Object-Oriented Design and Programming

Programming with Assertions and Exceptions

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What Are Assertions?

- Assertions are boolean expressions that serve to express the semantic properties of classes and member functions.

- Assertions are similar to the mathematical notion of a predicate.

- Assertions are tools for expressing and validating the correctness of modules, classes, and subprograms.
Four Purposes for Assertions

- Aid in constructing correct programs.
  - *e.g.*, specify input preconditions and output postconditions.

- Documentation aid.
  - *e.g.*, supports “programming by contract”

- Debugging aid.
  - Find out where/when assumptions are wrong…

- Basis for an exception mechanism.
  - *e.g.*, integrate with exceptions by allowing assertion failures to be caught dynamically.
Types of Assertions

- Assertions are used for several purposes:
  - **Preconditions**
    * State the requirements under which subprograms are applicable.
  - **Postconditions**
    * Properties guaranteed upon subprogram exit.
  - **Class Invariants**
    * Properties that characterize class instances over their lifetime
      - Note, subprogram preconditions and postconditions are implicitly assumed to include the class invariant.
  - **Loop Invariants**
    * Loop invariants specify properties that are always true during the execution of a loop.
Assertion Example

• -- Eiffel array

class ARRAY[T] export
  lower, upper, size, get, put

feature
  lower, upper, size : INTEGER;

Create (minb, maxb : INTEGER) is do ... end;

get (i : INTEGER): T is
  require -- precondition
    lower <= i; i <= upper;
  do ... end;

put (i : INTEGER; value : T) is
  require
    lower <= i; i <= upper;
  do ...
  ensure -- post condition
    get (i) = value;
  end;

invariant -- class invariant
  size = upper - lower + 1; size >= 0;
end -- class ARRAY
Programming by Contract

• Assertions support *Programming by Contract*.
  
  – This formally specifies the relationship between a class and its clients, expressing each party’s rights and obligations.

• *e.g.*,
  
  – A *precondition* and a *postcondition* associated with a subprogram describe a contract that binds the subprogram.

  * But only if callers observe the precondition. . .

• The contract guarantees that if the *precondition* is fulfilled the *postcondition* holds upon subprogram return.
Using Assertions to Specify ADTs

- Conceptually, ADTs consist of four parts:
  
  (1) *types*
  (2) *functions*
  (3) *preconditions/postconditions*
  (4) *axioms*

- However, most languages only allow specification of the first two parts (*i.e.*, *types* and *functions*)

- Assertions provide a mechanism to express the preconditions and axioms corresponding to ADTs.
  
  — However, few general purpose languages provide support for complete ADT specifications, Eiffel goes further than most in this regard.
Handling Assertion Violations

- If the client’s part of the contract is not fulfilled (i.e., if the caller does not satisfy the preconditions) then the class is not bound by the postcondition.

- This can be integrated with an exception handling mechanism, e.g.:
  
  Exceptions are generated:
  
  (1) when an assertion is violated at run-time
  (2) when the hardware or operating system signals an abnormal condition.

- Note, exceptions should not be used as non-local gotos.

* They are a mechanism for dealing with abnormal conditions by either:

  (1) **Termination**: cleaning up the environment and reporting to the caller,
  (2) **Resumption**: attempting to achieve the aim of the operation.
Assertions in C

- Enabled by including the `<assert.h>` header.

- It incurs no code size increase and no execution speed decrease in the delivered product.

- Typical definition via a macro definition such as:

```
#ifdef NDEBUG
#define assert( ignore) 0
#else
#define assert(ex)  
    ((ex) ? 1 : 
        ( __eprintf("Failed assertion " #ex  
            " at line %d of "%s":\n", \n            __LINE__, __FILE__), abort (), 0))
/* Note use of ANSI-C "stringize" facility.
#endif // NDEBUG
```
Assertions in C (cont’d)

- If the expression supplied to the `assert` macro is false, an error message will be printed and the program will STOP DEAD AT THAT POINT!

- e.g., provide array bounds checking

```c
#include <string.h>
/*@ ...*/
{
    char *callers_buffer;
    char buffer[100];
   /*@ ...*/
    assert (sizeof buffer > 1 + strlen (callers_buffer));
   /*@ Program aborts here if assertion fails. */
    strcpy (buffer, callers_buffer);
   /*@ ...*/
}
```
Assertions in C (cont’d)

- Another interesting application of assert is to extend it to perform other duties as well.
  
