Chapter 1

Demo problem: Upgrading a GeomObject to a GeneralisedElement – how to parametrise unknown domain boundaries

In many previous examples we demonstrated how to use `GeomObjects` to parametrise curvilinear, moving domain boundaries. We used this functionality extensively to perform simulations of problems in moving domains. The techniques illustrated in these examples are adequate for problems in which the motion of the boundary is prescribed; see e.g. the
`simulation of fluid flow in a 2D channel in which a part of one channel wall performs a prescribed oscillation`.

Here we shall demonstrate how to use `GeomObjects` to parametrise curvilinear, moving domain boundaries in problem in which the position of the boundary is unknown and has to be determined as part of the overall solution. We will also address the following questions:

- What is a `GeomObject's` geometric `Data`?
- What is a `GeneralisedElement's` external and internal `Data`?

1.1 Part 1: A closer look at the GeomObject class: Geometric Data

In an `earlier example`, we introduced the `GeomObject` as a base class for all objects that provide an analytical parametrisation of a geometric object by specifying its Eulerian coordinates (i.e. the position vector to "material points" in the object, $\mathbf{r}$) as a function of some intrinsic (Lagrangian) coordinates, ζ, so that $\mathbf{r} = \mathbf{r}(\zeta)$. Every specific `GeomObject` must implement the pure virtual function

```
void GeomObject::position(const Vector<double>& zeta, Vector<double>& r);
```

where the number of Lagrangian and Eulerian coordinates involved in the parametrisation (i.e. the sizes of the vectors `zeta` and `r`) are stored as unsigned integers in the protected member data, `GeomObject::NLagrangian` and `GeomObject::Ndim`, respectively.
Most specific geometric objects store some additional parameters as private data members. For instance, a `GeomObject` that represents a 2D circle, parametrised by the 1D Lagrangian coordinate ζ as

$$\mathbf{r}(\zeta) = \begin{pmatrix} X_c + R\cos(\zeta) \\ Y_c + R\sin(\zeta) \end{pmatrix}$$

may be implemented as follows:

```
//=====start_of_circle=================================================
/// \short Simple circle in 2D space.
/// \f[ x = X_c + R \cos(\zeta)  \f]
/// \f[ y = Y_c + R \sin(\zeta)  \f]
//=====================================================================
class SimpleCircle : public GeomObject
```

```
{
public:

 /// Constructor:  Pass x and y-coords of centre and radius
 SimpleCircle(const double& x_c, const double& y_c,
              const double& r) : GeomObject(1,2), X_c(x_c), Y_c(y_c), R(r)
  {}

 /// \short Position Vector at Lagrangian coordinate zeta
 void position(const Vector<double>& zeta, Vector<double>& r) const
  {
   // Position vector
   r[0] = X_c+R*cos(zeta[0]);
   r[1] = Y_c+R*sin(zeta[0]);
  }

 /// \short Position Vector at Lagrangian coordinate zeta  at time level t
 /// (t=0: present; t>0: previous level). Steady object, so we
 /// simply forward the call to the steady version.
 void position(const unsigned& t, const Vector<double>& zeta,
               Vector<double>& r) const
  {position(zeta,r);}
protected:

 /// X-coordinate of centre
 double X_c;

 /// Y-coordinate of centre
 double Y_c;

 /// Radius
 double R;
}; // end of SimpleCircle class
```

The shape and position of this `GeomObject` is defined by the parameters X_c, Y_c and R which are stored as double precision numbers in the object's private member data.

In many applications (e.g. in free-boundary problems) it is necessary to regard some (or all) of the parameters that specify the object's shape as (an) unknown(s) in the overall problem. Within `oomph-lib` all unknowns are values in `Data` objects. We refer to any `Data` objects whose values affect the shape of a `GeomObject` as the `GeomObject's` geometric `Data`. The `GeomObject` class defines interfaces for two functions that provide access to such `Data`. The function

```
virtual unsigned GeomObject::ngeom_data() const;
```

should return the number of geometric `Data` objects that affect a `GeomObject's` shape and position. The function

```
virtual Data* GeomObject::geom_data_pt(const unsigned& j);
```

should return a pointer to the `GeomObject's j` - th geometric `Data` object. Both functions are implemented as "broken" virtual functions in the `GeomObject` base class in order to facilitate the creation of new `GeomObjects`. The functions should be overloaded in `GeomObjects` that actually contain geometric `Data`. If this is not done, the broken versions in the base class issue a suitable explanation before throwing an error.

