ОБЪЕКТНО-ОРИЕНТИРОВАННОЕ ПРОГРАММИРОВАНИЕ

Лекция № 2 / 1
03.09.2019 г.

TEMPLATES IN C++

LANGUAGE C

```
#define max(x,y) ((x) > (y) ? (x) : (y))

#define min(x,y) ((x) < (y) ? (x) : (y))
```

LANGUAGE C++

```
inline int max(int x, int y)                { return x > y ? x : y; }
inline long max(long x, long y)             { return x > y ? x : y; }
inline float max(float x, float y)          { return x > y ? x : y; }
inline double max(double x, double y) { return x > y ? x : y; }

// ......???????
```

FUNCTION TEMPLATES

```
template <parameter-list> function-declaration
```

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```
template <typename T>
inline T const &max(T const &x, T const &y) {
    return x > y ? x : y;
}

template <class T>
inline T const &min(T const &x, T const &y) {
    return x < y ? x : y;
}
```

FUNCTION TEMPLATES

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template <parameter-list> function-declaration
```

```
template <typename T>
inline T const &max(T const &x, T const &y) {
    return x > y ? x : y;
}

template <class T>
inline T const &min(T const &x, T const &y) {
    return x < y ? x : y;
}
```

typename and class are equivalent.

```
template <typename T>
inline T const &min(T const &x, T const &y) {
    return x < y ? x : y;
}
```

A compiler is looking for ***min*** function.
Finds this template and infers type ***T*** by type of function arguments.

```
int a = 10;
int b = min(a, 7);
```

```
template <typename T>
inline T const &min(T const &x, T const &y) {
    return x < y ? x : y;
}
```

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Template instantiation

```
int a = 10;
int b = min(a, 7);
```

```
inline int const &min(int const &x, int const &y) {
    return x < y ? x : y;
}
```

```
template <typename T>
inline T const &min(T const &x, T const &y) {
    return x < y ? x : y;
}
```

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Finds this template and infers type ***T*** by type of function arguments.

Template instantiation

```
int a = 10;
int b = min(a, 7);
```

Instance Function Substitution

```
inline int const &min(int const &x, int const &y) {
    return x < y ? x : y;
}
```

```
min(1, 1.2);                    // Error: different types
min(double(1), 1.2);            // OK. typecasting
min<double>(1, 1.2);            // OK. explicit type T
```

MULTIPLE PARAMETERS

```
template <typename T1, typename T2>
inline T1 const &min(T1 const &x, T2 const &y) {
    return x < y ? x : y;
}
// ....
```

```
min(1, 1.2);              // OK. The return type is determined
                          //     by the type of x.

template <typename RT, typename T1, typename T2>
inline RT const &max(T1 const &x, T2 const &y) {
    return x > y ? x : y;
}
// ....
max<double>(4, 4.2);  // Type inference is not possible for RT
```

FUNCTION TEMPLATE OVERLOADING

```
inline int const &max(int const &x, int const &y) {
    return x > y ? x : y;
}

template <typename T>
inline T const &max(T const &x, T const &y) {
    return x > y ? x : y;
}
```

