CS11 Advanced C++

Spring 2012-2013

Lecture 5

Build Automation

- Standard development cycle:
  - Write more code
  - Compile
  - Test
  - Repeat until done…
- Automating this process saves lots of time
- Intelligent build tools *dramatically* improve build-times for large software projects
  - Projects that take minutes or hours to build

`make`

- **`make`** is a standard tool for automating builds
  - Command-line utility, very ubiquitous!
  - Takes input files and produces output files, based on a "makefile"
  - Several versions of **`make`**: GNU, BSD, …
- **`make`** is largely used for C and C++ projects
  - Sometimes other build tools are used for C/C++
    - Perforce Jam is one common alternative
    - Visual C++ provides **`nmake`** command-line build program
  - Other languages typically have their own build tools
    - e.g. Ant is frequently used for Java projects

Other Build-Tools

- For large projects, other tools are also used alongside **`make`**
  - **`autoconf`**, etc. for providing source-portability
    - Generates a **`configure`** script for configuring your program

      ```
      ./configure --prefix = /usr/local/myprog
      make
      make install
      ```
  - **`libtool`**, etc. for building shared libraries on different platforms
  - **`install`**, **`rpmbuild`**, etc. for updating system directories
  - **`doxygen`**, DocBook, etc. for doc-generation

Makefiles

- The makefile describes build targets
  - Each target specifies its dependencies
  - Each target also specifies how to build that target from the dependencies
- Typical filename is **`Makefile`** or **`makefile`**
  - **`make`** looks for these by default
  - Preferred name is **`Makefile`**
  - Can specify another makefile using **`-f`** option

Makefiles (2)

- When **`make`** is run, a build target can be specified
  - **`make raytrace`**
  - If no target is specified, the first target in the makefile is run
    - **`make`**
  - First target is usually named **`all`**, and builds everything
  - Can also specify multiple build targets:
    - **`make clean raytrace`**
- Whitespace matters in makefiles!
  - Indentation is significant!
  - Tabs must be used for indentation!

Example Makefile

- Form of rules:

```
target : dependencies
        commands
```

- Example:

```
lab4 : main.o entry.o except.o config.o
        g++ -o lab4 main.o entry.o except.o config.o

main.o : main.cc entry.hh except.hh config.hh
        g++ -Wall -c main.cc

... (more rules)

clean :
        rm -f lab4 *.o *~
```

- Lines indented with tab characters – spaces won't work!
- A line can be continued on next line, by ending it with \
- Can specify multiple commands, if rules are separated by a blank line

Real Build Targets

- From our example:

```
main.o : main.cc entry.hh except.hh config.hh
        g++ -Wall -c main.cc
```

- In this case, **`main.o`** is a real file
- **`make`** will only build what is *needed*
  - If target file's date is older than any dependency, **`make`** will rebuild the target
- To force a file to be rebuilt, **`touch`** it:
  - **`touch main.cc`**
  - Sets file's modification-time to current system time
  - Touching a nonexistent file will create a new empty file

Phony Build Targets

- From our example:

```
clean :
        rm -f lab4 *.o *~
```

- In this case, **`clean`** is *not* a real file
- What if there happened to be a file named **`clean`** ?
  - Our rule wouldn't run!
  - **`make`** would see the "build-target" file, and assume it didn't have to run
- Use **`.PHONY`** to say that **`clean`** target isn't a file

```
.PHONY : clean
```

  - Now if a file named **`clean`** exists, **`make`** ignores it

Chains of Build Rules

- make figures out the graph of dependencies

```
lab4 : main.o entry.o except.o config.o
        g++ -o lab4 main.o entry.o except.o config.o
```

- If any of **`lab4`**'s dependencies don't exist, **`make`** will use their build rules to make them

```
main.o : main.cc entry.hh except.hh config.hh
        g++ -Wall -c main.cc
```

- **`make`** will give up if:
  - A dependency can't be found, and there's no build rule that shows how to make it

Makefile Variables

- Makefiles can define variables

```
OBJS = main.o entry.o except.o config.o
```

  - Can use variables in build rules

```
lab4 : $(OBJS)
        g++ $(OBJS) -o lab4
```

  - **$(*var-name*)** tells **make** to expand the variable
- Use variables to avoid listing the same things all over the place
  - Same as code reuse: only make changes in one place
- Makefile variable names are usually **ALL_CAPS**

Implicit Build Rules

- **`make`** already knows how to build certain targets
  - Those targets have built-in rules for building them
  - These built-in rules are called *implicit* build rules
- Example:
  - A makefile has **`main.o`** as a dependency, but no build rule
  - If **`main.c`** exists, **`make`** will use **`gcc`** to generate **`main.o`**
  - If **`main.cc`** exists, **`make`** will use **`g++`** to generate **`main.o`**
- **`make`** has quite a few implicit build rules
  - Read **`make`** documentation for more details!

