```
class fnv1a
{
    std::size_t state_ = 14695981039346656037u;
public:
    using result_type = std::size_t;

    void
    operator()(void const* key, std::size_t len) noexcept
    {
        unsigned char const* p = static_cast<unsigned char const*>(key);
        unsigned char const* const e = p + len;
        for (; p < e; ++p)
            state_ = (state_ ^ *p) * 1099511628211u;
    }

    explicit
    operator result_type() noexcept
    {
        return state_;
    }
};
```

hash_append for primitive types calls this.

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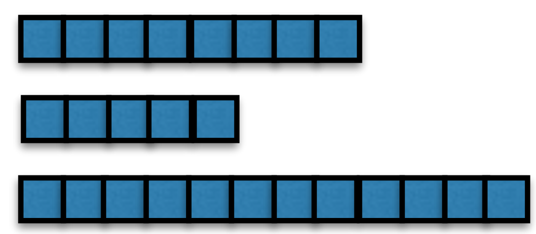
hash_append

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
};
```

- A complicated class like Sale is ultimately made up of scalars located in discontiguous memory.



hash_append

- A complicated class like Sale is ultimately made up of scalars located in discontiguous memory.

```
class Sale
{
    Customer customer_;
    Product  product_;
    Date     date_;
};
```

- hash_append appends each byte to the Hash Algorithm state by recursing down into the data structure to find the scalars.

hash_append

- Every type has a hash_append overload.
- The overload will either call hash_append on its bases and members, or it will send bytes of its memory to the HashAlgorithm.
- No type is aware of the concrete HashAlgorithm type.

To use hash_append

To use hash_append

Initialize the Hash Algorithm

```
HashAlgorithm h;
```

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To use hash_append

Append to the Hash Algorithm

```
HashAlgorithm h;
hash_append(h, t);
```

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To use hash_append

Finalize the Hash Algorithm

```
HashAlgorithm h;
hash_append(h, t);
return static_cast<result_type>(h);
```

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To use hash_append

```
template <class HashAlgorithm = fnv1a>
struct uhash
{
    using result_type = typename HashAlgorithm::result_type;

    template <class T>
    result_type
    operator()(T const& t) const noexcept
    {
        HashAlgorithm h;
        hash_append(h, t);
        return static_cast<result_type>(h);
    }
};
```

Wrap the whole thing up in a conforming hash functor!

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To use hash_append

```
template <class HashAlgorithm = fnv1a>
struct uhash
{
    using result_type = typename HashAlgorithm::result_type;

    template <class T>
    result_type
    operator()(T const& t) const noexcept
    {
        HashAlgorithm h;
        hash_append(h, t);
        return static_cast<result_type>(h);
    }
};
```

Wrap the whole thing up in a conforming hash functor!

```
unordered_set<Customer, uhash<fnv1a>> my_set;
```

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To Change Hashing Algorithms

To Change Hashing Algorithms

```
unordered_set<Sale, uhash< fnv1a > > my_set;
```

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To Change Hashing Algorithms

```
unordered_set<Sale, uhash< SipHash > > my_set;
```

- To change, simply replace the algorithm at the point of use.

To Change Hashing Algorithms

```
unordered_set<Sale, uhash< Spooky > > my_set;
```

- To change, simply replace the algorithm at the point of use.
- Sale does not change!

To Change Hashing Algorithms

```
unordered_set<Sale, uhash< Murmur  > > my_set;
```

- To change, simply replace the algorithm at the point of use.
- Sale does not change!
- Customer does not change!

To Change Hashing Algorithms

```
unordered_set<Sale, uhash< Murmur  > > my_set;
```

- To change, simply replace the algorithm at the point of use.
- Sale does not change!
- Customer does not change!

★ It becomes trivial to experiment with different hashing algorithms to optimize performance, minimize collisions, and secure against attacks.

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To seed a HashAlgorithm

To seed a HashAlgorithm

Initialize the Hash Algorithm

```
HashAlgorithm h{get_seed()};
```

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To seed a HashAlgorithm

Append to the Hash Algorithm

```
HashAlgorithm h{get_seed()};
hash_append(h, t);
```

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To seed a HashAlgorithm

Finalize the Hash Algorithm

```
HashAlgorithm h{get_seed()};
hash_append(h, t);
return static_cast<result_type>(h);
```

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To seed a HashAlgorithm

```
template <class HashAlgorithm = SipHash>
struct seeded_hash
{
    using result_type = typename HashAlgorithm::result_type;

    template <class T>
    result_type
    operator()(T const& t) const noexcept
    {
        HashAlgorithm h{get_seed()};
        hash_append(h, t);
        return static_cast<result_type>(h);
    }
private:
    result_type get_seed();
};
```

Wrap the whole thing up in a conforming hash functor!

```
unordered_set<Customer, seeded_hash<>> my_set;
```

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Set Up Defaults

- It is easy to set everything up to default your favorite hashing algorithm.

Set Up Defaults

- It is easy to set everything up to default your favorite hashing algorithm.

```
template <class T, class Hash = uhash<FavoriteHash>,
          class Pred = std::equal_to<T>,
          class Allocator = std::allocator<T>>
using hash_set = std::unordered_set <T, Hash, Pred, Allocator>;
```

```
hash_set<Customer> set;  // uses FavoriteHash
```

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Details

- There exist traits for optimization purposes:

```
template <class T>
struct is_contiguously_hashable
    : public true_type or false_type
{};
```

- This allows containers like **`tuple`**, **`string`** and **`vector`** to sometimes send all of their data to the hash algorithm at once, which can increase hashing performance, without changing the resulting hash code.

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Details

- There exists a way to write **`hash_append`** for PIMPL types.
- It involves writing a type-erasing **`HashAlgorithm`** *adaptor*.
  - Full source code is of course available.

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Details

- There exist ways to force endian for the input of scalars into the hash algorithms.
- This can be handy when machines with identical layout other than endian need to share hash codes across a network.

Summary

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Summary

- Every type that may be hashed, or participate in a hash computation, must have a `hash_append` overload.

This is the hard part!

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Summary

- Every type that may be hashed, or participate in a hash computation, must have a **`hash_append`** overload.
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- Hash functors initialize a HashAlgorithm, update it with an item to be hashed, and finalize the algorithm.

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- Hashing algorithms are easily seeded or padded (or not).
- Hashing algorithms are computed exactly as their designers intended — there is no hash code combining step.
- Hash support (`hash_append`) is implemented for any individual type ***exactly once***. This implementation is good for all hashing algorithms.

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- Open source code available at:

https://github.com/HowardHinnant/hash_append

http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2014/n3980.html

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