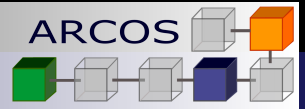


Contracts programming for C++20

Current proposal status

J. Daniel Garcia

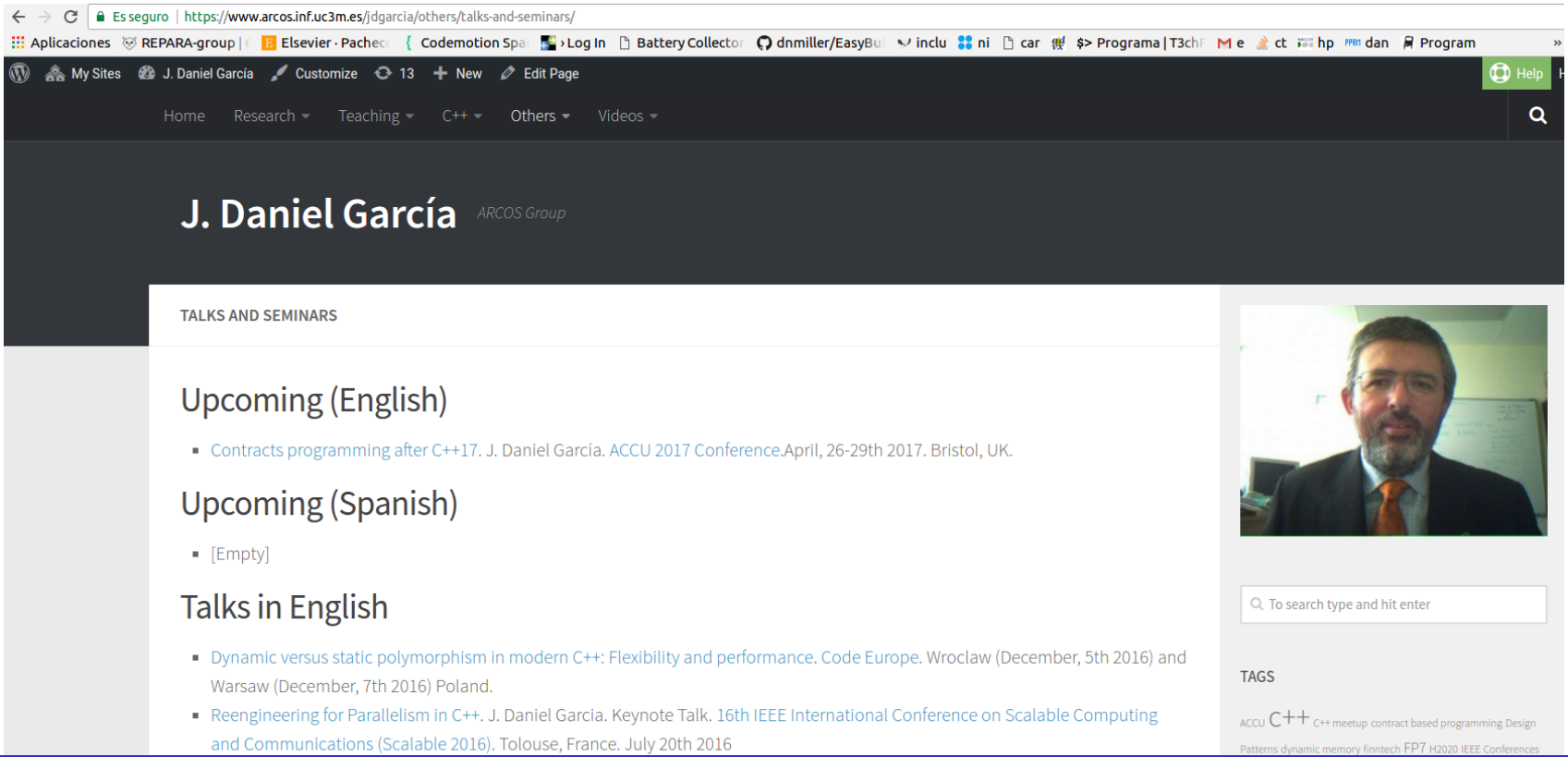
ARCOS Group
University Carlos III of Madrid
Spain

April, 28th, 2017

Warning

Download this slides

- Download the slides:
  https://www.arcos.inf.uc3m.es/jdgarcia/others/talks-and-seminars/



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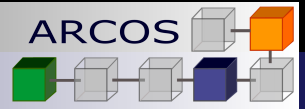

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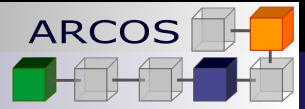

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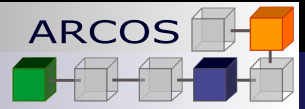
- **My goal**: Improve applications programming.
  - **Performance** → **faster** applications.
  - **Energy efficiency** → **better** performance per Watt.
  - **Maintainability** → **easier** to modify.
  - **Reliability** → **safer** components.
- More at:
  `https://www.arcos.inf.uc3m.es/jdgarcia`.