Using Implicit Rules

- Implicit rules make your makefiles *much* shorter
  - Can leave out rules for all the object files

```
OBJS = main.o entry.o except.o config.o

lab4 : $(OBJS)
        g++ -o lab4 $(OBJS)

clean :
        rm -f lab4 *.o *~

.PHONY : clean
```

- What about header file dependencies?
  - Can specify rules for each object file:

```
main.o : entry.hh except.hh config.hh
```

    - No command – these rules just specify dependencies
  - **`makedepend`** auto-generates these from your source files!

Definitions of Implicit Rules

- Examples of implicit rules:

```
# C compilation implicit rule
%.o : %.c
        $(CC) -c $(CPPFLAGS) $(CFLAGS) $< -o $@

# C++ compilation implicit rule
%.o : %.cc
        $(CXX) -c $(CPPFLAGS) $(CXXFLAGS) $< -o $@
```

- Variables are used for compiler and options!
  - **`CC`** is C compiler, **`CXX`** is C++ compiler
  - **`CFLAGS`**, **`CXXFLAGS`** are compiler-options
  - **`CPPFLAGS`** are the preprocessor flags
  - Default values are for **`gcc`** and **`g++`**
  - Can easily customize these rules, by setting these variables at the top of your makefile

Definitions of Implicit Rules

- Implicit rules use patterns:

```
# C compilation implicit rule
%.o : %.c
        $(CC) -c $(CPPFLAGS) $(CFLAGS) $< -o $@

# C++ compilation implicit rule
%.o : %.cc
        $(CXX) -c $(CPPFLAGS) $(CXXFLAGS) $< -o $@
```

- Special syntax for pattern-matching
  - `%` matches the filename
  - **`$<`** is the first prerequisite in the dependency list
  - **`$@`** is the filename of the target
  - These **`$`**... values are called automatic variables
  - Other automatic variables too!
    - e.g. **`$^`** is list of *all* prerequisites in the dependency list

`make` References

- For more details, see the GNU `make` manual
  - http://www.gnu.org/software/make/manual/

Automatic Document Generation

- Automating API-doc generation is a very powerful technique
  - Comment your code according to a specified style
  - Run a documentation-generator on your code
  - Produces API documentation of your code, in HTML, PDF, etc. formats, ready for distribution!
- The documentation is in one place – your source
  - Tools can use the code as well as your comments in the generated output
- Several different options for doc-generation
  - We will use doxygen: http://www.doxygen.org

Doxygen Configuration

- Doxygen is driven by a config file
  - It will generate a template file for you:
    - **`doxygen -g [`*`filename`*`]`**
  - Default filename is **`Doxyfile`**
- Customize the config file for your project
  - Set different configuration parameters as needed
  - Parameters are *well documented* in the config file
- Parameter names are **`ALL_CAPS`**
  - (just like makefile variables)
  - Parameter-value can extend to next line, if current line ends with **`\`** (backslash) character
  - Switches are specified with **`YES`** or **`NO`**

Doxygen Config Tips

- You should set:
  - **`INPUT`** (input files/directories)
  - **`OUTPUT_DIRECTORY`** (where results go)
  - **`PROJECT_NAME`**
- Other good settings to use:
  - **`JAVADOC_AUTOBRIEF = YES`**
  - **`EXTRACT_ALL = YES`**
  - **`EXTRACT_PRIVATE = YES`**
  - **`EXTRACT_STATIC = YES`**

Commenting Your Code

- Several different formats are recognized

```
/**
 * This is a comment for my class.  It is spiffy.
 */
class MyClass { ... };
```

