EECS 280

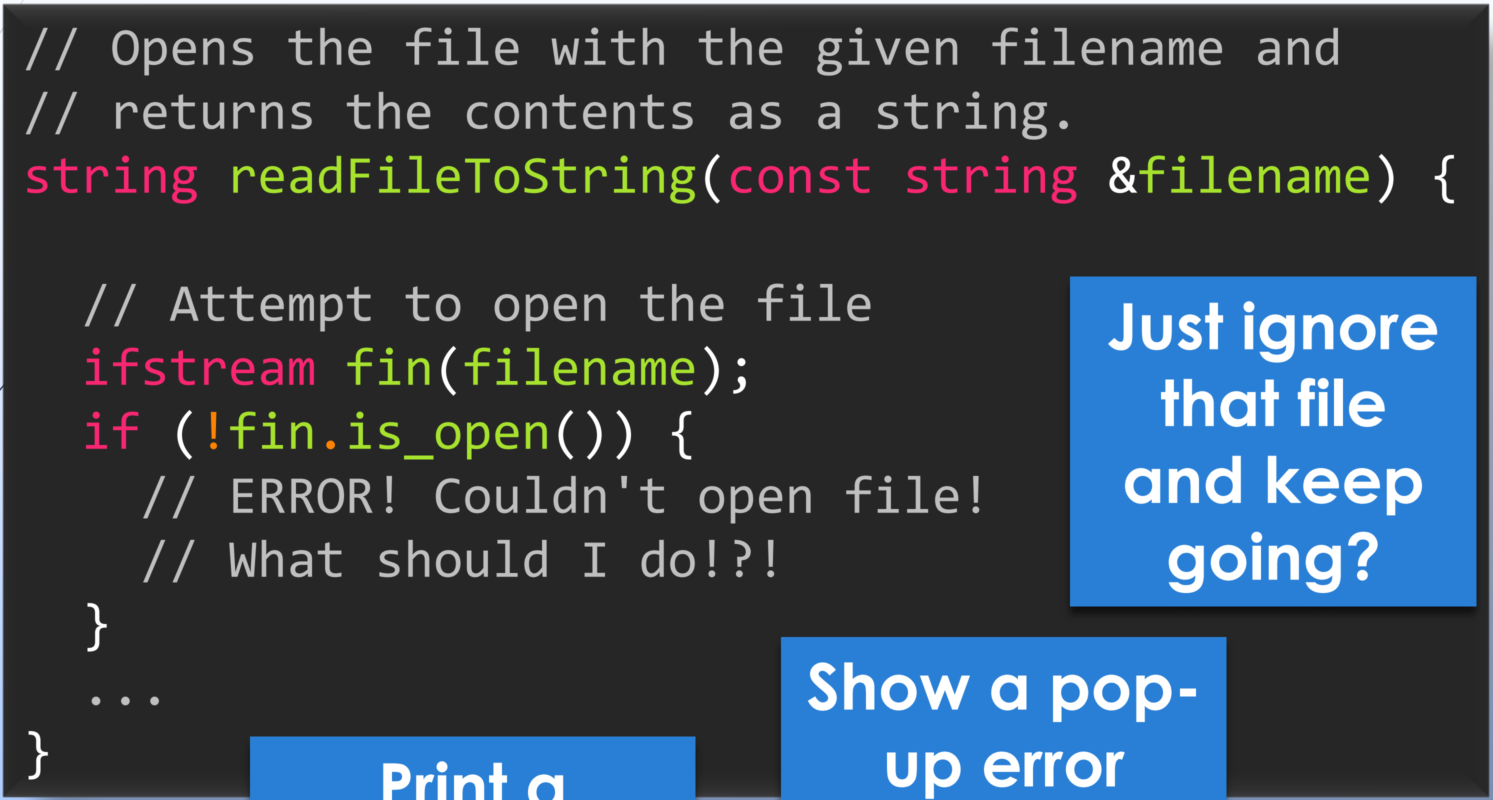
Error Handling and Exceptions

4/6/2022

Handling Errors

- Sometimes a function detects an error but doesn’t know what to do about it.
  - Think about going to your boss in an exceptional circumstance.
- We need to separate **error detection** from **error handling**.
  - Usually this means detecting the error in a function, but then letting the caller of that function handle the error.

Example: Error Detection



```
// Opens the file with the given filename and
// returns the contents as a string.
string readFileToString(const string &filename) {

  // Attempt to open the file
  ifstream fin(filename);
  if (!fin.is_open()) {
    // ERROR! Couldn't open file!
    // What should I do!?!
  }
  ...
}
```

Just ignore that file and keep going?

Print a message to cout?

Show a pop-up error message to the user?

Error Handling

- Strategies for communicating an error to the outside world (e.g. a function's caller):
  - Global Error Codes
  - Object Error States
  - Return Error Codes
  - Throw/Catch Exceptions
- Again, the idea is that the function that detected an error doesn’t have the context to know what should be done.
  - But the caller may know what to do!

Global Error Codes

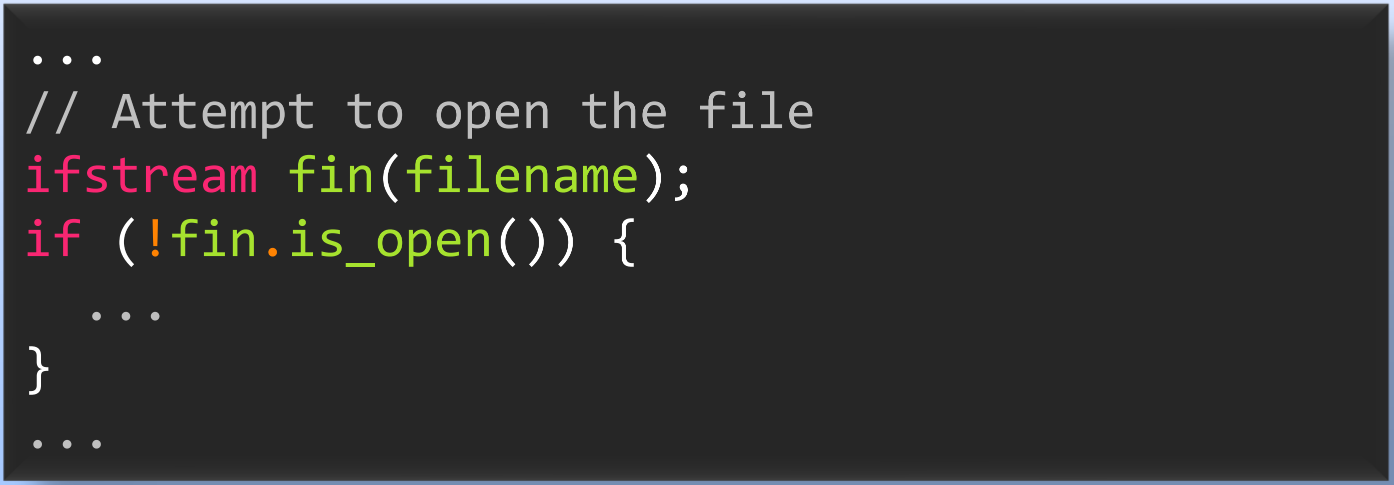
- Strategy:
  1. Store an error code in a global, then return.
  2. Caller must check the global variable for errors.

- Generally, global anything is poor style.
  - (A fairly reliable rule, at least.)

- In more complex programs, this approach becomes fragile.
  - You have to make sure to check the error code before any other error occurs, otherwise it gets overwritten!

Object Error States

- If a member function fails, it can put the object it was called on into an error state.
- You have to check whether the object is still in a good state after each operation that can fail.



```
...
// Attempt to open the file
ifstream fin(filename);
if (!fin.is_open()) {
  ...
}
...
```

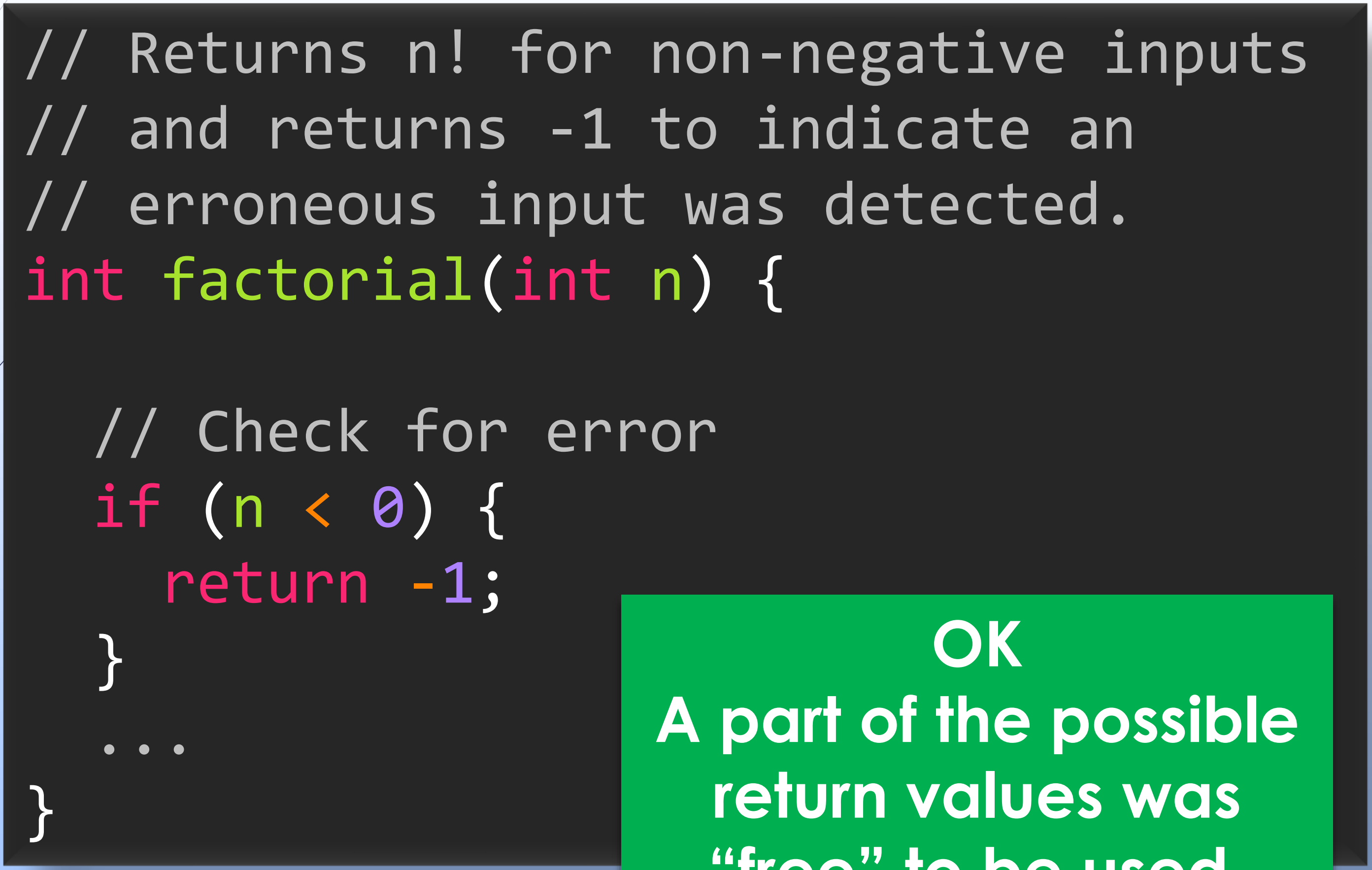
Return Error Codes

- Strategy:
  1. Return an error code.
  2. Caller must check the return value for errors.

