Brief Notes on Object-Oriented Software Design and Programming with C++

OpenSees Developer Workshop

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NEESit

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Objectives of Notes

- Introduction to topics in software engineering
- Describe data abstraction and modularity
- Demonstrate how objects represent data and operations on data
- Provide two examples (not related to OpenSees)

Problem of Software Design

- Complex problems
- Requirements change
- Unconstrained vs. constrained programs
- Collaborative development process

Data Abstraction

- Abstract data types describe the *behavior* of data.
- Specification of behavior is distinct from implementation of behavior
- Abstract data type defines:
  - Set of objects of the data type
  - Operations that are specified for objects in set

Example of ADT: Vector

- Vector is mathematical quantity
- Specification includes operations such as:
  - Define vector
  - Magnitude of vector
  - Addition of two vectors
  - Multiplication by scalar
  - Dot product of two vectors

Using a Vector Class

```
#include"vector.h"

void main ( void )
{
    Vector v1(4,1.0), v2(4,2.0);   // v1 initialed to 1; v2 to 2
    Vector s1, s2, v3;             // vectors of undefined size.
    float d;

    s1 = v1.vAdd(v2);         // addition with vAdd operator
    s2 = v1 + v2;             // addition with overloaded + operator

    Vector v4(4,10);          // create vector, initial to 10.
    d = v4*v1;                // inner product with overloaded *

    v2[0]=v2[0]+v2[1];        // example of index operation

    v2+=v1;                   // compound assignment, v2=v2+v1
}
```

Specification of Vector Class

```
// ADT for Vector in vector.h

class Vector {

   public:
      Vector ( int sz=3, float val=0.0);  // default to 3D
      Vector ( const Vector& );           // copy constructor
      ~Vector ( void );                   // destructor

      Vector& operator= ( const Vector& w );// assignment

      Vector& operator= ( float s );      // assign vector con

      float vMag   ( void )    const;
      Vector vAdd  ( const Vector& w ) const;
      Vector vMult ( float s         ) const;
      float vDot   ( const Vector &w ) const;

      int vGetSize ( void  ) const;


      // Overloaded operators
      Vector operator+ ( const Vector& w) const;     // add
      Vector operator- ( const Vector& w) const;     // subtra
      Vector operator* ( float s ) const;            // mult.
      Vector operator/ ( float s ) const;            // div. b
      float operator*  ( const Vector& w ) const;    // dot pr

      // Subscript operators
      float& operator[]  ( int i );             // LH side
      const float& operator[] (int i ) const;   // RHS

      // Compound assignment operators
      Vector& operator+= ( const Vector& w );  // add to obje
      Vector& operator-= ( const Vector& w );  // sub. from ol
      Vector& operator*= ( const float s  );   // multiply  s
      Vector& operator/= ( const float s  );   // divide by s

      // Equality operations
      int operator== ( const Vector& w ) const;
      int operator!= ( const Vector& w ) const;

   private:
      float *vec;
      int size;
};
```

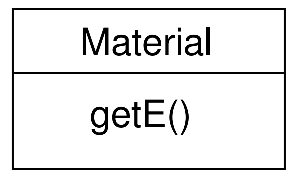
Object-Oriented Software Design

- Abstraction
- Hierarchy
- Encapsulation
- Concurrency
- Persistence

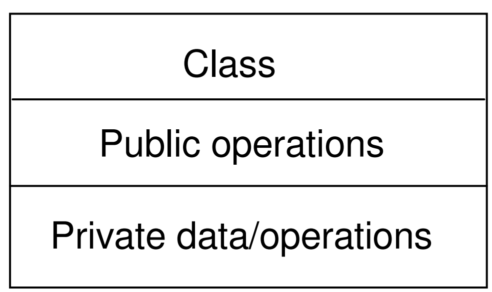
Example of Software Design

- Represent structural beams with different types of materials
- Illustrate abstraction principles
- Show benefit of dynamic binding: associating functions with objects depending on class of object
- Not the same classes as in OpenSees even though the class names are similar.