  - **`/**`** starts the comment (javadoc style)
  - Can also start with **`/*!`** (Qt style)
  - Also several other options (see doxygen manual)
- Classes, types, functions have a brief comment, and a detailed comment
  - If **`JAVADOC_AUTOBRIEF`** is defined in doxygen config, first sentence is used as brief comment.
  - Otherwise, must use **`\brief`** keyword in your comments

Structural Commands

- "Structural commands" specify what a comment is associated with
  - "This is a comment for the source file."
  - "This is a comment for class **`C`**."
  - "This is a comment for parameter **`x`** of the function."
  - etc.
  - Allows Doxygen comments to be separated from entities that are being commented. (Not always recommended…)
- Two different formats for structural commands
  - Doxygen format: **`\cmd`**
  - Javadoc format: **`@cmd`**
  - Can use either format, but be consistent! ☺

What Can Be Commented?

- Files can be given comments
  - Must do this for doxygen to pick up certain comments
  - Examples:
    - `/*! \file ... */` (Qt/Doxygen format)
    - `/** @file ... */` (Javadoc format)
- Any type can be given a doxygen comment
  - Classes, structs, enums, typedefs, unions, namespaces
  - Comment should immediately precede the type
    - …unless you are using structural commands
- Preprocessor definitions can also be commented!
  - **`#define`** symbols, macros

Commenting Variables and Functions

- Global/static variables, and member variables
  - Comments can precede the variable:

```
/** My special widget. */
SpecialWidget sw;
```

  - Or they can follow the variable, on the same line:

```
SpecialWidget sw;  /**< My special widget. */
```

    - (Note the < character)
- Functions and their parameters/return values
  - Parameters follow this pattern:
    - `@param name Description`
    - `\param name Description`
  - Return value is documented with `\return` or `@return`

Running **doxygen**

- Doxygen is simple to run:

  doxygen [*filename*]

  - **doxygen** uses **Doxyfile** if no config file is given
  - Basically no command-line arguments
    - Config file contains all the details!
- Results are stored in output directory
  - Each format gets its own subdirectory
  - **html** for HTML output, **latex** for LaTeX, etc.
  - Can specify alternate output directories if desired.

doxygen References

- For more details, see the **doxygen** manual
  - http://www.stack.nl/~dimitri/doxygen/manual.html
  - http://www.doxygen.org

C++ Exceptions

- Exceptions are nice for reporting many errors
  - Code throwing the exception can detect the problem, but doesn't know how to handle it.
  - Code that catches the exception knows what to do about the problem.
  - With *careful* implementation of constructors and destructors, resources get cleaned up, too.
- C++ Standard Library provides a number of standard exception classes

