Department I - C Plus Plus

Modern and Lucid C++ for Professional Programmers

Part 4 – Stream Iterators and Exceptions

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Recap Week 3

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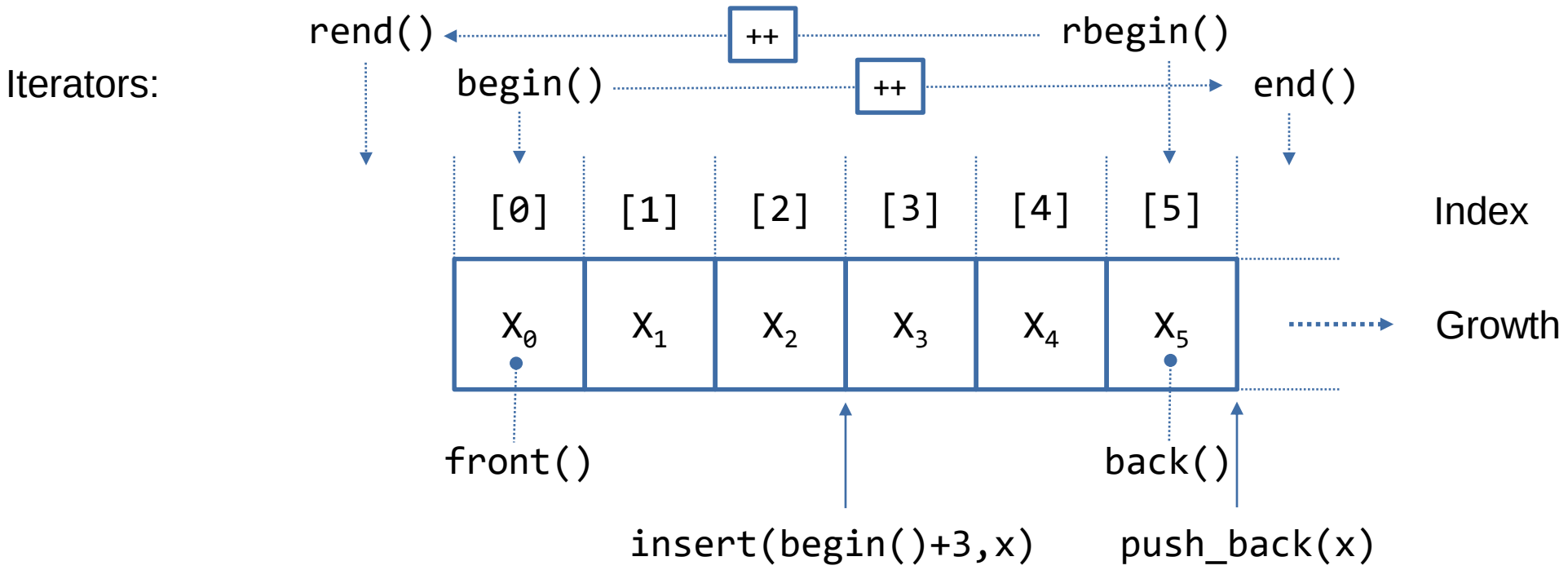
```
std::vector<int>(6);
```



Example: Iterators and Algorithms


```
void print(int x) {
  std::cout << "print: "<< x << ' ';
}

void printAll(std::vector<int> v) {
  std::for_each(std::cbegin(v), std::cend(v), print);
}

void printAllReverse(std::vector<int> v) {
  std::for_each(std::crbegin(v), std::crend(v), print);
}

int main() {
  std::vector<int> values{1, 2, 3, 4, 5};
  printAll(values);        //prints 1 2 3 4 5
  printAllReverse(values); //prints 5 4 3 2 1
}
```

Iterators for I/O

Goals:

- You know how to create iterators for `std::istreams` and `std::ostreams`
- You can specify ranges on streams with stream iterators

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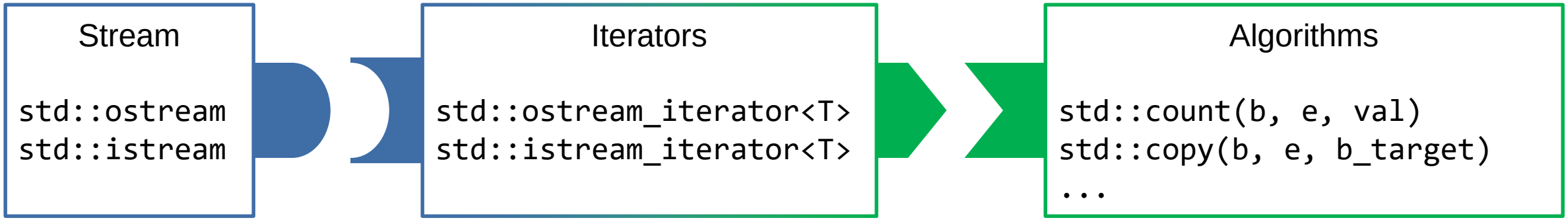
Iterators Connect Streams and Algorithms



