Shape Predicates

15-494 Cognitive Robotics
David S. Touretzky &
Ethan Tira-Thompson

Carnegie Mellon
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The World is Full of Shapes

- When we extract shapes from camera images, we may get a lot of objects.
- We needs ways of selecting and comparing shapes.
- “Find all the orange things.”
  “Find all the lines longer than this line.”
- Tekkotsu provides *shape predicates* for testing shapes. These can be composed to form complex tests.
- To use these, you need to understand C++ functors.

Function Objects (Functors)

A functor is an object that can accept function calls via operator():

```
#include <iostream>
using namespace std;


class MyFunctor {
 public:
  void operator() () const { cout << "Foo!" << endl; }
};


int main() {
  MyFunctor fluffy;

  cout << sizeof(fluffy) << " ";
  fluffy();
}
```

Functors Can Store Values

```
class BiggerThan {

 private:
  int value;

 public:
  BiggerThan(int val) : value(val) {}

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

};
```

Private comparison value

Constructor initializes the private value

Function call operator compares x against the private value

Testing BiggerThan

```
int main() {

  BiggerThan fivetest(5);

  for (int i = 3; i < 8; i++ )
    cout << i << (fivetest(i) ? " passes" : " fails" ) << endl;

}
```

---

3 fails
4 fails
5 fails
6 passes
7 passes

Function Conjunction

```
class AndBigSmall {
 private:
  BiggerThan bigtest;
  SmallerThan smalltest;

 public:
  AndBigSmall(BiggerThan b, SmallerThan s) :
    bigtest(b), smalltest(s) {}

  bool operator() (int x) const
        { return bigtest(x) && smalltest(x); }
};



int main() {
  AndBigSmall myconj(BiggerThan(0),SmallerThan(100));
  for ( int i = -10; i < 150; i+=40 )
    cout << i << " gives " << myconj(i) << endl;
}
```

```
-10 gives 0
30 gives 1
70 gives 1
110 gives 0
```

STL functional.h

- The STL (Standard Template Library) provides classes called unary_function and binary_function from which functors can be composed.

```
class BiggerThan : public unary_function<int,bool> {
 private:
  int value;
 public:
  BiggerThan(int val) : value(val) {}
  bool operator() (int x) const { return x > value; }
};
```

- These user-defined functor classes can then be used with STL functions for searching, etc.

- But they're kind of awkward.

Shape Predicates

- The Shape classes provide their own functor mechanism for defining shape predicates.
- Easier to use than the generic STL.
- Some predicates for common shape tests are built in, e.g.,
  - Comparing the positions of two shapes (left/right or above/below)
  - Comparing the lengths of two lines
  - Comparing line orientations
- New predicates are easy to define.

Shape<LineData> Functors

- Compare the lengths of all the lines in the image against that of the third line.

```
NEW_SHAPEVEC(lines, LineData,
             select_type<LineData>(camShS));

SHAPEVEC_ITERATE(lines, LineData, someLine)
  if ( LineData::LengthLessThan()(someLine,lines[2]) )
    cout << "Shorter: " << someLine->getId() << endl;
  else
    cout << "Longer: " << someLine->getId() << endl;
END_ITERATE;
```

LineData::LengthLessThan

- Class-specific shape predicates are defined with the respective shape, e.g., in LineData.h and LineData.cc.

In LineData.h:

```
class LengthLessThan : public BinaryShapePred<LineData> {
 public:
  bool operator() (const Shape<LineData> &ln1,
                   const Shape<LineData> &ln2) const;
};
```

In LineData.cc:

```
bool LineData::LengthLessThan::operator()
         (const Shape<LineData> &line1,
          const Shape<LineData> &line2) const {
  return line1->getLength() < line2->getLength(); }
```

Generic Shape Predicates

- Some predicates work for shapes of any type. They are defined on class ShapeRoot. Example: IsColor.

