```
      frame.addDrawable(charge);
   }

   public void reset() {
      control.println(
         "Calculate creates new charge and clears field lines.");
      control.println("You can drag charges.");
      control.println("Double click in display to compute field line");
      frame.clearDrawables(); // remove charges and field lines
      control.setValue("x", 0);
      control.setValue("y", 0);
      control.setValue("q", 1);
   }

   public void handleMouseAction(InteractivePanel panel,
         MouseEvent evt) {
      panel.handleMouseAction(panel, evt); // panel handles dragging
      switch(panel.getMouseAction()) {
      case InteractivePanel.MOUSE_DRAGGED:
         if(panel.getInteractive()==null) {
            return;
         }
         // field is invalid
         frame.removeObjectsOfClass(FieldLine.class);
         // repaint to keep the screen up to date
         frame.repaint();
         break;
      case InteractivePanel.MOUSE_CLICKED:
         // check for double click
         if(evt.getClickCount()>1) {
            double x = panel.getMouseX(), y = panel.getMouseY();
            FieldLine fieldLine = new FieldLine(frame, x, y, +0.1);
            panel.addDrawable(fieldLine);
            fieldLine = new FieldLine(frame, x, y, -0.1);
            panel.addDrawable(fieldLine);
         }
         break;
      }
   }

   public static void main(String[] args) {
      CalculationControl.createApp(new FieldLineApp());
   }
}
```

Problem 10.2 Verification of field line program

(a) Draw field lines for a few simple sets of one, two, and three charges. Choose sets of charges for which all have the same sign and sets for which they are different. Verify that the field lines never connect charges of the same sign. Why do field lines never cross? Are the units of charge and distance relevant?

(b) Compare `FieldLineApp` and `ElectricFieldApp`. Which representation conveys more information? Consider how each program provides (or does not provide) information about the electric field magnitude and direction. Discuss some of the difficulties with making an accurate field line diagram.

(c) `FieldLine` uses a constant value for Δs. Modify the algorithm so that the calculation continues when a field line moves off the screen but speed up the algorithm by increasing the value of Δs.

(d) Removing a field line from the drawing panel in the `reset` method does not stop the thread. Improve the performance of the program by modifying `ElectricFieldApp` so that a field line's `done` variable is set to false when it is removed from the drawing panel. ■

Problem 10.3 Electric field lines from point charges

(a) Modify `FieldLineApp` so that a charge starts ten field lines per unit of charge whenever a new charge is added to the panel or when a charge is moved. Start these field lines close to each charge in such a way that they propagate away from the charge. Should you start these field lines on both positive and negative charges? Explain your answer.

(b) Draw the field lines for an electric dipole.

(c) Draw the field lines for the electric quadrupole with `q(1)` $= 1$, `x(1)` $= 1$, `y(1)` $= 1$, `q(2)` $= -1$, `x(2)` $= -1$, `y(2)` $= 1$, `q(3)` $= 1$, `x(3)` $= -1$, `y(3)` $= -1$, and `q(4)` $= -1$, `x(4)` $= 1$, `y(4)` $= -1$.

(d) A continuous charge distribution can be approximated by a large number of closely spaced point charges. Draw the electric field lines due to a row of ten equally spaced unit charges located between -2.5 and $+2.5$ on the x-axis. How does the electric field distribution compare to the distribution due to a single point charge?

(e) Repeat part (c) with two rows of equally spaced positive charges on the lines $y = 0$ and $y = 1$, respectively. Then consider one row of positive charges and one row of negative charges. ■

Problem 10.4 Field lines due to infinite line of charge

(a) The `FieldLineApp` program plots field lines in two dimensions. Sometimes this restriction can lead to spurious results (see Freeman). Consider four identical charges placed at the corners of a square. Use the program to plot the field lines. What, if anything, is wrong with the results? What should happen to the field lines near the center of the square?

(b) The two-dimensional analog of a point charge is an infinite line (thin cylinder) of charge perpendicular to the plane. The electric field due to an infinite line of charge is proportional to the linear charge density and inversely proportional to the distance (instead of the distance squared) from the line of charge to a point in the plane. Modify the `FieldLine` class to compute the field lines from line charges with $E(r) = 1/r$. Use your modified class to draw the field lines due to four identical line charges located at the corners of a square and compare the field lines with your results in part (a).