- Better than the global strategy, because error handling is local and interference is not possible.

- However, now our “error code” must somehow fit into the return value...

Return Error Codes



```
// Returns n! for non-negative inputs
// and returns -1 to indicate an
// erroneous input was detected.
int factorial(int n) {

  // Check for error
  if (n < 0) {
    return -1;
  }
  ...
}
```

OK
A part of the possible return values was “free” to be used.

Return Error Codes

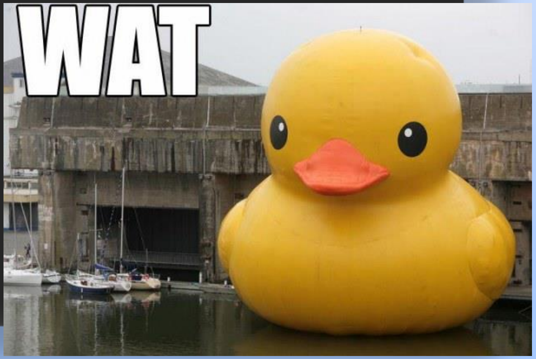
```
// Parses an int from a string.
// Returns the int. Returns ??? to
// indicate an error.
int parseInt(const string &str) {
  // Check for error
  if (/*Bad characters in string*/) {
    return ???;
  }
  ...
}
```

PROBLEM
All the ints we could use for an error code are also legitimate returns.

Return Error Codes

```
// Makes a Duck. If there was a
// problem, returns the WAT duck
// instead.
Duck makeDuck(/*Duck Parameters*/) {

  // Check for error
  if (/*ERROR*/) {
    return Duck("WAT");
  }
  ...
}
```

PROBLEM
Sometimes it just feels weird.



Return Error Codes

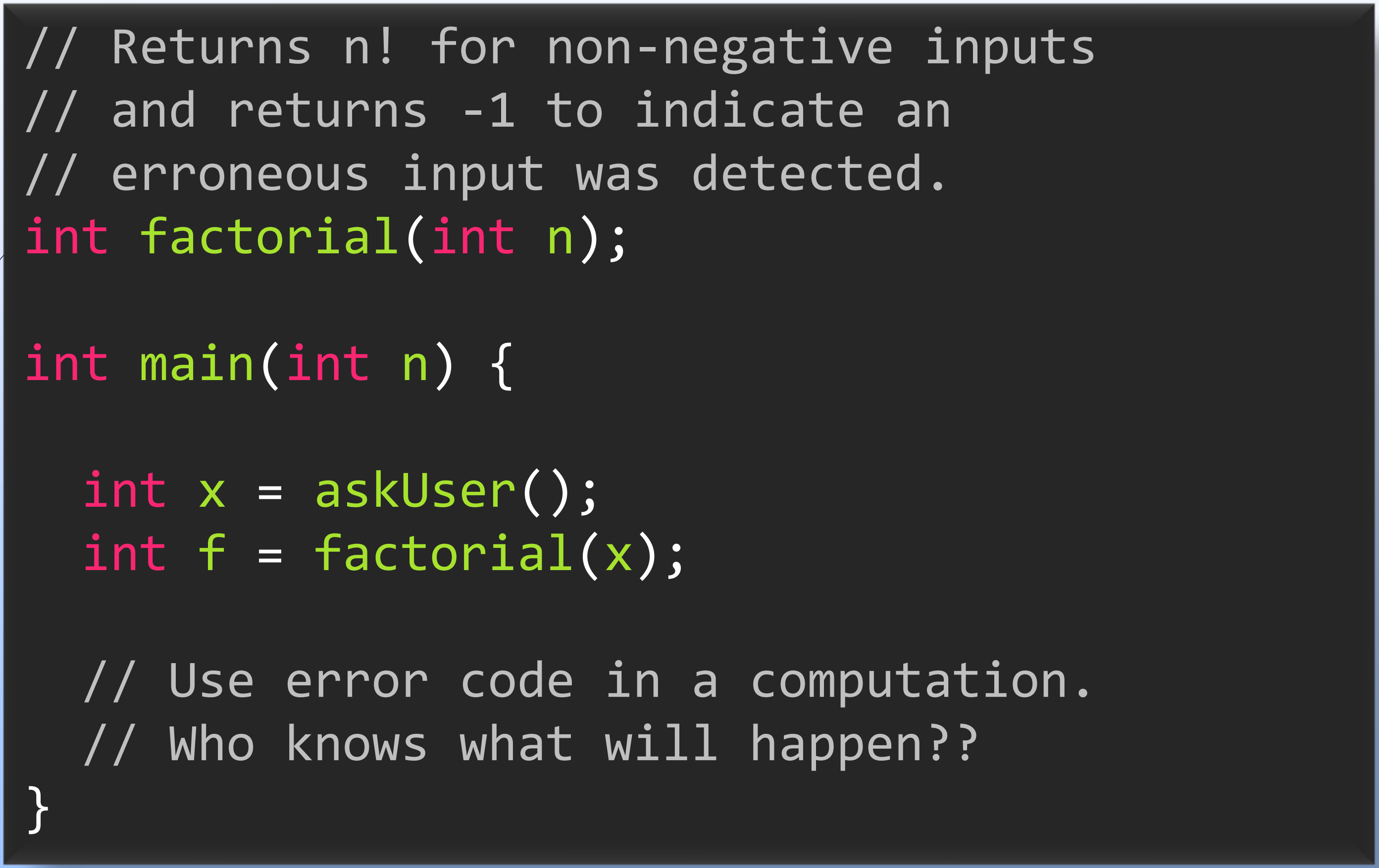
```
// Parses an int from a string. Returns a
// pair<int,int>. The second member of the pair is
// 0 if there's no error. Otherwise it’s an error
// code.
std::pair<int, int> parseInt(const string &str) {
  // Check for error
  if (/*Bad characters in string*/) {
    return {0, 1};
  }
  ...
  return {num, 0};
}
```

OK
Second member in the pair holds the error code.

Some modern languages use this approach, e.g. Go

Other Error Code Issues

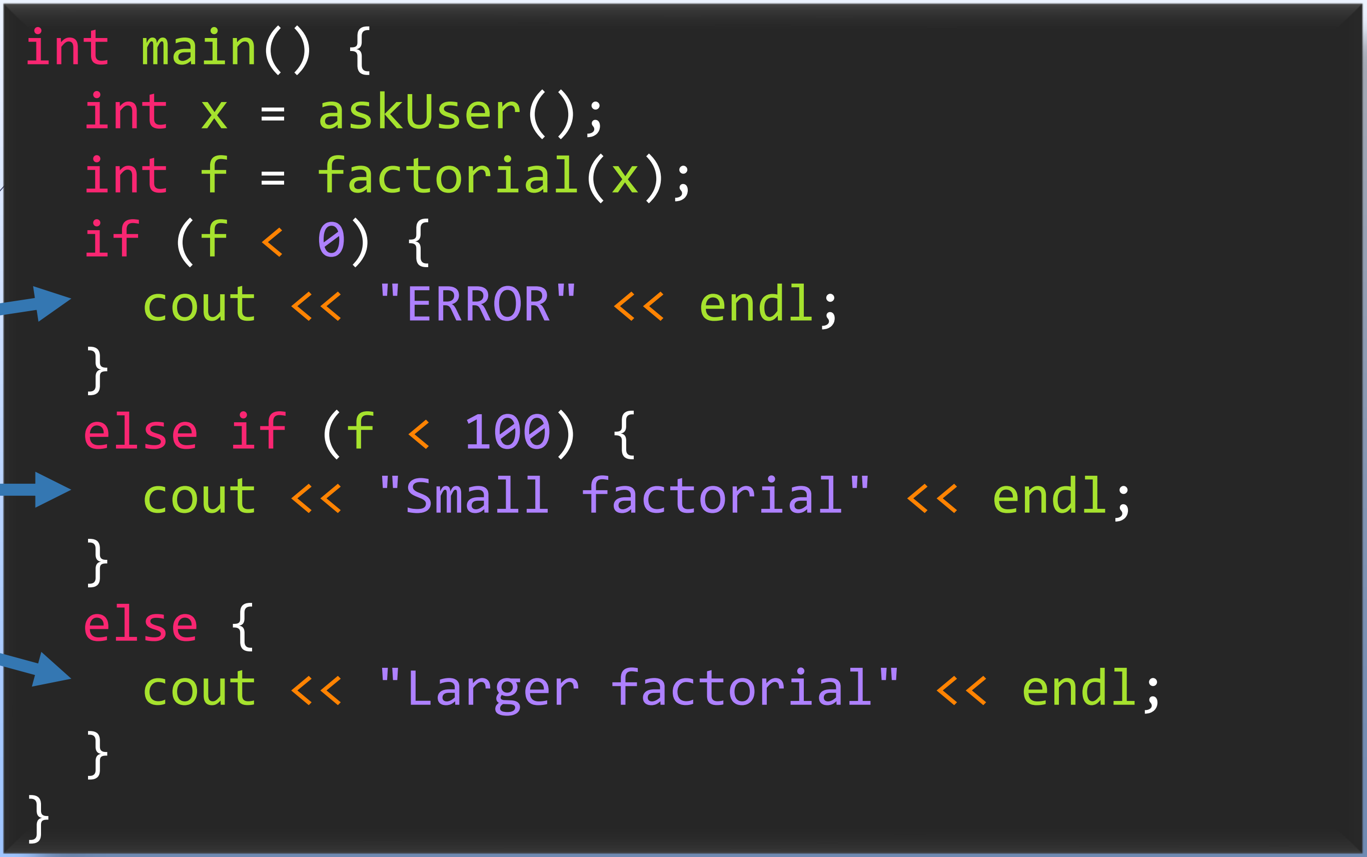
- The caller might forget to check for them.



```
// Returns n! for non-negative inputs
// and returns -1 to indicate an
// erroneous input was detected.
int factorial(int n);

int main(int n) {

  int x = askUser();
  int f = factorial(x);

  // Use error code in a computation.
  // Who knows what will happen??
}
```

Other Error Code Issues

- Error handling code is interleaved with regular control flow. This is poor style.



```
int main() {
  int x = askUser();
  int f = factorial(x);
  if (f < 0) {
    cout << "ERROR" << endl;
  }
  else if (f < 100) {
    cout << "Small factorial" << endl;
  }
  else {
    cout << "Larger factorial" << endl;
  }
}
```

Branches for normal code execution and for error cases are not always easy to tell apart.