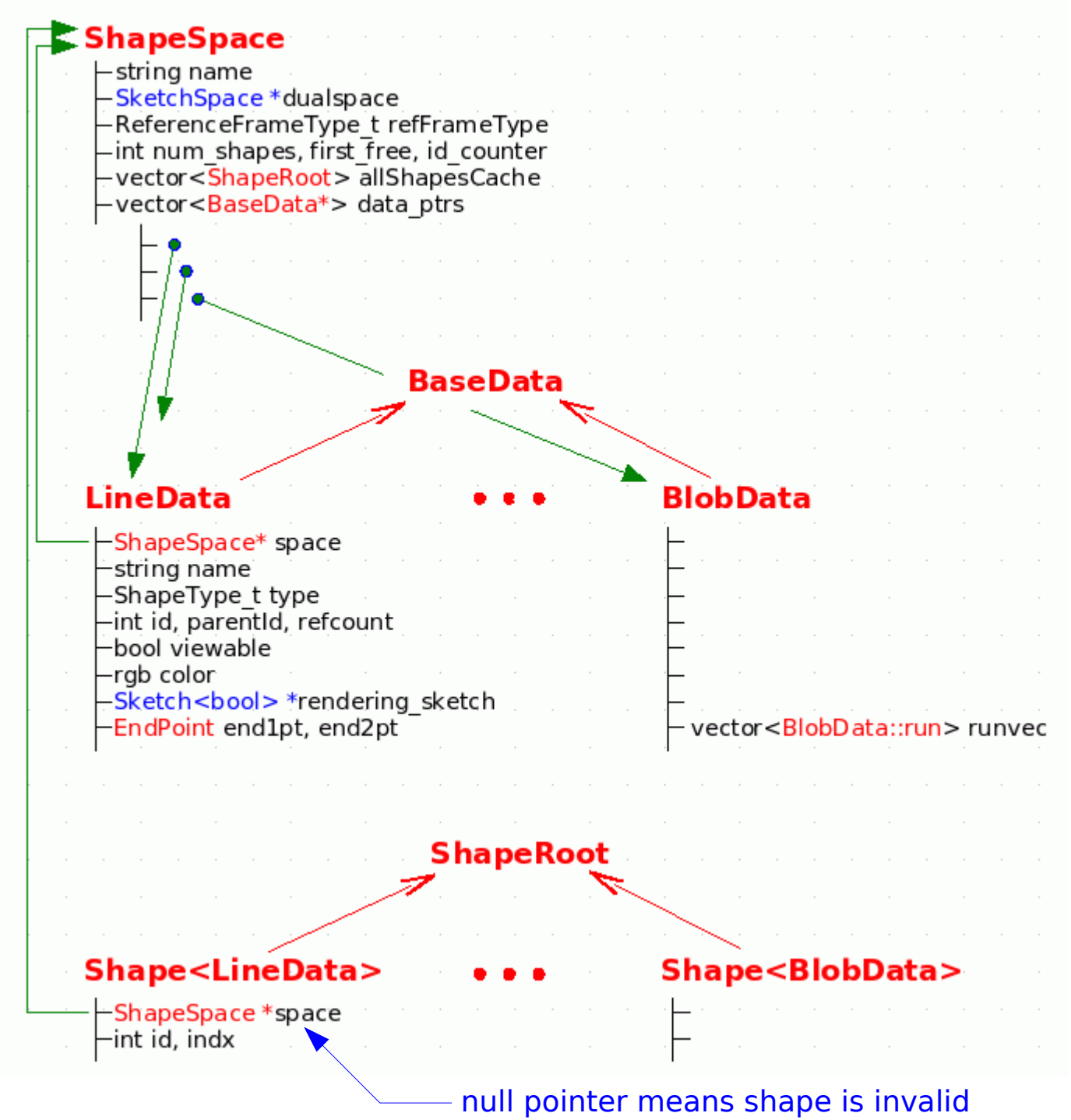
```
NEW_SHAPEVEC(blobs, BlobData,
             select_type<BlobData>(camShS));

IsColor redtest("red");

SHAPEVEC_ITERATE(blobs, BlobData, b)
  if ( redtest(b) )
    cout << "Red: " << b->getId() << endl;
  else
    cout << "Not red: " << b->getId() << endl;
END_ITERATE;
```