ARCOS@uc3m

- **UC3M**: A young, international, research oriented university.
- **ARCOS**: Applied research group:
  - Lines: High Performance Computing, Big data, Cyberphisical Systems, and Programming Models for Application Improvement
- **Improving Applications**:
  - **REPARA**: Reengineering and Enabling Performance and poweR of Applications. Funded by EU (FP7).
  - **RePhrase**: REfactoring Parallel Heterogeneous Resource Aware Applications. Funded by EU (H2020).
- **Standards**:
  - ISO/IEC JTC/SC22/WG21. ISO C++ Committee.

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> *Correctness is clearly the prime quality. If a system does not do what it is supposed to do, then everything else about it matters little.*

Bertrand Meyer

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- What did others do?
  - Several language solutions out there (D, Ada, C#).

Contracts in C++

- First proposal for contracts programming in 2005.
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- Next attempt in 2013.
  - **N3604**: Centralized Defensive-Programming Support for Narrow Contracts. John Lakos, Alexei Zakharov.

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- 2014-2015:Multiple proposals on contracts programming.
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Current contracts effort

- 2014-2015:Multiple proposals on contracts programming.
  - Discussions in the standards committee.
- 2016: Joint proposal trying to consider trade-offs.
  - Gabriel Dos Reis, J. Daniel Garcia, John Lakos, Alisdair Meredith, Nathan Myers, Bjarne Stroustrup.
  - Many others provided feedback and ideas.
  - **Targeting C++20!**.

Correctness and Robustness

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- In the design of a library two related properties need to be considered: **robustness** and **correctness**.
  - **Correctness** → Degree to which a software component matches its specification.
  - **Robustness** → Ability of a software component to react appropriately to abnormal conditions.
- Today many libraries use a single feature for managing both properties: **exception handling**.

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- **Robustness** and **correctness** are orthogonal properties and **should be managed independently**.

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- The C++ standard library identifies those cases by specifying
  i. the condition firing the situation.
  ii. the exception that will be thrown to notify.
- **T * allocator<T>::allocate(std::size_t n);**

  Throws: **bad_alloc** if storage cannot be obtained.

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- A contract violation happens because:
  - A caller does not fulfil the expectations before calling a function.
  - A callee does not fulfill what should be ensured after its own execution.
- A key difference:
  - A program failure is usually due to external conditions and cannot be avoided.
  - A contract violation ***should*** never happen in a correct program.

Correctness in the C++ standard library

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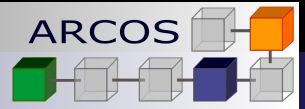
- In practice, there are two approaches in the standard library:
  - Do nothing → **Undefined behaviour**.
  - Notify → **Throw an exception**.

Can we do it better?

- Can we do more than just run-time checks?



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- Can we serve different communities with different needs?

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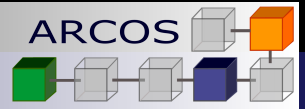
- It states **rights** and **obligations** of **client** and **supplier**.

Expectations

- **Precondition**
  - A predicate that should hold upon entry into a function.
  - It expresses a function's expectation on its arguments and/or the state of objects that may be used by the function.
  - Expressed by attribute **expects**.



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- Preconditions use a modified attribute syntax.
- The expectation is part of the function declaration.

Assurances

- **Postcondition**
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- Postconditions may introduce a name for the result of the function.