Simple Example

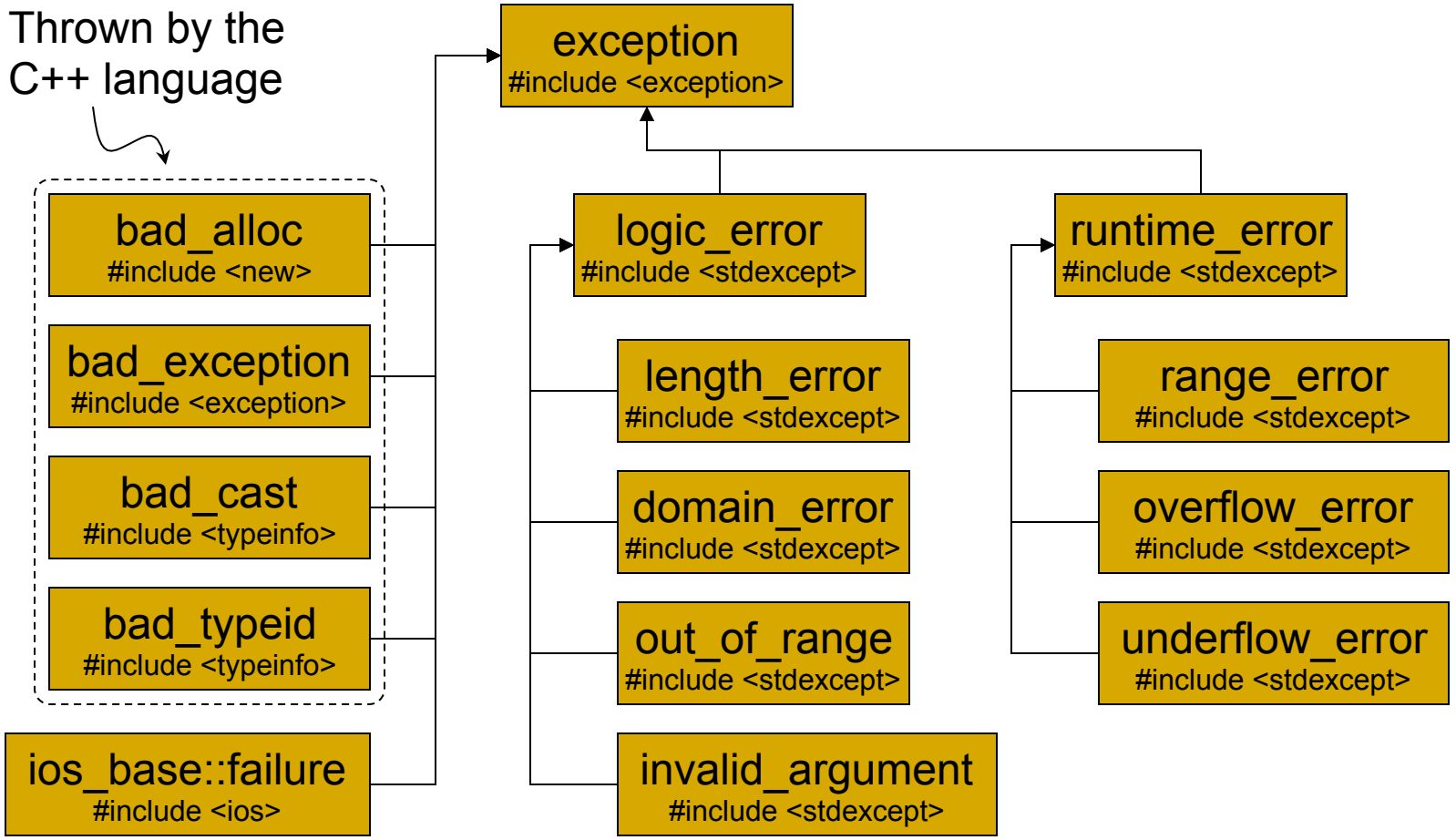
```
void calculate(float x) {
  if (x < 0)
    throw domain_error("x is negative");

  // Do our calculation.
  ...
}

int main() {
  float x;
  cin >> x;
  try {
    calculate(x);
  } catch (domain_error) {
    cout << "Caught a domain error!" << endl;
  }
}
```

What Happened?

```
void calculate(float x) {
  if (x < 0)
    throw domain_error("x is negative");

  // Do our calculation.
  ...
}

int main() {
  float x;
  cin >> x;
  try {
    calculate(x);
  } catch (domain_error &de) {
    cout << "Caught a domain error!" << endl;
    cout << de.what() << endl;
  }
}
```

C++ Standard Exceptions provide a **`what()`** function to retrieve error details.

C++ Standard Exceptions



Standard Exception Hierarchy

- Two major kinds of standard exceptions
- **`logic_error`**
  - Intended for “preventable” errors, a.k.a. bugs
  - Invalid function arguments, violated invariants, etc.
  - A potential alternative to using **`assert()`**
  - Steer clear of these for reporting runtime errors!
- **`runtime_error`**
  - “All other errors.”
  - Errors that can only be detected as the program executes

Using the Standard Exceptions

- These are available for use in your programs.
  - Use them as-is, subclass them, or ignore them and make your own!
  - You will *probably* have to handle them, at least…

"Some people view this as a useful framework for all errors and exceptions; I don't."