Subclasses of BaseData:

Subclasses of ShapeRoot:



Generic IsColor Predicate

```
class IsColor : public UnaryShapeRootPred {
 private:
  rgb color;

 public:
  IsColor(rgb col) : UnaryShapeRootPred(), color(col) {}

  IsColor(std::string const &colorname) :
    UnaryShapeRootPred(),
    color(ProjectInterface::getColorRGB(colorname)) {}

   bool operator() (const ShapeRoot &shape) const {
    return shape->getColor() == color; }

};
```

Note: the colorname string is looked up once, by the constructor, and the rgb value is stored in the private variable color. When the functor is invoked on a ShapeRoot, no lookup is necessary.

IsLeftOf / IsLeftOfThis

- IsLeftOf()
  - This is a BinaryShapeRootPred that requires two arguments, and compares their centroids:

    IsLeftOf() (line2,blob6)

- IsLeftOfThis(x)
  - This is a UnaryShapeRootPred that requires one argument:

    IsLeftofThis(line2) (blob6)

    constructor argument

Using IsLeftOfThis

- An instance of IsLeftOfThis stores a ShapeRoot inside it, and uses it for comparison tests.

```
IsLeftOfThis  mytest(lines[4]);


SHAPEVEC_ITERATE(lines, LineData, ln)
  if ( mytest(ln) )
    cout << "This is left of me: "
         << ln->getId() << endl;
END_ITERATE;
```

Built-In Shape Predicates

ShapeRoot:

IsColor
IsType
IsName

IsLeftOf / IsRightOf
IsAbove / IsBelow

IsLeftOfThis ...
IsAboveThis ...

Shape<LineData>:

LengthLessThan

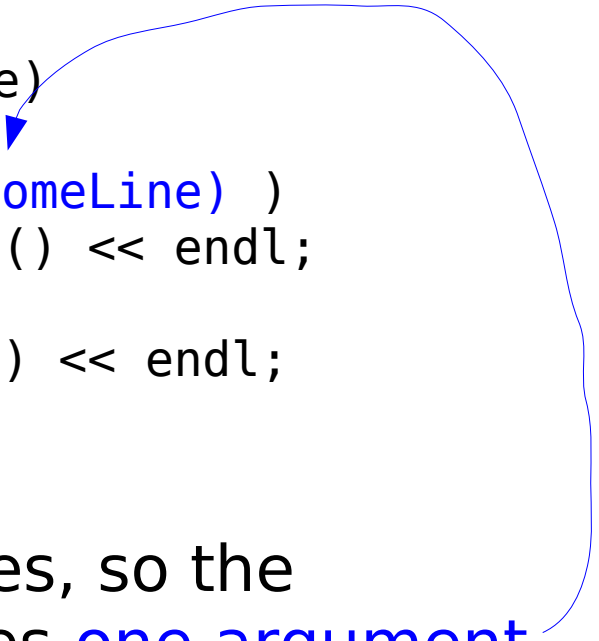
IsHorizontal
IsVertical

ParallelTest
PerpendicularTest
ColinearTest

AndPred / OrPred

- Because shape predicates are classes, we can compose them using the functors AndPred and OrPred.

```
SHAPEVEC_ITERATE(lines, LineData, someLine)
  if ( AndPred(IsColor("red"),
               IsLeftOfThis(lines[3])) (someLine) )
    cout << "winner: " << someLine->getId() << endl;
  else
    cout << "loser: " << someLine->getId() << endl;
END_ITERATE;
```



- We are composing two unary predicates, so the result is also a unary predicate: it takes one argument.

