GridWorld
AP® Computer Science
Case Study

Student Manual

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GridWorld Case Study

(2008 AP® CS Exam)

The AP® Program wishes to acknowledge and to thank the following individuals for their contributions to the GridWorld Case Study.

Narrative by Chris Nevison and Barbara Cloud Wells, Colgate University

Framework design and implementation by Cay Horstmann, San Jose State University

Images created by Chris Renard, a student at the School for the Talented and Gifted, Dallas Independent School District

Introduction

The GridWorld Case Study provides a graphical environment where visual objects inhabit and interact in a two-dimensional grid. In this case study, you will design and create "actor" objects, add them to a grid, and determine whether the actors behave according to their specifications. A graphical user interface (GUI) is provided that displays the grid and the actors. In addition, the GUI has a facility for adding actors to the grid and for invoking methods on them.

This guide for GridWorld is organized into the following parts:

Part 1: Provides experiments to observe the attributes and behavior of the actors.

Part 2: Defines `Bug` variations.

Part 3: Explores the code that is needed to understand and create actors.

Part 4: Defines classes that extend the `Critter` class.

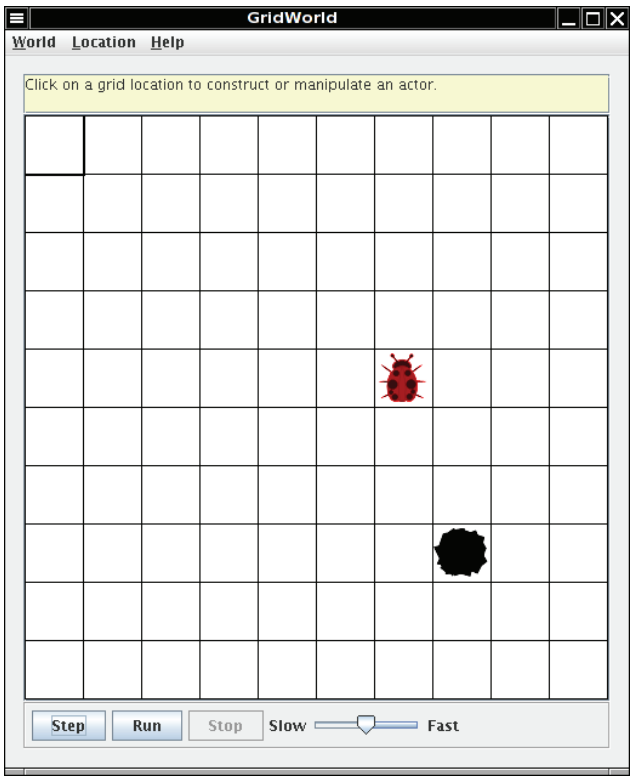
Part 5: (CS AB only) Explains grid data structures.

Part 1: Observing and Experimenting with GridWorld

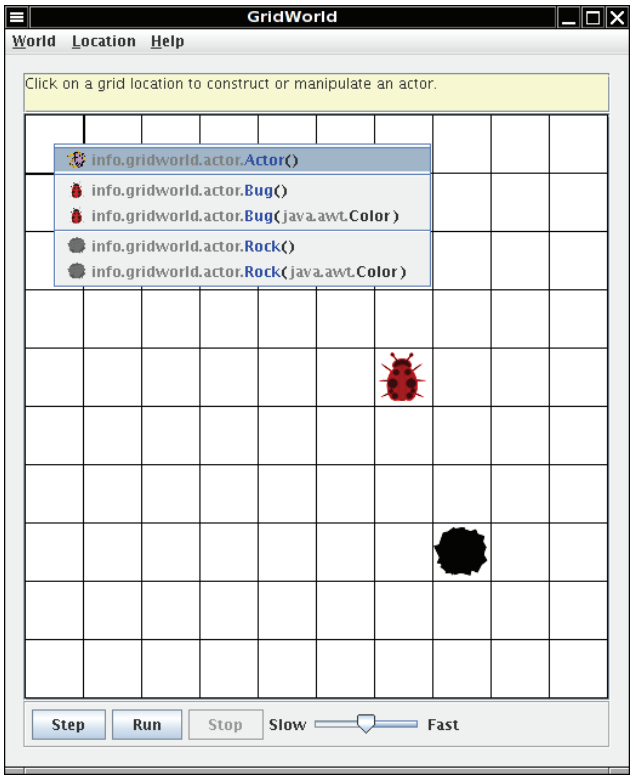
Running the Demo

You need to download and install the case study files. Instructions are provided in a separate document.

Once the code is installed, simply compile and run the `BugRunner.java` application supplied with the case study. The GridWorld GUI will show a grid containing two actors, a "bug" and a "rock." Clicking on the **Step** button runs one step, making each actor act once. Clicking on the **Run** button carries out a series of steps until the **Stop** button is clicked. The delay between steps during a run can be adjusted with the slider. Try it!

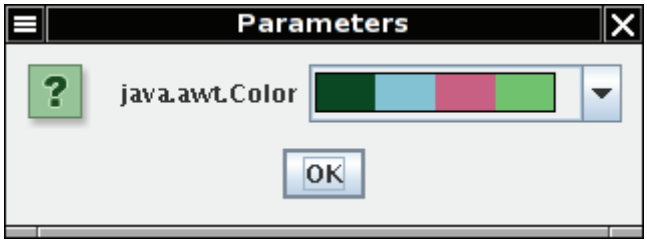


Clicking on an empty cell in the grid displays a drop-down menu that shows the constructors for different actor types.



The menu lists constructors for the classes of all objects that have ever been placed in the grid.

Selecting one of these constructors places an instance of that type in the grid. If the constructor has parameters, a dialog window appears, requesting parameter values. For example, after selecting the constructor **`info.gridworld.actor.Bug(java.awt.Color)`**, the following dialog window appears. Clicking in the color bar produces a drop-down menu from which to choose a color.



What's Happening?

The grid uses directions as on a map: north is up on the screen, east is to the right, south is down, west is to the left. The diagonal directions are northeast, southeast, southwest, and northwest.

One attribute of the bug is its direction (indicated by its antennae). Initially, the bug faces north.

Make a bug, take several steps and observe its behavior. Then add more rocks and bugs by clicking on empty cells and selecting the actors of your choice. Answer the following questions based on your observations using the **Step** and **Run** buttons.