- Bjarne Stroustrup

The C++ Programming Language §14.10

Local Variables and Destructors

- Normally, destructors are called when variables go out of scope

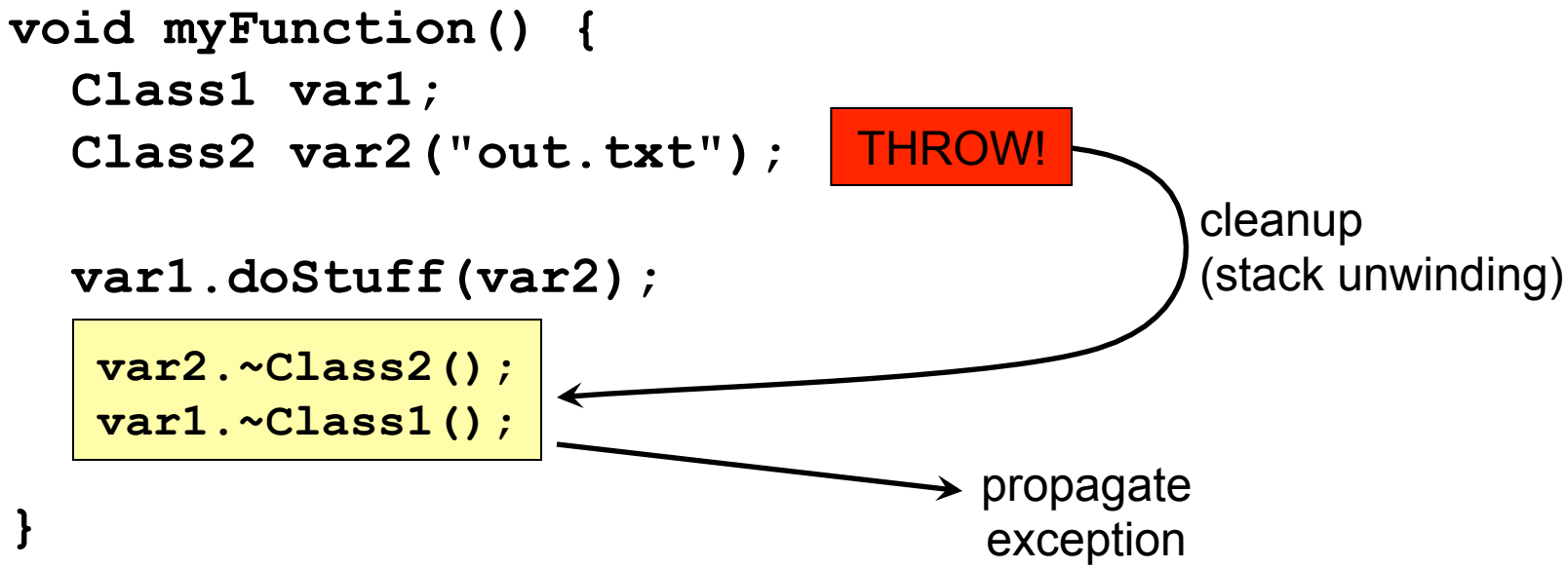
```
void myFunction() {
  Class1 var1;
  Class2 var2("out.txt");

  var1.doStuff(var2);
}
```

Compiler adds:

```
var2.~Class2();
var1.~Class1();
```

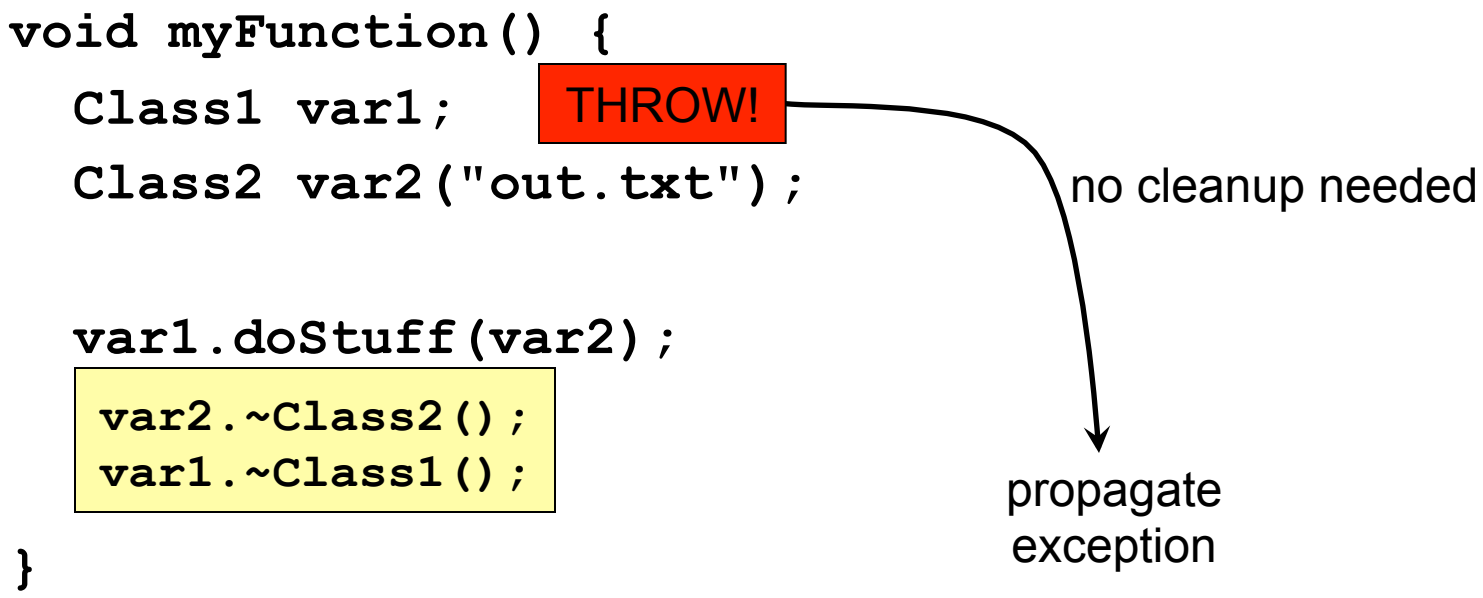
  - Compiler inserts destructor calls into the appropriate places
  - Your code doesn't manually call destructors, ever.