Vectors of ShapeRoots

- camShS.allShapes() returns all the shapes in the shape space, as a std::vector<ShapeRoot>.
- camShS will be automatically coerced to std::vector<ShapeRoot> by an implicit call to allShapes()
- Use SHAPEROOTVEC_ITERATE(vec,var) to iterate:

```
SHAPEROOTVEC_ITERATE(camShS, s)
  if ( OrPred(IsType(blobDataType),
              IsType(lineDataType)) (s) )
    cout << "Is blob or line: " << s->getId() << endl;
END_ITERATE;
```

- Shape type constants like blobDataType are defined in DualCoding/ShapeTypes.h

Inside SHAPEVEC_ITERATE

```
SHAPEVEC_ITERATE(lines, LineData, ln) {
    do_something_with(ln);
} END_ITERATE;
```

Expands into:

```
for ( vector<Shape<LineData> >::_iterator ln_it = lines.begin();
       ln_it != lines.end(); ln_it++ ) {
    Shape<LineData> &ln = *ln_it;
    do_something_with(ln);
  };
```

Mirroring STL Search Functions

- The STL provides a collection of functions for searching through a vector using either a binary comparison predicate or a unary test predicate.
- Tekkotsu provides similar functions for shape predicates:
  - find_if, subset, max_element, stable_sort, remove_copy_if
- There are also some new functions unique to shapes:
  - find_shape, select_type
- All are defined in DualCoding/ShapeFuns.h

Filtering Shapes

- Find the first blob:

```
NEW_SHAPE(blob0, BlobData, find_if<BlobData>(camShS));
```

- camShS is treated as shorthand for camShS.allShapes()
- If no blobs found, an invalid Shape is returned

- Find all the blobs:

```
NEW_SHAPE_VEC(all_blobs, BlobData,
              select_type<BlobData>(camShS));
```

More Filtering and Searching

- Find all the red blobs:

```
NEW_SHAPEVEC(red_blobs, BlobData,
    subset(all_blobs, IsColor("red")))
```

- Find the longest line:

```
NEW_SHAPE(longest, LineData,
    max_element(lines,
                LineData::LengthLessThan()))
```

- Test is “less than”, but max_element returns *longest*.

Implementing max_element

```
// from DualCoding/ShapeFuns.h

template<class T, typename ComparisonType>
Shape<T> max_element(const vector<Shape<T> > &vec,
                     ComparisonType comp) {

  typename vector<Shape<T> >::const_iterator result =
     max_element(vec.begin(),vec.end(),comp);

  if ( result != vec.end() )
    return *result;
  else
    return Shape<T>();
}
```

If no elements, return an invalid shape.

T = LineData

ComparisonType = LengthLessThan

vec is a SHAPEVEC of LineData

comp is an instance of LengthLessThan

Functors for Negating a Predicate

- Use not1(pred) to negate a unary predicate:

```
NEW_SHAPEROOTVEC(non_red,
        subset(camShS, not1(IsColor("red"))));
```

- Use not2(pred) to negate a binary (comparison) predicate:

```
NEW_SHAPEVEC(shortlines, LineData,
  stable_sort(lines, not2(LineData::LengthLessThan())));
```

Nested Iteration: Compare Lines, Longest First

```
NEW_SHAPEVEC(lines,LineData,select_type<LineData>(camShS));

lines = stable_sort(lines,not2(LineData::LengthLessThan()));

SHAPEVEC_ITERATE(lines, LineData, ln1)
  SHAPENEXT_ITERATE(lines, LineData, ln1, ln2)
    if ( LineData::ParallelTest()(ln1,ln2) )
      cout << ln1 << " parallel to " << ln2 << endl;
    if ( LineData::PerpendicularTest()(ln1,ln2) )
      cout << ln1 << " perpendicular to " << ln2 << endl;
    if ( LineData::ColinearTest()(ln1,ln2) )
      cout << ln1 << " colinear with " << ln2 << endl;
  END_ITERATE;
END_ITERATE;
```

Shape<LineData>(id=10002,indx=1) perpendicular to
Shape<LineData>(id=10005,indx=4)
... etc.