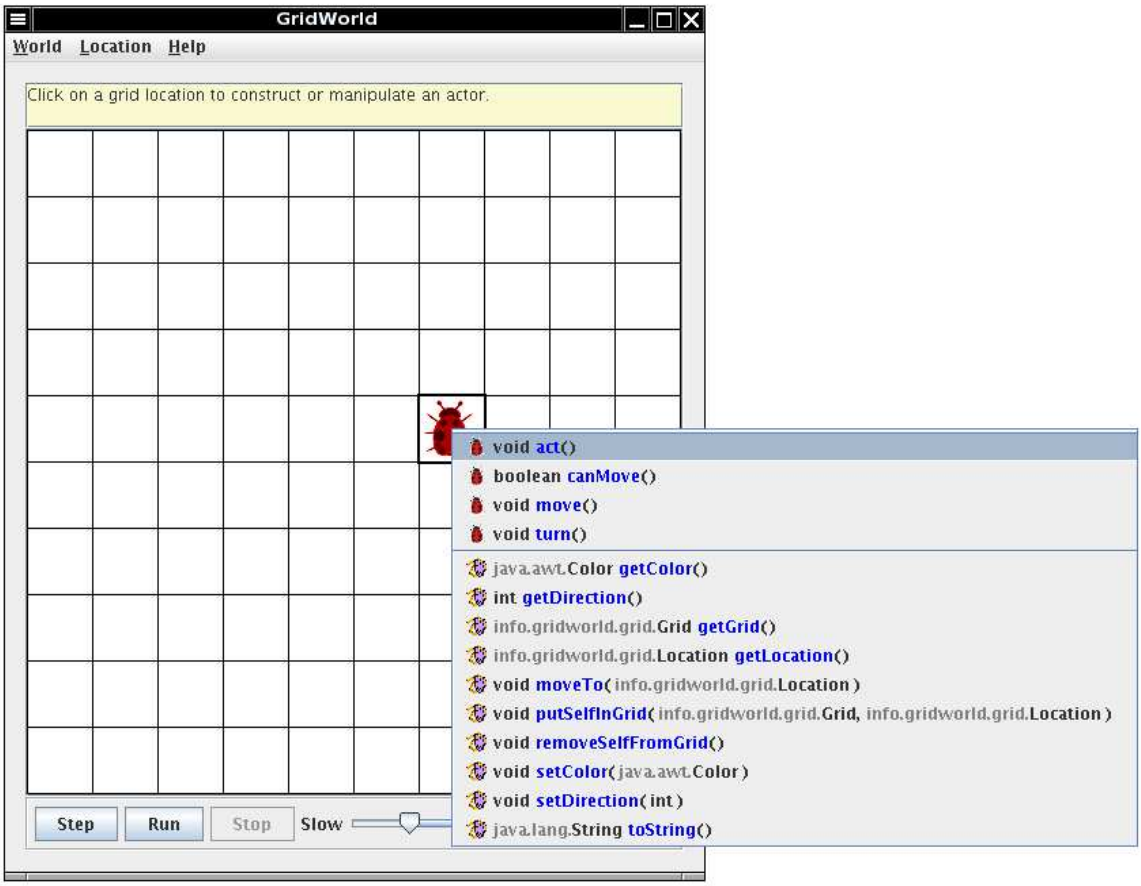
Do You Know?

Set 1

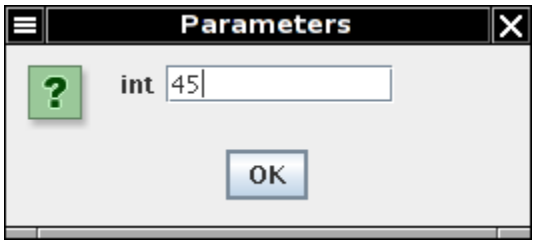
1. Does the bug always move to a new location? Explain.
2. In which direction does the bug move?
3. What does the bug do if it does not move?
4. What does a bug leave behind when it moves?
5. What happens when the bug is at an edge of the grid? (Consider whether the bug is facing the edge as well as whether the bug is facing some other direction when answering this question.)
6. What happens when a bug has a rock in the location immediately in front of it?
7. Does a flower move?
8. What behavior does a flower have?
9. Does a rock move or have any other behavior?
10. Can more than one actor (bug, flower, rock) be in the same location in the grid at the same time?

Exploring Actor State and Behavior

When you click on a cell containing an actor (bug, flower, or rock), a drop-down menu displays the methods that you can invoke on the actor. The methods that appear above the separator line are specified by the class that defines this actor; those that appear below the line are the methods inherited from the `Actor` class.



Experiment with the different methods to see how they work. Accessor methods will have their results displayed in a dialog window. Modifier methods will cause an appropriate change in the display of the actor in the grid. If parameters are needed for a method, you provide them through a dialog window such as the following.



If you select one of the methods in the menu, it will be invoked for this actor. As an example, click on a bug to see the menu of methods. Now observe what happens when you select the `void setDirection(int)` method. The bug will change its direction to the angle that you supply. Try selecting some of the other methods. What about the `act` method? If you invoked that method, the actor will behave as if you had clicked on the **Step** button, but no other actors will do anything. A bug will move forward or turn to the right, a flower's color will darken, and a rock will do nothing. The **Step** button simply causes the `act` method to be invoked on all actors in the grid.

Exercises

By clicking on a cell containing a bug, flower, or rock, do the following.

1. Test the `setDirection` method with the following inputs and complete the table, giving the compass direction each input represents.

Degrees	Compass Direction
0	North
45	
90	
135	
180	
225	
270	
315	
360	

2. Move a bug to a different location using the `moveTo` method. In which directions can you move it? How far can you move it? What happens if you try to move the bug outside the grid?

3. Change the color of a bug, a flower, and a rock. Which method did you use?

4. Move a rock on top of a bug and then move the rock again. What happened to the bug?

GUI Summary

Mouse Action	Keyboard Shortcut	Result
Click on an empty location	Select empty location with cursor keys and press the **Enter** key	Shows the constructor menu
Click on an occupied location	Select occupied location with cursor keys and press the **Enter** key	Shows the method menu
Select the **Location -> Delete** menu item	Press the **Delete** key	Removes the occupant in the currently selected location from the grid
Click on the **Step** button		Calls `act` on each actor
Click on the **Run** button		Starts run mode (in run mode, the action of the **Step** button is carried out repeatedly)
Click on the **Stop** button		Stops run mode
Adjust the **Slow**/**Fast** slider		Changes speed of run mode
Select the **Location -> Zoom in**/**Zoom out** menu item	Press the **Ctrl+PgUp** / **Ctrl+PgDn** keys	Zooms grid display in or out
Adjust the scroll bars next to grid	Move the location with the cursor keys	Scrolls to other parts of the grid (if the grid is too large to fit inside the window)
Select the **World -> Set grid** menu item		Changes between bounded and unbounded grids
Select the **World -> Quit** menu item	Press the **Ctrl+Q** keys	Quits GridWorld

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Part 2: Bug Variations

Methods of the `Bug` Class

The `Bug` class provides three methods that specify how bugs move and turn.

`public boolean canMove()`
tests whether the bug can move forward into a location that is empty or contains a flower

`public void move()`
moves the bug forward, putting a flower into the location it previously occupied

`public void turn()`
turns the bug 45 degrees to the right without changing its location

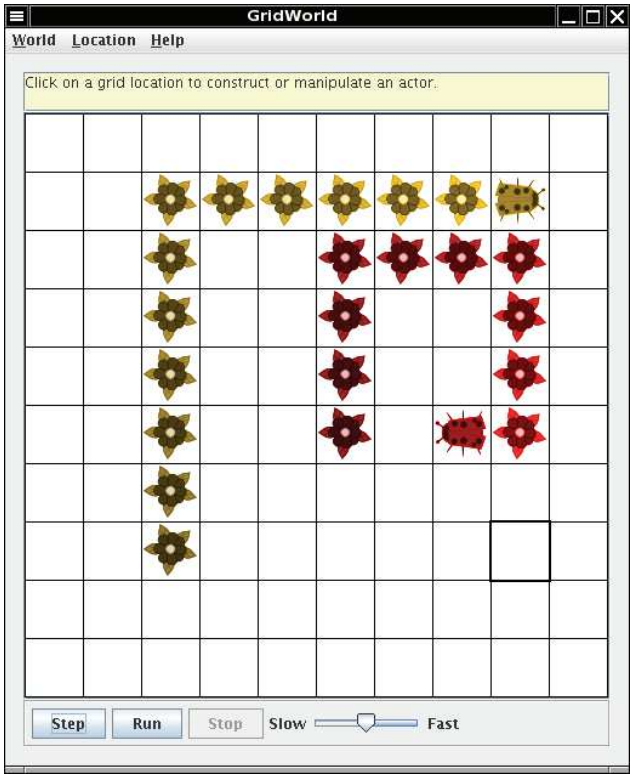
These methods are used in the bug's `act` method.

```
public void act()
{
   if (canMove())
      move();
   else
      turn();
}
```

The experiments in the previous section showed that the bug moves forward when it can. When the bug has a rock in front of it or is facing an edge of the grid, it cannot move, so it turns. However, it can step on a flower (which removes the flower from the grid). When the bug moves, it leaves a flower in its previous location. This behavior is determined by the `act` method and the three methods that the `act` method calls.