Assertions

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```
double add_distances(const std::vector<double> & v)
   [[ ensurres r:  r>=0.0]]
{
   double r = 0.0;
   for  (auto x :  v)  {
      [[ assert: x >=  0.0]];
      r  += x;
   }
   return r ;
}
```

Effect of contracts

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  - Attributes are not part of function type.
  - However, **contracts are not an optional feature**.
    - As any other standardized attribute.
- Contracts checking and corresponding effects depend on build system settings.
  - Default: Contract violation $\Rightarrow$ Program termination.

Repeating a contract

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```
int f(int x)
  [[expects: x>0]]
  [[ensures r: r >0]];

int f (int x) ; // OK. No contract.

int f ( int x)
  [[expects: x>=0]]; // Error missing ensures and different expects

int f(int x)
  [[expects: x>0]]
  [[ensures r: r >0]]; //OK. Same contract.
```

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```
int f(int x)
   [[expects: x>0]]
   [[ensures r: r >0]];

int f(int y)
   [[expects: y>0]]
   [[ensures z: z >0]];
```

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void f(element & x) [[expects: x.valid() ]];
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```

- Cost of checking is expected to be small compared to function execution.

Audit checks

- An **audit** *assertion level* is expected to be used in cases where the cost of a run-time check is assumed to be large compared to function execution.
  - Or at least significant.

```
template <typename It, typename T>
bool binary_search(It  first ,  It  last ,  const T & x)
   [[ expects audit: is_sorted( first , last ) ]];
```

Axiom checks

- An **axiom** *assertion level* is expected to be used in cases where the run-time check will **never** be performed.
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  - They are formal comments for humans and/or static analyzers.

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- Axioms are not evaluated.
  - They may contain calls to declared but undefined functions.

Build levels

- Every translation is performed in a *build level*:
  - **off**: No run-time checking is performed.
  - **default**: Checks with **default** levels are checked.
  - **audit**: Checks with **default** and **audit** levels are checked.

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- How do you select the *build level*:
  - **No way of selecting in source code.**
  - An option from your compiler.

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```
void f(int * p)
   [[expects: p!=nullptr]]
   [[expects: *p == 0]]  //  Only checked when p!=nullptr
{
   *p = 1;
}
```

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- A translation unit has an associated contract violation handler.
- A contract violation handler is the function to be called when a contract is broken.
  - Function with specific signature.

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void (const std::contract_violation &);
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- Function with specific signature.

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- Minimum information inf **contract_violation**:

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class contract_violation {
public:
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- Might get simplified by **std::experimental::source_location**.

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Continuation mode and optimizations

- Assertion information may be used by optimizers.

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[[assert: ptr!=nullptr]];
// ...
if (ptr!=nullptr) { // Can be optimized out
  do_stuff();
}
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- If continuation mode is **on**, then **if** would be reached.
  - But the **if** might get **optimized out**!
  - **Continuation after violation is technically undefined behavior**.

Contracts and **noexcept**

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    - Program invokes **terminate()** *as-if* an exception was thrown inside functions.

```
void f(int x) noexcept [[expects: x > 0]];

void g() {
  f(-1); // Invokes terminate if handler throws
}
```

Repeating a contract

- Any redeclaration of a function has either the same contract or completely omits the contract.

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```
int f(int x)
  [[expects: x>0]]
  [[ensures r: r >0]];

int f (int x) ; // OK. No contract.

int f ( int x)
  [[expects: x>=0]]; // Error missing ensures and different expects

int f(int x)
  [[expects: x>0]]
  [[ensures r: r >0]]; //OK. Same contract.
```

Preconditions on functions

- The expression of a precondition from a function may use:
  - The function's arguments.
  - Any non-local object.

```
constexpr int max = 100;
std :: string  name{"Daniel"};

bool f(int  x,  std :: string  s)
   [[expects: x>0]]  //  OK. x is  an argument.
   [[expects: x<max]] // OK max is non-local
   [[expects: s.length()>0]]  //  OK. s is  an argument
   [[expects: s!=name]]; //  OK. name is non-local
```

Preconditions on **constexpr** functions

- The expression of a precondition from a **constexpr** function may use:
  - The function's arguments.
  - Any non-local object that is **constexpr**.
  - **but it cannot access non-local objects that are not constexpr**.

```
constexpr int max = 100;
std :: string  name{"Daniel"};

constexpr bool f(int x,  std :: string  s)
   [[expects: x>0]]  //  OK. x is  an argument.
   [[expects: x<max]] // OK max is constexpr
   [[expects: s.length()>0]]  //  OK. s is  an argument
   [[expects: s!=name]]; // Error  name is a non-local variable
```

Modifications in contracts

- A program with a contract expression that performs an **observable modification** of an object is **ill-formed**.
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- A program with a contract expression that performs an **observable modification** of an object is **ill-formed**.
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```
int f(int x)
  [[expects: x++ > 0]]        // Error
  [[ensures r: r == ++x]];    // Error
```

Modified arguments and postconditions

- If a postcondition uses an argument and the function body modifies that value, the program is ill-formed.