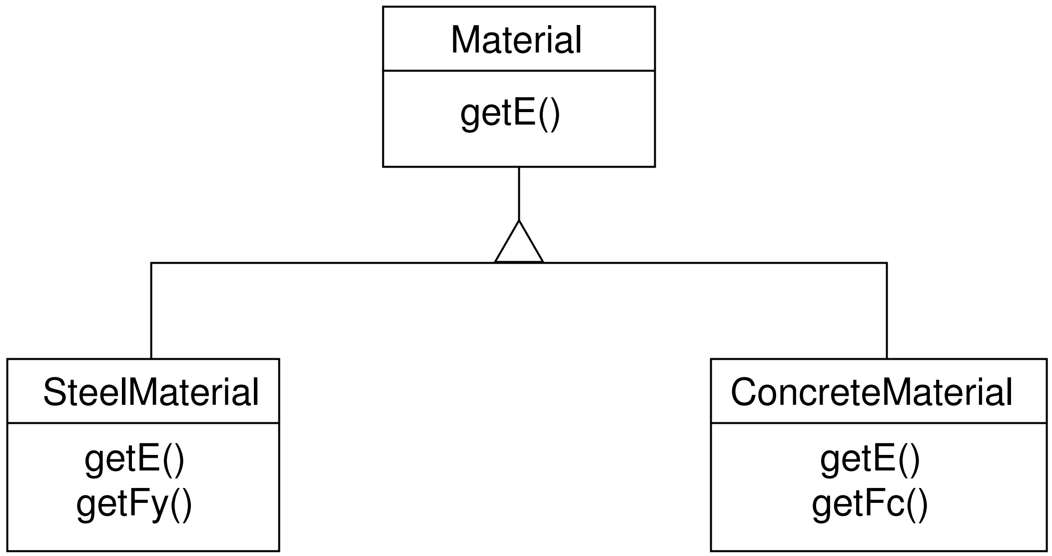
Material is a class that represents properties of materials used in structural beam. Objects of class *Material* have at least one operation, which is to determine the modulus of elasticity.



Object modeling notation for a class:

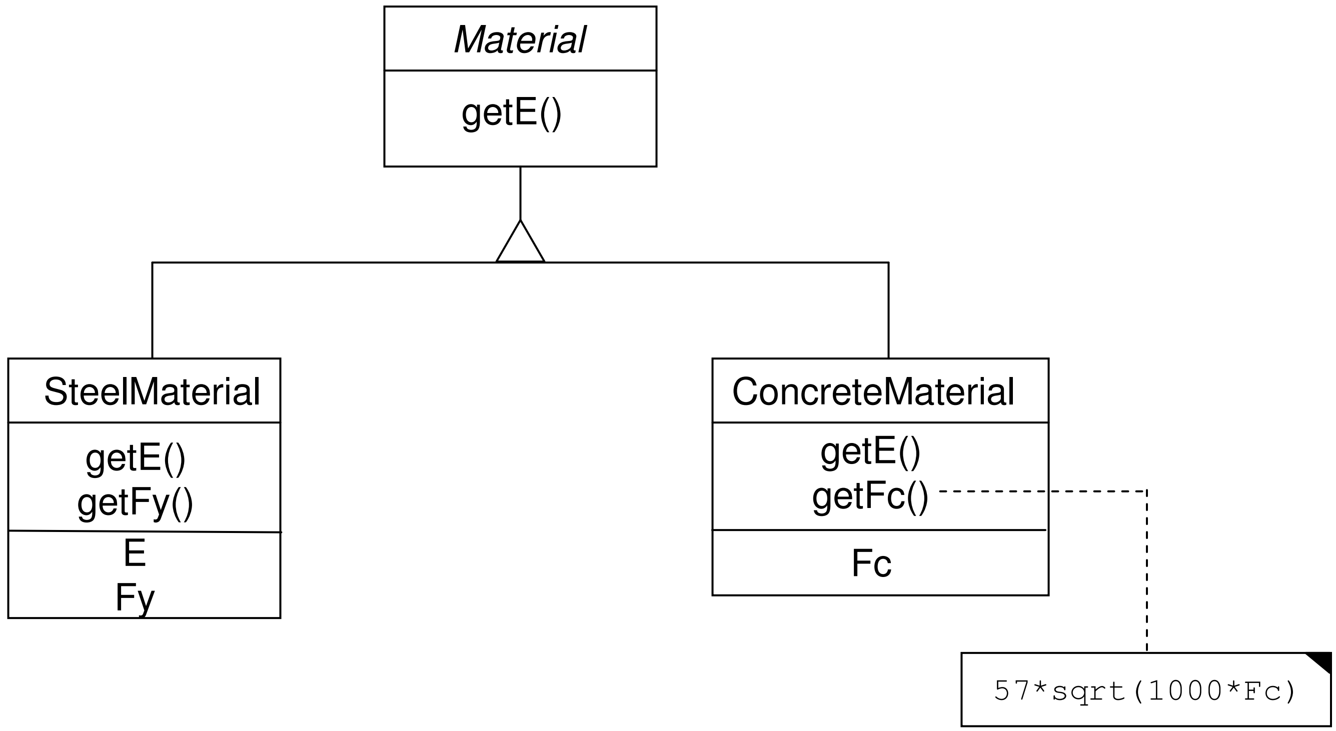


Details of specifics of materials can be provided by providing *subclasses*.



Material is a base class (superclass). *SteelMaterial* and *ConcreteMaterial* are derived classes (subclasses) in the inheritance hierarchy. This is an example of single inheritance. Inheritance is also called an “is-a” relationship

Decide on specific representation for concrete classes (i.e. not abstract classes):



Material is an abstract class since no instances will be created from it.

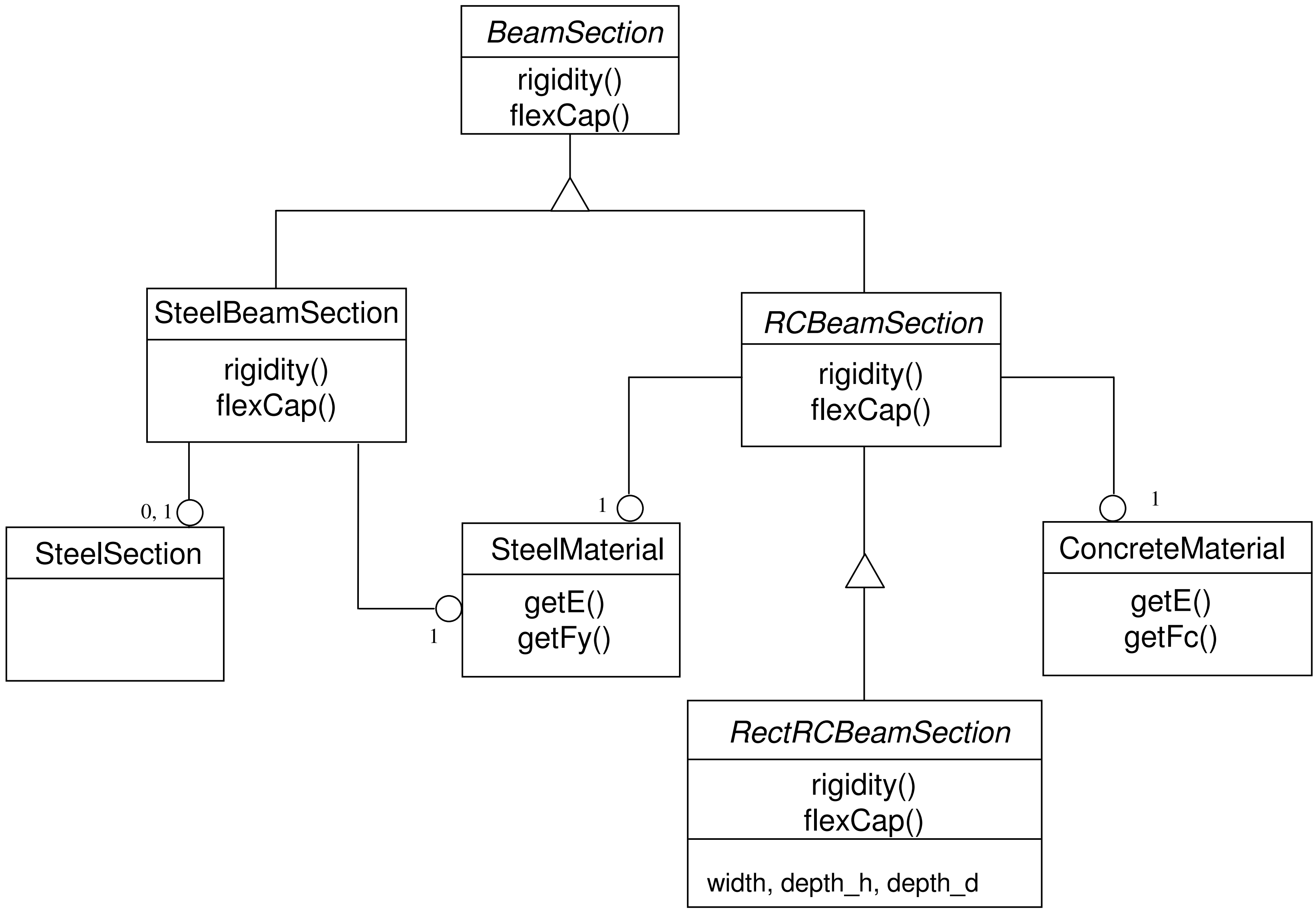
C++ class declaration for material classes:

```
class Material
{
            public:
                        virtual double getE ( void ) const = 0;
                        virtual ~Material (void);
};

class SteelMaterial : public Material
{
            public:
                        SteelMaterial ( double f, double e=29000 );
                        virtual double getE  ( void ) const;
                        virtual double getFy ( void ) const;

            private:
                        double E;   // Modulus of elasticity
                        double Fy;  // Nominal yield stress

};

class ConcreteMaterial : public Material
{
            public:
                        ConcreteMaterial ( double f );
                        virtual double getE  ( void ) const;
                        virtual double getFc ( void ) const;

            private:
                        double Fc;  // Compressive strength

};
```