Extending the `Bug` Class

A new type of bug with different behavior can be created by extending the `Bug` class and overriding the `act` method. No new methods need to be added; the `act` method uses the three auxiliary methods from the `Bug` class listed above. A `BoxBug` moves in a square pattern. In order to keep track of its movement, the `BoxBug` class has two instance variables, `sideLength` and `steps`.



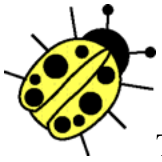
Do You Know?
Set 2

The source code for the `BoxBug` class is in Appendix C.

1. What is the role of the instance variable `sideLength`?
2. What is the role of the instance variable `steps`?
3. Why is the `turn` method called *twice* when `steps` becomes equal to `sideLength`?
4. Why can the `move` method be called in the `BoxBug` class when there is no `move` method in the `BoxBug` code?
5. After a `BoxBug` is constructed, will the size of its square pattern always be the same? Why or why not?
6. Can the path a `BoxBug` travels ever change? Why or why not?
7. When will the value of `steps` be zero?

Runner Classes

In order to observe the behavior of one or more actors, a "runner" class is required. That class constructs an `ActorWorld` object, places actors into it, and shows the world. For the bug, this class is `BugRunner`. For the box bug, it is `BoxBugRunner`. In each of these runner classes, the overloaded `add` method is used to place actors (instances of classes such as `Bug`, `BoxBug`, `Rock`) into the grid of the `ActorWorld`. The `add` method with an `Actor` parameter and a `Location` parameter places an actor at a specified location. The `add` method with an `Actor` parameter but no `Location` parameter places an actor at a random empty location. When you write your own classes that extend `Bug`, you also need to create a similar runner class.

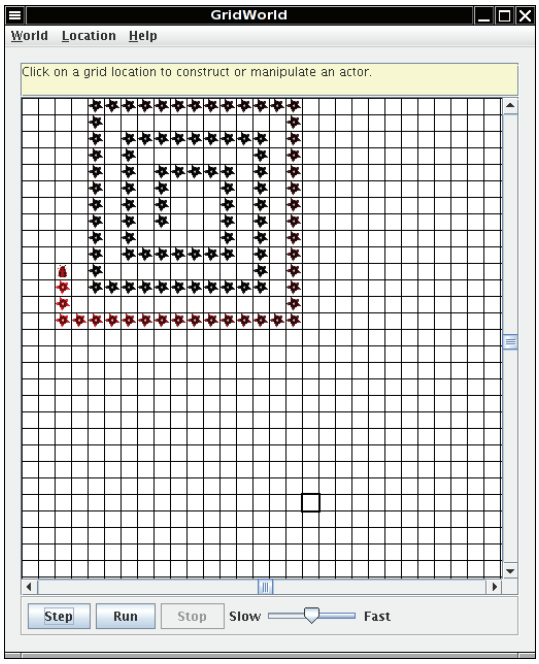


The source code for the `BoxBugRunner` class is at the end of this part of GridWorld.

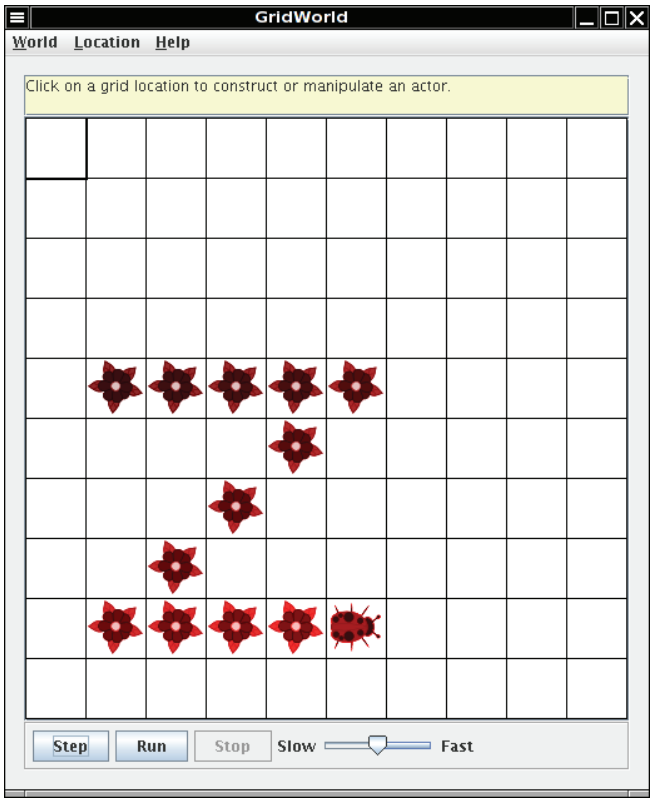
Exercises

In the following exercises, write a new class that extends the `Bug` class. Override the `act` method to define the new behavior.

1. Write a class `CircleBug` that is identical to `BoxBug`, except that in the `act` method the `turn` method is called once instead of twice. How is its behavior different from a `BoxBug`?
2. Write a class `SpiralBug` that drops flowers in a spiral pattern. Hint: Imitate `BoxBug`, but adjust the side length when the bug turns. You may want to change the world to an `UnboundedGrid` to see the spiral pattern more clearly.



3. Write a class `ZBug` to implement bugs that move in a "Z" pattern, starting in the top left corner. After completing one "Z" pattern, a `ZBug` should stop moving. In any step, if a `ZBug` can't move and is still attempting to complete its "Z" pattern, the `ZBug` does not move and should not turn to start a new side. Supply the length of the "Z" as a parameter in the constructor. The following image shows a "Z" pattern of length 4. Hint: Notice that a `ZBug` needs to be facing east before beginning its "Z" pattern.



4. Write a class `DancingBug` that "dances" by making different turns before each move. The `DancingBug` constructor has an integer array as parameter. The integer entries in the array represent how many times the bug turns before it moves. For example, an array entry of 5 represents a turn of 225 degrees (recall one turn is 45 degrees). When a dancing bug acts, it should turn the number of times given by the current array entry, then act like a `Bug`. In the next move, it should use the next entry in the array. After carrying out the last turn in the array, it should start again with the initial array value so that the dancing bug continually repeats the same turning pattern.

   The `DancingBugRunner` class should create an array and pass it as a parameter to the `DancingBug` constructor.

5. Study the code for the `BoxBugRunner` class. Summarize the steps you would use to add another `BoxBug` actor to the grid.

