NetLogo Tutorial Notes

Steven O. Kimbrough

April 11, 2014

Steven O. Kimbrough, `kimbrough[at]wharton.upenn.edu`

`$Id: NetLogo-tutorial-notes.tex 3684 2013-09-09 20:37:28Z sok $`

Contents

List of Figures

Preface

Assumptions:

- Previous exposure to NetLogo models. Previous exposure to programming. In either case exposure can be quite minimal.
- Working with an open, new NetLogo model. Version: 5.X. These notes separately.
- Here, highlights only. These tutorials are just a beginning, to get you started and to serve as notes and as a quick reference.
- RTFM principle: read the manual, from NetLogo. Most important: *Programming Guide* and *NetLogo Dictionary*. Read the *Programming Guide*. Keep the *NetLogo Dictionary* to hand as you write code and refer to it often. You can often find commands that will do exactly what you need. But there are a lot of commands. Notice that they are organized by category; see the top of the *NetLogo Dictionary*.

NetLogo demonstration files, written by me, can generally be downloaded (if available) at `http://opim.wharton.upenn.edu/~sok/mandms/nlogocode/` or perhaps more likely at `http://opim.wharton.upenn.edu/~sok/age/nlogo`.

There isn't much in the way of a NetLogo textbook or instruction manual at all, other than what is present on the NetLogo Web site—

- NetLogo home page: `http://ccl.northwestern.edu/netlogo/`.
- NetLogo user manual: `http://ccl.northwestern.edu/netlogo/docs/`.

  Note well: The user manual comes with three tutorials. I recommend them, especially for beginners. Also, NetLogo comes with a models library (under the File menu), which is full of interesting examples, including code examples. Well worth rooting around in.

—which is pretty good. NetLogo programmers should expect to consult it regularly, especially the dictionary (see the user manual). Also, see the programming examples that come with NetLogo. They are extensive and quite comprehensive. Recently, however, *Agent-Based and Individual-Based Modeling* [Railsback and Grimm, 2012] has appeared. It is excellent, if lengthy. I highly recommend it for going beyond these *Notes*.

Probably should switch to Python.

We use R, too, not just NetLogo. The home page for R is `http://www.r-project.org/`. You will find there, besides opportunity to download a free copy of R, manuals and documentation. The newbie should start (and probably finish) with *An Introduction to R*, which you can find online at `http://cran.r-project.org/doc/manuals/R-intro.html`.

This booklet is very much a work in progress. It is aimed at helping people new to NetLogo and with minimal programming experience get up and running very quickly. Also, I'm trying to build up enough examples that the booklet can be used as a reference work.

Comments and suggestions are most welcome and will be gratefully received.

For a quick start, see QuickStart.nlogo, with answers in QuickStartSolutions.nlogo.

Chapter 1

Starters

1.1 Starters

First of all, remember that NetLogo has a manual with *lots* of valuable information. RTFM! For purposes of getting started you might consider looking here *and* in the NetLogo manual. Here, begin immediately below. In the NetLogo manual, begin with "Introduction" then move on to "Learning NetLogo". Skim the "Interface Guide" and the "Programming Guide" and be prepared to consult them as you progress. The "NetLogo Dictionary" is especially useful on a day-to-day basis.

1.1.1 NetLogo world view (main metaphors)

The NetLogo program/application has a main window with three tabs, for three different functions:

Interface	Info	Code

The principal metaphors in NetLogo are these:

- From the manual:

  > The NetLogo world is made up of agents. Agents are beings that can follow instructions. Each agent can carry out its own activity, all simultaneously.
  >
  > In NetLogo, there are four types of agents: turtles, patches, links, and the observer. Turtles are agents that move around in the world. The world is two dimensional and is divided up into a grid of patches. Each patch is a square piece of

"ground" over which turtles can move. Links are agents that connect two turtles. The observer doesn't have a location – you can imagine it as looking out over the world of turtles and patches.

- The world: rectangular array of patches on which turtles may sit. Patches are (like) geographic locations and are fixed. Turtles are moveable entities. Both have properties. In addition, turtles may be connected by links, which are also agents.

- The observer: looks down at the world and what is in it.

  From the Command Center. From the Procedures.

- The View. A window onto the world of patches and turtles. By default, a black window on the Interface Tab.

We'll focus next on the Interface Tab.

1.2 The Interface Tab

1.2.1 The Observer

- Again: The observer: looks down at the world and what is in it.

  Can issue commands, from the Command Center. For example,

  `observer> create-turtles 1` creates a turtle at patch (0,0) or `patch 0 0` as it is called in NetLogo.

  Note: every patch has a planar or x-y coordinate address, measured away from 0 0 in the cartesian plane.

  `observer> ask turtle 0 [fd 12]` moves our turtle (ID is 0) forward 12 patches.

  `observer> ask turtle 0 [forward -12]` puts it back at the origin.

1.2.2 Inspecting

- Right-click on the turtle. Investigate: `inspect patch 0 0` and `turtle 0`. Inspect each. Note the properties of each.

  Try `observer> ask patch 2 2 [set pcolor red]`, and
  `observer> ask turtle 0 [set label "My first turtle!"]`.

Notice how NetLogo makes assignments to variables (and properties): `set <thing> <to value>`.