Here is a re-implementation of the above `GeomObject` in a form that allows the the parameters X_c, Y_c and R to be regarded as unknowns, by storing them as values in a suitable `Data` object:

```
//=============================================================================
/// \short GeneralCircle in 2D space.
/// \f[ x = X_c + R \cos(\zeta)  \f]
/// \f[ y = Y_c + R \sin(\zeta)  \f]
/// The three parameters \f$ X_c, Y_c \f$ and \f$ R \f$ are represented
/// by Data and can therefore be unknowns in the problem.
//=============================================================================
class GeneralCircle : public GeomObject
{
```

The object has two constructors which we will discuss separately. The arguments to the first constructor specify the x- and y-coordinates of the ring's centre (X_c and Y_c), and its radius, R, as double-precision numbers. The constructor creates storage for these values in the `Geom_data_pt` vector which is stored in the object's protected member data. First, the `Geom_data_pt` vector (empty by default) is resized to provide storage for a (pointer to a) single Data item. Next we create a Data object that provides storage for three values and store the pointer to this `Data` object in the first (and only) component of the `Geom_data_pt` vector. Finally, we set the values to those specified by the arguments and pin them to reflect the fact that, by default, the values are constants rather than unknowns in the problem. [**Note:** Clearly, there is some ambiguity as to how to distribute the values of the geometric parameters among the geometric `Data`. Here we chose to store the three values in a single `Data` object, but we could also have stored each value in its own `Data` object.]

```
 /// Constructor:  Pass x and y-coords of centre and radius (all pinned)
 GeneralCircle(const double& x_c, const double& y_c,
               const double& r) : GeomObject(1,2)
  {
   // Create Data: We have one Data item with 3 values. The Data object
   // stores the x position of the circle's centre as value 0,
```

```
   // the y position of the circle's centre as value 1, and the
   // circle's radius as value 2.
   Geom_data_pt.resize(1);
   Geom_data_pt[0] = new Data(3);

   // Assign data: X_c -- the value is free by default: Need to pin it.
   // Pin the data
   Geom_data_pt[0]->pin(0);
   // Give it a value:
   Geom_data_pt[0]->set_value(0,x_c);
   // Assign data: Y_c -- the value is free by default: Need to pin it.
   // Pin the data
   Geom_data_pt[0]->pin(1);
   // Give it a value:
   Geom_data_pt[0]->set_value(1,y_c);
   // Assign data: R -- the value is free by default: Need to pin it.
   // Pin the data
   Geom_data_pt[0]->pin(2);
   // Give it a value:
   Geom_data_pt[0]->set_value(2,r);
   // I've created the data, I need to clean up
   Must_clean_up=true;
  }
```

With this constructor, the geometric `Data` that controls the shape of the object is created internally – the "user" only specifies the values of the parameters. Their values are accessible via the access functions

```
 /// Access function to x-coordinate of centre of circle
 double& x_c(){return *Geom_data_pt[0]->value_pt(0);}

 /// Access function to y-coordinate of centre of circle
 double& y_c(){return *Geom_data_pt[0]->value_pt(1);}

 /// Access function to radius of circle
 double& R(){return *Geom_data_pt[0]->value_pt(2);}
```

but their internal representation as (pinned) values of a `Data` object remains hidden. Access to the geometric `Data` is, however, possible via the functions

```
 /// How many items of Data does the shape of the object depend on?
 unsigned ngeom_data() const {return Geom_data_pt.size();}

 /// \short Return pointer to the j-th Data item that the object's
 /// shape depends on
 Data* geom_data_pt(const unsigned& j) {return Geom_data_pt[j];}
```

which overload the broken versions in the `GeomObject` base class. Both functions access the protected vector of pointers to the object's geometric `Data`:

```
protected:

 /// \short Vector of pointers to Data items that affects the object's shape
 Vector<Data*> Geom_data_pt;
```