- **Streams (std::istream and std::ostream) cannot be used with algorithms directly**

```
std::copy(std::begin(v), std::end(v), std::ostream_iterator<int>{std::cout, ", "});
```

- **`std::ostream_iterator<T>` outputs values of type `T` to the given `std::ostream`**
  - No `end()` marker needed for ouput, it ends when the input range ends
- **`std::istream_iterator<T>` reads values of type `T` from the given `std::istream`**
  - End iterator is the default constructed `std::istream_iterator<T>{}`
  - It ends when the stream is no longer `good()`

Shorter Type Names With Using Alias Declarations

- The (stream) iterators have a very unpleasant name length, even with auto-completion
- A type alias can help to abbreviate that

```
using <alias-name> = <type>;
```

- Useful if long type names occur more than once
- Example
  - Copy strings from standard input to standard ouput

```
using input = std::istream_iterator<std::string>;
input eof{};
input in{std::cin};
std::ostream_iterator<std::string> out{std::cout, " "};
std::copy(in, eof, out);
```

- **`std::istream_iterator` uses operator >> for input**
  - Disadvantage: It skips white space
- **For an exact copy, we also need the rest**
- **`std::istreambuf_iterator<char>` uses `std::istream::get()` to get every character**
  - This only works with `char`-like types

```
using input = std::istreambuf_iterator<char>;
input eof{};
input in{std::cin};
std::ostream_iterator<char> out{std::cout, " "};
std::copy(in, eof, out);
```

Filling an std::vector<T> from Standard Input

- **To fill a vector from a stream you can either use copy with std::back_inserter(v)**
  - It uses v.push_back() internally

```
using input = std::istream_iterator<int>;
input eof{};
std::vector<int> v{};
std::copy(input{std::cin}, eof, std::back_inserter(v));
```

- **Or, construct the std::vector<T> directly from two iterators**

```
using input = std::istream_iterator<int>;
input eof{};
std::vector<int> const v{input{std::cin}, eof};
```

References

Goals:

- You know the difference between a value and a reference

- **A reference is an alias for a variable or value**
  - The original must exist as long as it is referred to!
- **Mostly useful for function parameters**
  - Avoids copying large objects (const reference)
  - Provides side-effects on call-side variable (non-const reference)
- **Sometimes useful for member/local variables**
  - Caution: Dangling References
- **Rarely useful as return type**

- **For demonstration purposes only!**

```
int i{42};
int & ri{i};           // must initialize ref
int const & cri{ i }; // const alias
int const & cr{6*7};  // extend lifetime of 6*7
ri = 43;               // changes i, ri only an alias
//--cri;               // doesn't work -> const
```

- **Ampersand (&) prefix for lvalue references**
  - Must always be initialized!
  - No null-references
- **`const` & prefix for const references**
  - `const` reference to non-const value is possible
- **Rvalue references (&&) are a topic in C++ Advanced**

Local Variables and Scopes

- **Scoping rules are similar to other languages**
- **Parameters are visible in function block**
- **In C++: Lifetime is equally important**
  - When block scope ends, lifetime is over
    (**}** "collects garbage")
  - Dependability on destruction is a key feature of C++
- **Beware of redefining the same name**
  - Shadowing happens and is not an error as in Java

```
void showScopingRules(int i, double d) {
  unsigned j{1};
  // cannot use name i instead of j
  std::cout << i << "\n";
  {
    char i{'d'}; // shadows parameter i
    // parameter i not accessible but d is
    std::cout << i << " " << d << "\n";
  }
  ++i; // that is the parameter i
       // no longer shadowed
  for (auto i = 0u; i < j; ++i) {
    // another i
    std::cout << i << "\n";
  }
  std::cout << i << "\n";
  // parameter i again
}
```

Functions (One More Time)

Goals:

- You know the different ways of passing parameters to functions
- You know how to pass default arguments to functions
- You know how to write a lambda