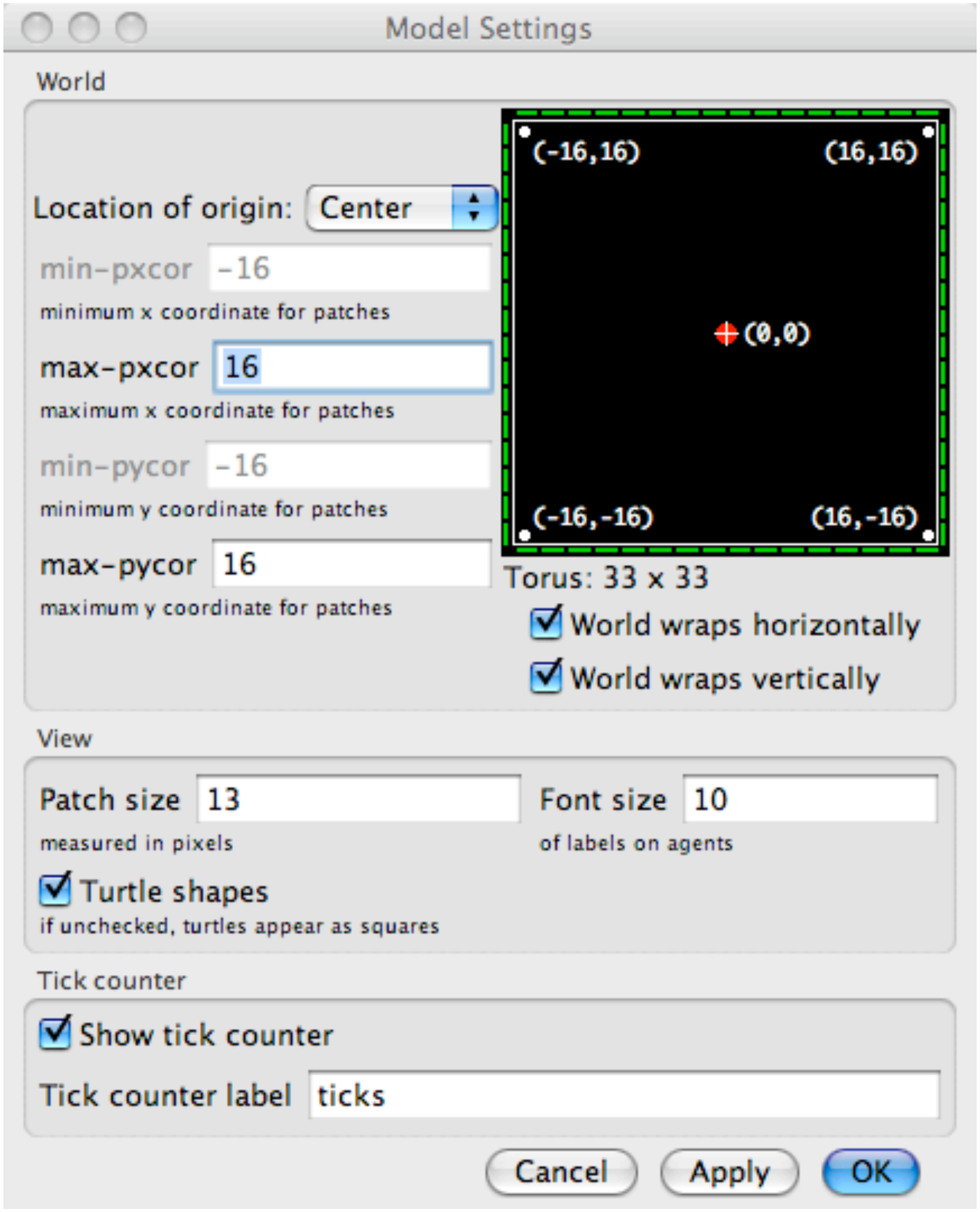
Try `observer> print count patches`
and `observer> print count turtles`.

Now start over: `observer> clear-all`.

1.2.3 Editing the View (and the World)

- Click on `Edit...` in the View window.

  You get (by default) the window/dialog box shown in Figure 1.1, page 4.


Model Settings

World

Location of origin: Center

min-pxcor -16
minimum x coordinate for patches

max-pxcor 16
maximum x coordinate for patches

min-pycor -16
minimum y coordinate for patches

max-pycor 16
maximum y coordinate for patches

Torus: 33 x 33

☑ World wraps horizontally

☑ World wraps vertically

View

Patch size 13
measured in pixels

Font size 10
of labels on agents

☑ Turtle shapes
if unchecked, turtles appear as squares

Tick counter

☑ Show tick counter

Tick counter label ticks

Figure 1.1: World & View Edit Dialog Box

1.2.4 More on Editing the World

- You control the size of the world—the number of patches—here.

  Notice the coordinate system (by default): in horizontally and vertically symmetrical offsets from `patch 0 0`. The boundaries of the world always have an odd number of patches.

  By default, the world is a torus: it wraps horizontally and vertically. You can modify that here.

  If you want to create a world with very many patches, you will probably also want to reduce the patch size (in pixels), which is done in the View section of this dialog box.

1.2.5 Interface Widgets (on the Toolbar)

NetLogo has icons on the Toolbar for interface widgets.
Click and draw. Right-click to edit.
There are nine types (see the manual):

1. button
2. slider
3. switch
4. chooser
5. input
6. monitor
7. plot
8. output
9. note

1.2.5.1 NetLogo Interface Tab: The Interface Toolbar: Buttons

- Button: “Buttons can be either *once-only* buttons or *forever* buttons. When you click on a once button, it executes its instructions once. The forever button executes the instructions over and over, until you click on the button again to stop the action.”

  Click and draw a button. In the “Commands” text area put:

```
print Mutation?
if-else (Mutation?)
   [set Mutation? false]
   [set Mutation? true]
```

Accept and try it out.

1.2.5.2 NetLogo Interface Tab: The Interface Toolbar: Sliders

- Slider: "Sliders are global variables, which are accessible by all agents. They are used in models as a quick way to change a variable without having to recode the procedure every time. Instead, the user moves the slider to a value and observes what happens in the model."

  Click and draw a slider. Set "Global variable" to `myFirstVariable`, leave "Minimum" at 0, set "Increment" to 0.1, "Maximum" to 10, and "Value" to 7.3. Click "OK". Move the slider to a new value.