The second constructor is appropriate for cases in which the `Data` object that specifies the object's shape has already been created elsewhere. In this case, we simply pass the pointer to the Data object to the constructor and store it in the first entry of the `Geom_data_pt` vector:

```
 /// \short Alternative constructor:  Pass x and y-coords of centre and radius
 /// (all as part of Data)
 /// \code
 /// Geom_data_pt[0]->value(0) = X_c;
 /// Geom_data_pt[0]->value(1) = Y_c;
 /// Geom_data_pt[0]->value(2) = R;
 /// \endcode
 GeneralCircle(Data* geom_data_pt) : GeomObject(1,2)
  {
#ifdef PARANOID
   if (geom_data_pt->nvalue()!=3)
    {
     std::ostringstream error_stream;
     error_stream << "Geometric Data must have 3 values, not "
                  << geom_data_pt->nvalue() << std::endl;
     throw OomphLibError(error_stream.str(),
                         OOMPH_CURRENT_FUNCTION,
                         OOMPH_EXCEPTION_LOCATION);
    }
#endif
   Geom_data_pt.resize(1);
   Geom_data_pt[0]=geom_data_pt;
   // Data has been created externally: Must not clean up
   Must_clean_up=false;
  } //end of alternative constructor
```

The boolean flag `Must_clean_up` is stored as private member data in the class. It is used in the destructor to decide if the geometric `Data` should be deleted. If the `Data` was created internally by the object (i.e. if the first constructor was used), the `Data` must also be deleted by the object; if the `Data` was created externally (i.e. if the second constructor was used), the `Data` must not be deleted as it may still be required in other parts of the code.

```
 /// Destructor:  Clean up if necessary
 virtual ~GeneralCircle()
```

```
 {
  // Do I need to clean up?
  if (Must_clean_up)
   {
    unsigned ngeom_data=Geom_data_pt.size();
    for (unsigned i=0;i<ngeom_data;i++)
     {
      delete Geom_data_pt[i];
      Geom_data_pt[i]=0;
     }
   }
 } // end of destructor
```

The function `GeomObject::position(...)` simply extracts the relevant parameters (X_c, Y_c, R) from the `Geom_data_pt` vector and computes the position vector as a function of the 1D Lagrangian coordinate ζ:

```
/// \short Position Vector at Lagrangian coordinate zeta
void position(const Vector<double>& zeta, Vector<double>& r) const
 {
  // Extract data
  double X_c= Geom_data_pt[0]->value(0);
  double Y_c= Geom_data_pt[0]->value(1);
  double R= Geom_data_pt[0]->value(2);
  // Position vector
  r[0] = X_c+R*cos(zeta[0]);
  r[1] = Y_c+R*sin(zeta[0]);
 } // end of position(...)
```

1.2 Part 2: Upgrading a GeomObject to a GeneralisedElement

We will now consider a (toy!) problem in which the ability to treat a parameter that specifies the shape and/or the position of a geometric object as an unknown (i.e. as a value in a `Data` object) is essential: A circular ring of radius R is mounted on a linearly elastic spring of stiffness k_{stiff}. We wish to find the ring's equilibrium position when it is subjected to a vertical load, f_{load}.

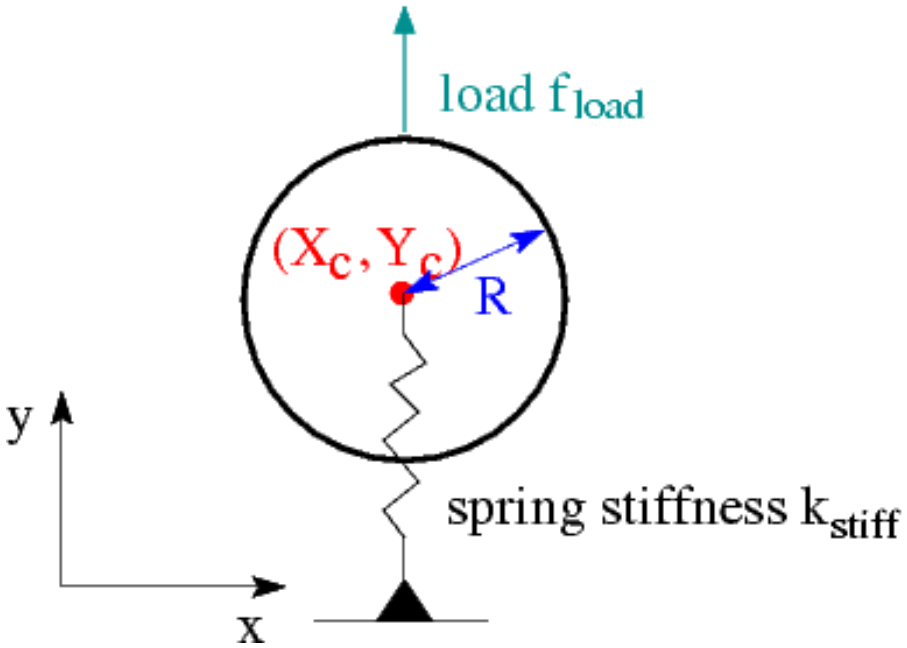

Figure 1.1 Sketch of the example problem.