Material class implementation:

```
// Default destructor
Material::~Material ( void )
{ }

// SteelMaterial methods
SteelMaterial::SteelMaterial ( double f, double e)
{
            if ( e > 0 )
                        E = e;
            else
                        errorExit("SteelMaterial", "Invalid modulus of elasticity.");

            if ( f > 0 )
                        Fy = f;
            else
                        errorExit("SteelMaterial", "Invalid yield strength.");
}

double SteelMaterial::getE  ( void ) const { return E;  }
double SteelMaterial::getFy ( void ) const { return Fy; }

// ConcreteMaterial methods
ConcreteMaterial::ConcreteMaterial ( double f )
{
            if ( f > 0 )
                        Fc = f;
            else
                        errorExit("ConcreteMaterial","Invalid compressive strength");
}

double ConcreteMaterial::getE ( void ) const
{
            return 57.0*sqrt(Fc*1000); // per ACI,  normal weight concrete
}

double ConcreteMaterial::getFc ( void ) const { return Fc; }
```

Decide on representation of beam sections:



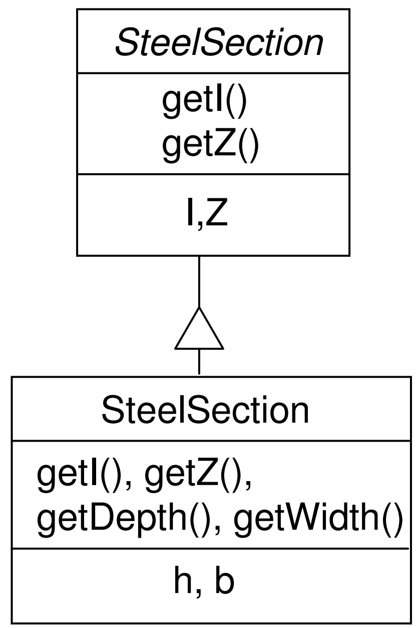
RectSingleRCBeamSection
is a specialized class