Using Exceptions

- The **exception** mechanism introduces an additional **control flow path** for error handling.

```
int main() {
  int x = askUser();
  try {
    int f = factorial(x);
    if (f < 100) {
      cout << "Small" << endl;
    }
    else {
      cout << "Larger" << endl;
    }
  }
  catch (const FactorialError &e) {
    cout << "ERROR" << endl;
  }
}
```

Put code that might throw in a try block.

In separate code, we catch the exception and handle the error.

```
class FactorialError { };

// Returns n! for non-negative
// inputs. Throws an exception
// on negative inputs.
int factorial(int n) {

  // Check for error
  if (n < 0) {
    throw FactorialError();
  }
  ...
}
```

When something goes wrong, we throw an exception.

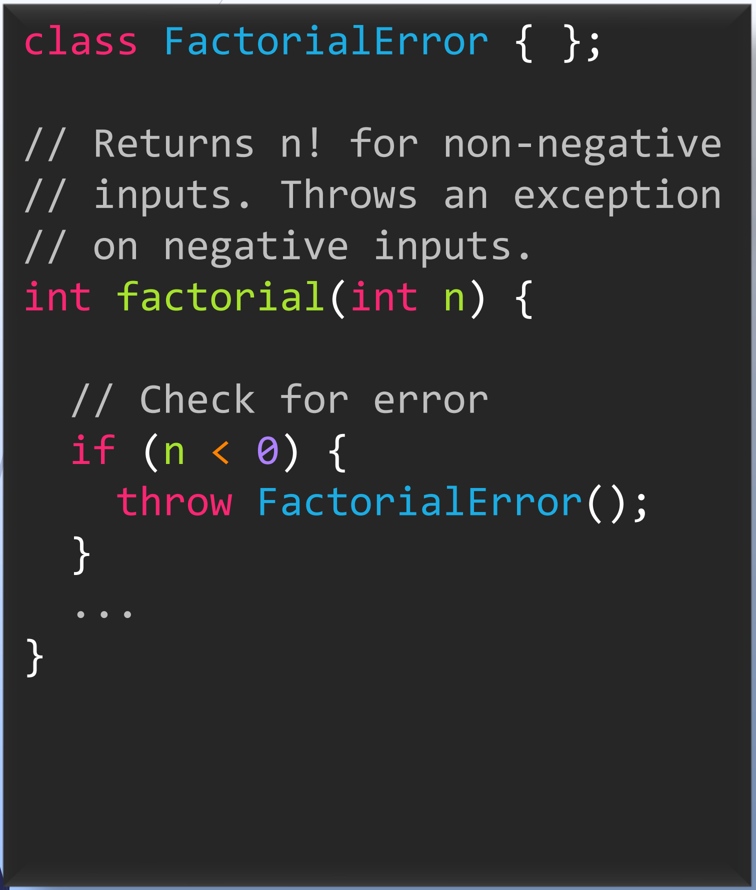
Using Exceptions

- The **exception** mechanism introduces an additional **control flow path** for error handling.

- The language is essentially providing us with a structured way to...

  1. **Detect Errors**: Create and **throw** an error-like object called an exception, which contains information about what happened.
  2. Propagate the exception outward from a function to its caller until it is handled.
  3. **Handle Errors**: **Catch** the exception in a special block of code that handles the error.

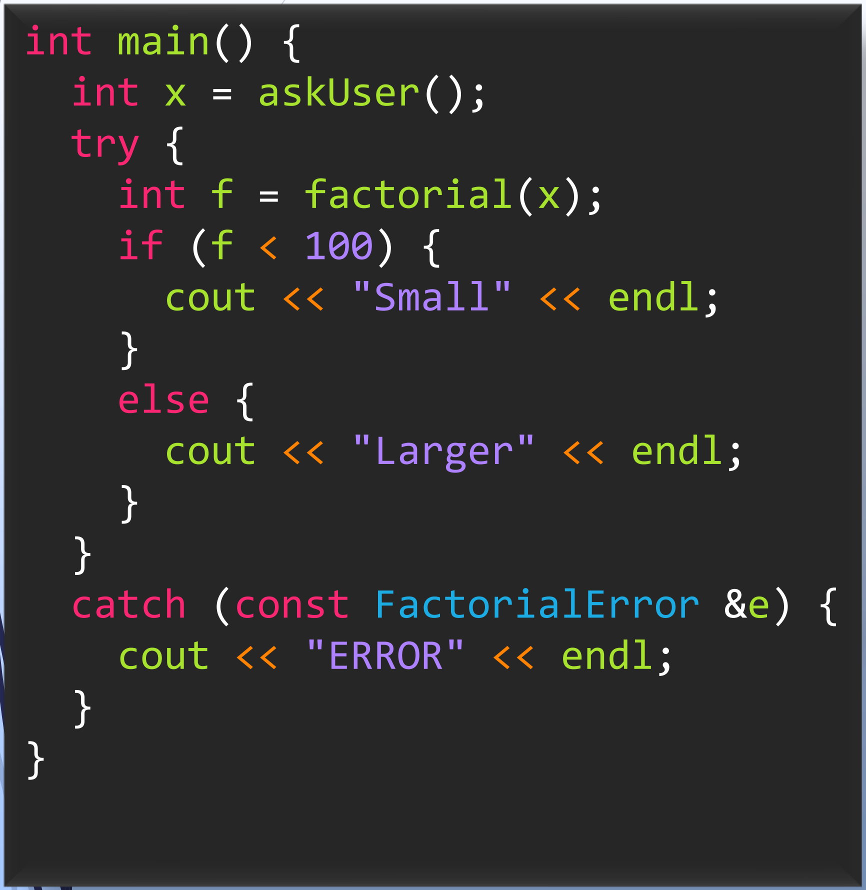
The throw Statement



```
class FactorialError { };

// Returns n! for non-negative
// inputs. Throws an exception
// on negative inputs.
int factorial(int n) {

  // Check for error
  if (n < 0) {
    throw FactorialError();
  }
  ...
}
```

- When a **throw statement** is encountered, regular control flow ceases.
- The program proceeds **outward through each scope** until an appropriate `catch` is found.
- You can throw any kind of object, but generally we use a class type created to represent a particular kind of error.
  - e.g. `FactorialError`
- Only one object can ever be thrown at a given time. (No juggling allowed.)

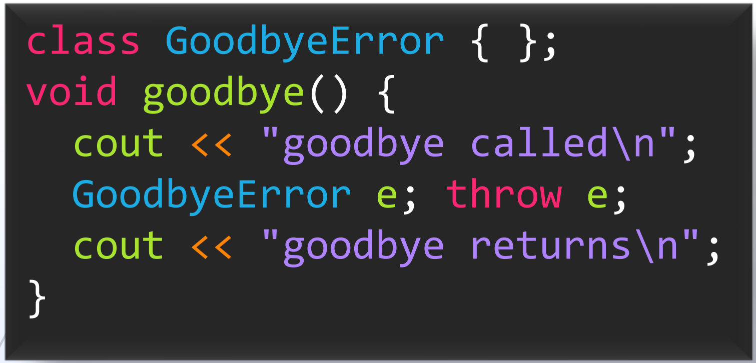
The try-catch block



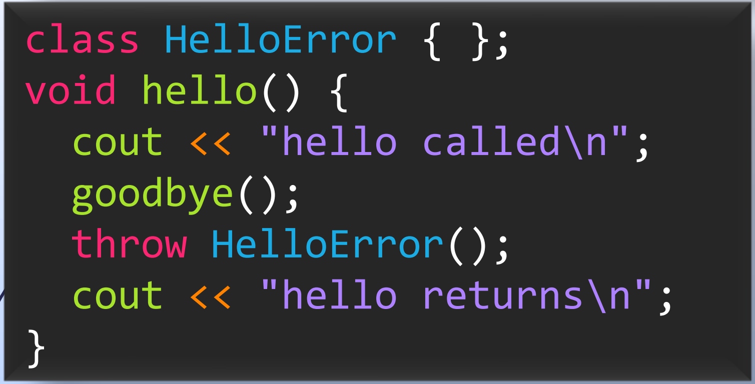
```
int main() {
  int x = askUser();
  try {
    int f = factorial(x);
    if (f < 100) {
      cout << "Small" << endl;
    }
    else {
      cout << "Larger" << endl;
    }
  }
  catch (const FactorialError &e) {
    cout << "ERROR" << endl;
  }
}
```

- A **try block** is always matched up with one or more **catch blocks**.
- If an exception is thrown inside a try block, the corresponding catch blocks are examined.
- If a catch block matches the type of the exception, the code in that block executes.
- If there is no matching catch, the exception continues outward.
- Uncaught exception == crash.