To solve this problem with `oomph-lib` [Yes, the solution is $Y_c = f_{load}/k_{stiff}$ but let's pretend we don't know this...], we employ C++ inheritance to "upgrade" the `GeneralCircle` object, discussed above, to a `GeneralisedElement` in which the vertical position of the ring, Y_c, is one of the unknowns whose value is determined by the equilibrium equation (in residual form),

$$f_{load} - Y_c \, k_{stiff} = 0. \qquad (1)$$

In the present problem, the load on the ring is a control parameter, but in different applications it may be an unknown whose value has to be determined as part of the solution. (For instance, in fluid-structure interaction problems, the

load on an elastic structure depends on the unknowns in the adjacent fluid elements.) Therefore, we also represent f_{load} by a Data object.
To solve the above problem with oomph-lib, the residual equation (1) must be implemented in the get_residuals(...) function of a suitable GeneralisedElement. Recall that the elemental residual vector computed by a GeneralisedElement can depend on two types of Data:

- **Internal *Data*** stores values that are "internal" to the element, i.e. values that the element is "in charge of". Such Data is accessible via the pointer-based access function GeneralisedElement::internal_data_pt(...)
- **External *Data*** stores values that are "external" to the element. The values stored in such Data *affect* the element's residual vector but its values are not determined *by* the element. Such Data is accessible via the pointer-based access function GeneralisedElement::external_data_pt(...)

In the present context, it is most natural to regard the GeneralCircle's geometric Data as internal to the element and the load Data as external.
Here is the class definition for the ElasticallySupportedRingElement which combines the GeneralisedElement and GeneralCircle classes by multiple inheritance. Its role as a GeomObject allows the object to be used in the parametrisation of domain boundaries; its role as a GeneralisedElement allows the value of Y_c to be determined as part of the solution.

```
//==========start_of_general_circle======================================
/// \short GeneralCircle "upgraded" to a GeneralisedElement: Circular
/// ring whose position is given by
/// \f[ x = X_c + R \cos(\zeta)  \f]
/// \f[ y = Y_c + R \sin(\zeta)  \f]
/// The ring's vertical position \f$ Y_c \f$ is
/// determined by "pseudo elasticity":
/// \f[
/// 0 = f_{load} - Y_c \ k_{stiff}
/// \f]
/// This simulates the case where the centre of the ring is mounted on
/// an elastic spring of stiffness \f$ k_{stiff} \f$ and loaded by
/// the force \f$ f_{load}. \f$ The "load" is specified by the
/// Data object \c load_pt().
//========================================================================
class ElasticallySupportedRingElement : public GeneralisedElement,
                                        public GeneralCircle
```

The arguments to the constructor specify the initial geometric parameters, X_c, Y_c and R. We pass them to the constructor of the GeneralCircle object and assign a default value for the spring stiffness k_{stiff} (stored as a private data member of the class; see below):

```
 /// \short Constructor: Build  ring from doubles that describe
 /// the geometry: x and y positions of centre and the radius.
 /// Initialise stiffness to 1.0. By default, no load is set.
 ElasticallySupportedRingElement(const double& x_c, const double& y_c,
                                 const double& r) :
  GeneralCircle(x_c,y_c,r), K_stiff(1.0), Load_data_has_been_set(false)
```

Next, we add the GeneralCircle's geometric Data (created automatically by the constructor of the GeneralCircle object; see above) into the element's storage for its internal Data. This ensures that the geometric Data is included in the element's equation numbering procedures. Within the context of the GeneralCircle, all geometric parameters were regarded as constants and their values were pinned. Here, the vertical position [stored in the second entry in the geometric Data] is unknown, therefore we un-pin it.

```
  {
   // The geometric data is internal to the element -- we copy the pointers
   // to the GeomObject's geometric data to the element's internal
   // data to ensure that any unknown values of geometric data are
   // given global equation numbers. The add_internal_data(...)
   // function returns the index by which the added Data item
   // is accessible from internal_data_pt(...).
   Internal_geometric_data_index=add_internal_data(Geom_data_pt[0]);
   // Geometric Data for the GeomObject has been set up (and pinned) in
   // constructor for geometric object. Now free the y-position
   // of the centre because we want to determine it as an unknown
   internal_data_pt(Internal_geometric_data_index)->unpin(1);
```