BoxBugRunner.java

```
import info.gridworld.actor.ActorWorld;
import info.gridworld.grid.Location;

import java.awt.Color;

/**
 * This class runs a world that contains box bugs.
 * This class is not tested on the AP CS A and AB exams.
 */
public class BoxBugRunner
{
  public static void main(String[] args)
  {
    ActorWorld world = new ActorWorld();
    BoxBug alice = new BoxBug(6);
    alice.setColor(Color.ORANGE);
    BoxBug bob = new BoxBug(3);
    world.add(new Location(7, 8), alice);
    world.add(new Location(5, 5), bob);
    world.show();
  }
}
```

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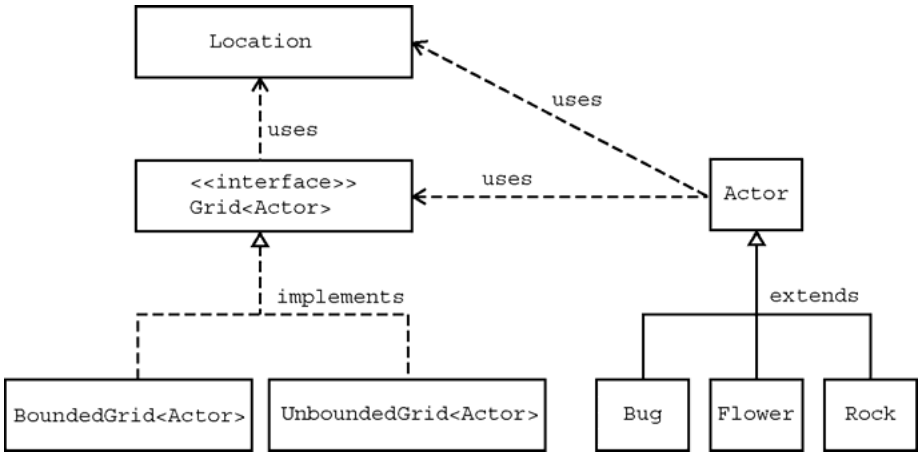
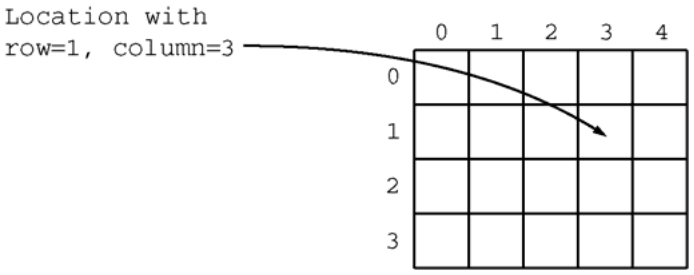
Part 3: GridWorld Classes and Interfaces

In our example programs, a grid contains actors that are instances of classes that extend the `Actor` class. There are two classes that implement the `Grid` interface: `BoundedGrid` and `UnboundedGrid`. Locations in a grid are represented by objects of the `Location` class. An actor knows the grid in which it is located as well as its current location in the grid. The relationships among these classes are shown in the following figure.



The `Location` Class

Every actor that appears has a location in the grid. The `Location` class encapsulates the coordinates for an actor's position in a grid. It also provides methods that determine relationships between locations and compass directions.



Every actor in the grid also has a direction. Directions are represented by compass directions measured in degrees: 0 degrees is north, 45 degrees is northeast, 90 degrees is east, etc. The `Location` class provides eight constants that specify the compass directions.

```
public static final int NORTH = 0;
public static final int EAST = 90;
public static final int SOUTH = 180;
public static final int WEST = 270;
public static final int NORTHEAST = 45;
public static final int SOUTHEAST = 135;
public static final int SOUTHWEST = 225;
public static final int NORTHWEST = 315;
```

In addition, the `Location` class specifies constants for commonly used turn angles. For example, `Location.HALF_RIGHT` denotes a turn by 45 degrees. Here are the constants for the turn angles.

```
public static final int LEFT = -90;
public static final int RIGHT = 90;
public static final int HALF_LEFT = -45;
public static final int HALF_RIGHT = 45;
public static final int FULL_CIRCLE = 360;
public static final int HALF_CIRCLE = 180;
public static final int AHEAD = 0;
```

To make an actor turn by a given angle, set its direction to the sum of the current direction and the turn angle. For example, the `turn` method of the `Bug` class makes this call.

```
setDirection(getDirection() + Location.HALF_RIGHT);
```

A location in a grid has a row and a column. These values are parameters of the `Location` constructor.

```
public Location(int r, int c)
```

Two accessor methods are provided to return the row and column for a location.

```
public int getRow()
public int getCol()
```

Two other `Location` methods give information about the relationships between locations and directions.

`public Location getAdjacentLocation(int direction)`
returns the adjacent location in the compass direction that is closest to `direction`

`public int getDirectionToward(Location target)`
returns the closest compass direction from this location toward `target`

For example, assume you have the statement below.

```
Location loc1 = new Location(5, 7);
```

The following statements will result in the values indicated by the comments.

```
Location loc2 = loc1.getAdjacentLocation(Location.WEST);
// loc2 has row 5, column 6

Location loc3 = loc1.getAdjacentLocation(Location.NORTHEAST);
// loc3 has row 4, column 8

int dir = loc1.getDirectionToward(new Location(6, 8));
// dir has value 135 (degrees)
```

Note that the row values increase as you go south (down the screen) and the column values increase as you go east (to the right on the screen).

The `Location` class defines the `equals` method so that `loc.equals(other)` returns `true` if `other` is a `Location` object with the same row and column values as `loc` and returns `false` otherwise.

The `Location` class implements the `Comparable` interface. The `compareTo` method compares two `Location` objects. The method call `loc.compareTo(other)` returns a negative integer if `loc` has a smaller row coordinate than `other`, or if they have the same row and `loc` has a smaller column coordinate than `other`. The call returns 0 if `loc` and `other` have the same row and column values. Otherwise, the call returns a positive integer.

Do You Know?

Set 3

The API for the `Location` class is in Appendix B.

Assume the following statements when answering the following questions.

```
Location loc1 = new Location(4, 3);
Location loc2 = new Location(3, 4);
```

1. How would you access the row value for `loc1`?
2. What is the value of `b` after the following statement is executed?

```
boolean b = loc1.equals(loc2);
```

3. What is the value of `loc3` after the following statement is executed?

```
Location loc3 = loc2.getAdjacentLocation(Location.SOUTH);
```

4. What is the value of `dir` after the following statement is executed?

```
int dir = loc1.getDirectionToward(new Location(6, 5));
```

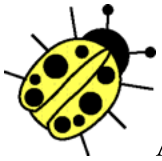
5. How does the `getAdjacentLocation` method know which adjacent location to return?

The Grid Interface

The interface `Grid<E>` specifies the methods for any grid that contains objects of the type `E`. Two classes, `BoundedGrid<E>` and `UnboundedGrid<E>` implement the interface.

You can check whether a given location is within a grid with this method.

```
boolean isValid(Location loc)
```
returns `true` if `loc` is valid in this grid, `false` otherwise
Precondition: `loc` is not `null`



All methods in this case study have the implied precondition that their parameters are not `null`. The precondition is emphasized in this method to eliminate any doubt whether `null` is a valid or invalid location. The `null` reference does not refer to any location, and you must not pass `null` to the `isValid` method.

The following three methods allow us to put objects into a grid, remove objects from a grid, and get a reference to an object in a grid.

```
E put(Location loc, E obj)
```
puts `obj` at location `loc` in this grid and returns the object previously at that location (or `null` if the location was previously unoccupied)
Precondition: (1) `loc` is valid in this grid (2) `obj` is not `null`

```
E remove(Location loc)
```
removes the object at location `loc` and returns it (or `null` if the location is unoccupied)
Precondition: `loc` is valid in this grid

```
E get(Location loc)
```
returns the object at location `loc` (or `null` if the location is unoccupied)
Precondition: `loc` is valid in this grid

An additional method returns all occupied locations in a grid.

```
ArrayList<Location> getOccupiedLocations()
```

Four methods are used to collect adjacent locations or neighbor elements of a given location in a grid. The use of these methods is demonstrated by the examples in Part 4.