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Function Parameter Declarations

	const: • Parameter cannot be changed	**non-const:** • Parameter can be changed

reference:
• Argument on call-site is accessed
	`void f(std::string const & s) {`
	`  //no modification`
	`  //efficient for large objects`
	`}`
		`void f(std::string & s) {`
		`  //modification possible`
		`  //side-effect also at call-site`
		`}`

copy:
• Function has its own copy of the parameter
	`void f(std::string const s) {`
	`  //no modification`
	`  //rarely used`
	`}`
		`void f(std::string s) {`
		`  //modification possible`
		`  //side-effect only locally`
		`}`

- **Call-site always looks the same**
  - You cannot pass a const argument to a non-const reference

```
std::string name{"John"};
f(name);
```

When to Use & and const for Parameters

- **Value Parameter:** `void f(type par);`
  - Default for parameters
- **Reference Parameter:** `void f(type & par);`
  - When side-effect is required at call-site
- **Const-Reference Parameter:** `void f(type const & par);`
  - Possible optimization, when type is large (costly to copy) and no side-effects desired at call-site
  - For non-copyable objects
- **Const Value Parameter:** `void f(type const par);`
  - Hardly ever
  - Could prevent changing the parameter in the function inadvertently

Function Return Type

- **By Value:** `type f();`
  - Default for return types
- **By Reference:** `type & f(); or type const & f();`
  - Only return a reference parameter (or a class member variable from a member function)

```
std::ostream & sayHello(std::ostream & out) {
  return out << "Hello";
}
```

  - Never return a reference to a local variable!

```
std::string & create() {
  std::string name{"John"};
  return name;
}
```

- **By Const Value:** `type const f();`
  - Don't do this, it just annoys the caller

```
void incr(int & var);
void incr(int & var, unsigned delta);
```

- **The same function name can be used for different functions if parameter number or types differ**
  - Functions cannot be overloaded just by their return type
  - If only the parameter type is different there might be ambiguities
- **Resolution of overloads happens at compile-time = Ad hoc polymorphism**
- **Internal name of a function also contains its parameter types as significant information (not the parameter names)**
  - Information required by the linker

Overloading Ambiguity


```
int factorial(int n) {
  if (n > 1) {
    return n * factorial(n - 1);
  }
  return 1;
}

double factorial(double n) {
  double result = 1;
  if (n < 15) {
    return factorial(static_cast<int>(n));
  }
  while (n > 1) {
    result *= n;
    --n;
  }
  return result;
}
```

```
void demoAmbiguity() {
  std::cout << factorial(3) << '\n';
  std::cout << factorial(1e2) << '\n';

  std::cout << factorial(10u) << '\n';
  std::cout << factorial(1e1L) << '\n';
}
```

```
void incr(int & var, unsigned delta = 1);
```

- **A function declaration can provide default arguments for its parameters from the right**
  - Definition doesn't need to/shouldn't repeat
  - = is required as part of the parameter declaration

```
void incr(int & var, unsigned delta) {
  var += delta;
}
```

- **Implicit overload of the function with fewer parameters**
  - If n default arguments are provided, n+1 versions of the function are declared
- **Default arguments can be omitted when calling the function**

```
int counter{0};
incr(counter);     //uses default for delta
incr(counter, 5);
```

```
void applyAndPrint(double x, double f(double)) {
  std::cout << "f(" << x << ") = " << f(x) << '\n';
}
```

- **Functions are "first class" objects in C++**
  - You can pass them as argument
  - You can keep them in references variables
  - In C you could do that with function pointers (only)
- **Syntax for function reference types**

```
double (&h)(double)
```

- **Later more with generic parameters in template functions, which also allow passing lambdas**

- **Defining inline functions**

```
auto const g = [](char c) -> char {
  return std::toupper(c);
};
g('a');
```

- **auto const for function variable from Lambda**
- **`[]` introduces a Lambda function**
  - Can contain captures: `[=]` or `[&]` to access variables from scope
- **`(Parameters)` as with other functions, but optional if empty**
  - Parameters can be `auto` (Generic Lambda)
- **Body block with statements**

Lambda Capture Examples

- **Capturing a local variable by value**
  - Local copy lives as long as the lambda lives
  - Local copy is immutable, unless lambda is declared `mutable`

```
int x = 5;
auto l = [x]() mutable {
  std::cout << x;
};
```

- **Capturing a local variable by reference**
  - Allows modification of the captured variable
  - Side-effect is visible in the surrounding scope, but referenced variable must live at least as long as the lambda lives

```
int x = 5;
auto const l = [&x]() {
  std::cout << ++x;
};
```