  Try `observer> print Myfirstvariable`. (We see that NetLogo is not case-senstive.) Try `observer> set myFirstVariable 9.9`
  then `observer> set myFirstVariable 29`,
  and then `observer> print myFirstVariable`.

Note well

Note well: Starting in version 4, NetLogo allows you to change slider variables to values outside those declared in the slider. I'm not sure this is an improvement, but there you have it. So, you can't rely on there being a maximum or minimum value to a slider variable. You will need to program them yourself.

1.2.5.3 NetLogo Interface Tab: The Interface Toolbar: Switches

- Switch: "Switches are a visual representation for a true/false variable. The user is asked to set the variable to either on (true) or off (false) by flipping the switch."

  Click and draw a switch. Set "Global variable" to `Mutation?`. Toggle the switch and try `observer> print Mutation?`.

- Sliders, switches and choosers are the only interface widgets available for sending information from the user interface to the Observer (or NetLogo procedures).

1.2.5.4 The Interface Toolbar: Choosers

- Chooser: "Choosers let the user choose a value for a global variable from a list of choices, presented in a drop down menu."

  One per line. Put strings in double quotes. Numbers directly.

  Click and draw a chooser. In the "Global variable" text area, type `person`. In the "Choices" text area type:

  ```
  "Bob"
  "Carol"
  "Ted"
  "Alice"
  9
  23.34
  ```

  Accept and try it out. Note: Choosers don't accept functions to evaluate. (Choosers can't be beggars?)

  Right-click on the monitor and choose "Edit". Insert `person` as the global variable. Accept and try it out.

  Comment: You can also use a chooser to control execution of the program. Think of the choices as determining scenarios.

1.2.5.5 The Interface Toolbar: Input boxes

- Input: "Input Boxes are global variables that contain strings or numbers. The model author chooses what types of values the user can enter. Input boxes can be set to check the syntax of a string for commands or reporters. Number input boxes read any type of constant number expression which allows a more open way to express numbers than a slider. Color input boxes offer a NetLogo color chooser to the user."

- Try one out. Use the variable name `bob`. Type `print bob` from the command center.

1.2.5.6 The Interface Toolbar: Monitor

- Monitor: "Monitors display the value of any expression. The expression could be a variable, a complex expression, or a call to a reporter. Monitors automatically update several times per second."

A *reporter* is a procedure that returns a value. We're not there yet (but we will be).

Click and draw a monitor. In the "Reporter" text area, type `Mutation?`. Accept and try it out.

1.2.5.7 The Interface Toolbar: Plot

See §1.2.6 below, page 8.

1.2.5.8 The Interface Toolbar: Output

- Output: "The output area is a scrolling area of text which can be used to create a log of activity in the model. A model may only have one output area."

  Click and draw an output area. Edit the button and change the first line from `print Mutation?` to `output-print Mutation?`.

  Accept and try it out. You can essentially achieve this by writing to the Command Center with `print` etc. However, `clear-all` clears the output area, but not the command center output area.

  See also: `print, show, type, write`.

1.2.5.9 The Interface Toolbar: Note

- Note: "Notes lets [sic] you add informative text labels to the Interface tab. The contents of notes do not change as the model runs."

  Nor can your program modify them. Useful for giving basic directions to users.

  Click and draw a note. Insert "Click here to initialize:" in the text area. Accept. Right-click and choose "Select". Move (mouse down and drag) the note to a point above the button. Click outside the note to deselect it.

1.2.6 The Interface Toolbar: Plot

We're going to create a stream (eventually two streams) *random walk* data, and plot the results. This will be a bit more complex than what we have done so far.

1. Begin by creating two buttons: Setup and Random Walking. For now, just give them display names only, with nothing to do.

2. Create a slider whose global variable is `daNewA`. Set the minimum to `-1`, the increment to `0.000001`, the maximum to `1`, and the value to `0.1`.

   Note: Setting the increment to `0.000001` or `1.0E-6` (or some similarly small value) is crucial. If you set it too high, say to `0.1`, then I get unusual and implausible numbers set via the random number generator.

3. Create a slider whose global variable is `streamA`. Set the minimum to `0`, the increment to `1.0E-5`, the maximum to `50`, and the value to `30`.

4. In the "Commands" text area of the Setup button, type:

   ```
   clear-all
   set daNewA 0.0
   set streamA 25.0
   random-seed 1
   ```

   Accept and click the button. The two slider values should change.

   This button now: (1) reinitializes the system (clears the World, clears the plots). (2) Sets the global variable `daNewA` to have the value `0.0`. (3) Sets the global variable `streamA` to have the value `25.0`. And, (4), initializes the random number generator using the seed `1`.

   Comment on random number generators: They play an absolutely critical role in simulations and experimental mathematics, such as we are doing. They are, however, only pseudo-random. In fact, given a starting seed value, they are absolutely deterministic and eventually they cycle! The thing that unless you know the generator, just looking at its stream of random numbers you can't tell (ideally that is), that they aren't being generated from an ideal random number generator.

   If you don't set the seed, NetLogo uses the system clock, so on each run you will see a different random number stream. It is useful when you are developing a model to set the random number seed yourself, since that will produce predictable output. When you are exploring your model, after it is developed, you should explore using multiple random seeds, either by letting NetLogo pick them or by explicitly setting them yourself.

   It is typical in NetLogo models to have a setup button that initializes the system and a second button—ours here is called "Random

Walking”–to run the model. You may find it useful to add other buttons. Especially during development, they can be useful for debugging.

5. Now create a plot. Click and drag the plot widget to an appropriate spot. In the “Name” field, type:

   `My first plot`

   Set “X min” to `0`, “X max” to `10.0`, “Y min” to `20`, and “Y max” to `30`. Note: these settings are *not* crucial, because NetLogo will change them dynamically as needed.

   Click on the “Create” button and name the new plot pen `daStreamAPen`. Select its color to be cyan.

   Click “Ok”.

