ECE 2400 Computer Systems Programming
Fall 2021

Topic 15: Functional Programming

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zyBooks The zyBooks logo is used to indicate additional material included in the course zyBook which will not be discussed in detail in lecture. Students are responsible for all material covered in lecture and in the course zyBook.

- Functional programming treats computation as the evaluation of pure mathematical functions
  - First-class functions: functions can be stored, copied, etc
  - Closures: functions remember environment at which it was created
  - Higher-order functions: functions take functions as parameters
  - Lambda functions: anonymous functions
  - Function composition: output of one function is input to another
  - Currying: chaining functions each with one parameter
  - Pure functions: functions cannot have mutable state
  - Recursion: without mutable state, need recursion to repeat
  - Strong underlying mathematical theory (lambda calculus)

Develop a generic `count` algorithm

Develop a generic `count` function that takes as input a sequence (`seq`), a value to search for, and returns the number of elements in the sequence that match the given value as an `int`. The function should be generic across any kind of sequence which might store any type of values. In other words, the function should work for a `List<int>`, a `List<float>`, a `Vector<int>`, etc. *Hint: Develop a version of the algorithm specialized for a `List<int>` and then make it generic.*

- Generic over the sequence, specialized for a given *predicate*
- Can only check for equality
- Can we make this function parameterized by the predicate?
- Pass in a function pointer to use for testing the predicate

Using C function pointers for generic count algorithm

```
bool threshold_25( int x ) { return ( x > 25 ); }

typedef bool (*pred_func_t) (int);

template < typename S >
int count_if( const S& seq, pred_func_t pred )
{
  int count = 0;
  for ( auto v : seq )
    if ( pred(v) ) // notice dereference is optional!
      count++;
  return count;
}

int main( void )
{
  List<int> lst;
  lst.push_front( 12 );
  lst.push_front( 15 );
  lst.push_front( 50 );
  lst.push_front( 06 );
  lst.push_front( 76 );

  int a = count_if( lst, &threshold_25 );
  return 0;
}
```

1. C++ Functors

- Use object-oriented and generic programming to implement:
  - First-class functions: objects will act like functions
  - Closures: environment will be explicitly stored in object
  - Higher-order functions: functions can be generic over functor parameters
- Overload the call operator to enable true "function-call" syntax

```
class Threshold25
{
 public:
  bool call( int x ) const
  {
    return ( x > 25 );
  }
};

int main( void )
{
  // create a functor
  Threshold25 pred0();

  // copy a functor
  Threshold25 pred1 = pred0;

  // call a stored functor
  bool b = pred1.call( 15 );

  // call a stored functor
  bool c = pred1.call( 30 );
}
```

```
class Threshold25
{
 public:
  bool operator()( int x ) const
  {
    return ( x > 25 );
  }
};

int main( void )
{
  // create a functor
  Threshold25 pred0();

  // copy a functor
  Threshold25 pred1 = pred0;

  // call a stored functor
  bool b = pred1( 15 );

  // call a stored functor
  bool c = pred1( 30 );
}
```

```cpp
class Threshold25
{
 public:
  bool operator()( int x ) const
  {
    return ( x > 25 );
  }
};

int main( void )
{
  // create a functor
  Threshold25 pred0();

  // copy a functor
  Threshold25 pred1 = pred0;

  // call a stored functor
  bool b = pred1( 15 );

  // call a stored functor
  bool c = pred1( 30 );
}
```

- Use arrow pointing to the *code* to represent a functor with no state

stack

```
class Threshold
{
 public:

  Threshold( int t ) : m_t( t )
  { }

  bool operator()( int x ) const
  {
    return ( x > m_t );
  }

 private:
  int m_t;
};

int main( void )
{
  // create a functor
  Threshold pred0(25);

  // copy a functor
  Threshold pred1 = pred0;

  // call a stored functor
  bool b = pred1( 15 );

  // call a stored functor
  bool c = pred1( 30 );
}
```