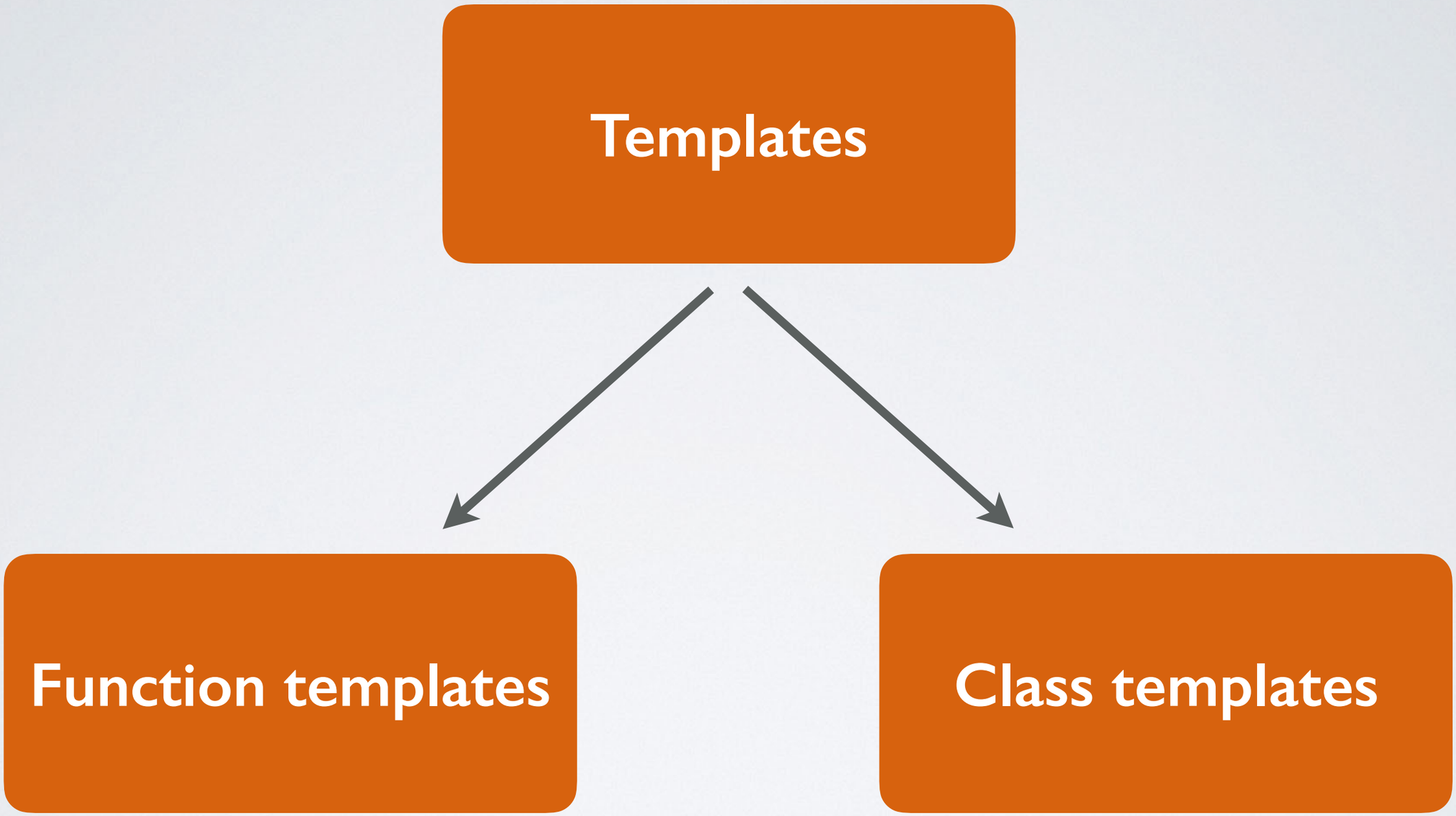
```
template <typename T>
inline T const &max(T const &x, T const &y, T const &z) {
    return max(max(x,y), z);
}

int main() {
    max(7, 42, 68);     // use template with 3 arguments
    max(7.0, 42.0);     // max<double> (template argument deduction)
    max('a', 'b');      // max<char> (template argument deduction)
    max(7, 42);         // usual function
    max<>(7, 42);       // max<int> (template argument deduction)
    max<double>(7, 42); // max<double>
    max('a', 42.7);     // usual function with 2 int arguments
}
```

```
// From <algorithm>

template<class InpIt, class OutIt>
OutIt copy(InpIt first, InpIt last, OutIt result)
{
    while (first != last) {
      *result = *first;
      ++result; ++first;
    }

    return result;
}
```


Templates
Function templates
Class templates

CLASS TEMPLATES

```
template <typename T>
class Stack {
    std::vector<T> elems;
public:
    void push(T const &);
    void pop();
    T top() const;

    bool empty() const {
        return elems.empty()
    }
};

template <typename T>
void Stack<T>::push(T const &elem) {
    elems.push_back(elem);
}

template <typename T>
void Stack<T>::pop() {
    if (elems.empty())
        throw std::out_of_range("empty stack");

    elems.pop_back();
}

template <typename T>
T Stack<T>::top() const {
    if (elems.empty())
        throw std::out_of_range("empty stack");

    elems.back();
}
```

```
int main() {
    try {
        Stack<int> intStack;
        Stack<std::string> stringStack;

        intStack.push(7);
        stringStack.push("hello");

        stringStack.pop();
        stringStack.pop();
    }

    catch (std::exception const &ex) {
        std::cerr << "Exception " <<
        ex.what() << std::endl;
        return -1;
    }
}
```