`ArrayList<Location> getValidAdjacentLocations(Location loc)`
returns all valid locations adjacent to `loc` in this grid
Precondition: `loc` is valid in this grid

`ArrayList<Location> getEmptyAdjacentLocations(Location loc)`
returns all valid empty locations adjacent to `loc` in this grid
Precondition: `loc` is valid in this grid

`ArrayList<Location> getOccupiedAdjacentLocations(Location loc)`
returns all valid occupied locations adjacent to `loc` in this grid
Precondition: `loc` is valid in this grid

`ArrayList<E> getNeighbors(Location loc)`
returns all objects in the occupied locations adjacent to `loc` in this grid
Precondition: `loc` is valid in this grid

Finally, you can get the number of rows and columns of a grid.

```
int getNumRows();
int getNumCols();
```

For unbounded grids, these methods return -1.

Do You Know?

Set 4

The API for the `Grid` interface is in Appendix B.

1. How can you obtain a count of the objects in a grid? How can you obtain a count of the empty locations in a bounded grid?
2. How can you check if location (10,10) is in a grid?
3. `Grid` contains method declarations, but no code is supplied in the methods. Why? Where can you find the implementations of these methods?
4. All methods that return multiple objects return them in an `ArrayList`. Do you think it would be a better design to return the objects in an array? Explain your answer.

The `Actor` Class

The following accessor methods of the `Actor` class provide information about the state of the actor.

```
public Color getColor()
public int getDirection()
public Grid<Actor> getGrid()
public Location getLocation()
```

One method enables an actor to add itself to a grid; another enables the actor to remove itself from the grid.

```
public void putSelfInGrid(Grid<Actor> gr, Location loc)
public void removeSelfFromGrid()
```

The `putSelfInGrid` method establishes the actor's location as well as the grid in which it is placed. The `removeSelfFromGrid` method removes the actor from its grid and makes the actor's grid and location both `null`.

When adding or removing actors, do *not* use the `put` and `remove` methods of the `Grid` interface. Those methods do not update the `location` and `grid` instance variables of the actor. That is a problem since most actors behave incorrectly if they do not know their location. To ensure correct actor behavior, always use the `putSelfInGrid` and `removeSelfFromGrid` methods of the `Actor` class.

To move an actor to a different location, use the following method.

```
public void moveTo(Location loc)
```

The `moveTo` method allows the actor to move to any valid location. If the actor calls `moveTo` for a location that contains another actor, the other one removes itself from the grid and this actor moves into that location.

You can change the direction or color of an actor with the methods below.

```
public void setColor(Color newColor)
public void setDirection(int newDirection)
```

These `Actor` methods provide the tools to implement behavior for an actor. Any class that extends `Actor` defines its behavior by overriding the `act` method.

```
public void act()
```

The `act` method of the `Actor` class reverses the direction of the actor. You override this method in subclasses of `Actor` to define actors with different behavior. If you extend `Actor` without specifying an `act` method in the subclass, or if you add an `Actor` object to the grid, you can observe that the actor flips back and forth with every step.

The `Bug`, `Flower`, and `Rock` classes provide examples of overriding the `act` method.

The API for the `Grid` interface and the `Location` and `Actor` classes is provided in Appendix B. The following questions help analyze the code for `Actor`.

Do You Know?

Set 5

The API for the `Actor` class is in Appendix B.

1. Name three properties of every actor.
2. When an actor is constructed, what is its direction and color?
3. Why do you think that the `Actor` class was created as a class instead of an interface?
4. Can an actor put itself into a grid twice without first removing itself? Can an actor remove itself from a grid twice? Can an actor be placed into a grid, remove itself, and then put itself back? Try it out. What happens?
5. How can an actor turn 90 degrees to the right?

Extending the `Actor` Class

The `Bug`, `Flower`, and `Rock` classes extend `Actor` in different ways. Their behavior is specified by how they override the `act` method.

The `Rock` Class

A rock acts by doing nothing at all. The `act` method of the `Rock` class has an empty body.

The `Flower` Class

A flower acts by darkening its color, without moving. The `act` method of the `Flower` class reduces the values of the red, green, and blue components of the color by a constant factor.

The `Bug` Class

A bug acts by moving forward and leaving behind a flower. A bug cannot move into a location occupied by a rock, but it can move into a location that is occupied by a flower, which is then removed. If a bug cannot move forward because the location in front is occupied by a rock or is out of the grid, then it turns right 45 degrees.

In Part 2, exercises were given to extend the `Bug` class. All of the exercises required the `act` method of the `Bug` class to be overridden to implement the desired behavior. The `act` method uses the three auxiliary methods in the `Bug` class: `canMove`, `move`, and `turn`. These auxiliary methods call methods from `Actor`, the superclass.

The `canMove` method determines whether it is possible for this `Bug` to move. It uses a Java operator called `instanceof` (not part of the AP CS Java subset). This operator is used as in the following way.

```
expr instanceof Name
```

Here, *`expr`* is an expression whose value is an object and *`Name`* is the name of a class or interface type. The `instanceof` operator returns `true` if the object has the specified type. If *`Name`* is a class name, then the object must be an instance of that class itself or one of its subclasses. If *`Name`* is an interface name, then the object must belong to a class that implements the interface.

This statement in the `canMove` method checks whether the object in the adjacent location is `null` or if it is a `Flower`.

```
return (neighbor == null) || (neighbor instanceof Flower);
```

The following statement in the `canMove` method checks that the bug is actually in a grid—it would be possible for the bug not to be in a grid if some other actor removed it.

```
if (gr == null) return false;
```

The other code for `canMove` is explored in the questions at the end of this section.

The `move` method for `Bug` moves it to the location immediately in front and puts a flower in its previous location. The `turn` method for `Bug` turns it 45 degrees to the right. The code for these methods is explored in the following questions.

Do You Know?

Set 6

The source code for the `Bug` class is in Appendix C.

1. Which statement(s) in the `canMove` method ensures that a bug does not try to move out of its grid?
2. Which statement(s) in the `canMove` method determines that a bug will not walk into a rock?
3. Which methods of the `Grid` interface are invoked by the `canMove` method and why?
4. Which method of the `Location` class is invoked by the `canMove` method and why?
5. Which methods inherited from the `Actor` class are invoked in the `canMove` method?
6. What happens in the `move` method when the location immediately in front of the bug is out of the grid?
7. Is the variable `loc` needed in the `move` method, or could it be avoided by calling `getLocation()` multiple times?

8. Why do you think the flowers that are dropped by a bug have the same color as the bug?
9. When a bug removes itself from the grid, will it place a flower into its previous location?
10. Which statement(s) in the `move` method places the flower into the grid at the bug's previous location?
11. If a bug needs to turn 180 degrees, how many times should it call the `turn` method?

Group Activity

Organize groups of 3–5 students.

1. Specify: Each group creates a class called `Jumper`. This actor can move forward two cells in each move. It "jumps" over rocks and flowers. It does not leave anything behind it when it jumps.