6. In the “Commands” text area of the Random Walking button, type:

   ```
   print (word "streamA "  streamA)
   set daNewA ((random-float 1) - 0.5)
   print (word "daNewA  "  daNewA)
   set streamA (streamA + daNewA)
   ```

   Click the “Forever” check box. Click “Ok”.

   Note well: NetLogo now uses the reporter `word` to concatenate strings. See the NetLogo Dictionary on `word` for details.

   What this code does is the following. We’ve initialized `streamA` to be 25.0. We draw a random number between 0 and 1 (with `random-float 1`) and add it to `streamA`, subtracting 0.5 at the same time. So, the new value of `streamA` is the old value plus or minus a random amount between 0 and 0.5. `streamA` will drift aimlessly, in what is called a random walk. Note that step intervals other than $(0, 0.5)$ are possible; we’ve just chosen that one for convenience.

   Another comment on the code. `word` in the first line is being used as a string concatenator (“concatenator” = “putter together”). In the third and fourth lines the plus sign is being used for numerical addition. Notice especially that in NetLogo the operators must have white space surrounding them. `a + b` is OK, but `a+b` is not.

   Then click the Setup button followed by the Random Walking button.

You will see output scrolling by in the Command Center output window. After a short time, click on the Random Walking button again to stop the run.

Now click on the double-headed arrow, next to the “Clear” button, at the far right of the Command Center output window. See the image that follows.

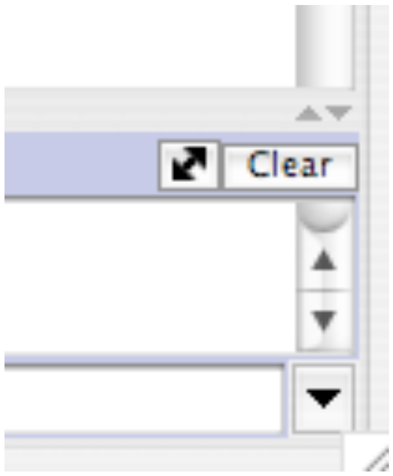


Figure 1.2: Double-Headed Arrow of the Command Center

The Command Center output window will expand for easier viewing. This is what you get:

```
streamA 25.0
daNewA  -0.082978
streamA 24.917022
daNewA  -0.4998856316786342
streamA 24.417136368321366
daNewA  -0.353244107423887
streamA 24.06389
daNewA  -0.3137397857321689
streamA 23.75015
daNewA  -0.10323251879902084
streamA 23.64692
daNewA  -0.08080549071321619
```

```
streamA 23.566114509286784
daNewA  -0.295548
streamA 23.270561999999998
daNewA  -0.47261240282038
streamA 22.79795
daNewA  -0.08269519422643179
streamA 22.71525480577357
```

Note again: Seeding the random number generator with 1 should produce these values reliably. (Actually, sometimes NetLogo seems to round off the values. I'm not clear why this seemingly irregular behavior occurs.)

Click the Clear button to remove the text from the Command Center window. Click the double-headed arrow again to return the Command Center window to its original and diminished position.

7. Now let's do some plotting. Add the following code to the code area of the Random Walking button:

   ```
   set-current-plot "My first plot"
   set-current-plot-pen "daStreamAPen"
   plot-pen-down
   plot streamA
   ```

   This snippet of code should be readily understandable. First, we tell NetLogo which (of possibly many) plots we want to access. Next we tell NetLogo which (of possibly many) pens (for distinct streams of data) we wish to use. We place the pen down and we plot the current value of our variable of interest, here `streamA`. And that's it.

   Click the Ok button in the Random Walking dialog box. Click the Setup button, then click Random Walking and watch the plot unfold!

8. Now we'll add a second random walk stream. First, add two new sliders, for global variables `daNewB` and `streamB`, analogous to `daNewA` and `streamA`. Second, edit (right-click then choose "Edit") your plot, creating a new pen called `daStreamBPen` and set its color to magenta.

   Third, modify the code for the Setup button to read as follows:

   ```
   clear-all
   ```

```
set daNewA 0.0
set streamA 25.0
set daNewB 0.0
set streamB 25.0
random-seed 1
```

And fourth, modify the code for the Random Walking button to read as follows:

```
;print (word "streamA "  streamA)
set daNewA ((random-float 1) - 0.5)
;print (word "daNewA  "  daNewA)
set streamA (streamA + daNewA)
set daNewB ((random-float 1) - 0.5)
set streamB (streamB + daNewB)
set-current-plot "My first plot"
set-current-plot-pen "daStreamAPen"
plot-pen-down
plot streamA
set-current-plot-pen "daStreamBPen"
plot-pen-down
plot streamB
```

Note that lines 1 and 3 now begin with a semicolon – ; – which is the NetLogo comment symbol. Presumably we don't need to print out the values anymore. Commenting out the lines serves the useful purpose of reminding us of what we did and allows us to quickly remove the comments if we want to regain the lines of code. Even better would be to comment profusely, as in this tutorial, but in the code itself, using comment lines.

9. Experiment!

   How long does it take the streams to cross over? Try a different random number seed. What happens?

