Exceptions
- General way to handle errors
- Error handling without exceptions:
  o Requires a lot of tedious and error prone programming
  o All functions must agree on “error” return values
  o Complicated flow control
  o Must remember to release resources
  o Hard to get out of deeply nested loops
  o Hard to deal with deeply nested function calls
- Constructors errors are especially problematic
  o No return value, so must use flags
  o Must remember to check flags
- Need flexible ways to deal with error conditions
  o Especially for library code

Syntax of C++ Exceptions
- Similar to Java exceptions
- No keyword exception, and no exception type
  o Any object can be thrown as an exception
  o An exception is just a piece of data
- Two perspectives of exceptions
  o Generating the exception (throwing the exception)
  o Dealing with the event of the exception (catching the exception)
- Exceptions are generated with the reserved word throw
  o Indicates change of flow control, just like return
  o Usually requires an expression – the exception to be thrown
    ▪ May be any type of data
  o If no expression, then the current exception is re-thrown
    ▪ Run time error if there is no current exception
  o Other use of the reserved word throw is as an interface specification
    ▪ Indicates that a function will throw a particular exception
    ▪ throw() indicates function will not throw any exception
    ▪ May enclose comma separated list of exception types that will be thrown
    ▪ If another type is thrown, then std::unexpected() called, which terminates
    ▪ Default is that any exception type can be thrown
- Exceptions are handled by a combination of reserved words try and catch
  o The try block defines an area during which we want exceptions to be handled by our catching code
    ▪ try delineates the “normal” code to be executed, not the handling code
  o A try block is followed one or more catch blocks
    ▪ Each catch block indicates the exception type it is catching
    ▪ Exception value is like a function argument – type and identifier
    ▪ Delineates the code to be executed to handle the exception
Control Flow
- Each try block pushes another set of exception handlers on the runtime stack
- When an exception is thrown, the exception type is matched against the most recently pushed handler for that type
  - Inheritance relations hold for the matching of handlers
- If there is no matching handler, the default action is to terminate
- Think of the exception throw-catch as a long jump
- May be local within same function (e.g., throw could be nested inside of try block)
- May be transfer to calling function
- May be very long jump, unwinding an arbitrary number of function calls
- Housekeeping is done along the way
  - Stack frames are popped
    - Destructors for locals called
    - Basically all the housekeeping of an explicit return
    - But also applies to all intervening function calls
    - Exceptions do not violate consistent treatment expected from well defined constructors and destructors
    - Exception thrown from constructor means the object is not constructed (and if partially constructed, e.g., base classes, that work is undone, i.e., base destructors are called)
- No finally clause as in Java

Coding Conventions
- Exceptions thrown by a class can be nested definitions in throwing class
  - Allows name spaces to be simpler
- Use inheritance hierarchies to group related exceptions
  - virtual functions to provide exception specific information or handling

Exception Example
- Class IntArray is the integer array, now with exception handling
- Throws two types of exceptions
  - OutOfSpace from constructors, assignment
  - OutOfBounds from array operator
  - Both derive from IntArray::Error
- The code:
  ```cpp
  class IntArray {
    public:
      IntArray(int size) : len(size) {
        try {
          data = new int[len];
        } catch(const exception &) { throw OutOfSpace(len); }
      }
      IntArray(const IntArray & a) : len(a.len) {
        try {
          data = new int[len];
        } catch(const exception &) { throw OutOfSpace(len); }
      }
  }
  ```
for (int i = 0; i < len; ++i) data[i] = a.data[i];
}

// Array element access - lvalue and rvalue
virtual int & operator [] (int i) {
    if (i < 0 || i >= len) throw OutOfBounds(i, len);
    else return data[i];
}

virtual int operator [] (int i) const {
    if (i < 0 || i >= len) throw OutOfBounds(i, len);
    else return data[i];
}

// Assignment (sizes need not match)
IntArray & operator = (const IntArray & a) {
    if (this == &a) return *this;
    try {
        delete [] data; data = new int[len = a.len];
    } catch(const exception &) { throw OutOfSpace(len); }
    for (int i = 0; i < len; ++i) data[i] = a.data[i];
    return *this;
}

. . .

public:
    // Exceptions
    class Error {
    public:
        Error(int n) : _size(n) { }
        virtual ~Error() { }
        virtual void print(ostream & o) const = 0;
        int size() const { return _size; }
    private:
        const int _size;
    };

    class OutOfSpace : public Error {
    public:
        OutOfSpace(int n) : Error(n) { }
        void print(ostream & o) const {
            o << "IntArray out of space, size " << size();
        }
    private:
    };

    class OutOfBounds : public Error {
    public:
        OutOfBounds(int i, int n) : Error(n), _index(i) { }
        void print(ostream & o) const {
            o << "IntArray out of bounds access, index "
               << _index << ", size " << size();
        }
    private:
        const int _index;
    };

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};

inline
ostream & operator << (ostream & o, const IntArray::Error & e) {
    e.print(o);
    return o;
}

- And here’s some of the driver code:

    try {
        IntArray a(size);
        for (int i = 0; i < a.length(); ++i)
            a[i] = i;
        IntArray b(2*size);
        for (int i = 0; i < b.length(); ++i)
            b[i] = 2*i + 1;
        a = b;
        a[index] = -1;
    } catch (const IntArray::Error & err) {
        // Report the caught exception
        cout << "* Caught array error: " << err << endl;
    }