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```
int f(int x)
   [[ensures r: r==x]
{
   return ++x; // Error x used in postcondition
}
```

Modified arguments and postconditions

- If a postcondition uses an argument and the function body modifies that value, the program is ill-formed.

```
int f(int x)
  [[ensures r: r==x]
{
  return ++x; // Error x used in postcondition
}
```

- Workaround:

```
int f(int x) {
  int oldx = x;
  auto r = ++x;
  [[assert: r==oldx]];
}
```

But you con modify pointer contents

- A pointer value is different from the pointed value.

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```
void f(int * ptr)
   [[ensures: ptr!=nullptr]]
{
   *ptr = 42
}
```

Contracts in templated function

- The expression of a contract from a function template or a member function of a class template may use the template arguments.

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```
template <typename T, int size>
class table  {
public:
   // ...
   T & operator[](int  i )
      [[ expects: 0<=i && i<size ]];
};
```

Contracts and visibility

- The contract from a public function shall not use members from protected or private interfaces.
- The contract from a protected function shall not use members from private interface.

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- The contract from a public function shall not use members from protected or private interfaces.
- The contract from a protected function shall not use members from private interface.

```
template <typename T>
class table  {
public:
   // ...
   T & operator[](int  i )
      [[ expects: 0<=i && i<size_]];  // Error. size_ is private

private:
   // ...
   int  size_;
};
```

Contracts on lambdas

- The expression of a contract from a lambda-expression:
  - may use any entity captured implicitly or explicitly.
  - shall not use any entity that is not accessible by the lambda-expression.

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```
void f(int x) {
  auto g = [](int z) [[expects: z>x]] // Error. x not captured
    { return z+1; }
  auto h = [x](int z) [[expects: z>x]] // OK
  // ...
}
```

Contracts and function pointers

- A function pointer shall not include a contract.
- A call through a function pointer to functions with a contract shall perform contract assertions checking once.

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```
using fpt = int (*)(int x)
   [[expects: x>=0]]
   [[ensures r: r>0]];  // Error.

int g(int x)  [[expects: x>=0]] [[ensures r: r>0]]
{
 return x+1;
}

int (*pf)(int) = g;  // OK
```

Contracts and inheritance

- An **overriding function** shall have exactly the **same contract** that was declared for that function in the base class.
  - But the contract may be omitted in the overridden function.

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```
struct B {
public:
  virtual void f (int x) [[expects: x>0]];
  // ...
};

struct D : public B {
public:
  virtual void f (int x) override; // OK. expects: x>0
  // ...
};
```

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struct B {
public:
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  // ...
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public:
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  // ...
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Precondition weakening

- Precondition weakening is not supported.
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```
class A {
pubic:
   // ...
   virtual void f(int x)
      [[expects: x>0]]
   {
      [[assert: x<max]];
      // ..
   }
};
```

```
class B : public A {
pubic:
   // ...
   virtual void f(int x) override
      [[expects: x>0]]
   {
      // ...
   }
};
```

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pubic:
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      [[ensures r: r>=0]]
   {
      // ..
   }
};
```

```
class B : public A {
pubic:
   // ...
   virtual int g() override
      [[ensures r: r>=0]]
   {
      // ...
      [[assert: result<max]];
      return result ;
   }
};
```

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  - Get ready with C++ Core Guidelines Support Library (GSL).

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```
class account {
  account(int b)
    [[expects: b >= min]]
    [[ensures: balance_ == b]]
  : balance_{b}
  {}
  // ...
private:
  constexpr int min = 1000;
  int  balance_;
};
```

```
class account {
  account(int b)  : balance_{b}
  {
    Expects(b >= min);
    Ensures(balance_ == b);
  }
  // ...
private:
  constexpr int min = 1000;
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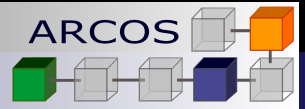

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- Do not forget to get ready with GSL.
- But most important, you can still **provide feedback**:
  - `josedaniel.garcia@uc3m.es`.

Contracts programming for C++20

Current proposal status

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April, 28th, 2017