FUNCTION TEMPLATE SPECIALIZATION

```
template<typename T>
inline void exchange(T *a, T *b)
{
    T tmp(*a);
    *a = *b;
    *b = tmp;
}

// ....
void swap_arrays(Array<int> *a1, Array<int> *a2) {
    exchange(a1, a2);
}
```

Как заставить **exchange** использовать **Array::exchange_with**?

```
template<typename T>
class Array {
    T *data;

public:
    // ...
    void exchange_with(Array<T> *b) {
        T *tmp = data;
        data = b->data;
        b->data = tmp;
    }
};
```

```cpp
// template 1
template<typename T>
inline void quick_exchange(T *a, T *b)
{
    T tmp(*a);
    *a = *b;
    *b = tmp;
}

// template 2
template<typename T>
inline void quick_exchange(Array<T> *a, Array<T> *b)
{
    a->exchange_with(b);
}

void demo(Array<int> *a1, Array<int> *a2) {
    int x = 1, y = 2;

    quick_exchange(&x, &y);   // template 1
    quick_exchange(a1, a2);   // template 2
}
```

«More specialized template»
for a C++ compiler

CLASS TEMPLATE SPECIALIZATION

```
template <typename T>
class Storage8 {
    T objects[8];

public:
    void set(int idx, const T &t) {
        objects[idx] = t;
    }

    const T& operator[](int idx) {
        return objects[idx];
    }
};
```

Storage8<bool> can be optimized.

```
template <>
class Storage8<bool> {
    unsigned char bits;

public:
    void set(int idx, bool t) {
        unsigned char mask = 1 << idx;

        if (t)
            bits |= mask;
        else
            bits &= ~mask;
    }

    bool operator[](int idx) {
        return bits & (1 << idx);
    }
};
```

PARTIAL TEMPLATE SPECIALIZATION

```
template <typename T>
class List {
public:
    // ...
    void append(T const &);
    inline size_t length() const;
    // ...
};
```

- Класс **List** будет инстанцироваться для всех вариантов **T**. В большом проекте это может привести к разбуханию кода (**code bloat)**.
- С низкоуровневой точки зрения реализации **List<int *>::append()** и **List<void *>::append()** идентичны.
- Нельзя ли использовать этот факт для оптимизации списков указателей?

```
// Explicit or full specialization of List<void *>
template<>
class List<void *> {
    // ...
    void append(void *p);
    inline size_t length() const;
    // ...
};

// Partial specialization of List<T *>
template <typename T>
class List<T *> {
    List<void *> impl;
public:
    // ...
    void append(T *p) { impl.append(p); }
    inline size_t length() const { return impl.length(); }
    // ...
};
```

MEMBER TEMPLATES

```
template <typename T>
class Vector {
    T *base;
public:
    // ...

    // Dynamic polymorphism
    void print(ostream &os) {
        for (auto const &v : *this)
            os << v;
    }

    // Static polymorphism
    template <typename Out>
    void print(Out &out) {
        for (auto const &v : *this)
            out << v;
    }
};
```

TRAITS CLASSES

- Шаблоны позволяют иметь произвольное количество аргументов.

- Можно настроить любой аспект поведения класса или функции.

- Но передавать всегда и везде по 100 аргументов неудобно…

```cpp
template <typename T>
inline T accum(const T *beg, const T *end) {
    T total = T();  // T() возвращает ноль
                    // Но лучше писать T{}
    while (beg != end)
        total += *beg++;

    return total;
}
```

```cpp
///////

int num[] = { 1, 2, 3, 4, 5 };
int avg1 = accum(&num[0], &num[5]) / 5;  // 3

char name[] = "templates";
int len = sizeof(name) - 1;
int avg2 = accum(&name[0], &name[len]) / len; // -5
```

- Переменная **total** имеет тип **char** (8 бит), которого не хватает для суммирования.

- Можно тип суммы сделать аргументом шаблона… но это очень неудобно.