Destructors and Exceptions



- What happens if **`var2`** constructor throws?
  - Only **`var1`** was constructed, so only **`var1`** destructor gets called

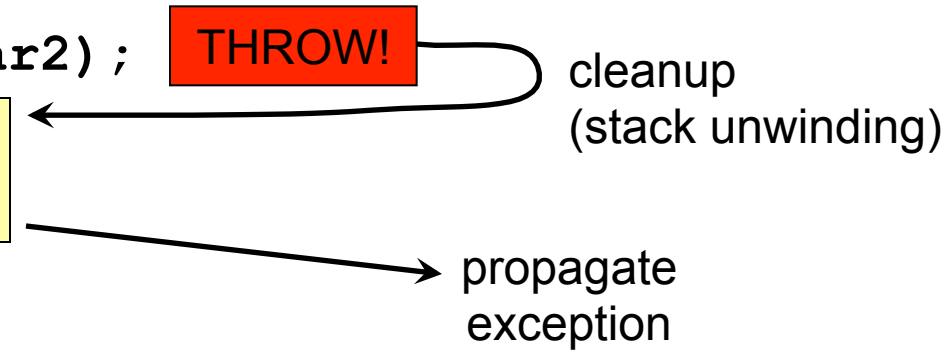
Destructors and Exceptions (2)



- What happens if **`var1`** constructor throws?
  - Nothing was constructed, so no destructors get called

Destructors and Exceptions (3)

```
void myFunction() {
  Class1 var1;
  Class2 var2("out.txt");

  var1.doStuff(var2);
  var2.~Class2();
  var1.~Class1();
}
```



- What happens if **`var1.doStuff(var2)`** throws?
  - Both **`var1`** and **`var2`** were constructed, so both destructors get called (in reverse order of construction)

Classes and Exceptions

- Similar model used when constructors throw

```
class Logger {
  LogConfig config;
  RotatingFile outputFile;
public:
  Logger(const string &configFile) {
    ...  // initialize logger
  }
  ...
};
```

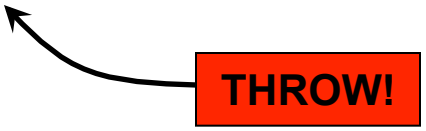
THROW!

  - What happens if the constructor body throws?
    - The new **`Logger`** instance failed to be constructed
    - **`config`** and **`outputFile`** have already been initialized, so their destructors are automatically called

Classes and Exceptions (2)

- Member initialization might also throw

```
class Logger {
  LogConfig config;
  RotatingFile outputFile;
public:
  Logger(const string &configFile) :
    config(configFile), outputFile(config)
  {
    ...  // initialize logger
  }
  ...
};
```

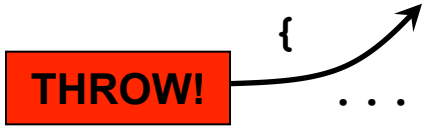


  - What happens if **`outputFile`** constructor throws?
    - The new **`Logger`** instance failed to be constructed (again)
    - **`config`** was already initialized, so its destructor gets called

