Alice's adventures in Template Land

Whoo are youuu?

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'Begin at the beginning'

C++ 17 only

A sample Model class

```
struct Person {
  std::string firstName;
  std::string lastName;
  int age;
  int birthYear() const;
  std::string fullName() const;
  void setAge(int age);
};
```

'Why?', said the Caterpillar

In-memory database

```
template<typename Model, typename… Indexes>
struct Table {

  std::map<int, Model> data;

  std::tuple<Indexes…> indices;
  int insert(Model const& model) {
    //...
  }
};
```

'Why?', said the Caterpillar

Table::insert function

```
template<typename Model, typename… Indexes>
struct Table {

  int insert(Model const& model) {
    int id = generateID();
    data.insert(std::pair(id, model));
    for_each(indices, [&](auto& index) {
      index.insert(index.extractKey(model), id);
    });
  }
};
```

'Why?', said the Caterpillar

Templated Index class

```
template<typename Key>
struct Index {
  std::map<Key, int> index_data;

  void insert(Key const& key, int id) {
    index_data.insert(std::pair(key, id));
  }
};
```

'Why?', said the Caterpillar

Every index class needs a static extractKey method

```
class ByNameIndex :
  public Index<std::string>
{
  static std::string extractKey(Person const& p) {
    return p.name;
  }
};
```

'That is not said right,' said the Caterpillar

Boost.MultiIndex container has a nice way of defining indexes using:

```
multi_index_container<Person,
  indexed_by<
    hashed_non_unique<
      member<Person, std::string, &Person::firstName>
    >,
    hashed_non_unique<
      member<Person, int, &Person::age>
    >
  >
>
```

'That is not said right,' said the Caterpillar

Boost.MultiIndex container could be better:

```
multi_index_container<Person,
  indexed_by<
    hashed_non_unique<&Person::firstName>,
    hashed_non_unique<&Person::age>
  >
>
```

'That is not said right,' said the Caterpillar

We'll look at how to declare and define such a class:

```
Index<&Person::firstName> myFirstNameIndex;
```

Pointers to data members

Not your normal pointer!

Declaration:

```
MemberType SomeClass::* pDMem;

int Person::* pPersonIntMember;
```

Pointers to data members

Not your normal pointer!

Declaration:

```
MemberType SomeClass::* pDMem;
```

```
int Person::* pPersonIntMember;
```

Pointer to data member values:

```
pPersonIntMember = &Person::age;
```

Pointers to data members

```
MemberType SomeClass::* pDMem;
int Person::* pPersonIntMember;
pPersonIntMember = &Person::age;
```

Invocation:

```
Person alice;
alice.*pPersonIntMember = 8;

Person* pAlice = &alice;
pAlice->*pPersonIntMember = 9;
```

Pointers to member functions

Declaration:

```
Ret SomeClass::* pMemFunc(argTypes);
```

```
int Person::*() pIntMemFn =
      &Person::getBirthYear;

void Person::*(int) pSetter =
      &Person::setAge;
```

Pointers to member functions

Declaration:

```
int Person::*()
  pIntMemFn = &Person::birthYear;
```

Invocation:

```
Person alice;
int birth = alice.*pIntMemFn();
alice.*pSetter(10);
```

"Would you tell me, please, which way I ought to go from here?"

```
template<auto pmember>
struct Index {
  using Key = ???;
  using Model = ???;
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};
```

Declaring our template: V1

```
template<auto pmember, typename Key, typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};

using AgeIndex = Index<&Person::age, int, Person>;
```

Declaring our template: V1

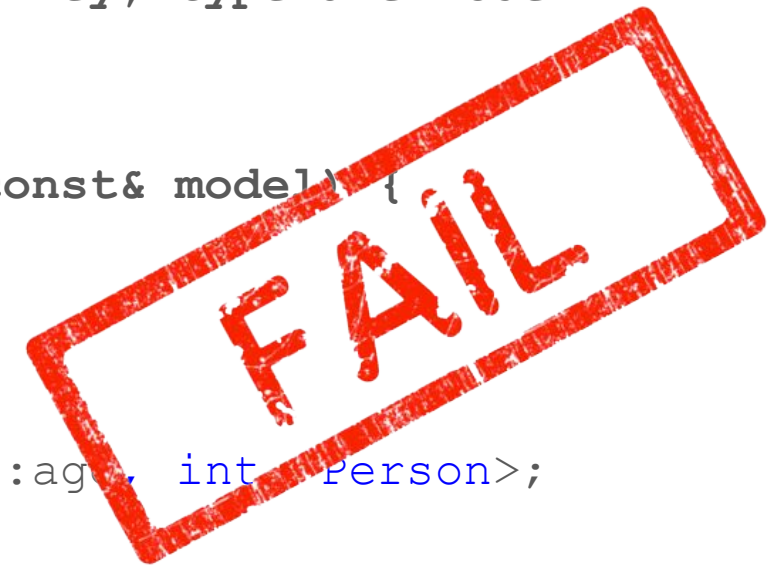
```
template<auto pmember, typename Key, typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};

using AgeIndex = Index<&Person::age, int, Person>;
```