1.2.7 Introduce a Bug

The first line of the code for the Random Walking button is now

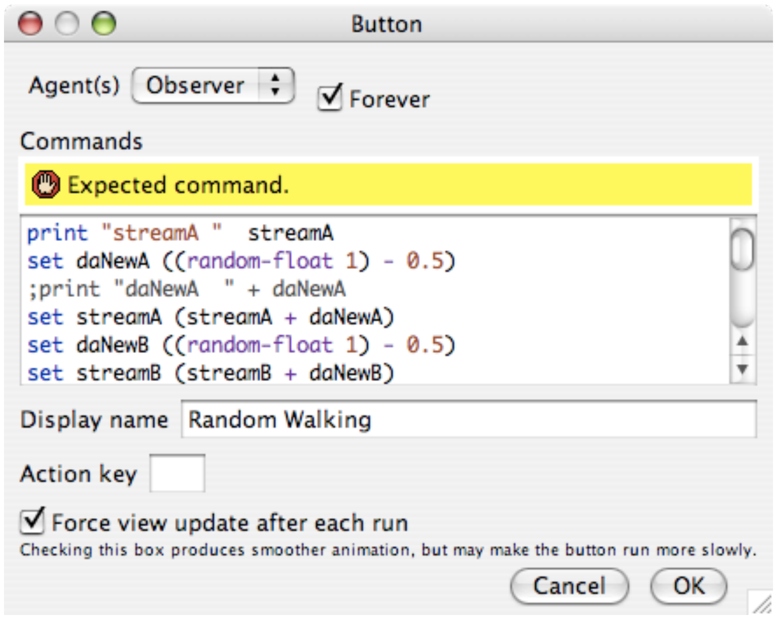
```
;print (word "streamA "  streamA)
```

Change it to

```
print  "streamA "  streamA
```

That is, remove the semicolon, the parentheses, and `word`.

Click the Ok button. Notice that we return to the Interface Tab but the lettering on the Random Walking button is now in red. This indicates an error. Edit the button. Here is what you will see:



Expected command.

```
print "streamA "  streamA
set daNewA ((random-float 1) - 0.5)
;print "daNewA  " + daNewA
set streamA (streamA + daNewA)
set daNewB ((random-float 1) - 0.5)
set streamB (streamB + daNewB)
```

Display name: Random Walking

Action key:

✓ Force view update after each run

Checking this box produces smoother animation, but may make the button run more slowly.

Figure 1.3: NetLogo Error Message from a Button

The cursor will also be on the offending line. Fix it.

1.3 The Info Tab

Not a lot to say here. A nice design. Two modes: view and edit. Go to edit mode and notice the simple pattern.

[Later: Using the *ODD protocol* here for documentation: `http://bio.uib.no/te/papers/Grimm_2010_The_ODD_protocol_.pdf`.

1. Purpose

2. State variables and scales

3. Process overview and scheduling
4. Design concepts
5. Initialization
6. Input
7. Submodels

See also nice discussion in *Agent-Based and Individual-Based Modeling* by Railsback and Grimm.]

Add in—

```
EXTRA STUFF
-----------

You can add categories of your own.
```

—and return to view mode.

Notice that full URLs are "live," e.g., try inserting `http://opim-sky.wharton.upenn.edu/~sok/`.

Also, vertical bars at the beginning of lines indicate special shading for emphasis, e.g., to present code.

```
| clear-all
| set daNewA 0.0
| set streamA 25.0
| set daNewB 0.0
| set streamB 25.0
| random-seed 1
```

Notice that the shaded area uses "typewriter" font (conventional for code).

1.4 The Code Tab

We can do a great deal of NetLogo programming by proceeding as we have, adding code to buttons on the Interface Tab. This quickly becomes a software engineering nightmare, however. The Procedures Tab helps us avoid, or at least postpone, this unhappy eventuality.

Open a new (blank) NetLogo file and click on the Procedures Tab. Here's what you see (and get):

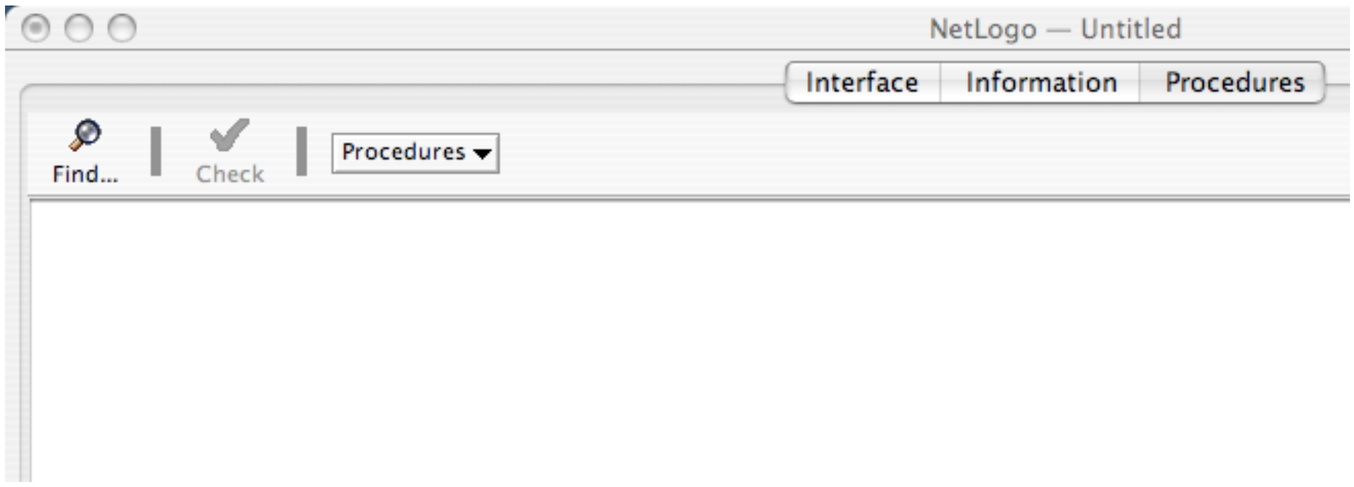


Figure 1.4: The Window for the Code Tab

The "Find..." function is for searching for text in the edit area (the large white area extending below). The "Check" function is for validating your code, looking for syntax errors. The "Procedures" function is a drop-down list that allows you to see, select, and go to a particular procedure. The rest is the large white editing area extending below.