- Воспользуемся другим подходом.

```
template <typename T>
class AccumulationTraits;

template<>
class AccumulationTraits<char> {
public:
    typedef int AccT;
};

template<>
class AccumulationTraits<short> {
public:
    typedef int AccT;
};

template<>
class AccumulationTraits<int> {
public:
    typedef long AccT;
};

// unsigned int -> unsigned long
// float -> double
// .....
```

```
template <typename T>
inline typename AccumulationTraits<T>::AccT
accum(const T *beg, const T *end) {
    typedef typename AccumulationTraits<T>::AccT AccT;

    AccT total = AccT();  // AccT() возвращает нулевое значение

    while (beg != end)
        total += *beg++;

    return total;
}

char name[] = "templates";
int len = sizeof(name) - 1;
int avg2 = accum(&name[0], &name[length]) / len; // 108
```

```
template <typename T>
class AccumulationTraits;

template<>
class AccumulationTraits<char> {
public:
    typedef int AccT;
    static AccT zero() { return 0; }
};

template<>
class AccumulationTraits<short> {
public:
    typedef int AccT;
    static AccT zero() { return 0; }
};

template<>
class AccumulationTraits<int> {
public:
    typedef long AccT;
    static AccT zero() { return 0; }
};

template <typename T>
inline typename AccumulationTraits<T>::AccT accum(const T *beg, const T *end) {
    typedef typename AccumulationTraits<T>::AccT AccT;

    AccT total = AccumulationTraits<T>::zero();

    while (beg != end)
        total += *beg++;

    return total;
}
```

Member function zero()

```
template <typename T, typename AT = AccumulationTraits<T> >
inline typename AT::AccT accum(const T *beg, const T *end) {
    // ...
}
```

Traits as template parameters

TRAITS CLASSES

- Вместо того чтобы свойства *(типы, константы, …)* делать параметрами шаблона по **T**, помещаем их в дополнительный класс свойств (**Traits**).

- Создаем набор полных специализаций **Traits** для всех нужных **T**.

#include <type_traits>

```
#include <iostream>
#include <array>
#include <string>
#include <type_traits>

using namespace std;

int main() {
    cout << boolalpha;
    cout << "is_array:" << endl;
    cout << "int: " << std::is_array<int>::value << endl;
    cout << "int[3]: " << std::is_array<int[3]>::value << endl;
    cout << "array<int,3>: " << std::is_array<array<int,3>>::value << endl;
    cout << "string: " << std::is_array<string>::value << endl;
    cout << "string[3]: " << std::is_array<string[3]>::value << endl;
    return 0;
}
```

```
is_array:
int: false
int[3]: true
array<int,3>: false
string: false
string[3]: true
```

POLICY CLASSES

```
class SumPolicy {
public:
    template <typename T1, typename T2>
    static void accumulate(T1 &total, const T2 &value) {
        total += value;
    }
};
```

Операция суммирования вынесена в Policy

```
template <typename T,
          typename Policy = SumPolicy,
          typename Traits = AccumulationTraits<T> >
inline
typename Traits::AccT accum(const T *beg, const T *end) {
    typename Traits::AccT total = Traits::zero();

    while (beg != end) {
        Policy::accumulate(total, *beg);
        ++beg;
    }

    return total;
}
```

```
class MultPolicy {
public:
    template <typename T1, typename T2>
    static void accumulate(T1 &total, const T2 &value) {
        total *= value;
    }
};
```

Умножение

Тонкая настройка суммирования

```
template <bool use_compound_op = true>
class SumPolicy {
public:
    template <typename T1, typename T2>
    static void accumulate(T1 &total, const T2 &value) {
        total += value;
    }
};

template <>
class SumPolicy<false> {
public:
    template <typename T1, typename T2>
    static void accumulate(T1 &total, const T2 &value) {
        total = total + value;
    }
};
```

```
#include <functional>
```

```cpp
#include <iostream>     // std::cout

int main() {
    int first[] = { 1, 2, 3, 4, 5};
    int second[] = { 10, 20, 30, 40, 50};
    int results[5];

    for (int i = 0; i < 5; ++i)
        results[i] = first[i] + second[i];

    for (int i = 0; i < 5; i++)
        std::cout << results[i] << ' ';

    std::cout << '\n';
    return 0;
}
```

```cpp
#include <iostream>     // std::cout
#include <functional>   // std::plus
#include <algorithm>    // std::transform

int main() {
    int first[]  = { 1, 2, 3, 4, 5};
    int second[] = { 10, 20, 30, 40, 50};
    int results[5];

    std::transform(first, first+5, second, results,
                   std::plus<int>());

    for (int i = 0; i < 5; i++)
        std::cout << results[i] << ' ';

    std::cout << '\n';
    return 0;
}
```