Declaring our template: V1

```
template<auto pmember, typename Key, typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};

using AgeIndex = Index<&Person::age, int, Person>;
```



Declaring our template: V2

```
template<Key Model::*pmember, typename Key,
  typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};
```

Declaring our template: V2

```
template<Key Model::*pmember, typename Key,
  typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};
```

Invalid syntax. Doesn't compile :-(

`Key` and `Model` are only declared after they are used

Declaring our template: V2

```
template<Key Model::*pmember, typename Key,
  typename Model>
struct Index {
  std::map<Key, int> data;
  static Key extractKey(Model const& model) {
    return model.*pmember;
  }
};
```

Invalid syntax. Doesn't compile :(

`Key` and `Model` are only declared after they are used

Declaring our template: V3

Our template must take a single non-type parameter

We want the compiler to deduce 2 types to our pointer to member.

How?

With a templated function!

Declaring our template: V3

```
template<typename Key, typename Model>
Key determineKeyType(Key Model::* pMember);
```

Compiler does argument deduction

We need to invoke the function, or **pretend** to invoke the function

Compiler argument deduction

```
template<typename Key, typename Model>
Key determineKeyType(Key Model::* pMember);


determineKeyType(&Person::age);
```

Compiler deduces `Person` as `Model`

and `int` as `Key`

Compiler argument deduction

```
template<typename Key, typename Model>
Key determineKeyType(Key Model::* pMember);
```

```
template<auto pMember>
using Key_t = decltype(determineKeyType(pMember));
```

decltype gives the return type of the expression

Example: same_v<Key_t<&Person::age>, int>

Compiler argument deduction

```
template<typename Key, typename Model>
Key determineKeyType(Key Model::* pMember);
```

Why no implementation?

```
template<auto pMember>
using Key_t = decltype(determineKeyType(pMember));
```

`decltype` pretends to evaluate its argument, but doesn't!

It returns the type the result would be, if evaluated.

Ugly syntax

```
template<typename Key, typename Model>
Key determineKeyType(Key Model::* pMember);
```

Alias template to avoid ugly syntax

```
template<typename Key, typename Model>
using P2Mem = Key Model::*;

template<typename Key, typename Model>
Key determineKeyType(P2Mem<Key, Model> pMember);
```

Aliases help to give better names to types

Extracting the Model type similar to Key

```
template<typename Key, typename Model>
Model determineModelType(P2Mem<Key, Model> pMember);

template<auto pMember>
alias Model_t = decltype(determineModelType(pMember));
```

Almost there

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;
};
```

How to define extractKey function

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return model ??? pMember;
  }
};
```

How to define extractKey function

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return model.*pMember;
  }
};
```

Indexes on data members

```
using AgeIndex = Index<&Person::age>;

using FirstNameIndex = Index<&Person::firstName>;
```

Indexes on pointers to member functions?

```
using YobIndex = Index<&Person::birthYear>;

using FullNameIndex = Index<&Person::fullName>;
```

Indexes on pointers to function members?

```
using YobIndex = Index<&Person::getBirthYear>;

using FullNameIndex = Index<&Person::fullName>;
```

Indexes on pointers to function members?

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return model.*pMember; // Compiler complains here
  }
};
```

extractKey for pointer to function members

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return model.*pMember();
  }
};
```

extractKey for pointer to function members

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return model.*pMember();
  }
};
```

But now we break pointers to data members

std::invoke(F&& f, Args…&& args)

Works on:

Ordinary functions

string foo(int, string const&);

```
string s = std::invoke(foo, 1, "hi")
string s = foo(1, "hi")
```

std::invoke(F&& f, Args…&& args)

Works on:

Ordinary functions

Function objects

```
std::invoke(f, 1, "hello")
 f(1, "hello")
```

std::invoke(F&& f, Args…&& args)