  - e.g., code profiling and error logging:

    ```c
    #define assert(x) { \
    static int once_only = 0; \
    if (0 == once_only) { \
        once_only = 1; \
        profile_assert ("__LINE__", "__FILE__"); \
    } \
    /* ...*/ \
    /* standard assert test code goes here */ \
    }
    ```

- However, the main problem C assert is that it doesn’t integrate with any exception handling scheme.

  - e.g., as contrasted to Eiffel.
Assertions in C++

• The overall purpose of the proposed ANSI-C++ assertion implementation is twofold:

  1. To provide a default behavior similar to the C `assert` facility.

  2. To rely on specific C++ facilities (e.g., templates and exceptions) to provide a more generic and powerful support than simple macros.
Assertions in C++ (cont’d)

- What follows is the proposed implementation:

```cpp
// -- file assert.h --
#ifndef __ASSERT_H
#define __ASSERT_H
#ifndef NDEBUG
#include <iostream.h>
extern "C" void abort (void);
// -- generic implementation
template <class E> class __assert {
 public:
  __assert (int expr, const char *exp, const char* file, int line) {
    if (!expr) throw E (exp, file, line);
  }
  __assert (void *ptr, const char *exp, const char* file, int line) {
    if (!ptr) throw E (exp, file, line);
  }
};
```
Assertions in C++ (cont’d)

• Proposed implementation (cont’d)

    // -- specific C++ macro (needed for preprocessing!)
    #define Assert (expr, excep) \n        ( __assert<excep> (expr, #expr, \n            _FILE__, _LINE__) )

    // -- standard exception
    class Bad_Assertion {
        public:
            Bad_Assertion (const char *exp,
                            const char* file, int line) {
                cerr << "Assertion failed: " << exp
                << ", file " << file
                << ", line " << line << 'n';
                abort ();
            }
    };
    // -- C-like macro
    #define assert(expr) (Assert (expr, Bad_Assertion))
    #else /* !NDEBUG */
    #define Assert (expr, excep) (0)
    #define assert (expr) (0)
    #endif /* NDEBUG */
    #endif /* __ASSERT_H */
Assertions in C++

- The C++ assert Macro

  - As with the C macro, the C++ assert macro is intended to be used as the irrevocable detection of a program failure.

  - A trivial example is null pointer testing, as in:

    ```
    class String {
    // ...
    public:
        String (const char* p) {
            assert (p != 0); // C++ macro
            /* Aborts if p == 0 */
            ...  
        }
    }
    ```

  - Validity of the expression is checked and a rudimentary message is printed in case of failure.
Assertions in C++ (cont’d)

- The C++ Assert Macro

  - The primary goal of the Assert macro is to delegate the responsibility for handling the failure to the caller.

  * e.g., print appropriate error messages, make a call to exit instead of abort...

  - A typical example is range checking of a subscript operator, as in:

    ```
    class Checked_Vector : public Vector {
    public:
        class Out_of_Range {
            int l;
        public:
            Out_of_Range (const char *, const char *, int line) :
                l (line) {}
            int line (void) { return l; }
        };
        int& Checked_Vector::operator[](int index) {
            Assert (index >= 0 && index < size, Checked_Vector::Out_of_Range);
            // ...
        }
    };
    ```
Assertions in C++ (cont’d)

- The Assert Macro (cont’d)

  - e.g.,

```cpp
int f (Checked_Vector &v, int index) {
  int elem;
  try {
    elem = v[index];
  }
  catch (Checked_Vector::Out_Of_Range &e) {
    cerr << " Checked_Vector:"
    << " range checking failed:"
    << " index="
    << index
    << ", size= " << v.size ()
    << ", line= " << e.line ()
    << 'n';
    exit (-1);
  }
  return elem;
}
```
Assertions in C++ (cont’d)

- The Assert Macro (cont’d)

  - Since the exception is thrown before the program failure occurs (e.g., Out_Of_Range), the environment is not corrupted when the runtime flow returns to the caller.

  - If an exception is not caught (as is the case for the Checked_Vector::Out_Of_Range above), a call to terminate is performed.

    - The default behavior of terminate is to call abort.

  - An uncaught exception resulting from a call to Assert will thus unwind the stack, unlike a call to assert. Calls to local destructors will be performed.

    - Note, this can alter the conditions under which the failure occurred.