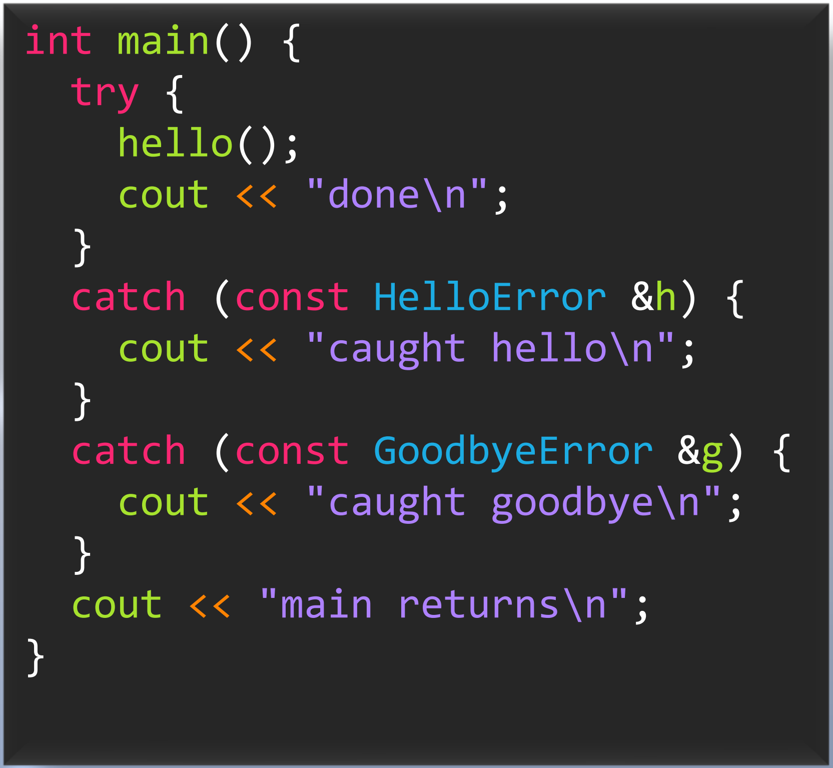
Exercise: Exception Tracing 1



```
class GoodbyeError { };
void goodbye() {
  cout << "goodbye called\n";
  GoodbyeError e; throw e;
  cout << "goodbye returns\n";
}
```



```
class HelloError { };
void hello() {
  cout << "hello called\n";
  goodbye();
  throw HelloError();
  cout << "hello returns\n";
}
```



```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const HelloError &h) {
    cout << "caught hello\n";
  }
  catch (const GoodbyeError &g) {
    cout << "caught goodbye\n";
  }
  cout << "main returns\n";
}
```

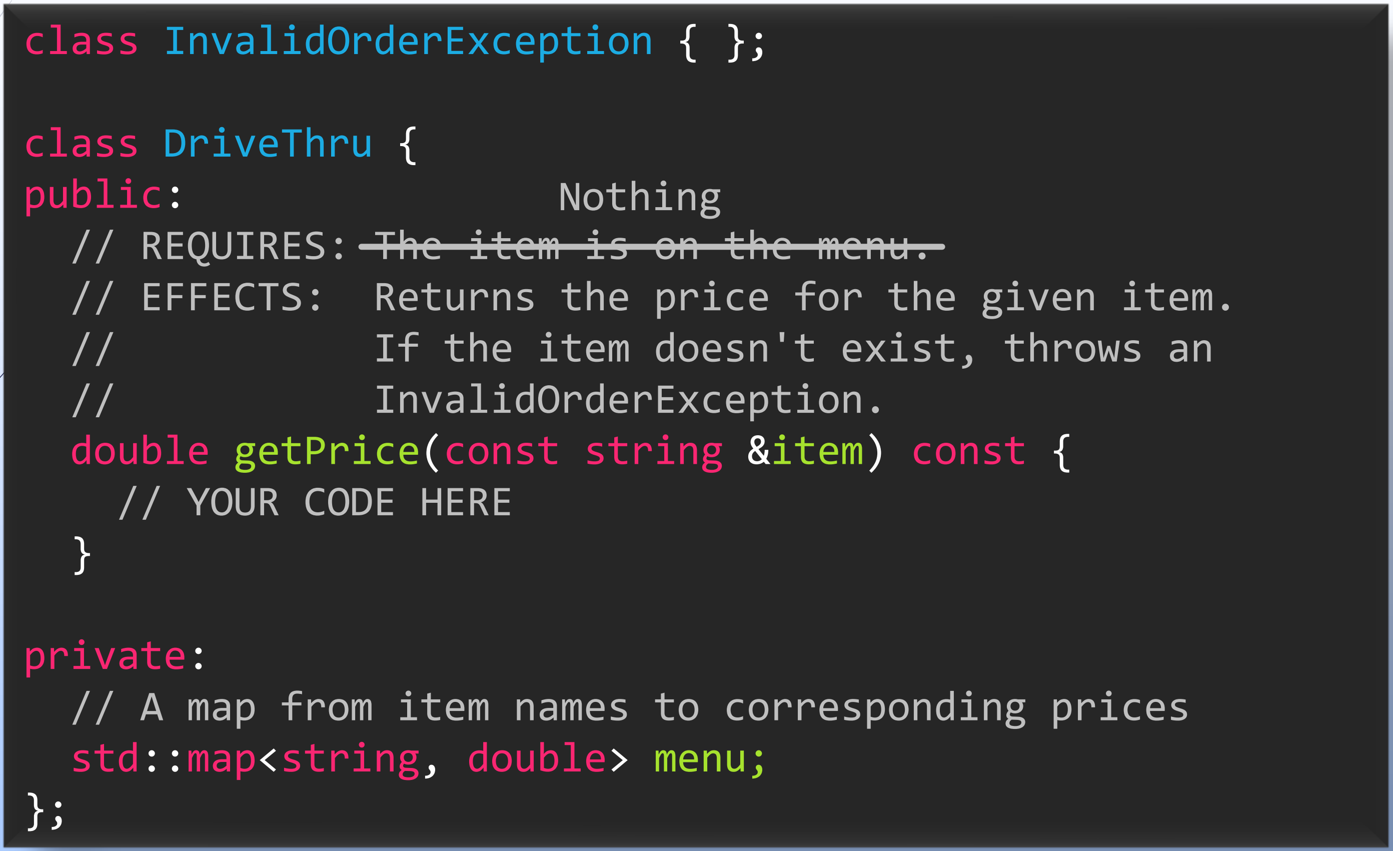
Question What is the output of `main()`?

A) hello called
goodbye called
hello returns
caught hello
main returns

B) hello called
goodbye called
caught goodbye
main returns

C) hello called
goodbye called
done
caught goodbye
main returns

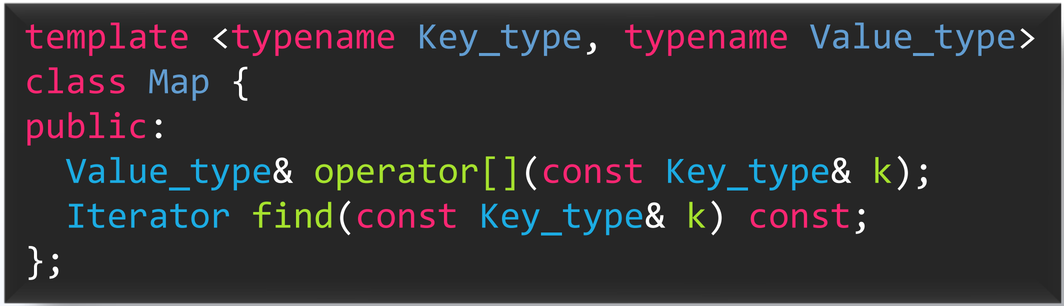
Example: Drive Thru



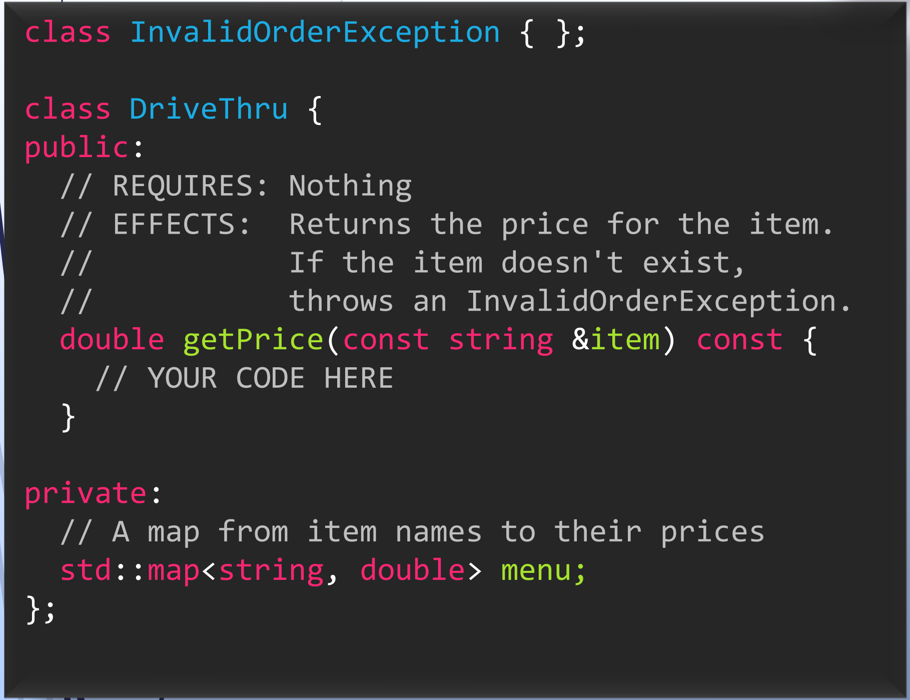
```
class InvalidOrderException { };

class DriveThru {
public:                        Nothing
  // REQUIRES: ~~The item is on the menu.~~
  // EFFECTS:  Returns the price for the given item.
  //           If the item doesn't exist, throws an
  //           InvalidOrderException.
  double getPrice(const string &item) const {
    // YOUR CODE HERE
  }

private:
  // A map from item names to corresponding prices
  std::map<string, double> menu;
};
```

Question

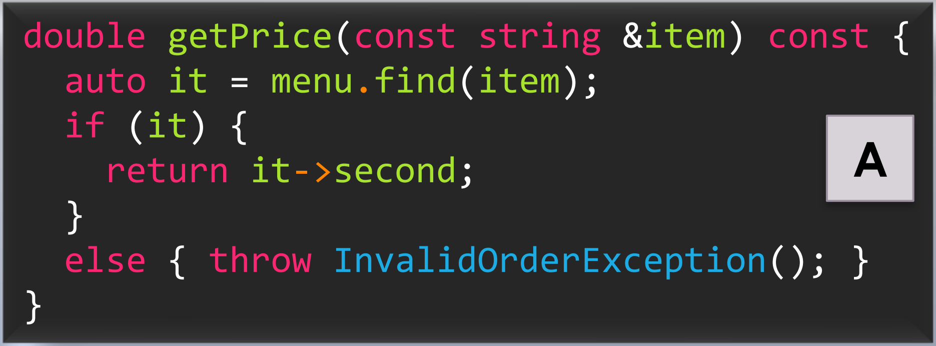
Which of these getPrice functions is correct?



```
template <typename Key_type, typename Value_type>
class Map {
public:
  Value_type& operator[](const Key_type& k);
  Iterator find(const Key_type& k) const;
};
```