Works on:

- Ordinary functions
- Function objects
- **Pointers to function members**

```
std::invoke(&Person::setAge, alice, 8)
 alice.setAge(8)
```

std::invoke(F&& f, Args…&& args)

Works on:

- Ordinary functions
- Function objects
- Pointers to function members
- **Pointers to data members**
  - `std::invoke(&Person::age, alice)`
  - `alice.age`

extractKey using std::invoke

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return std::invoke(pMember, model);
  }
};
```

extractKey using std::invoke

```
template<auto pMember>
struct Index {
  using Key = Key_t<pMember>;
  using Model = Model_t<pMember>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    return std::invoke(pMember, model);
  }
};
```

Extracting types for pointers to function members

```
template<typename Key, typename Model>
using P2MemFn = Key Model::*();

template<typename Key, typename Model>
Model determineModelType(P2Mem<Key, Model> pMember);

template<typename Key, typename Model>
Model determineModelType(P2MemFn<Key, Model> pMember);
```

Extracting types for pointers to function members

```
template<typename Key, typename Model>
using P2MemFn = Key Model::*();

template<typename Key, typename Model>
Model determineModelType(P2Mem<Key, Model> pMember);

template<typename Key, typename Model>
Model determineModelType(P2MemFn<Key, Model> pMember);
```

Fails, as C++ does not allow overloaded template functions.

https://stackoverflow.com/questions/47060448

Barry advised me to do the following:

```
template<typename>
struct TypeExtractor;
```

Forward declare a templated class

Why?

Future partial specializations

https://stackoverflow.com/questions/47060448

Specialize the template so we can match on Key and Model.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = ???;
};
```

https://stackoverflow.com/questions/47060448

Specialize the template so we can match on Key and Model.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = Key;
};
```

https://stackoverflow.com/questions/47060448

Specialize the template so we can match on Key and Model.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = Key;
};
```

Works fine for pointers to data members
Fails with pointers to member functions

https://stackoverflow.com/questions/47060448

Specialize the template so we can match on Key and Model.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = std::conditional_t<
    std::is_function_v<Key>,
    std::invoke_result_t<Key Model::*, Model>,
    Key>;
};
```

https://stackoverflow.com/questions/47060448

Specialize the template so we can match on Key and Model.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = std::conditional_t<
    std::is_function_v<Key>,
    std::invoke_result_t<Key Model::*, Model>,
    Key>;
};
```

https://stackoverflow.com/questions/47060448

Daniel Frey suggested to use decay_t to simplify all of this.

```
template<typename Key, typename Model>
struct TypeExtractor<Key Model::*> {
  using Model_t = Model;
  using Key_t = std::decay_t<
    std::invoke_result_t<Key Model::*, Model>
  >;
};
```

Alias templates

```
template<auto pMember>
using Key_t = typename
  TypeExtractor<decltype(pMember)>::Key_t;
```

Alias templates

```
template<auto pMember>
using Key_t = typename
  TypeExtractor<decltype(pMember)>::Key_t;

template<auto pMember>
using Model_t = typename
  TypeExtractor<decltype(pMember)>::Model_t;
```

Curiouser and curiouser

Why decltype(pMember)?

```
template<auto pMember>
using Key_t = typename
  TypeExtractor<decltype(pMember)>::Key_t;
```

But in the template specialization we have a non-type parameter,

```
struct TypeExtractor<Key Model::*> {
```

Using ordinary functions

```
int yearsToRetirement(Person const& person) {
  return 65 - person.age;
}
```

Can we write `Index<yearsToRetirement>`?

Using ordinary functions

```
int yearsToRetirement(Person const& person) {
  return 65 - person.age;
}
```

Can we write `Index<yearsToRetirement>`?

Yes, by adding another specialization of TypeExtractor

Using ordinary functions

```
template <typename Key, typename Model>
struct TypeExtractor<Key (*)(Model const&)> {
  using Model_t = Model;
  using Key_t = Key;
};
```

Using ordinary functions

```
int yearsToRetirement(Person const& person) {
  return 65 - person.age;
}

Index<yearsToRetirement> myPensionIndex;
```

Summary

We can create Indexes using

- pointers to data members: `Index<&Person::age>`
- pointers to member functions: `Index<&Person::birthYear>`
- standalone functions: `Index<yearsToRetirement>`