- Functors can also be used to explicitly capture their environment when constructed to create a closure
- Use pointer to the object to represent a functor with state (just like any object)

stack

- Use templates to make algorithms generic over function pointers and functors

```
bool threshold_25( int x ) { return ( x > 25 ); }

class Threshold
{
 public:
  Threshold( int t ) : m_t( t ) { }
  bool operator()( int x ) const { return ( x > m_t ); }
 private:
  int m_t;
};

template < typename S, typename Pred >
int count_if( const S& seq, Pred pred )
{
  int count = 0;
  for ( auto v : seq )
    if ( pred(v) )
      count++;
  return count;
}

int main( void )
{
  List<int> lst;
  lst.push_front( 12 );
  lst.push_front( 15 );
  lst.push_front( 50 );
  lst.push_front( 06 );
  lst.push_front( 76 );

  int a = count_if( lst, &threshold_25 );
  int b = count_if( lst, Threshold(25) );
  return 0;
}
```

```
class Threshold
{
 public:

  Threshold( int t ) : m_t( t )
  { }

  bool operator()( int x ) const
  {
    return ( x > m_t );
  }

 private:
  int m_t;
};

template <>
int count_if<int[2],Threshold>(
  const int[2]& seq,
  Threshold     pred )
{
  int count = 0;
  for ( auto v : seq )
    if ( pred(v) )
      count++;
  return count;
}

int main( void )
{
  int arr[] = { 15, 35 };
  int a = 25;
  Threshold p(a);
  int b = count_if( arr, p );
  return 0;
}
```

stack

2. C++ Lambdas

- Use new C++ syntax along with object-oriented and generic programming to implement:
  - Lambdas: create anonymous functors on the fly

```
int main( void )
{
  int a = 25                    // environment for functor

  // creates an anonymous functor that explicitly captures a
  auto pred0 = [a]( int x )
  {
    return x > a;
  };

  auto pred1 = pred0;           // copy a lambda
  bool b = pred1( 15 );         // call a stored lambda
  bool c = pred1( 30 );         // call a stored lambda
}
```

- Use [] to specify how to capture the environment
  - explicit list of variable names to capture
  - = captures all referenced variables by value
  - & captures all referenced variables by reference

```
  // lambda that implicitly captures a (by value)
  auto pred0 = [=]( int x )
  {
    return x > a;
  };

  // lambda that implicitly captures a (by reference)
  auto pred0 = [&]( int x )
  {
    return x > a;
  };
```