- **Capturing all local variables by value or reference**

```
int x = 5;
auto l = [=]() mutable {
  std::cout << x;
};
```

```
int x = 5;
auto const l = [&]() {
  std::cout << ++x;
};
```

(More) Lambda Capture Examples

- **Capturing `this` pointer**
  - Accessing and modify members of the class is possible

```
struct S {
  void foo() {
    auto square = [this] {
      member *= 2;
    };
  }
private:
  int member{};
};
```

- **New local variable can be specified in capture**
  - New variable in capture has type `auto`
  - Can be modified if lambda is `mutable`

```
auto squares = [x=1]() mutable {
  std::cout << x *= 2;
};
```

- **In capture above examples can be combined and separated with commas (,)**

Failing Functions

Goals:

- You know 5 different ways to react to errors in functions
- You know how to throw, catch and test exceptions

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When Could a Function Fail?

- **Precondition (Assumption) is violated**
  - Negative index
  - Divisor is zero
  - Usually caller provided wrong arguments
- **A function without preconditions has a so-called "wide contract" as opposed to "narrow contract"**
- **Postcondition could not be satisfied**
  - Resources for computation are not available
  - Can not open a file

Contract cannot be fulfilled

Functionality Guarantees (Contract)

- **What should you do, if a function cannot fulfill its purpose?**
  1. Ignore the error and provide potentially **undefined behavior**
  2. Return a **standard result** to cover the error
  3. Return an **error code** or error value
  4. Provide an **error status** as a side-effect
  5. Throw an **exception**
- **But first you need to know, if it can fail at all!**

1. Ignore the Error

```
std::vector<int>{1, 2, 3, 4, 5};
v[5] = 7;
```

- **Relies on the caller to satisfy all preconditions**
- **Viable only if not dependent on other resources**
- **Most efficient implementation**
  - No unnecessary checks
- **Simple for the implementer but harder for the caller**
- **Should be done consciously and consistently!**

```
std::string inputName(std::istream & in) {
  std::string name{};
  in >> name;
  return name.size() ? name : "anonymous";
}
```

- **Reliefs the caller from the need to care if it can continue with the default value**
- **Can hide underlying problems**
  - Debugging can give you nightmares
- **Often better if caller can specify its own default value**

```
std::string inputNameWithDefault(std::istream & in,
                                 std::string const & def = "anonymous") {
  std::string name{};
  in >> name;
  return name.size() ? name : def;
}
```

- **Only feasible if result domain is smaller than return type**
  - There exists a value that can be used
  - Sometimes invented artificially: std::string::npos

```
bool contains(std::string const & s, int number) {
  auto substring = std::to_string(number);
  return s.find(substring) != std::string::npos;
}
```

  - POSIX defines -1 to mark failure of many system calls
- **Burden on the caller to check the result**
  - Danger of ignoring significant errors if result is otherwise insignificant
  - In C++17 we get the `std::optional<T>` type

```
std::optional<std::string> inputName(std::istream & in) {
  std::string name{};
  if (in >> name) return name;
  return {};
}
```

- **Requires reference parameter**
  - Can be `this` object in member functions
  - Annoying when error variable must be provided

```
int connect(std::string url, bool & error) {
  //set error when an error occurred
}
```

- **(Bad!) Alternative: Global variable**
  - POSIX' `errno` is the glorious example of that
- **Example: `std::istream`'s state (`good()`, `fail()`) is changed as a side-effect of input**

```
std::string name{};
in >> name;
if (in.fail()) { //Member variable
  //Handle error case
}
```

```
throw std::invalid_argument{"Description"};
throw 15;
```

- **To throw an exception:** `throw value;`
  - Any (copyable) type can be thrown
- **No means to specify what could be thrown**
  - No checks if you catch an exception that might be thrown at call-site
- **No meta-information is available as part of the exception**
  - No stack trace, no source position of throw
- **Exception thrown while exception is propagated results in program abort (not while caught)**