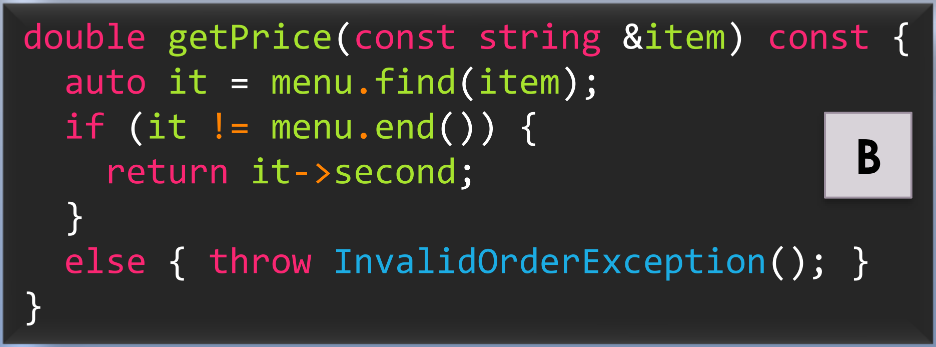


```
class InvalidOrderException { };

class DriveThru {
public:
  // REQUIRES: Nothing
  // EFFECTS:  Returns the price for the item.
  //           If the item doesn't exist,
  //           throws an InvalidOrderException.
  double getPrice(const string &item) const {
    // YOUR CODE HERE
  }

private:
  // A map from item names to their prices
  std::map<string, double> menu;
};
```



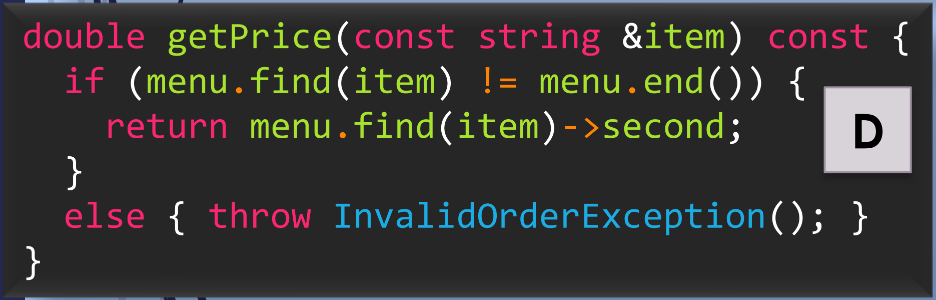
```
double getPrice(const string &item) const {
  auto it = menu.find(item);
  if (it) {
    return it->second;
  }
  else { throw InvalidOrderException(); }
}
```

A



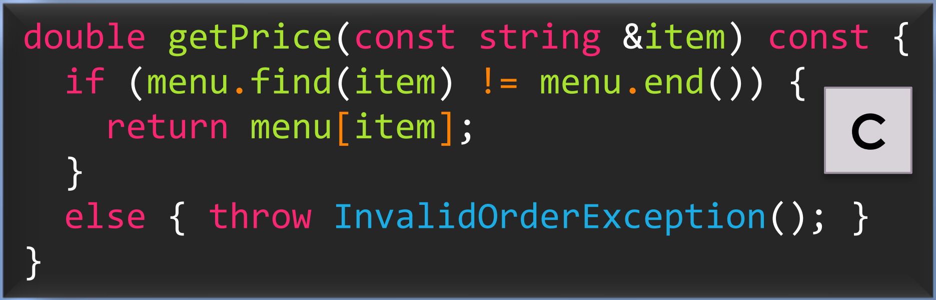
```
double getPrice(const string &item) const {
  auto it = menu.find(item);
  if (it != menu.end()) {
    return it->second;
  }
  else { throw InvalidOrderException(); }
}
```

B



```
double getPrice(const string &item) const {
  if (menu.find(item) != menu.end()) {
    return menu.find(item)->second;
  }
  else { throw InvalidOrderException(); }
}
```

D

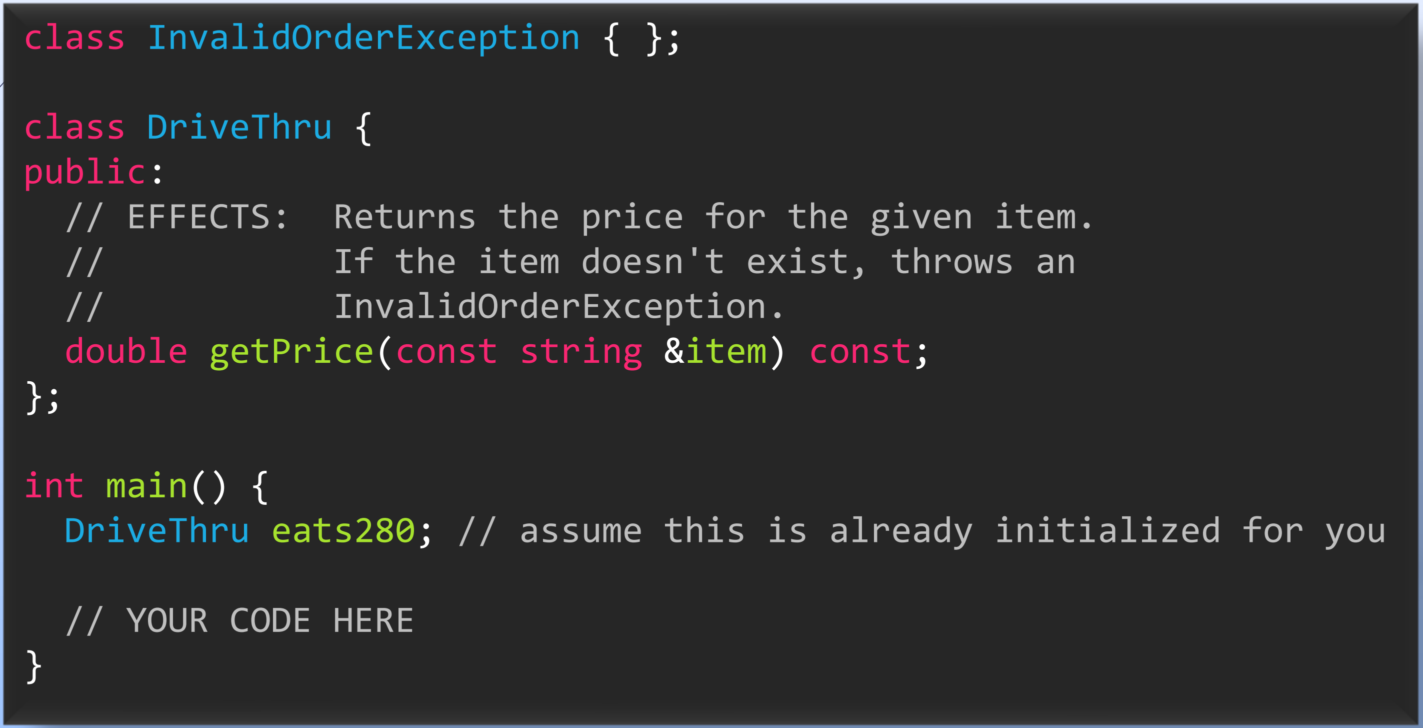


```
double getPrice(const string &item) const {
  if (menu.find(item) != menu.end()) {
    return menu[item];
  }
  else { throw InvalidOrderException(); }
}
```

C

Exercise: Drive-Thru Order (part 2)

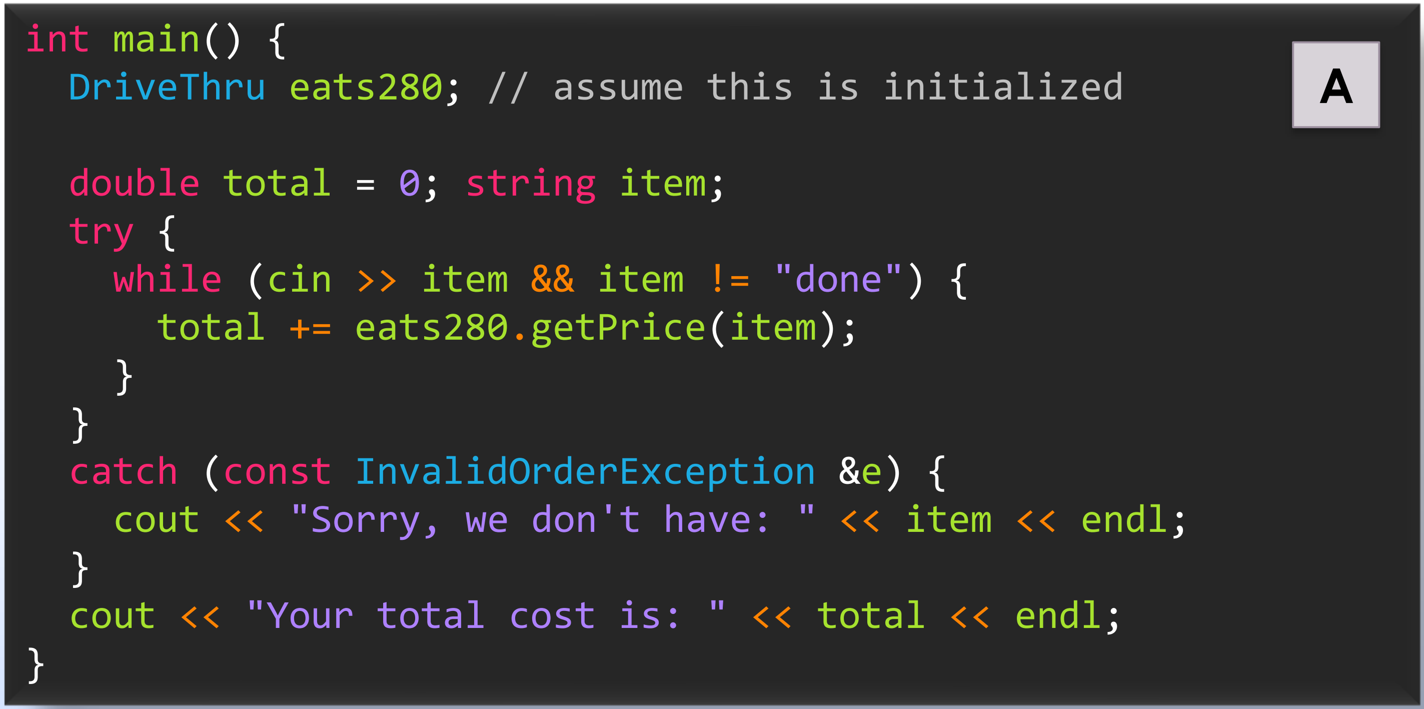
- Write a `main` function that takes an order as a sequence of items from `cin` and reports the total price.
- If an invalid item is ordered, print a message, but keep going. Stop the order when the user types `"done"`.



```
class InvalidOrderException { };

class DriveThru {
public:
  // EFFECTS:  Returns the price for the given item.
  //           If the item doesn't exist, throws an
  //           InvalidOrderException.
  double getPrice(const string &item) const;
};

int main() {
  DriveThru eats280; // assume this is already initialized for you

  // YOUR CODE HERE
}
```