Classes and Exceptions (3)

- Another member constructor throws

```
class Logger {
  LogConfig config;
  RotatingFile outputFile;
public:
  Logger(const string &configFile) :
    config(configFile), outputFile(config)
  {
    ...  // initialize logger
  }
  ...
};
```



  - What happens if **`config`** constructor throws?
    - The new **`Logger`** instance failed to be constructed (yet again)
    - Nothing was initialized, so no member destructors are called

Heap-Allocation and Exceptions

- What if members are heap-allocated?

```
Simulator::Simulator(SimConfig *pConf) {
  // Initialize my simulator members.
  entityData = new Entity[pConf->maxEntities];
  playerData = new Player[pConf->maxPlayers];
}
```

  - If an allocation fails, **`new`** will throw **`bad_alloc`**
- What happens if second allocation throws **`bad_alloc`**?
  - Simple: **`entityData`** doesn't get cleaned up

A Safer Constructor

- Can fix the problem by doing this:

```
Simulator::Simulator(SimConfig *pConf) :
  entityData(0), playerData(0)
{
  try {
    entityData = new Entity[pConf->maxEntities];
    playerData = new Player[pConf->maxPlayers];
  }
  catch (bad_alloc &ba) {
    delete[] entityData;
    delete[] playerData;
    throw;   // Don't forget to propagate this!
  }
}
```

  - Not the prettiest code, but at least it's safe.

Again and Again!

- This pattern gets old fast:

```
void initSimulation() {
  SimConfig *pConf = new SimConfig("sim.conf");
  Simulator *pSim = new Simulator(pConf);
  ...
}
```

  - What if **`Simulator`** constructor throws?
    - (sigh)

- This approach to leak-free, exception-safe code is a pain!

Safe Dynamic-Resource Management

- Problem:
  - Dynamic allocation of resources, plus exception-handling, is a potentially dangerous mix!
    - Memory allocated with **`new`**
    - Opening files, pipes, etc.
    - Threads, mutexes, condition variables, semaphores, …
  - Just catching exceptions isn't enough!
  - Also need to release any resources that were allocated before the exception was thrown.

Typical Resource Allocation Model

- General form of the problem:

```
void doStuff() {
  // acquire resource 1
  // ...
  // acquire resource N

  // use the resources

  // release resource N
  // ...
  // release resource 1
}
```

  - Resources usually released in opposite order of allocation
- Hey, C++ constructors and destructors do this!
  - Local variables are created and destroyed this way

Easier Leak-Proofing Approach!

- Make a wrapper class for managing a dynamic resource
  - Constructor allocates the dynamic resource
    - (or constructor assumes ownership of the resource)
  - Destructor frees the resource
  - Use the wrapper class for local variables
    - (Otherwise, you're back to the old problems again…)
- "Clean up" handlers become unnecessary
  - When exception is thrown, C++ calls wrapper-class destructor automatically, since it's local.

“Resource Allocation Is Initialization”

- This pattern is called “Resource allocation is initialization.”
  - A local variable’s constructor immediately assumes ownership of the dynamic resource
  - C++ will call the destructor at the Right Time.
- Typically realized as “smart pointers”
  - They follow this model for heap-allocated memory
- This can be applied to *any* dynamic resource
  - Files! Semaphores! Mutexes! …

The C++ `auto_ptr` Template

- C++ Standard Library's contribution to memory management tools
  - A simple smart pointer, in **`std`** namespace
  - Implements "resource allocation is initialization" pattern for object-pointers.
  - Great tool, *when used correctly!*
- Must understand what **`auto_ptr`** does!
  - It is a single-ownership smart pointer
  - Only one **`auto_ptr`** instance owns a given object-pointer.