Catching Exceptions

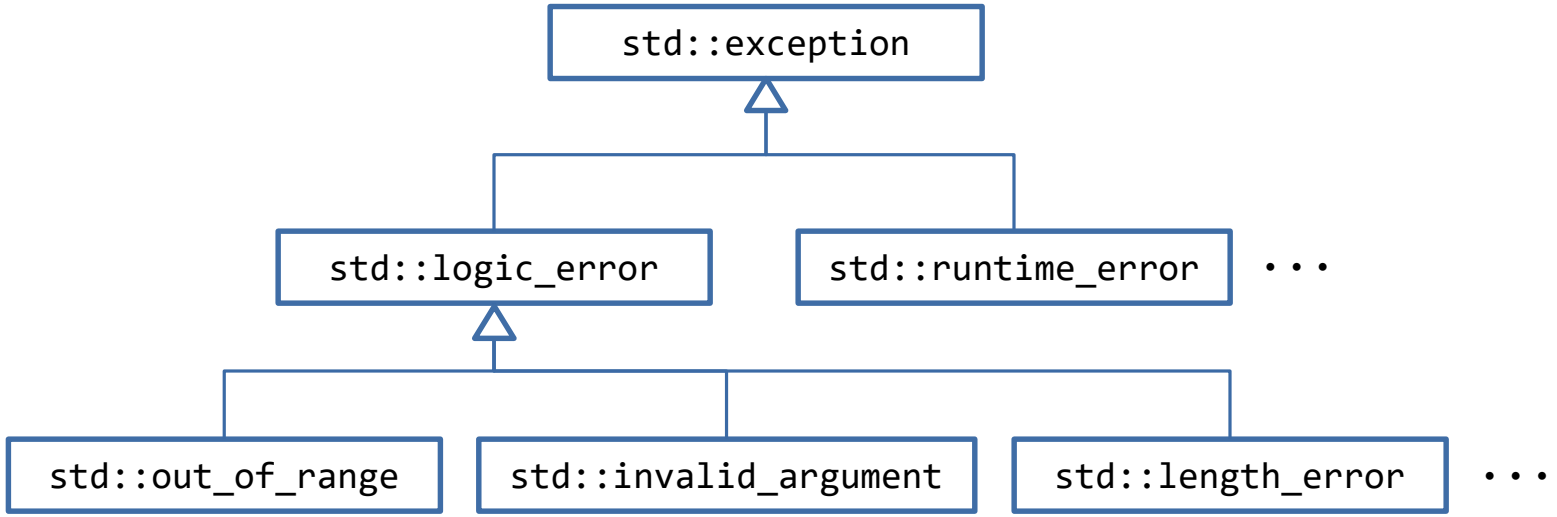
- **Try-catch block as in Java**
  - Can be the whole function body
- **Principle: Throw by value, catch by const reference**
  - Avoids unnecessary copying
  - Allows dynamic polymorphism for class types
- **Sequence of catches is significant**
  - First match wins
- **Catch all with ellipsis (...):**
  - Must be last catch
- **Caught exceptions can be rethrown with `throw;`**

```
try {
  throwingCall();
} catch (type const & e) {
  //Handle type exception
} catch (type2 const & e) {
  //Handle type2 exception
} catch (...) {
  //Handle other exception types
}
```

Predefined Exception Types

```
#include <stdexcept>
```


- **The Standard Library has some pre-defined exception types that you can also use in <stdexcept>**



- **All have a constructor parameter for the "reason" of type `std::string`**
- **`std::exception` is the base class**
  - It provides the `what()` member function to obtain the "reason"

Functions with "Narrow Contract"

- **Functions that have a precondition on their caller**
  - When not all possible argument values are useful for the function

```
double square_root(double x) {
  if (x < 0) {
    throw std::invalid_argument{"square_root imaginary"};
  }
  return std::sqrt(x);
}
```

- **Do NOT use exceptions as a second means to return values**
  - Catch then becomes a "come from" and throw a "go to"

- **CUTE provides ASSERT_THROWS(code, exception)**

```
void testSquareRootNegativeThrows() {
  ASSERT_THROWS(square_root(-1.0), std::invalid_argument);
}
```

```
void testEmptyVectorAtThrows() {
  std::vector<int> empty_vector{};
  ASSERT_THROWS(empty_vector.at(0), std::out_of_range);
}
```

- **You can also use try-FAILM()-catch**

```
void testForExceptionTryCatch() {
  std::vector<int> empty_vector{};
  try {
    empty_vector.at(1);
    FAILM("expected Exception");
  } catch (std::out_of_range const &) {
    // expected
  }
}
```

Summary

- **A good function**
  - Does one thing well and is named after that ("High Cohesion")
  - Has only few parameters (<=3, max 5)
  - Consists of only a few lines without deeply nested control structure
  - Provides guarantees about its result (aka its contract)
  - Is easy to use with all possible argument values its parameter types allow or provides consistent error reporting if argument values prohibit delivering its result (exception)
- **Pass parameters and return results by value (unless there is a good reason not to)**