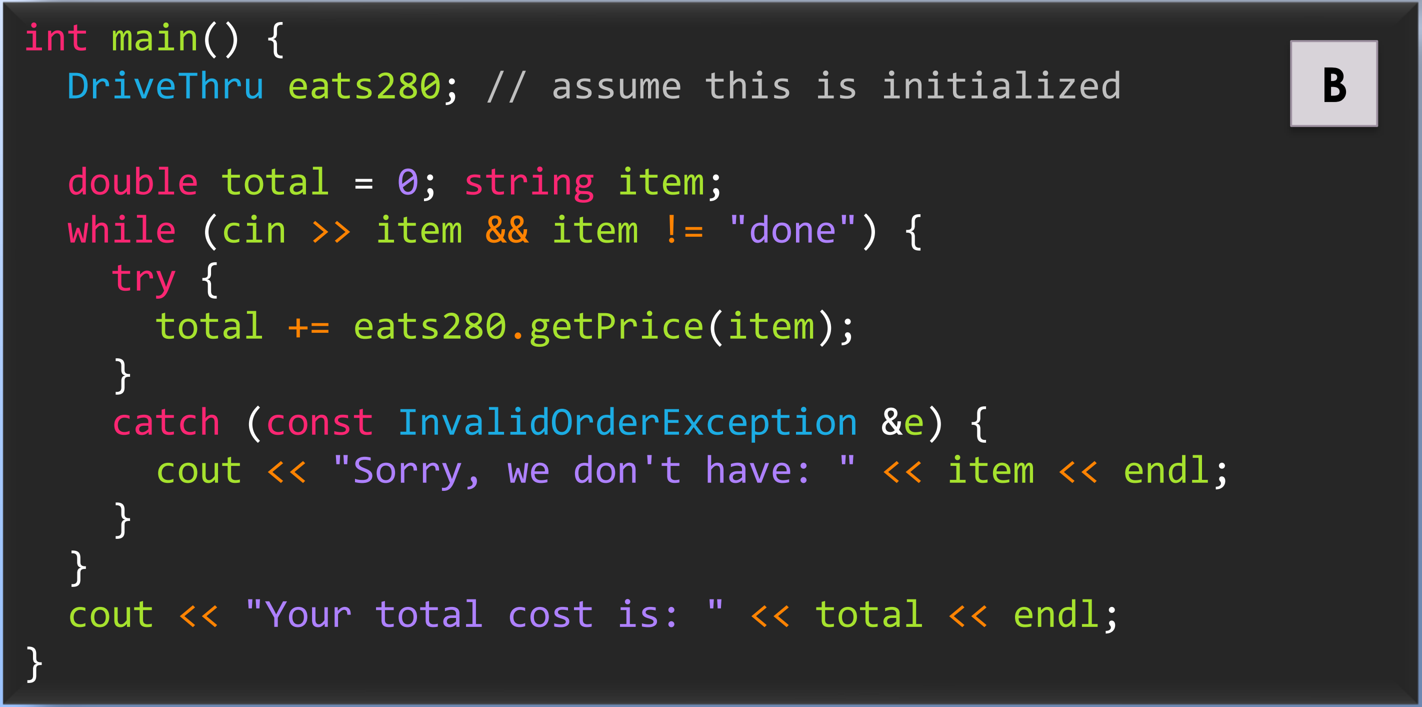
<u>Question</u>

Which of these main functions works as desired?



A

```
int main() {
  DriveThru eats280; // assume this is initialized

  double total = 0; string item;
  try {
    while (cin >> item && item != "done") {
      total += eats280.getPrice(item);
    }
  }
  catch (const InvalidOrderException &e) {
    cout << "Sorry, we don't have: " << item << endl;
  }
  cout << "Your total cost is: " << total << endl;
}
```

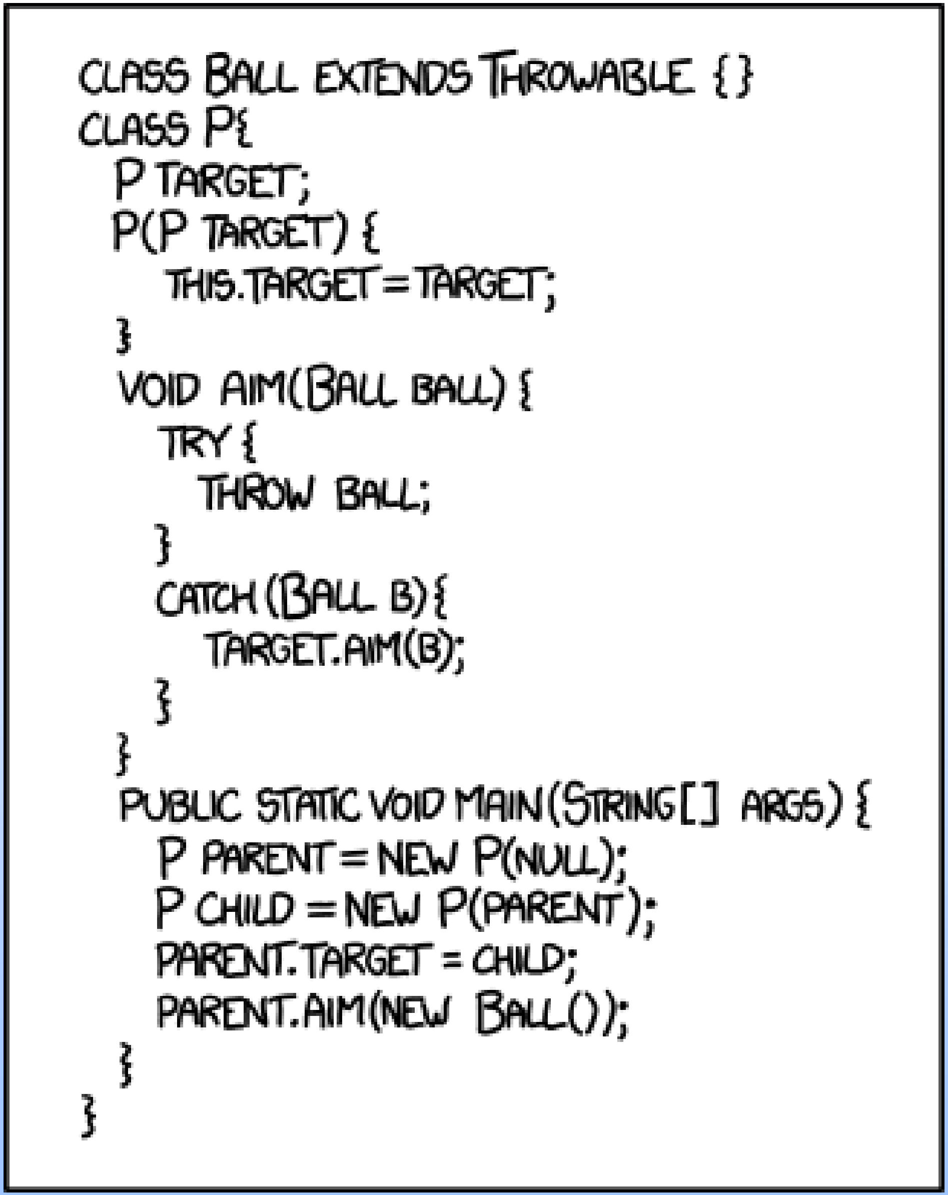


B

```
int main() {
  DriveThru eats280; // assume this is initialized

  double total = 0; string item;
  while (cin >> item && item != "done") {
    try {
      total += eats280.getPrice(item);
    }
    catch (const InvalidOrderException &e) {
      cout << "Sorry, we don't have: " << item << endl;
    }
  }
  cout << "Your total cost is: " << total << endl;
}
```

C - Neither

Break Time!



```
CLASS BALL EXTENDS THROWABLE {}
CLASS P{
  P TARGET;
  P(P TARGET) {
     THIS.TARGET = TARGET;
  }
  VOID AIM(BALL BALL) {
    TRY {
       THROW BALL;
    }
    CATCH (BALL B) {
       TARGET.AIM(B);
    }
  }
  PUBLIC STATIC VOID MAIN(STRING[] ARGS) {
    P PARENT = NEW P(NULL);
    P CHILD = NEW P(PARENT);
    PARENT.TARGET = CHILD;
    PARENT.AIM(NEW BALL());
  }
}
```

https://xkcd.com/1188/

Break Time!

We'll start again in three minutes.