Implications of Single-Ownership

- Assigning one **`auto_ptr`** to another, changes what is assigned.

```
auto_ptr<Widget> spw(new Widget());
auto_ptr<Widget> spw2;
...
spw2 = spw;  // Now spw == 0!
```

- Copying one **`auto_ptr`** into another (e.g. with copy-constructor), changes what is copied.

```
auto_ptr<Widget> spw(new Widget());
...
auto_ptr<Widget> spw2(spw);   // Now spw == 0!
```

- Makes sense in context of single-ownership idea
- Will catch you off guard if you don't know this!
  - Copying or assigning something doesn't usually change it

STL Containers and `auto_ptr`

- STL containers and **`auto_ptr`** don't mix!
  - Copy operations on STL container-items should not change what is copied
  - **`auto_ptr`** has a nonstandard meaning for copying and assignment
- Don't ever use **`auto_ptr`** to wrap items in STL containers. It is forbidden.
  - Unfortunately, some (bad) STL implementations will allow it…

Smart-Pointer Operator Overloads

- Smart pointer classes overload these operators:
  - Dereference (member-access) operator **->**
  - Dereference operator ***** (not multiplication…)
  - Allows the smart-pointer to act like a pointer
- STL iterators do basically the same thing…
  - Slightly different use cases
  - Smart pointers don't support pointer-arithmetic
    - For example: no **++** and **--** operators!

A Smart-Pointer Sketch

- A simple (and very incomplete) example:

```
template<typename T>
class PointerToT {
    // Pointer to the resource being managed
    T *ptrT;
public:
    PointerToT(T *p) : ptrT(p) { }
    ~PointerToT() { delete ptrT; }
    T * operator->() { return ptrT; }
    T & operator*() { return *ptrT; }
    ...
};
```

- The hard parts:
  - Define semantics of copy-construction, assignment, casting operations up/down class hierarchies, etc.

The Boost Libraries

- Boost is a collection of portable, peer-reviewed libraries
  - Some libraries in process of being added to C++ Standard
  - Some Boost developers are C++ Standards Committee members
  - Freely available, good license
- A bit of a pain to set up
  - Uses Boost.Jam build tool (derived from Perforce Jam)
  - Some templates have binaries to build and link against
  - Can exclude libraries with binaries (if you config it just right)
  - Or, can use some Boost headers without building it all…

Boost **shared_ptr** Template

- In Boost's smart pointer library
- **shared_ptr** supports multiple-ownership
  - Uses reference-counting to know when to delete
  - Uses templates and operator overloading to make use seamless.

```
// Use a typedef to avoid unnecessary typing
typedef boost::shared_ptr<Widget> SPWidget;

vector<SPWidget> widgetSPs;
SPWidget wsp(new Widget(...));

cout << wsp->getID();        // Can treat smart-pointer
Widget w = *wsp;             // like a normal Widget*

widgetSPs.push_back(wsp);    // No need to clean up!
```

Shared Pointers: The Good

- Clean up is automatic!
  - No cleanup exception handlers
  - No looping over collections of pointers, to delete the contents
  - No delete functors
- If you assign the result of every **`new`** to a suitably clever, *named* smart-pointer variable:
  - No need for explicit **`delete`** code
  - The need for **`try`**/**`catch`** blocks will be rare

Shared Pointers: The Bad

- Can *still* have subtle bugs. (Thanks, C++!)
- This works fine:

```
vector<SPWidget> widgetSPs;  // Vector of shared_ptrs
widgetSPs.push_back(SPWidget(new Widget()));
```

- This *might* leak:

```
processWidget(SPWidget(new Widget()), getTicket());
```

  - No guarantee on order of evaluation in function arguments!
    - New **`Widget`** is constructed…
    - …then **`getTicket()`** goes and throws an exception!
    - **`shared_ptr`** constructor never got called! Leaky…
- Moral: "Avoid using unnamed **`shared_ptr`** temporaries to save typing…"

Final Pointer Tips

- **`auto_ptr`** is a nice tool, when used properly
  - Remember that it's a single-ownership pointer
  - Good for heap-allocated memory used within one function
  - Never use it inside STL containers
- Use Boost's **`shared_ptr`** for multiple-ownership smart pointers
- Remember other smart pointer pitfalls, too
  - Anonymous smart pointers in function args, for example
- See the Boost smart-pointer documentation
  - http://www.boost.org/libs/smart_ptr/smart_ptr.htm
- Effective STL by Scott Myers

This Week's Assignment

- Create a **`makefile`** for your program
- Update your source code to use Boost smart pointers
- Update your source code to use doxygen-style comments
  - Add a **`docs`** target that runs doxygen
  - Make sure your commenting is complete!
  - Every class, member function, data-member, etc.