There are two types of procedures: *commands* (which correspond to subroutines in other languages or procedures with void returns) and *reporters* (which in other languages are often called functions, or procedures that return values). Commands do things, but do not return values. Reporters return values. NetLogo is not case-sensitive. Even so, I'll try to follow this stylistic convention:

- Procedures—commands and reporters—begin with an upper-case letter

- Variables begin with a lower-case letter

- After the first character, both procedures and variables UseTheCamelBackConvention.

1.4.1 Commands and reporters

To declare a reporter, call it `SumOfTwoNumsSquared`, that accepts one argument and returns the argument plus one squared, do this:

```
to-report SumOfTwoNumsSquared [daFirstNumber daSecondNumber]
  report (daFirstNumber + daSecondNumber) * (daFirstNumber + daSecondNumber)
end
```

To declare a command, call it `MyFirstCommand`, use the following format:

```
to MyFirstCommand
   print "Hello from MyFirstCommand."
   print (word "The square of 3 + 2 is "  SumOfTwoNumsSquared(3)(2)  ".")
end
```

Try typing these into the procedures edit area. Then create a button and call `MyFirstCommand`. Points arising:

1. Reporters and commands may or may not require accompanying arguments to be specified. If arguments are specified you show this as in the declaration for the reporter `SumOfTwoNumsSquared`, with the arguments specified between square brackets and separated by white space if there is more one.

2. NetLogo uses square brackets, `[...]`, to indicate lists (of which more later). Items in a list are separated by white space.

3. NetLogo supports various arithmetic and mathematical operators, e.g., `+` for addition, `*` for multiplication, `^` for exponentiation, and so forth. NetLogo requires that these operators be surrounded by white space. So, `2*3` is not legal, but `2 * 3` is.

1.4.2 Global and local variables

NetLogo's variables are not typed, but they must be declared. NetLogo supports both global and local variables. Global variables may be declared in either of two ways. First, using a variable in a slider or switch on the Interface Tab counts as declaring the variable as global. Second, at the top of the procedures edit area, you can declare NetLogo global variables using this format:

```
globals [myFirstVariable mySecondVariable
               myThirdVariable
               ]
```

So, the notation for declaring global variables in the Procedures Tab is the keyword `globals` followed by a list of variables.

There are similarly two ways of declaring local variables. The first is demonstrated in the reporter `SumOfTwoNumsSquared`, above. There, `[daFirstNumber daSecondNumber]` declares two variables whose scope is the reporter `SumOfTwoNumsSquared`. Second, you can place this sort of expression within any procedure:

```
let myFirstLocalVariable 0
let mySecondLocalVariable ""
let myThirdLocalVariable one-of patches
```

Use `let` to declare variables and give them initial values. Thereafter use `set` to give them new values.

1.4.3 Comments and line breaks

The semicolon— ; —is NetLogo's comment symbol. Anything appearing after a semicolon in a line is considered a comment. NetLogo does not have multiline commenting.

NetLogo is remarkably forgiving and loose about line breaks. The following is entirely OK:

```
print (word "Sum from several lines: "
 ( 3 +
 4 -
 3
 +
 1 )
 )
```

The parentheses *are* required, but not because of the line breaks. If you want to use mathematical operators in this string context, you need to group things with parentheses.

1.4.4 Assignment: `Set`

Use `Set` to assign values to variables.

```
Set myFirstVariable 17.2
```

Variables may hold complex objects, including lists, turtles and patches. Just use `Set`.

1.4.5 Agent properties, `turtles-own`, and `patches-own`

Turtles and patches are agents, objects with properties. By default every patch has the properties: `pxcor`, `pycor` (its x and y coordinates on the world grid), `pcolor` (its color), `plabel`, and `plabel-color`. You can see the properties of a patch by right-clicking on it, then choosing to inspect it. Turtles come by default with a longer list of properties. These, too, you can see (and edit) by right-clicking on a turtle and choosing to inspect it.

Your program can alter any properties a patch or turtle has. In addition, and most usefully, your program can add properties to turtles and to patches. For example, placing

```
patches-own [ playerType ]
```

at the beginning of the procedures edit area, below `globals` and above the first procedure will cause all patches to have a new property, `playerType`. If you want more properties added, just add them to the list, which above contains just `playerType`. Similarly, you can add properties to turtles with, e.g.,

```
turtles-own [ speed availableEnergy]
```

If you want to set a property of a turtle or patch to a certain value, you `ask`, e.g.,

```
ask turtle 0 [set shape "airplane"]
```

Note: every turtle has an ID number. Numbering is in sequence, beginning with 0. There are a number of shapes that ship with NetLogo (ship shapes?). You can see the current list by typing

```
show shapes
```

in the Command Center. Similarly, you can ask a patch to set one of its properties, whether given by default or added by you, e.g.,

```
ask patch  1 2 [set playerType "type01"]
```

Note that every patch is identified uniquely by its x-y coordinate numbers on the world grid.

If you want *all* the patches or turtles to do something, you just `ask`, e.g.,

```
ask patches [set pcolor "blue"]
```

And similarly for `ask turtles`. With these commands you exploit NetLogo's simulation of parallel programming. NetLogo updates the agents in random order.

NetLogo's `of` and `one-of` mechanisms are also quite useful. `-of` is used with a property, e.g.

```
set [color] of turtle 0 blue
```

Use `of` when dealing with one turtle or one patch. You can also use it for *agentsets*, collections of NetLogo agents (see §1.4.6 below). See *of* in the Dictionary.

You use `with` to select a set of turtles or patches from a larger group, e.g.,

```
ask turtles with [shape = "default"] [set color green]
```

Again, see the Dictionary.

NetLogo's `one-of` randomly selects one item from a list. For example,

```
print one-of ["Bob" "Carol" "Ted" "Alice"]
```

1.4.6 Agentsets

See the discussion in the NetLogo manual. An *agentset* is a set of patches or a set of turtles. Agentsets are unordered. They are a fundamental and crucial concept in NetLogo. The `turtles` built-in primitive is a reporter that reports the agentset of all turtles presently in the model. Similarly for `patches`. Great power of expression comes from the fact that agentsets can be given as arguments to reporters, which then operate on them, and the fact that agentsets may be composed or defined under program control, for example by filtering another agentset. Examples:

`count patches` applies the `count` reporter to the `patches` agentset.