Summary

We can create Indexes using

- pointers to data members: `Index<&Person::age>`
- pointers to member functions: `Index<&Person::birthYear>`
- standalone functions: `Index<yearsToRetirement>`

We can go further! But maybe not this evening :-(

Tools

- godbolt
- cppinsights.io
- Metashell

Questions

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Code: https://github.com/ninkibah/talks

Down the rabbit hole

Indexes with multiple fields

```
Index<&Person::age, &Person::fullname>
```

Indexes with multiple fields

```
Index<&Person::age, &Person::fullname>
```

```
struct AgeAndFullNameIndex :
public Index<std::tuple<int, std::string>, Person>
{
  static auto extractKey(Person const& p) {
    return std::make_tuple(p.age, p.fullName());
  }
};
```

Variadic templates

Making sure we have a common POD type

```
// forward declare our variadic template
template<auto...>
struct model_type;
```

The implementation pattern used gcc's type_traits std::__and and std::__or

Specialize for no arguments

```
template<> // Specific specialization
struct model_type<> {
  static constexpr bool value = true;
  using type = void;
};
```

value is true if all arguments have the same Model type.

Specialize for one argument

```
template<auto V1>
struct model_type<V1> {
  static constexpr bool value = true;
  using type = Model_t<V1>;
};
```

Specialize for two arguments

```
template<auto V1, auto V2>
struct model_type<V1, V2> {
  static constexpr bool value =
    std::is_same_v<Model_t<V1>, Model_t<V2>>;
  using type = Model_t<V1>;
};
```

Specialize for three or more arguments

```
template<auto V1, auto V2, auto V3, auto...Vn>
struct pod_type<V1, V2, V3, Vn...> {
  static constexpr bool value =
    std::is_same_v<Model_t<V1>, Model_t<V2>> &&
    model_type<V2, V3, Vn…>::value;
  using type = Model_t<V1>;
};
```

Generating the Key type

```
template<auto...>
struct key_type;
```

This uses the same pattern used by model_type

Specialize for one argument

```
template<auto V1>
struct key_type<V1> {
  using type = Key_t<V1>;
};
```

Specialize for many arguments

```
template<auto V1, auto...Vn>
struct key_type<V1, Vn...> {
  using type =
    std::tuple<Key_t<V1>, Key_t<Vn>...>;
};
```

Figuring out where to put the ...

Instead of Vn… imagine V2, V3, V4

Write the code you need for them:

```
std::tuple<Key_t<V1>, Key_t<V2>, Key_t<V3>, Key_t<V4>>;
```

Now look for the common part:

Figuring out where to put the ...

Instead of Vn… imagine V2, V3, V4

Write the code you need for them:

```
std::tuple<Key_t<V1>, Key_t<V2>, Key_t<V3>, Key_t<V4>>;
```

Now look for the common part:

```
std::tuple<Key_t<V1>, Key_t<V2>, Key_t<V3>, Key_t<V4>>;
```

Figuring out where to put the ...

Instead of Vn… imagine V2, V3, V4

Write the code you need for them:

```
std::tuple<Key_t<V1>, Key_t<V2>, Key_t<V3>, Key_t<V4>>;
```

Now look for the common part:

```
std::tuple<Key_t<V1>, Key_t<V2>, Key_t<V3>, Key_t<V4>>;
```

Replace the first common part with an expression using Vn, and append ...

```
std::tuple<Key_t<V1>, Key_t<Vn>...>;
```

alias templates for model_type_t and key_type_t

```
template<auto… Values>
using model_type_t =
    typename model_type<Values...>::type;

template<auto… Values>
using key_type_t = typename key_type<Values...>::type;
```

I'm late, I'm late

```
template<auto… Extractors>
struct Index {
  using Model = model_type_t<Extractors…>;
  using Key = key_type_t<Extractors…>;
  std::map<Key, int> data;

  static Key extractKey(Model const& model) {
    // ???
  }
};
```

I'm late, I'm late

sizeof…

fold expressions

```
static auto extractKey(Model const& model) {
  if constexpr (sizeof...(Extractors) == 1)
    return std::invoke(Extractors..., model);
  else
    return std::make_tuple(
      std::invoke(Extractors, model)...);
}
```

Where next?

Support for parent classes of a model class

```
struct Person;

struct Employee : public Person {
  int employeeNr;
};

Index<&Person::fullName, &Employee::employeeNr>

Index for table of Employees.
```

In Memoriam: John Carolan

The Cheshire Cat's smile pattern

AKA PIMPL

First used by John circa 1987

Questions