Exceptions Example

```cpp
int main() {
  try {
    gradeSubmissions();
    cout << "Grading done!" << endl;
  }
  catch (const csvstream_exception &e) {
    cout << e.what() << endl;
    return 1;
  }
}
```

```cpp
void gradeSubmissions() {
  vector<string> students = loadRoster();
  for (const string &s : students) {
    try {
      auto sub = loadSubmission(s);
      double result = grade(sub);
      emailStudent(s, result);
    }
    catch (const FileError &e) {
      cout << "Can't grade: " << s << endl;
    }
    catch (const EmailError &e) { ... }
  }
}
```

```cpp
class FileError { };
class EmailError { };
```

```cpp
vector<string> loadRoster() {
  // If the file couldn't be opened,
  // csvstream ctor throws an exception.
  csvstream csvin("280roster.csv");

  // Read in and return the roster
}
```

```cpp
Submission loadSubmission(
                     const string &id) {

  // Attempt to open student files

  if (/* can't open files */) {
    throw FileError();
  }

  // Create Submission object from
  // files and return it.
}
```

Custom Exception Types

- DO: Use custom exception types.
  - The type itself indicates the kind of error.
  - The thrown object may also carry along extra information.

```
class EmailError : public std::exception {
public:
  EmailError(const string &msg_in) : msg(msg_in) { }
  const char * what() const override { return msg.c_str(); }
private:
  string msg;
};
```

Best practice is to derive from std::exception.

Override what() member function to retrieve message.

```
throw EmailError("Error sending email to: " + address);
```

- Always use catch-by-reference (to const).

```
try { ... }
catch (const EmailError &e) {
  cout << e.what() << endl;
}
```

- DO NOT: Throw "regular" types (e.g. `int`, `string`, `vector`).

Exceptions and Polymorphism

- It is common to define a hierarchy of exception types, which can be caught polymorphically.

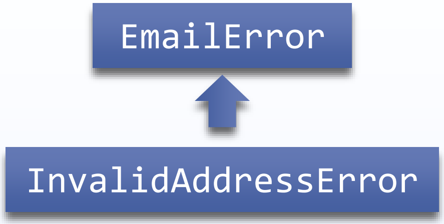
```
class EmailError : public std::exception { ... };
class InvalidAddressError : public EmailError { ... };
class SendFailedError : public EmailError { ... };
```

```
void gradeSubmissions() {
  vector<string> students = loadRoster();
  for (const string &s : students) {
    try {
      auto sub = loadSubmission(s);
      double result = grade(sub);
      emailStudent(s, result);
    }
    catch (const FileError &e) {
      cout << "Can't grade: " << s << endl;
    }
    catch (const EmailError &e) { ... }
  }
}
```

This catches any kind of `EmailError`. Note the catch by reference is necessary for polymorphism.

Multiple Catch Blocks

Recall:


EmailError

InvalidAddressError

- Catch blocks are tried in order.
- The **first matching block** is used.
- At most **one** catch block will ever be used.
- If none match, the exception continues outward.

```
try {

  // Some code that may throw many different kinds of exceptions

}
catch (const InvalidAddressError &e) {
  cout << e.getMessage() << endl;
  // Also, remove the recipient from our address book
}
catch (const EmailError &e) {
  cout << "Error sending mail: <<  e.getMessage() << endl;
}
catch (const SomeOtherError &e) {
  // Do something to handle this specific other error.
}
catch (...) {
  cout << "Error occurred!" << endl;
}
```

First, attempt to match a specific kind of email error.

Match any remaining email errors.

Writing ... will match anything.

This last catch with ... is a bad idea. Why?

To catch or not to catch?

- Only catch an exception if you can responsibly handle it.

```
void gradeSubmissions() {
  vector<string> students = loadRoster();
  for (const string &s : students) {
    try { /* Open files, grade submission, email student */ }
    catch (const FileError &e) {
      cout << "Can't grade: " << s << endl;
    }
  }
}
```

In this context, just logging an error message and moving on is reasonable.

- Don't catch an exception if you don't know how to handle it and still "do your job" successfully.

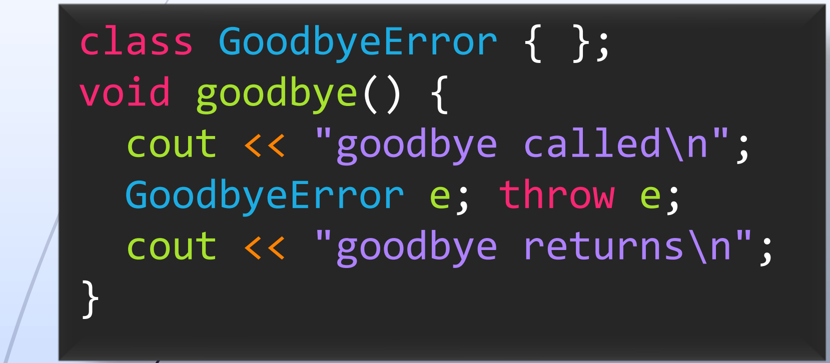
```
vector<string> loadRoster() {
  try {
    csvstream csvin("280roster.csv"); // ctor may throw
    // Use the stream to load the roster...
  }
  catch (const csvstream_exception &e) {
    cout << e.what() << endl;
  }
}
```

If the csvstream fails, we can't do our job (load/return a vector).

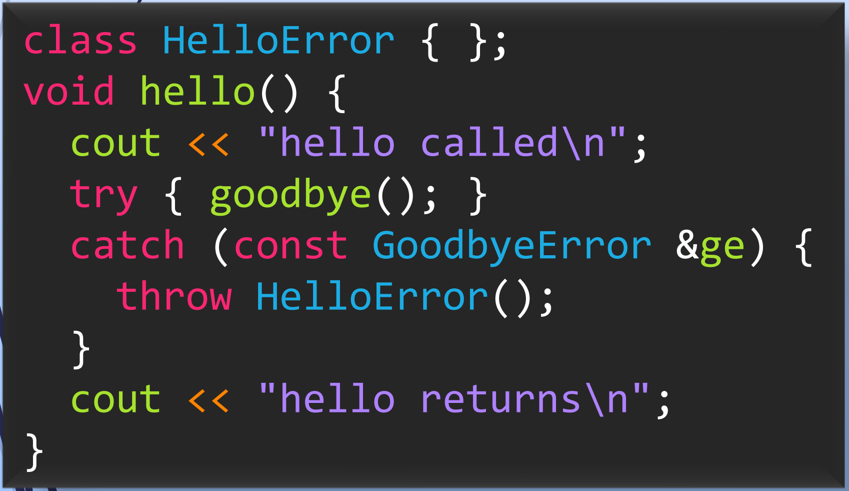
Instead, we should NOT catch the error here and allow the exception to propagate out of the function.

Exercise: Exception Tracing 2

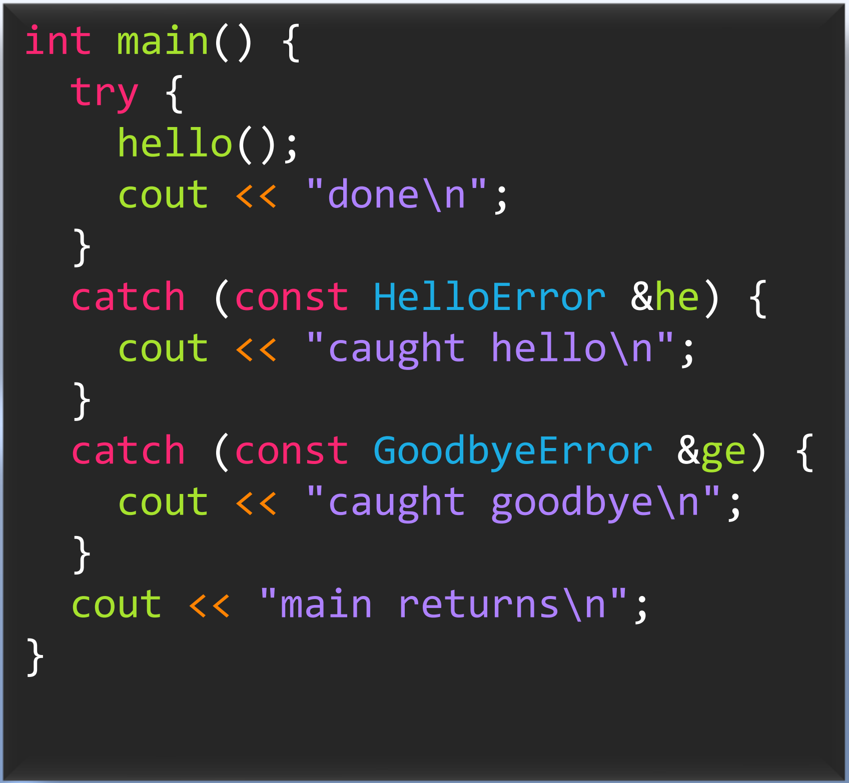
- What is the output of this code?



```cpp
class GoodbyeError { };
void goodbye() {
  cout << "goodbye called\n";
  GoodbyeError e; throw e;
  cout << "goodbye returns\n";
}
```



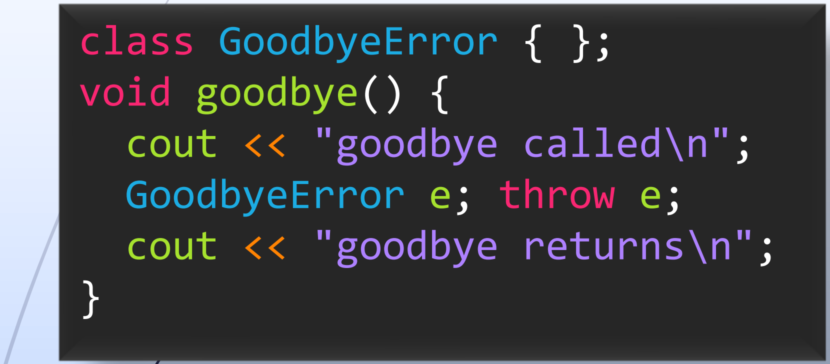
```cpp
class HelloError { };
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const GoodbyeError &ge) {
    throw HelloError();
  }
  cout << "hello returns\n";
}
```