Once Data has been added to a GeneralisedElement's internal Data, it is deleted by the destructor of the GeneralisedElement when the GeneralisedElement goes out of scope. The Data must therefore not be deleted again by the destructor of the GeneralCircle class, and we change the cleanup responsibilities accordingly:

```
   // Change cleanup responsibilities: The GeomData will now be killed
   // by the GeneralisedElement when it wipes its internal Data
   Must_clean_up=false;
  }
```

Since the GeneralisedElement's destructor will delete the internal Data, the destructor can remain empty:

```
 /// Destructor:
```

```
 virtual ~ElasticallySupportedRingElement()
  {
   // The GeomObject's GeomData is mirrored in the element's
   // Internal Data and therefore gets wiped in the
   // destructor of GeneralisedElement --> No need to kill it here
  }
```

The `Data` whose one-and-only value represents the load must be set by the "user", using the function `set_load_pt(...)` As discussed above, we store the pointer to the load `Data` object in the `GeneralisedElement's` external `Data` and record its index within that storage scheme.

```
 /// \short Set pointer to Data object that specifies the "load"
 /// on the ElasticallySupportedRingElement
 void set_load_pt(Data* load_pt)
  {
#ifdef PARANOID
   if (load_pt->nvalue()!=1)
    {
     std::ostringstream error_stream;
     error_stream << "The data object that stores the load on the "
                  << "ElasticallySupportedRingElement\n"
                  << "should only contain a single data value\n"
                  << "This one contains " << load_pt->nvalue() << std::endl;
     throw OomphLibError(error_stream.str(),
                         OOMPH_CURRENT_FUNCTION,
                         OOMPH_EXCEPTION_LOCATION);
    }
#endif
   // Add load to the element's external data and store
   // its index within that storage scheme: Following this assignment,
   // the load Data is accessible from
   // GeneralisedElement::external_data_pt(External_load_index)
   External_load_index = add_external_data(load_pt);
   // Load has now been set
   Load_data_has_been_set=true;
  } // end of set_load_pt(...)
```

[Note the sanity check which asserts that the load `Data` object only contains a single value; see Comments and Exercises for a further discussion of this aspect.]

The `load()` function provides access to the load specified by the load `Data`. It returns zero if no load was set – a sensible default.

```
 /// "Load" acting on the ring
 double load()
  {
   // Return the load if it has been set
   if (Load_data_has_been_set)
    {
     return external_data_pt(External_load_index)->value(0);
    }
   // ...otherwise return zero load
   else
    {
     return 0.0;
    }
  } // end of load()
```

Next, we provide an access functions to the spring stiffness parameter,

```
 /// Access function for the spring stiffness
 double& k_stiff() {return K_stiff;}
```

and functions that allow the vertical displacement of the ring to be pinned and un-pinned:

```
 /// Pin the vertical displacement
 void pin_yc()
  {
   // Vertical position of centre is stored as value 1 in the
   // element's one and only internal Data object.
   internal_data_pt(Internal_geometric_data_index)->pin(1);
  }

 /// Unpin the vertical displacement
 void unpin_yc()
  {
   // Vertical position of centre is stored as value 1 in the
   // element's one and only internal Data object.
   internal_data_pt(Internal_geometric_data_index)->unpin(1);
  } // end of unpin_yc()
```

Finally, we implement the pure virtual functions `GeneralisedElement::get_jacobian(...)` and `GeneralisedElement::get_residuals(...)` which are required to make the element functional. These functions must compute the element's contributions to the `Problem's` global residual vector and Jacobian matrix. As usual, we implement them as wrappers to a single function that computes the residual and (optionally) the Jacobian matrix:

```
 /// Compute element residual vector (wrapper)
 void get_residuals(Vector<double> &residuals)
  {
   //Initialise residuals to zero
```

```
  residuals.initialise(0.0);
  //Create a dummy matrix
  DenseMatrix<double> dummy(1);
  //Call the generic residuals function with flag set to 0
  fill_in_generic_residual_contribution(residuals,dummy,0);
  }

/// Compute element residual Vector and element Jacobian matrix (wrapper)
void get_jacobian(Vector<double> &residuals,
                  DenseMatrix<double> &jacobian)
 {
  //Initialise residuals to zero
  residuals.initialise(0.0);
  //Initialise the jacobian matrix to zero
  jacobian.initialise(0.0);
  //Call the generic routine with the flag set to 1
  fill_in_generic_residual_contribution(residuals,jacobian,1);
 } // end of get_jacobian(...)
```