How fix?

```cpp
#include <iostream>     // std::cout
#include <functional>   // std::plus
#include <algorithm>    // std::transform

int main() {
    int first[]  = { 1, 2, 3, 4, 5};
    int second[] = { 10, 20, 30, 40, 50};
    int results[5];

    std::transform(first, first+5, second, results,
                   std::plus<int>());

    std::copy(result, result+5,
              std::ostream_iterator<int>(std::cout, ' ');

    std::cout << '\n';
    return 0;
}
```

```
template <class _Arg1, class _Arg2, class _Result>
struct binary_function
{
    typedef _Arg1 first_argument_type;   ///< the type of the first argument
                                         ///  (no surprises here)

    typedef _Arg2 second_argument_type;  ///< the type of the second argument
    typedef _Result result_type;         ///< type of the return type
};

template <class _Tp>
struct plus : public binary_function<_Tp, _Tp, _Tp> {
    _Tp operator()(const _Tp& __x, const _Tp& __y) const {
        return __x + __y;
    }
};
```

```cpp
#include <iostream>
#include <functional>

int main() {
    int ary[] = { 1, 2, 3, 4, 5 }, res[5];

    using namespace std::placeholders;    // _1, _2, _3,...

    auto inc_10 = std::bind(std::plus<int>(), _1, 10);

    std::transform(ary, ary+5, res, inc_10);

    for (int x: res)
        std::cout << x << std::endl;    // 11… 12… 13… 14… 15
        return 0;
    }
}
```

Currying

```
bool all_under_20 = std::all_of(ary, ary + 5,
    std::bind(std::less<int>(), _1, 20));
```

```
bool all_under_20 = std::all_of(ary, ary + 5,
    [](int n) { return n < 20; });
```

Lambda-expression

```
// Сколько элементов вектора v принадлежат отрезку [loBo, upBo)?
size_t rangeMatch(const vector<int> &v, int loBo, int upBo) {
    return std::count_if(v.begin(), v.end(),
        [loBo, upBo](int _n) {
            return loBo <= _n && _n < upBo;
        });
}
```

"Capturing" variables

```
[loBo, upBo](int _n) {
    return loBo <= _n && _n < upBo;
}

// примерно соответствует:

struct AutomaticallyGenerated {
    AutomaticallyGenerated(int lo, int up)
        : loBo(lo), upBo(up) {}

    bool operator()(int _n) {
        return loBo <= _n && _n < upBo;
    }

    int loBo, upBo;
};
```

```cpp
#include <iostream>
#include <functional>

int main() {
    int ary[] = { 1, 2, 3, 4, 5 }, res[5];

    auto incGen = [] (int _val) -> std::function<int (int)> {
        return [_val] (int _n) -> int { return _n + _val; };
    };

    auto inc_10 = incGen(10);

    std::transform(ary, ary+5, res, inc_10);

    for (int x: res)
        std::cout << x << std::endl;    // 11… 12… 13… 14… 15

        return 0;
    }
}
```