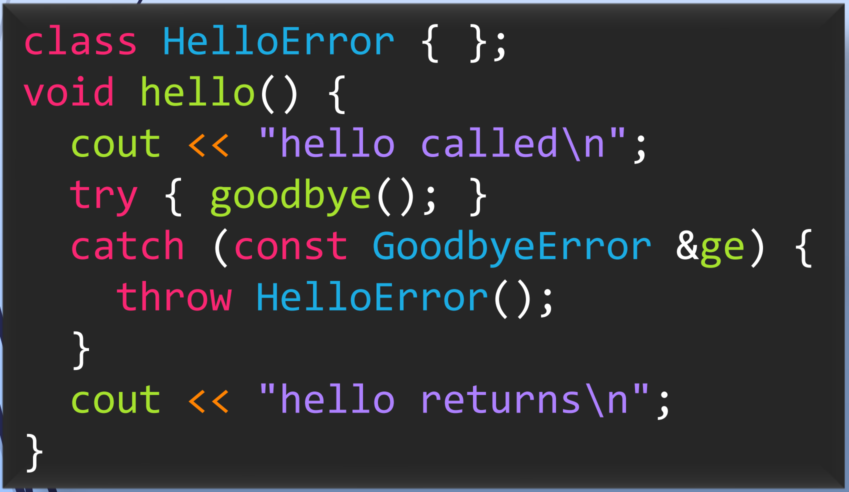
```cpp
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const HelloError &he) {
    cout << "caught hello\n";
  }
  catch (const GoodbyeError &ge) {
    cout << "caught goodbye\n";
  }
  cout << "main returns\n";
}
```

Solution: Exception Tracing 2

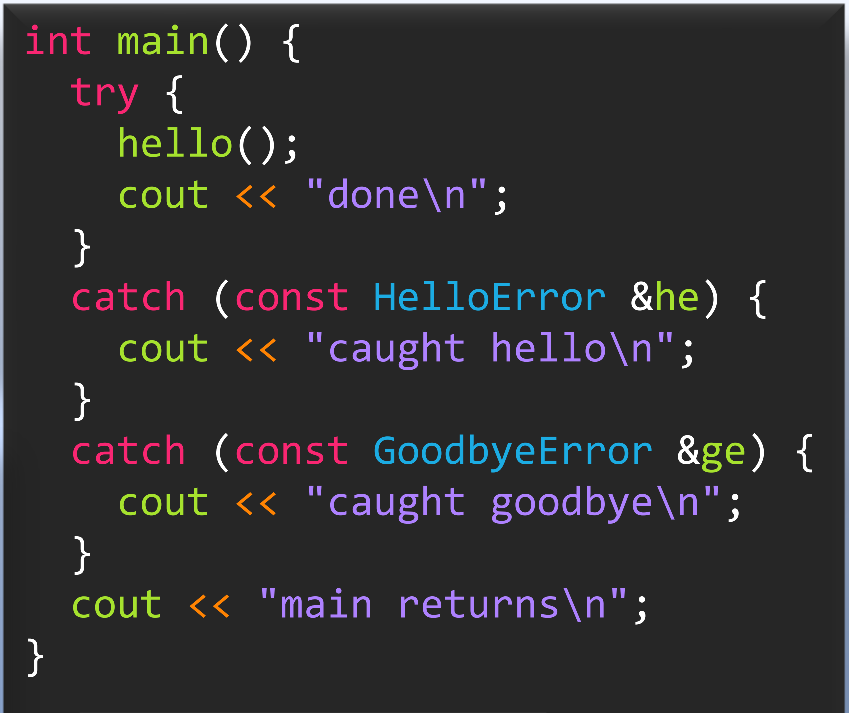
- What is the output of this code?



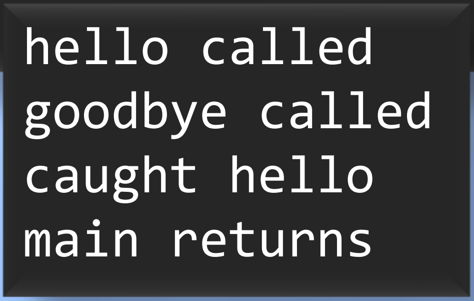
```
class GoodbyeError { };
void goodbye() {
  cout << "goodbye called\n";
  GoodbyeError e; throw e;
  cout << "goodbye returns\n";
}
```



```
class HelloError { };
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const GoodbyeError &ge) {
    throw HelloError();
  }
  cout << "hello returns\n";
}
```



```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const HelloError &he) {
    cout << "caught hello\n";
  }
  catch (const GoodbyeError &ge) {
    cout << "caught goodbye\n";
  }
  cout << "main returns\n";
}
```



```
hello called
goodbye called
caught hello
main returns
```

Exercise: Exception Tracing 3

- What is the output of this code?

```
class Error {
  string msg;
public:
  Error(const string &s) : msg(s) { }
  const string &get_msg() { return msg; }
};
```

```
void goodbye() {
  cout << "goodbye called\n";
  throw Error("bye");
  cout << "goodbye returns\n";
}
```

```
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const Error &e) { throw Error("hey"); }
  cout << "hello returns\n";
}
```

```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const Error &e) {
    cout << e.get_msg();
    cout << endl;
  }
  catch (...) {
    cout << "unknown error\n";
  }
  cout << "main returns\n";
}
```

Solution: Exception Tracing 3

- What is the output of this code?

```
class Error {
  string msg;
public:
  Error(const string &s) : msg(s) { }
  const string &get_msg() { return msg; }
};
```

```
void goodbye() {
  cout << "goodbye called\n";
  throw Error("bye");
  cout << "goodbye returns\n";
}
```

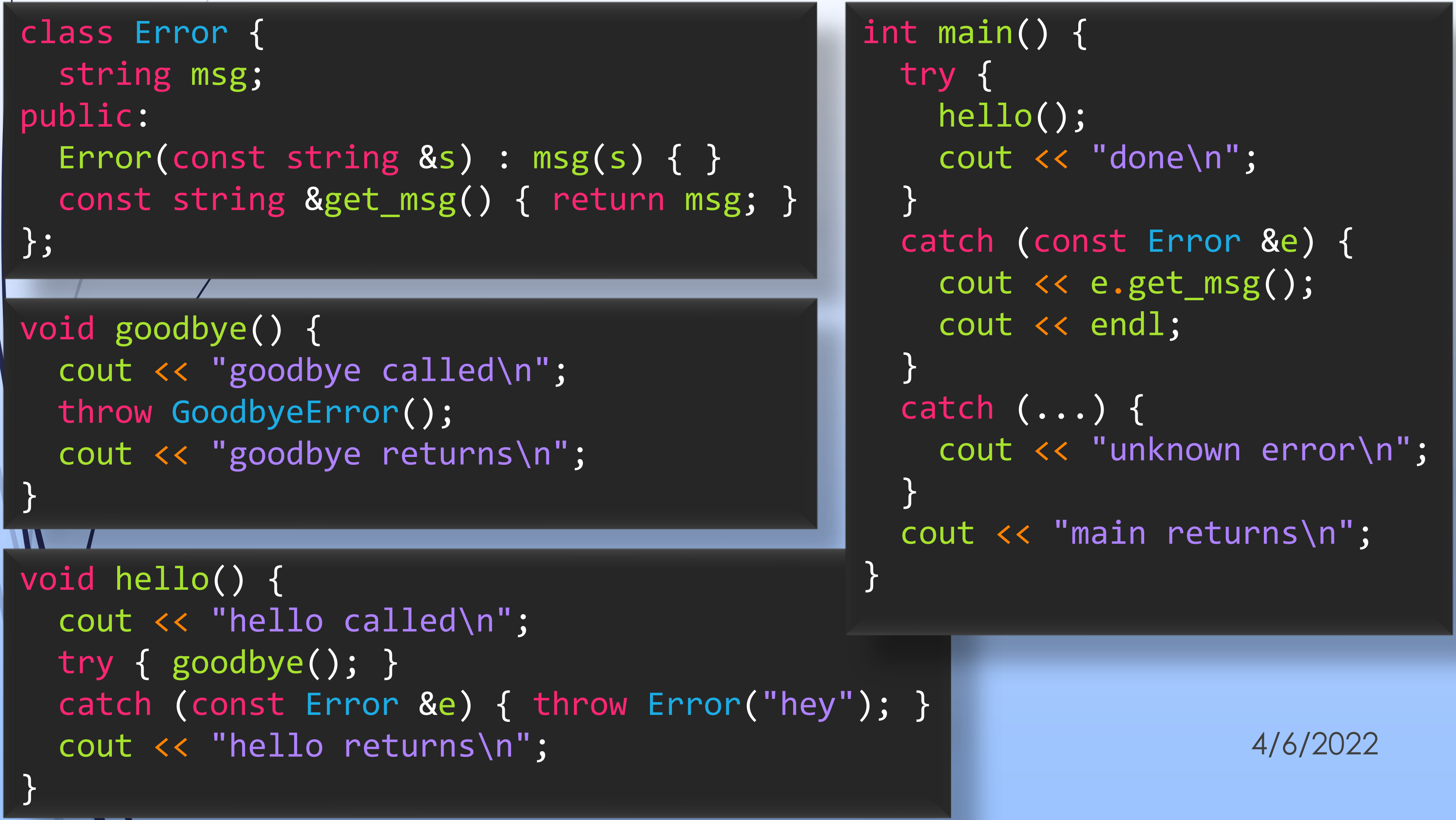
```
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const Error &e) { throw Error("hey"); }
  cout << "hello returns\n";
}
```

```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const Error &e) {
    cout << e.get_msg();
    cout << endl;
  }
  catch (...) {
    cout << "unknown error\n";
  }
  cout << "main returns\n";
}
```

```
hello called
goodbye called
hey
main returns
```

Exercise: Exception Tracing 4

- What is the output of this code?



```
class Error {
  string msg;
public:
  Error(const string &s) : msg(s) { }
  const string &get_msg() { return msg; }
};
```

```
void goodbye() {
  cout << "goodbye called\n";
  throw GoodbyeError();
  cout << "goodbye returns\n";
}
```

```
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const Error &e) { throw Error("hey"); }
  cout << "hello returns\n";
}
```

```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const Error &e) {
    cout << e.get_msg();
    cout << endl;
  }
  catch (...) {
    cout << "unknown error\n";
  }
  cout << "main returns\n";
}
```

Solution: Exception Tracing 4

- What is the output of this code?

```
class Error {
  string msg;
public:
  Error(const string &s) : msg(s) { }
  const string &get_msg() { return msg; }
};
```

```
void goodbye() {
  cout << "goodbye called\n";
  throw GoodbyeError();
  cout << "goodbye returns\n";
}
```

```
void hello() {
  cout << "hello called\n";
  try { goodbye(); }
  catch (const Error &e) { throw Error("hey"); }
  cout << "hello returns\n";
}
```

```
int main() {
  try {
    hello();
    cout << "done\n";
  }
  catch (const Error &e) {
    cout << e.get_msg();
    cout << endl;
  }
  catch (...) {
    cout << "unknown error\n";
  }
  cout << "main returns\n";
}
```

```
hello called
goodbye called
unknown error
main returns
```