The "real work" is done in the protected member function `get_residuals_generic(...)`, where we distinguish two cases.

1. The load is prescribed, i.e. the (single) value in the load `Data` object is pinned. In this case, the element's `Data` contains only one unknown – the vertical displacement Y_c, stored as value 1 in the internal `Data`. The element's residual vector has a single entry, given by

   $$\mathtt{r}_0 = f_{load} - Y_c \, k_{stiff}$$

   and the element's Jacobian matrix is a 1x1 matrix whose single entry is given by

   $$\mathtt{J}_{00} = \frac{\partial \mathtt{r}_0}{\partial Y_c} = -k_{stiff}$$

2. If the load is unknown (i.e. an unknown in the overall problem) the element's `Data` contains two unknowns. Recall that an element only makes a contribution to the residuals associated with unknowns that it is "in charge of" – the external `Data` is assumed to be "determined" by another element. Therefore, the elements residual vectors (i.e. its contribution to the `Problem's` global residual vector) is given by

   $$\left(\begin{array}{c} \mathtt{r}_0 \\ \mathtt{r}_1 \end{array} \right) = \left(\begin{array}{c} f_{load} - Y_c \, k_{stiff} \\ 0 \end{array} \right).$$

   The element's 2x2 Jacobian matrix contains the derivatives of the residuals with respect to the element's unknowns, Y_c and f_{load},

   $$\left(\begin{array}{cc} \mathtt{J}_{00} & \mathtt{J}_{01} \\ \mathtt{J}_{10} & \mathtt{J}_{11} \end{array} \right) = \left(\begin{array}{cc} \partial \mathtt{r}_0/\partial Y_c & \partial \mathtt{r}_0/\partial f_{load} \\ \partial \mathtt{r}_1/\partial Y_c & \partial \mathtt{r}_1/\partial f_{load} \end{array} \right) = \left(\begin{array}{cc} -k_{stiff} & 1 \\ 0 & 0 \end{array} \right)$$

Note that we have (correctly!) assumed that the (fully automatic) local equation numbering procedure, implemented in `GeneralisedElement::assign_local_eqn_numbers()`, regards the internal degree of freedom as local unknown "0" and the external one (if it exists) as unknown "1". However, to be on the safe side, we determine the local equation numbers via the access functions `internal_local_eqn(i,j)` and `external_local_eqn(i,j)`, which return the local equation numbers of the j-th value, stored in the element's i-th internal (or external) `Data` object:

```
/// \short Compute element residual Vector (only if flag=0) and also
/// the element Jacobian matrix (if flag=1)
void fill_in_generic_residual_contribution(Vector<double> &residuals,
                                           DenseMatrix<double> &jacobian,
                                           unsigned flag)
 {
  //Find out how may dofs there are in the element
  unsigned n_dof = ndof();
  //If everything is pinned return straight away
  if (n_dof==0) return;

  // Pseudo-elastic force balance to determine the position of the
  // ring's centre for a given load.
  // What's the local equation number of the force balance equation
  // [It's the equation that "determines" the value of the internal
  // dof, y_c, which is stored as the second value of the one-and-only
```

```
   // internal data object in this element]
   int local_eqn_number_for_yc =
    internal_local_eqn(Internal_geometric_data_index,1);
   // Add residual to appropriate entry in the element's residual
   // vector:
   residuals[local_eqn_number_for_yc]=load()-K_stiff*y_c();
   // Work out Jacobian:
   if (flag)
    {
     // Derivative of residual w.r.t. the internal dof, i.e. the vertical
     // position of the ring's centre: d residual[0]/d y_c
     jacobian(local_eqn_number_for_yc,local_eqn_number_for_yc) = -K_stiff;


     // Derivative with respect to external dof, i.e. the applied
     // load: d residual[0]/d load -- but only if the load is an unknown
     if (n_dof==2)
      {
       // What's the local equation number of the load parameter?
       // It's stored as the 0th value in the the element's
       // one-and-only external data item:
       int local_eqn_number_for_load =
        external_local_eqn(External_load_index,0);
#ifdef PARANOID
       if (local_eqn_number_for_load<0)
        {
         throw OomphLibError(
          "Load is pinned and yet n_dof=2?\n This is very fishy!\n",
          OOMPH_CURRENT_FUNCTION,
          OOMPH_EXCEPTION_LOCATION);
        }
#endif

       // Add entry into element Jacobian
       jacobian(local_eqn_number_for_yc,local_eqn_number_for_load) = 1.0;
      }
    }
  } // end of get_residuals_generic(...)
```