   In the small groups, discuss and clarify the details of the problem:

   a. What will a jumper do if the location in front of it is empty, but the location two cells in front contains a flower or a rock?
   b. What will a jumper do if the location two cells in front of the jumper is out of the grid?
   c. What will a jumper do if it is facing an edge of the grid?
   d. What will a jumper do if another actor (not a flower or a rock) is in the cell that is two cells in front of the jumper?
   e. What will a jumper do if it encounters another jumper in its path?
   f. Are there any other tests the jumper needs to make?
2. Design: Groups address important design decisions to solve the problem:
   a. Which class should `Jumper` extend?
   b. Is there an existing class that is similar to the `Jumper` class?
   c. Should there be a constructor? If yes, what parameters should be specified for the constructor?
   d. Which methods should be overridden?
   e. What methods, if any, should be added?
   f. What is the plan for testing the class?
3. Code: Implement the `Jumper` and `JumperRunner` classes.
4. Test: Carry out the test plan to verify that the `Jumper` class meets the specification.

What Makes It Run? (Optional)

A graphical user interface (GUI) has been provided for running GridWorld programs. The `World` class makes the connection between the GUI and the classes already described. The GUI asks the world for its grid, locates the grid occupants, and draws them. The GUI allows the user to invoke the `step` method of the world, either taking one step at a time or running continuously. After each step, the GUI redisplays the grid.

For our actors, a subclass of the `World` class called `ActorWorld` is provided. `ActorWorld` defines a `step` method that invokes `act` on each actor.

The `World` and `ActorWorld` classes are not tested in the AP CS Exam.

Other worlds can be defined that contain occupants other than actors. By providing different implementations of the `step` method and other methods of the `World` class, one can produce simulations, games, and so on. This is not tested on the AP CS Exam.

In order to display the GUI, a runner program constructs a world, adds occupants to it, and invokes the `show` method on the world. That method causes the GUI to launch.

The `ActorWorld` class has a constructor with a `Grid<Actor>` parameter. Use that constructor to explore worlds with grids other than the default 10 x 10 grid.

The `ActorWorld` has two methods for adding an actor.

```
public void add(Location loc, Actor occupant)
public void add(Actor occupant)
```

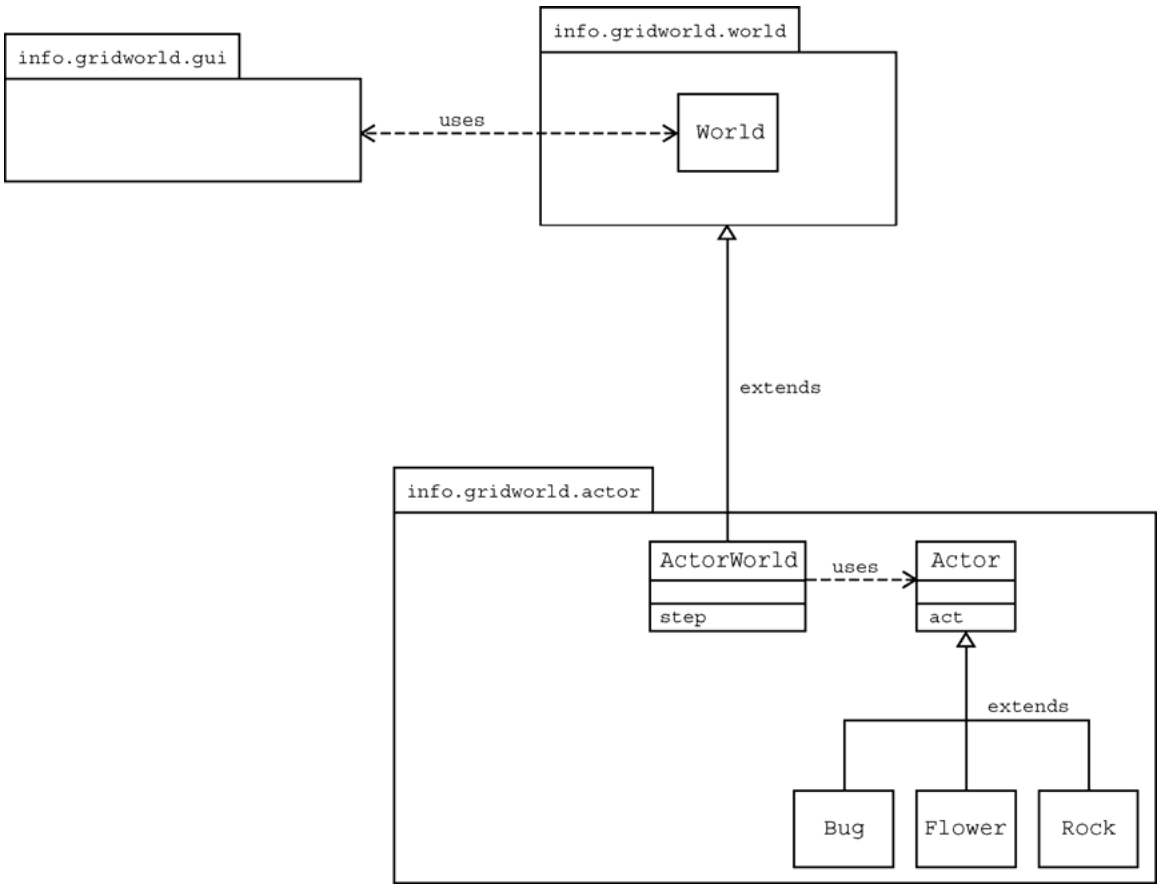
The `add` method without a `Location` parameter adds an actor at a random empty location.

When adding actors to a world, be sure to use the `add` method of the `ActorWorld` class and not the `put` method of the `Grid` interface. The `add` method calls the `Actor` method `putSelfInGrid`. As explained previously, the `putSelfInGrid` method sets the actor's references to its grid and location and calls the grid method `put`, giving the grid a reference to the actor.

The `remove` method removes an actor from a given location and returns the `Actor` that has been removed.

```
public Actor remove(Location loc)
```

The relationship between the GUI, world, and actor classes is shown in the following figure. Note that the GUI has no knowledge of actors. It can show occupants in any world. Conversely, actors have no knowledge of the GUI.



GridWorld Case Study

Part 4: Interacting Objects

The `Critter` Class

Critters are actors that share a common pattern of behavior, but the details may vary for each type of critter. When a critter acts, it first gets a list of actors to process. It processes those actors and then generates the set of locations to which it may move, selects one, and moves to that location.

Different types of critters may select move locations in different ways, may have different ways of selecting among them, and may vary the actions they take when they make the move. For example, one type of critter might get all the neighboring actors and process each one of them in some way (change their color, make them move, and so on). Another type of critter may get only the actors to its front, front-right, and front-left and randomly select one of them to eat. A simple critter may get all the empty neighboring locations, select one at random, and move there. A more complex critter may only move to the location in front or behind and make a turn if neither of these locations is empty.

Each of these behaviors fits a general pattern. This general pattern is defined in the `act` method for the `Critter` class, a subclass of `Actor`. This `act` method invokes the following five methods.

```
ArrayList<Actor> getActors()
void processActors(ArrayList<Actor> actors)
ArrayList<Location> getMoveLocations()
Location selectMoveLocation(ArrayList<Location> locs)
void makeMove(Location loc)
```

These methods are implemented in the `Critter` class with simple default behavior—see the following section. Subclasses of `Critter` should override one or more of these methods.

It is usually not a good idea to override the `act` method in a `Critter` subclass. The `Critter` class was designed to represent actors that process other actors and then move. If you find the `act` method unsuitable for your actors, you should consider extending `Actor`, not `Critter`.