`print count turtles with [color = green]` filters the agentset `turtles`, creating a new agentset of green turtles, then applies the `count` reporter to this.

See additional examples on page 81 of the manual. Useful agentset constructors:

- `with`
- `turtles-here`
- `in-radius`
- `at-points`
- `neighbors4`, `neighbors`
- `turtles-on`

Useful built-in reporters taking agentsets as arguments:

- `max-one-of` and `min-one-of`
- `one-of`, `n-of`
- `values-from`

1.4.7 Breeds of turtles

Turtles, but not patches, can be organized by breeds, which are classes—distinct agentsets—of turtles. Use `breed` at the top of the procedures edit area, before the procedures, to declare new breeds, e.g.,

```
breed [ optimists optimist]
breed [ pessimists pessimist]
```

Then, where you might say `turtles` you can now say `optimists` or `pessimists`, and where you might say `turtle` you can now say `optimist` or `pessimist`. You can still write

```
create-turtles 17
```

and you can also write

```
create-optimists 23
```

1.4.8 Lists

Lists are ordered collections of things and may be heterogeneous, e.g.,

```
print (list "Bob" 5 [2 "Carol"] turtle 0)
```

prints out `[Bob 5 [2 Carol] (turtle 0)]`.

If you have more than 2 things to put into the list you must use parentheses in creating it (see above).

There are several built-in reporters that can be used to change a list. Examples:

```
set daList replace-item 3 daList (list 1 2 3)
```

This replaces whatever item 3 was (the fourth item, since we count starting at 0) with `[1 2 3]`.

```
set daList fput "Bob" daList
```

Note well

This adds `"Bob"` to the beginning (position 0) of `daList`, making it one item longer. Use `lput` for adding to the end. **Note well:** In NetLogo lists are naturally accessed from the front. If you need to access (add, delete, find something in) a list towards the end, it will often be faster to reverse the list, access it, and then reverse it again.

```
set daList but-first daList
```

This removes the first item in `daList`. Use `but-last` to remove the last item.

List are used for controlling iteration. Example:

```
foreach [1 2 3]
  [crt ?]
```

This does what in other languages might be done with

```
for i=1 to 3
   crt(i)
next i
```

or with

```
for (int i=1; i < 4; i++) {
   crt(i)
   }
```

Note that the counter— `?` —is anonymous, so that nesting interations (with `foreach`) requires reading the `?` into a variable, e.g.,

```
foreach [1 2 3]
  [set myi ?
   crt myi]
```

You can use `n-values` to create a list for `foreach` iteration, e.g.,

```
set myIterationList n-values 10 [ ? ]
```

`myIterationList` is now `[0 1 2 3 4 5 6 7 8 9]`.
See the manual, the "Programming Guide," for additional examples.

1.4.9 Character strings

Are indicated with double quotes, e.g., `"Bob"`. Generally, if a built-in reporter works on a list it will work on a string, too. Example:

```
print length (list 2 4 6 8)
print length "Now is the time"
```

In addition there are string-specific built-ins: `is-string?`, `substring`, `word`.
Recall that *string concatenation* is done with `word`, e.g.,
`print (word 17 " is " "an odd number")`.

1.4.10 I/O

You can read from and write to files, in simple ways. You can make QuickTime movies of the execution of your NetLogo program.

Here, too briefly, is example code for writing to a file. It's taken from Chapter 9. NetLogo's file handling capabilities are very basic (maybe primitive would be a better word). Anyway, only one file open at a time, be sure to close files when you're done, and writing to a file appends to what's there, so if you want a blank file, first check to see if it exists and if it does, delete it.

```
; Delete the existing output file, if it exists.
if file-exists? "runsOutput.txt"
  [file-delete "runsOutput.txt"]

   file-print (word currentRunNumber "," meanCustomerInterarrivalTime ","
     meanCustomerServiceTime "," maxTicks "," length(customerQueue))
   file-close
```

1.4.11 Control flow and logic

See Control/Logic in the NetLogo Dictionary. Main ones:

1. `foreach` From the manual:

   ```
   foreach [1.1 2.2 2.6] [ show (word ? " -> " round ?) ]
   => 1.1 -> 1
   => 2.2 -> 2
   => 2.6 -> 3
   ```

   Issues: (a) use of `?`; getting a list. On the latter, see `n-values`. From the manual:

   ```
   show n-values 5 [1]
   => [1 1 1 1 1]
   show n-values 5 [?]
   => [0 1 2 3 4]
   show n-values 3 [turtle ?]
   => [(turtle 0) (turtle 1) (turtle 2)]
   show n-values 5 [? * ?]
   => [0 1 4 9 16]
   ```

2. `if` and `ifelse`

   From the manual:

   ```
    ifelse reporter [ commands1 ] [ commands2 ]

   Reporter must report a boolean (true or false) value.

   If reporter reports true, runs commands1.

   If reporter reports false, runs commands2.

   ask patches
     [ ifelse pxcor > 0
         [ set pcolor blue ]
         [ set pcolor red ] ]
   ;; the left half of the world turns red and
   ;; the right half turns blue
   ```

3. `while`

   From the manual:

   ```
    while [reporter] [ commands ]

   If reporter reports false, exit the loop. Otherwise run commands and repeat.

   The reporter may have different values for different agents,
   so some agents may run commands a different number of times
   than other agents.

   while [any? other turtles-here]
     [ fd 1 ]
   ;; turtle moves until it finds a patch that has
   ;; no other turtles on it
   ```