1.3 Part 3: The driver code

Finally, we provide an example that shows our `ElasticallySupportedRingElement` in action. The animation below shows the result of the computational simulation of the toy problem described at the beginning of the previous section: An elastically supported ring, subjected to a vertical load. The animation shows the position of the ring for various values of the load.

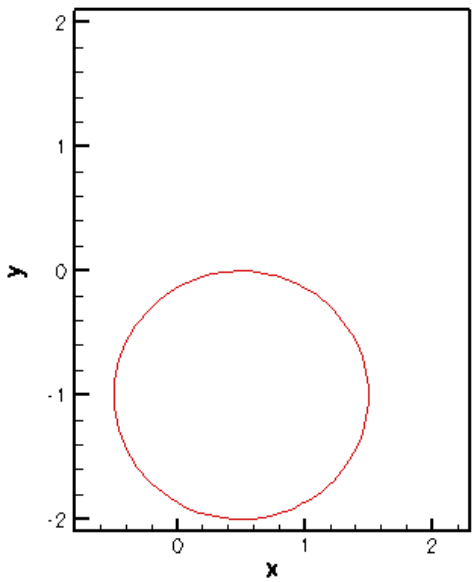

Figure 1.2 Vertical displacement of a Circle, mounted on an elastic support.

1.3.1 The driver code

The driver builds the `Problem` object and solves the problem for various load levels:

```
//===============start_of_driver=============================================
/// Driver
//============================================================================
int main()
{
 // Set up the problem
 GeomObjectAsGeneralisedElementProblem problem;

 // Initial value for the load
 problem.load()=-0.3;

 // Loop for different loads
 //-------------------------

 // Number of steps
 unsigned nstep=5;

 // Increment in load
 double dp=0.6/double(nstep-1);

 for (unsigned istep=0;istep<nstep;istep++)
  {
   // Solve/doc
   problem.newton_solve();
   problem.doc_solution();

   //Increment counter for solutions
   problem.doc_info().number()++;

   // Change load on ring
   problem.load()+=dp;
  }

} // end of driver
```

1.3.2 The problem class definition

Here is the problem class definition which requires little comment:

```
//======start_of_problem=================================================
/// Problem to demonstrate the use of a GeomObject as a
/// GeneralisedElement: A geometric object (a Circle) is "upgraded"
/// to a GeneralisedElement. The position of the Circle is
/// determined by a balance of forces, assuming that the
/// Circle is mounted on an elastic spring of specified
/// stiffness and loaded by a vertical "load".
//========================================================================
class GeomObjectAsGeneralisedElementProblem : public Problem
{
public:

 /// Constructor
 GeomObjectAsGeneralisedElementProblem();

 /// Update the problem specs after solve (empty)
 void actions_after_newton_solve(){}

 /// Update the problem specs before solve (empty)
 void actions_before_newton_solve() {}

 /// Doc the solution
 void doc_solution();

 /// Return value of the "load" on the elastically supported ring
 double& load()
  {
   return *Load_pt->value_pt(0);
  }

 /// Access to DocInfo object
 DocInfo& doc_info() {return Doc_info;}
private:

 /// Trace file
 ofstream Trace_file;

 /// \short Pointer to data item that stores the "load" on the ring
 Data* Load_pt;

 /// Doc info object
 DocInfo Doc_info;
};
```