Do You Know?
Set 7

The source code for the `Critter` class is in Appendix C.

1. What methods are implemented in `Critter`?
2. What are the five basic actions common to all critters when they act?
3. Should subclasses of `Critter` override the `getActors` method? Explain.
4. Describe three ways that a critter could process actors.
5. What three methods must be invoked to make a critter move? Explain each of these methods.
6. Why is there no `Critter` constructor?

Default `Critter` Behavior

Before moving, critters process other actors in some way. They can examine them, move them, or even eat them.

There are two steps involved:

1. Determination of which actors should be processed
2. Determination of how they should be processed

The `getActors` method of the `Critter` class gets a list of all neighboring actors. This behavior can be inherited in subclasses of `Critter`. Alternatively, a subclass can decide to process a different set of actors, by overriding the `getActors` method.

The `processActors` method in the `Critter` class eats (that is, removes) actors that are not rocks or critters. This behavior is either inherited or overridden in subclasses.

When the critter has completed processing actors, it moves to a new location. This is a three-step process.

1. Determination of which locations are candidates for the move
2. Selection of one of the candidates
3. Making the move

Each of these steps is implemented in a separate method. This allows subclasses to change each behavior separately.

The `Critter` implementation of the `getMoveLocations` method returns all empty adjacent locations. In a subclass, you may want to compute a different set of locations. One of the examples in the case study is a `CrabCritter` that can only move sideways.

Once the candidate locations have been determined, the critter needs to select one of them. The `Critter` implementation of `selectMoveLocation` selects a location at random. However, other critters may want to work harder and pick the location they consider best, such as the one with the most food or the one closest to their friends.

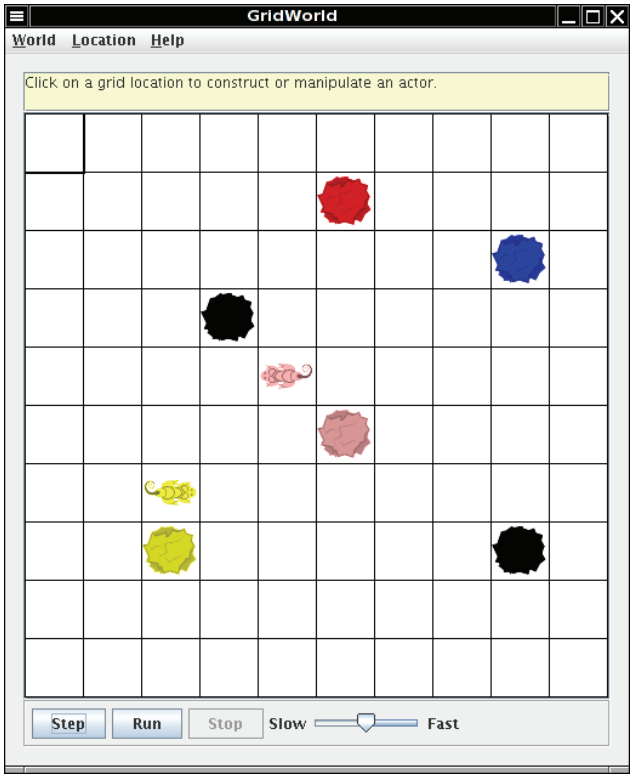
Finally, when a location has been selected, it is passed to the `makeMove` method. The `makeMove` method of the `Critter` class simply calls `moveTo`, but you may want to override the `makeMove` method to make your critters turn, drop a trail of rocks, or take other actions.

Note that there are postconditions on the five `Critter` methods called by `act`. When you override these methods, you should maintain these postconditions.

The design philosophy behind the `Critter` class is that the behavior is carried out in separate phases, each of which can be overridden independently. The postconditions help to ensure that subclasses implement behavior that is consistent with the purpose of each phase.

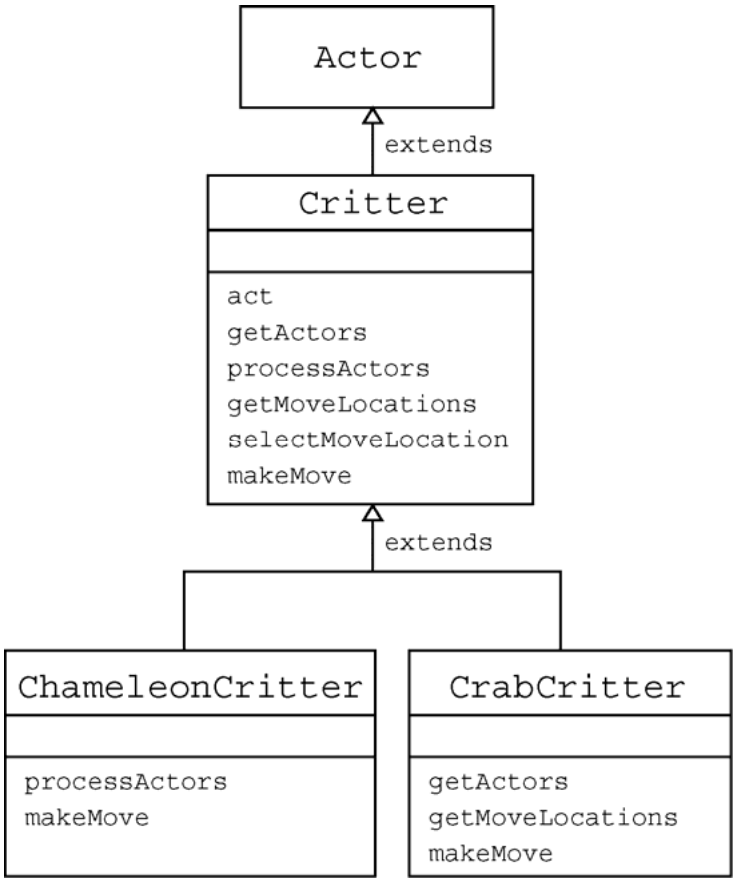
Extending the Critter Class

The `ChameleonCritter` class defines a new type of critter that gets the same neighboring actors as a `Critter`. However, unlike a `Critter`, a `ChameleonCritter` doesn't process actors by eating them. Instead, when a `ChameleonCritter` processes actors, it randomly selects one and changes its own color to the color of the selected actor.



The `ChameleonCritter` class also overrides the `makeMove` method of the `Critter` class. When a `ChameleonCritter` moves, it turns toward the new location.

The following figure shows the relationships among `Actor`, `Critter`, and `ChameleonCritter`, as well as the `CrabCritter` class that is discussed in the following section.



Do You Know?
Set 8

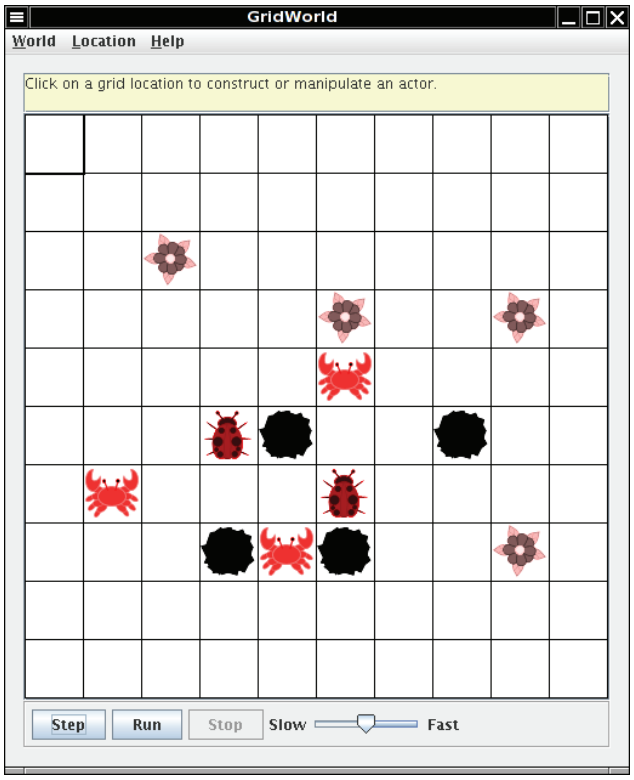
The source code for the `ChameleonCritter` class is in Appendix C.