Beam class specifications:

```
class BeamSection
{
     public:
          virtual double rigidity ( void ) const = 0;
          virtual double flexCap  ( void ) const = 0;
          virtual ~BeamSection ( void );
};

class SteelBeamSection : public BeamSection
{
     public:
          SteelBeamSection ( void );
          SteelBeamSection ( const SteelMaterial& b );
          SteelBeamSection ( const SteelMaterial& b, const SteelSection& a

          virtual double rigidity ( void ) const;
          virtual double flexCap  ( void ) const;
          virtual void setSteelSection ( const SteelSection& a );

     private:
          SteelSection*  aSteelSec;
          const SteelMaterial* aSteelMat;
};

class RConcreteBeamSection : public BeamSection
{
     public:
          virtual double rigidity ( void ) const = 0;
          virtual double flexCap  ( void ) const = 0;

     protected:
          RConcreteBeamSection ( const SteelMaterial& a,
               const ConcreteMaterial& b );
          virtual double getIcr ( void ) const = 0;

          const SteelMaterial*    aSteelMat;
          const ConcreteMaterial* aConcreteMat;
};
```

```
class RectRConcreteBeamSection : public RConcreteBeamSection
{
     public:
          virtual double rigidity ( void ) const = 0;
          virtual double flexCap  ( void ) const = 0;
          virtual void setWidth ( double w );
          virtual void setDepth ( double h );
          virtual void setEffectiveDepth ( double d );
          virtual double getWidth ( void ) const;
          virtual double getDepth ( void ) const;
          virtual double getEffectiveDepth ( void ) const;

     protected:
          RectRConcreteBeamSection ( const SteelMaterial& a,
               const ConcreteMaterial& b,
               double w = 0, double h = 0, double d = 0 );
          virtual double getIcr ( void ) const;

     private:
          double width;
          double depth_h;
          double depth_d;
};

class RectSingleRConcreteBeamSection : public RectRConcreteBeamSection
{
     public:
          RectSingleRConcreteBeamSection ( const SteelMaterial& a,
               const ConcreteMaterial& b,
               double w = 0, double h = 0, double d = 0, double A = 0 );
          virtual double rigidity ( void ) const;
          virtual double flexCap  ( void ) const;
          virtual void setAs ( double A );
          virtual double getAs ( void ) const;

     private:
          double As;
};
```

For different steel section shapes, develop class hierarchy to provide specific representations:



Steel section class specifications:

```
class SteelSection
{
     public:
          virtual double getZ ( void ) const;
          virtual double getI ( void ) const;
          virtual ~SteelSection ( void );

     protected:
          SteelSection ( double zxx, double ixx );

     private:
          double Z;
          double I;
};

class WFSteelSection : public SteelSection
{
     public:
          WFSteelSection ( double zxx, double ixx, double depth, double
width );
          double getDepth ( void ) const;
          double getWidth ( void ) const;

     private:
          double h;
          double b;
};
```

Example Application

```
int main ( void )
{
     // Create material objects
     SteelMaterial   a36 = SteelMaterial(36);
     SteelMaterial   a60 = SteelMaterial(60);
     ConcreteMaterial   f4  = ConcreteMaterial(4);

     // Create a steel WF section
     SteelSection sec1 = WFSteelSection(400,300,12,8);

     // Create beam sections with material only
     SteelBeamSection beam1 = SteelBeamSection (a36);
     RectSingleRConcreteBeamSection beam2 =
                        RectSingleRConcreteBeamSection(a60,f4);

     // Set section for steel beam
     beam1.setSteelSection(sec1);

     // Define a singly reinforced concrete beam
     double h = 24;
     beam2.setWidth(h/2);
     beam2.setDepth(h);
     beam2.setEffectiveDepth(h-3);
     beam2.setAs(6);

     // Cast upward to test dynamic binding of member functions
     BeamSection *beam3 = dynamic_cast<BeamSection*>(&beam2);

     // Get flexural properties of two beams
     double EI = beam1.rigidity();
     double Mp = beam1.flexCap();

     double EI2=beam3->rigidity();
     double Mn =beam3->flexCap();

     cout << "Steel Beam:    EI=" << EI  << "  Mp=" << Mp << endl;
     cout << "Concrete Beam: EI=" << EI2 << "  Mn=" << Mn << endl;
}
```

Questions?