1.3.3 The problem constructor

In the problem constructor, we create the (single) `ElasticallySupportedRingElement` and and assign a value to its "spring stiffness" parameter.

```
//==========================start_of_problem_constructor==============
/// Constructor
//====================================================================
GeomObjectAsGeneralisedElementProblem::GeomObjectAsGeneralisedElementProblem()
{

 // Set coordinates and radius for the circle
 double x_c=0.5;
 double y_c=0.0;
 double R=1.0;
 // Build GeomObject that's been upgraded to a GeneralisedElement
 // GeneralisedElement*
 ElasticallySupportedRingElement* geom_object_element_pt =
  new ElasticallySupportedRingElement(x_c,y_c,R);
 // Set the stiffness of the elastic support
 geom_object_element_pt->k_stiff()=0.3;
```

Next, we create the problem's mesh: We start by creating an (empty) `Mesh` object and then add the (pointer to the) newly created `ElasticallySupportedRingElement` (in its incarnation as a `GeneralisedElement`) to it:

```
 // Build mesh
 mesh_pt()=new Mesh;
 // So far, the mesh is completely empty. Let's add the
 // one (and only!) GeneralisedElement to it:
 mesh_pt()->add_element_pt(geom_object_element_pt);
```

As discussed in the previous section, the load must be specified as a `Data` object that stores a single value. In our example, the load is prescribed (i.e. not an unknown in the problem) therefore the value must be pinned:

```
 // Create the load (a Data object with a single value)
 Load_pt=new Data(1);

 // The load is prescribed so its one-and-only value is pinned
 Load_pt->pin(0);
 // Set the pointer to the Data object that specifies the
 // load on the ring
 geom_object_element_pt->set_load_pt(Load_pt);
```

Finally, we set up the equation numbering scheme, set the output directory and open a trace file in which we will document the load/displacement characteristics.

```
 // Setup equation numbering scheme.
 cout <<"Number of equations: " << assign_eqn_numbers() << std::endl;
 // Set output directory
 Doc_info.set_directory("RESLT");

 // Open trace file
 char filename[100];
 sprintf(filename,"%s/trace.dat",Doc_info.directory().c_str());
 Trace_file.open(filename);
 Trace_file << "VARIABLES=\"load\",\"y<sub>circle</sub>\"" << std::endl;
} // end of constructor
```

1.3.4 The post-processing function

The post-processing routine is straightforward and is listed only to highlight the need to cast the pointer to the `GeneralisedElement` (as returned by `Mesh::element_pt(...)`) to the specific element used here – obviously, a `GeneralisedElement` does not have member functions that return the load on the ring or its vertical displacement.

```
//========================start_of_doc_solution=======================
/// Doc the solution in tecplot format.
//====================================================================
void GeomObjectAsGeneralisedElementProblem::doc_solution()
{
 ofstream some_file;
 char filename[100];
 // Number of plot points
 unsigned npts=100;
 // Lagrangian coordinate and position vector (both as vectors)
 Vector<double> zeta(1);
 Vector<double> r(2);

 // Output solution
 sprintf(filename,"%s/soln%i.dat",Doc_info.directory().c_str(),
         Doc_info.number());
 some_file.open(filename);
 for (unsigned i=0;i<npts;i++)
  {
   zeta[0]=2.0*MathematicalConstants::Pi*double(i)/double(npts-1);
   static_cast<ElasticallySupportedRingElement*>(mesh_pt()->element_pt(0))->
    position(zeta,r);
```

```
   some_file « r[0] « " " « r[1] « std::endl;
  }
 some_file.close();
 // Write "load" and vertical position of the ring's centre
 Trace_file
  « static_cast<ElasticallySupportedRingElement*>(
   mesh_pt()->element_pt(0))->load()
  « " "
  « static_cast<ElasticallySupportedRingElement*>(
   mesh_pt()->element_pt(0))->y_c()
  « " "
  « std::endl;
} // end of doc_solution
```

1.4 Comments and Exercises

1.4.1 Exercises

1. In the current implementation of the `ElasticallySupportedRingElement`, the load `Data` must only store a single value: Generalise this to the case where the `Data` object can contain an arbitrary number of values. You could add an additional argument to the `set_load_pt(...)` function to specify which value in the `Data` object represents the load. Think carefully in which other parts of the code this index will be required.

1.5 Source files for this tutorial

- The source files for this tutorial are located in the directory:

  demo_drivers/interaction/free_boundary_poisson/

- The driver code is:

  demo_drivers/interaction/free_boundary_poisson/geom_object_element.cc

1.6 PDF file

A pdf version of this document is available.