Lambda-expression generates lambda-expressions

SFINAE

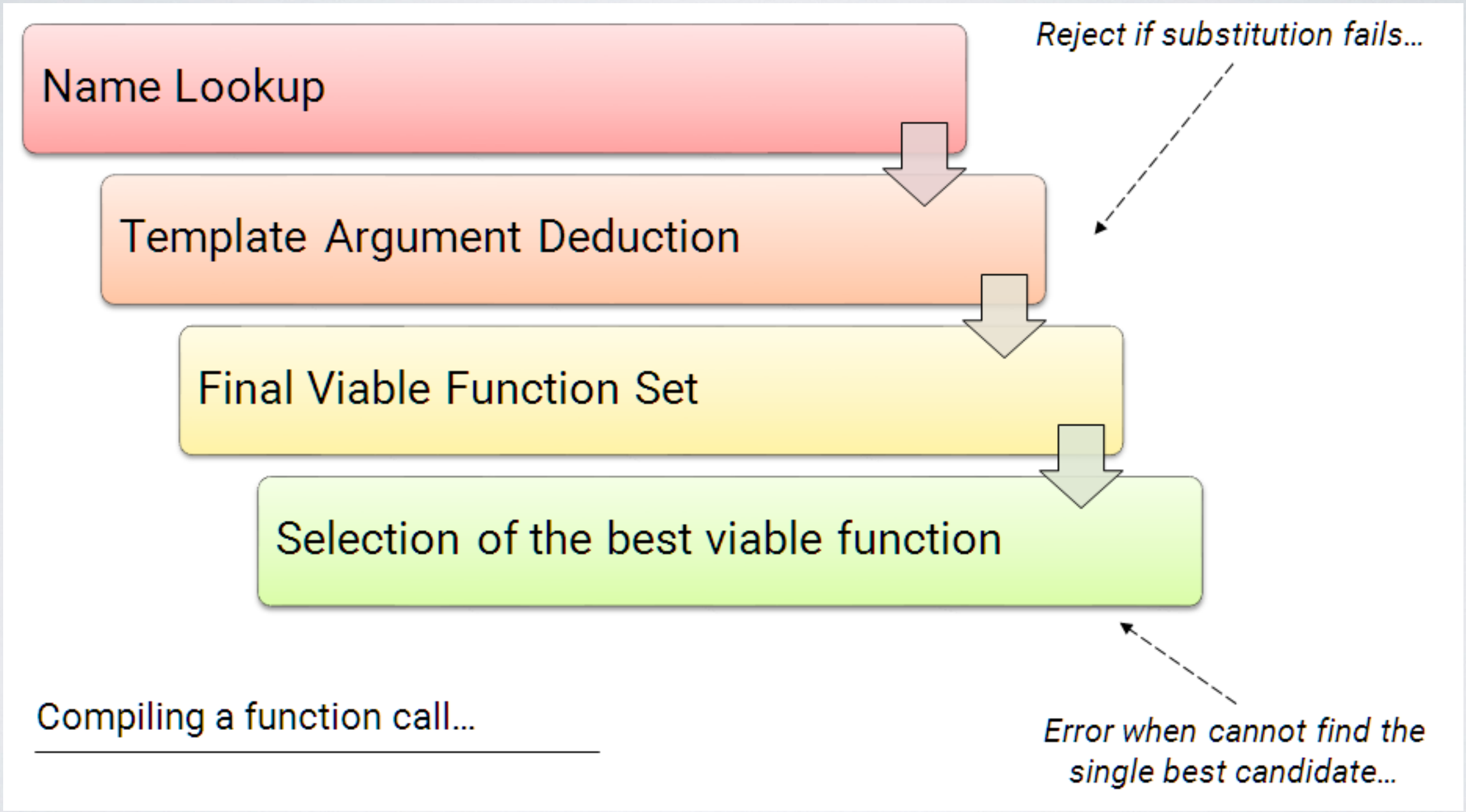
```
struct Bar{
    typedef double internalType;
};

template <typename T>
typename T::internalType foo(const T& t) {
    std::cout << "foo<T>" << std::endl;
    return 0;
}

int main(){
    foo(Bar());
    foo(0);   // error
              // no matching function for call to 'foo(int)'
              // ...
              // template argument deduction/substitution failed:
}
```

Substitution **F**ailure **I**s **N**ot **A**n **E**rror

SFINAE


Name Lookup
Template Argument Deduction
Final Viable Function Set
Selection of the best viable function
Reject if substitution fails…
Compiling a function call…
Error when cannot find the single best candidate…

ENABLE_IF

```
std::enable_if<condition, T>::type

template <typename T>
typename std::enable_if<std::is_arithmetic<T>::value, T>::type
foo(T t) {
    std::cout << "foo<arithmetic T>" << std::endl;
    return t;
}
```

ITERATORS

```
// Until C++17
class num_iterator :
    std::iterator<std::forward_iterator_tag, int>
{
    int i;
public:
    explicit num_iterator(int pos = 0) : i{ pos } {}

    int operator*() const { return i; }

    num_iterator& operator++() {
        ++i;
        return *this;
    }

    bool operator!=(const num_iterator &other) const
    {
        return i != other.i;
    }

    bool operator==(const num_iterator &other) const
    {
        return !(*this != other);
    }
};
```

```
// Since C++17 std::iterator - deprecated
class num_iterator
{
    int i;
public:
    explicit num_iterator(int pos = 0) :
        i{ pos } {}

    ...
};

namespace std {

    template <>
    struct iterator_traits<num_iterator> {
        using iterator_category =
            std::forward_iterator_tag;
        using value_type = int;
        //using pointer = ...;
        //using reference = ...;
        //using difference_type = ...;
    };

}
```

КОНЕЦ ПЕРВОЙ ЛЕКЦИИ