1. Why does `act` cause a `ChameleonCritter` to act differently from a `Critter` even though `ChameleonCritter` does not override `act`?
2. Why does the `makeMove` method of `ChameleonCritter` call `super.makeMove`?
3. How would you make the `ChameleonCritter` drop flowers in its old location when it moves?
4. Why doesn't `ChameleonCritter` override the `getActors` method?

5. Which class contains the `getLocation` method?
6. How can a `Critter` access its own grid?

Another `Critter`

A `CrabCritter` is a critter that eats whatever is found in the locations immediately in front, to the right-front, or to the left-front of it. It will not eat a rock or another critter (this restriction is inherited from the `Critter` class). A `CrabCritter` can move only to the right or to the left. If both locations are empty, it randomly selects one. If a `CrabCritter` cannot move, then it turns 90 degrees, randomly to the left or right.



Do You Know?

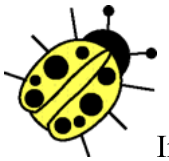
Set 9

The source code for the `CrabCritter` class is reproduced at the end of this part of GridWorld. This code is not required for the AP CS Exam, but working with the code is good practice as preparation for the exam.

1. Why doesn't `CrabCritter` override the `processActors` method?
2. Describe the process a `CrabCritter` uses to find and eat other actors. Does it always eat all neighboring actors? Explain.
3. Why is the `getLocationsInDirections` method used in `CrabCritter`?
4. If a `CrabCritter` has location (3, 4) and faces south, what are the possible locations for actors that are returned by a call to the `getActors` method?
5. What are the similarities and differences between the movements of a `CrabCritter` and a `Critter`?
6. How does a `CrabCritter` determine when it turns instead of moving?
7. Why don't the `CrabCritter` objects eat each other?

Exercises

1. Modify the `processActors` method in `ChameleonCritter` so that if the list of actors to process is empty, the color of the `ChameleonCritter` will darken (like a flower).

   In the following exercises, your first step should be to decide which of the five methods—`getActors`, `processActors`, `getMoveLocations`, `selectMoveLocation`, and `makeMove`—should be changed to get the desired result.

2. Create a class called `ChameleonKid` that extends `ChameleonCritter` as modified in exercise 1. A `ChameleonKid` changes its color to the color of one of the actors immediately in front or behind. If there is no actor in either of these locations, then the `ChameleonKid` darkens like the modified `ChameleonCritter`.

3. Create a class called `RockHound` that extends `Critter`. A `RockHound` gets the actors to be processed in the same way as a `Critter`. It removes any rocks in that list from the grid. A `RockHound` moves like a `Critter`.

4. Create a class `BlusterCritter` that extends `Critter`. A `BlusterCritter` looks at all of the neighbors within two steps of its current location. (For a `BlusterCritter` not near an edge, this includes 24 locations). It counts the number of critters in those locations. If there are fewer than *c* critters, the `BlusterCritter`'s color gets brighter (color values increase). If there are *c* or more critters, the `BlusterCritter`'s color darkens (color values decrease). Here, *c* is a value that indicates the courage of the critter. It should be set in the constructor.

5. Create a class `QuickCrab` that extends `CrabCritter`. A `QuickCrab` processes actors the same way a `CrabCritter` does. A `QuickCrab` moves to one of the two locations, randomly selected, that are two spaces to its right or left, if that location and the intervening location are both empty. Otherwise, a `QuickCrab` moves like a `CrabCritter`.

6. Create a class `KingCrab` that extends `CrabCritter`. A `KingCrab` gets the actors to be processed in the same way a `CrabCritter` does. A `KingCrab` causes each actor that it processes to move one location further away from the `KingCrab`. If the actor cannot move away, the `KingCrab` removes it from the grid. When the `KingCrab` has completed processing the actors, it moves like a `CrabCritter`.

Group Activity

Organize groups of 2–4 students.

1. Specify: Each group specifies a new creature that extends `Critter`. The specifications must describe the properties and behavior of the new creature in detail.
2. Design: The groups exchange specifications. Each group reads the specification that it received and determines the needed variables and basic algorithms for the creature.
3. Code: Each group implements the code for the creature in the specification that it received.
4. Test: Each group writes test cases for the creature that it specified in step 1. Test cases are exchanged as in step 2. The recipients verify that the implementations meet the specifications.

CrabCritter.Java

```
import info.gridworld.actor.Actor;
import info.gridworld.actor.Critter;
import info.gridworld.grid.Grid;
import info.gridworld.grid.Location;

import java.awt.Color;
import java.util.ArrayList;

/**
 * A CrabCritter looks at a limited set of neighbors when it eats and moves.
 * This class is not tested on the AP CS A and AB Exams.
 */
public class CrabCritter extends Critter
{
  public CrabCritter()
  {
    setColor(Color.RED);
  }

  /**
   * A crab gets the actors in the three locations immediately in front, to its
   * front-right and to its front-left
   * @return a list of actors occupying these locations
   */
  public ArrayList<Actor> getActors()
  {
    ArrayList<Actor> actors = new ArrayList<Actor>();
    int[] dirs ={ Location.AHEAD, Location.HALF_LEFT, Location.HALF_RIGHT };
    for (Location loc : getLocationsInDirections(dirs))
    {
      Actor a = getGrid().get(loc);
      if (a != null)
        actors.add(a);
    }

    return actors;
  }


  /**
   * @return list of empty locations immediately to the right and to the left
   */
  public ArrayList<Location> getMoveLocations()
  {
    ArrayList<Location> locs = new ArrayList<Location>();
    int[] dirs = { Location.LEFT, Location.RIGHT };
    for (Location loc : getLocationsInDirections(dirs))
      if (getGrid().get(loc) == null)
        locs.add(loc);

    return locs;
  }
```

```
  /**
   * If the crab critter doesn't move, it randomly turns left or right.
   */
  public void makeMove(Location loc)
  {
    if (loc.equals(getLocation()))
    {
      double r = Math.random();
      int angle;
      if (r < 0.5)
        angle = Location.LEFT;
      else
        angle = Location.RIGHT;
      setDirection(getDirection() + angle);
    }
    else
      super.makeMove(loc);
  }

  /**
   * Finds the valid adjacent locations of this critter in different
   * directions.
   * @param directions - an array of directions (which are relative to the
   * current direction)
   * @return a set of valid locations that are neighbors of the current
   * location in the given directions
   */
  public ArrayList<Location> getLocationsInDirections(int[] directions)
  {
    ArrayList<Location> locs = new ArrayList<Location>();
    Grid gr = getGrid();
    Location loc = getLocation();

    for (int d : directions)
    {
      Location neighborLoc = loc.getAdjacentLocation(getDirection() + d);
      if (gr.isValid(neighborLoc))
        locs.add(neighborLoc);
    }
    return locs;
  }
}
```