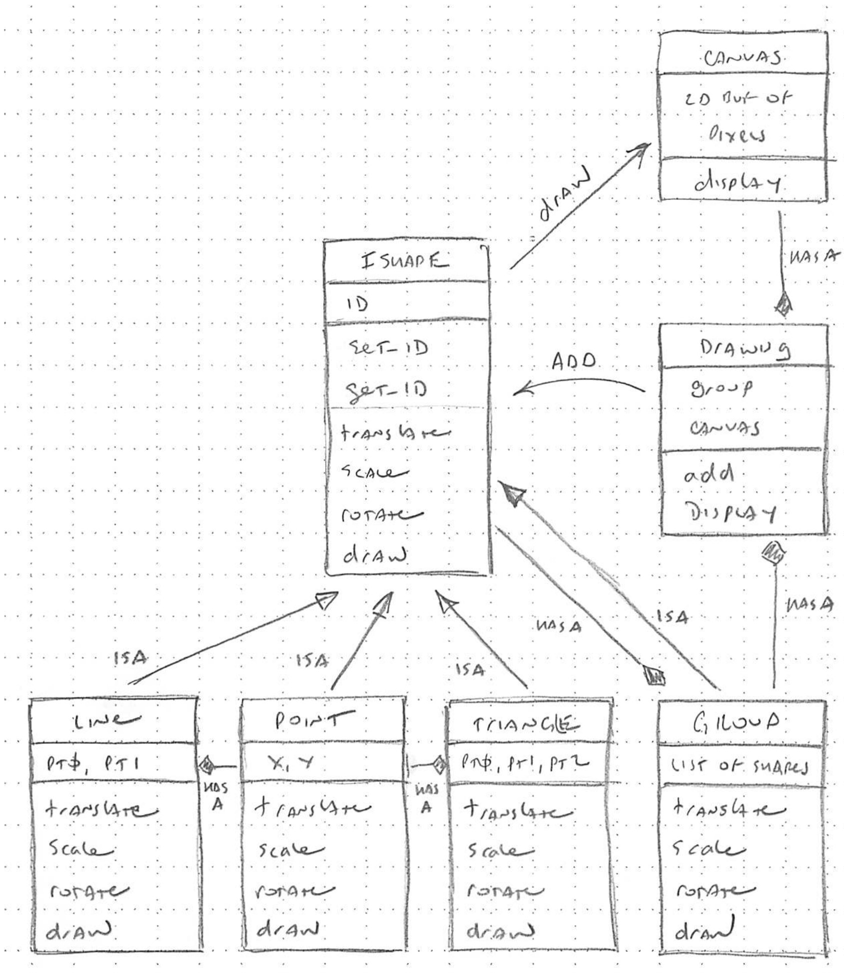
- Use templates to make algorithms generic over function pointers, functors, and lambdas

```
bool threshold_25( int x ) { return ( x > 25 ); }

class Threshold
{
 public:
  Threshold( int t ) : m_t( t ) { }
  bool operator()( int x ) const { return ( x > m_t ); }
 private:
  int m_t;
};

template < typename S, typename Pred >
int count_if( const S& seq, Pred pred )
{
  int count = 0;
  for ( auto v : seq )
    if ( pred(v) )
      count++;
  return count;
}

int main( void )
{
  List<int> lst;
  lst.push_front( 12 );
  lst.push_front( 15 );
  lst.push_front( 50 );
  lst.push_front( 06 );
  lst.push_front( 76 );

  int a = count_if( lst, &threshold_25 );
  int b = count_if( lst, Threshold(25) );
  int c = count_if( lst, []( int x ) { return x > 25; } );
  return 0;
}
```

```
template <>
int count_if<int[2],__lambda0>(
  const int[2]& seq,
  __lambda_0    pred )
{
  int count = 0;
  for ( auto v : seq )
    if ( pred(v) )
      count++;
  return count;
}

int main( void )
{
  int arr[] = { 15, 35 };

  int a = 25;
  auto p =
    [=]( int v ) {
      return v > a;
    };

  int b = count_if( arr, p );
  return 0;
}
```

stack

3. Drawing Framework Case Study



- Create animations by repeatedly drawing and clearing screen

```
int main( void )
{
  // Create a group of lines forming a star
  Group star;
  for ( int i = 0; i < 8; i++ )
    star.add( Line( Point(0,0), Point(0,3) ) % (i*45) );

  // Randomly place stars in a group
  Group stars;
  for ( int i = 0; i < 6; i++ ) {
    int x_offset = ( rand() % 30 ) - 15;
    int y_offset = ( rand() % 30 ) - 15;
    stars.add( star + Point( x_offset, y_offset ) );
  }

  // Make it snow
  for ( int i = 0; i < 80; i++ ) {

    // Clear the screen
    if ( i != 0 ) {
      for ( size_t j = 0; j < 33; j++ )
        printf("\x1b[A");
    }

    // Draw the snowflakes
    Drawing drawing;
    drawing.add( stars + Point(0,30-i) );
    drawing.display();

    // Wait between frames
    usleep(100000);
  }

  return 0;
}
```

https://repl.it/@cbatten/ece2400-T15-ex1

- We can use functional programming to refactor the animation code creating a true animation *framework*

```
template < typename DrawFrame >
void animate( int num_frames, DrawFrame draw_frame )
{
  for ( int i = 0; i < num_frames; i++ ) {

    // Clear the screen
    if ( i != 0 ) {
      for ( size_t j = 0; j < 33; j++ )
        printf("\x1b[A");
    }

    // Draw the frame
    Drawing drawing;
    draw_frame( i, &drawing );
    drawing.display();

    // Wait between frames
    usleep(100000);
  }
}

int main( void )
{
  ...

  animate( 80, [&]( int i, Drawing* drawing_p ) {
    drawing_p->add( stars + Point(0,30-i) );
  });

  return 0;
}
```

https://repl.it/@cbatten/ece2400-T15-ex2