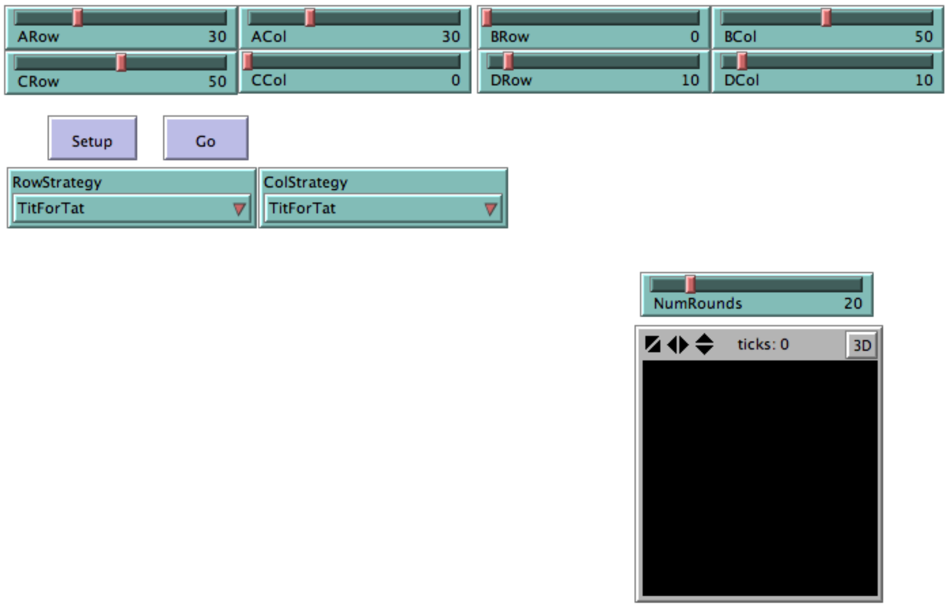
1.4.12 Typical program structure

Two main command procedures: `Setup` and (then) `Go`, both called by buttons on the Interface tab, and `Go` a forever button. `Setup` initializes, `Go` handles the main loop of execution. Both can (and usually should) call various reporters and command procedures as subroutines.

Chapter 2

Exercise: Testing Strategies in 2×2 Games

Figure 2.1 shows the interface tab for the NetLogo program Simple2x2.nlogo.

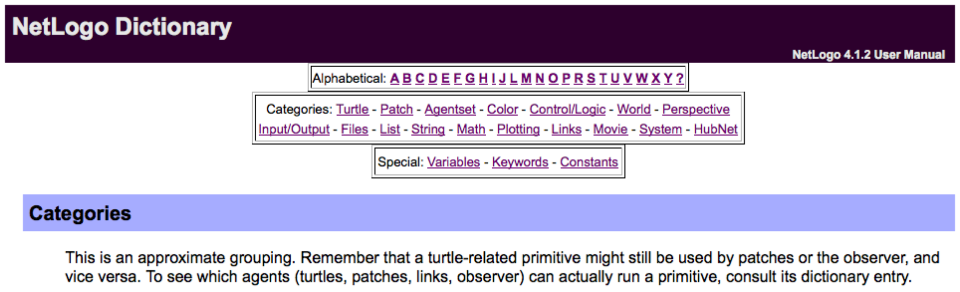


ARow 30
ACol 30
BRow 0
BCol 50
CRow 50
CCol 0
DRow 10
DCol 10
RowStrategy TitForTat
ColStrategy TitForTat
NumRounds 20

Figure 2.1: Interface tab for Simple2x2.nlogo

This program is for testing strategies in iterated 2×2 games. Our aim with this exercise is to understand how Simple2x2.nlogo works and then to modify and improve it. Before we do that, however, we need to review a number of NetLogo programming elements.

2.1 Needed Programming Elements


NetLogo Dictionary

NetLogo 4.1.2 User Manual

Alphabetical: A B C D E F G H I J L M N O P R S T U V W X Y ?

Categories: Turtle - Patch - Agentset - Color - Control/Logic - World - Perspective
Input/Output - Files - List - String - Math - Plotting - Links - Movie - System - HubNet

Special: Variables - Keywords - Constants

Categories

This is an approximate grouping. Remember that a turtle-related primitive might still be used by patches or the observer, and vice versa. To see which agents (turtles, patches, links, observer) can actually run a primitive, consult its dictionary entry.

Figure 2.2: The NetLogo Dictionary. Use it!

2.1.1 Local and Global Variables

Variables set on the Interface tab are global, as are variables declared with `globals` (at the top of the Procedures window).

```
globals [Row ; the row player
         Col  ; the column player
         ]
```

To set a global variable, use `set`, e.g.,

```
  set Row turtle 0
  set Col turtle 1
```

All other variables are local. To declare a local variable use `let` and give it a value, e.g.,

```
let carol 8
```

Once declared (assuming you are in its scope) you change the value of a local variable with `set`, e.g.,

```
set carol (carol + 1)
```

Note: you need white space before and after arithmetic operations.

2.1.2 Reporters

```
to-report bob [x y]
  report (list 3 4 x y)
end

to test
  let carol bob ("hello")("there")
  print first carol
  print last carol
  print carol
end
```

This code is in Simple2x2.nlogo. Try typing `test` in the command line (on the interface tab). Note that using a test procedure like this is a good idea during program development.

Note well: use of square and round brackets.

2.1.3 Lists

A list is just an sequence of things. In NetLogo, these things can be …anything more or less, including numbers, strings, turtles and so on. NetLogo uses square brackets to delineate lists: `[bob carol ted alice]`. Notice: spaces not commas separate the elements.

Note to create lists use `list` as in

```
let bob (list 2 3 4 5 "hello")
```

Note further this is how you do string building (concatentation):

```
let myString (word "Now is" " the time " "for all etc.")
```

Let's look at the List category in the Dictionary. …

2.1.4 Random Numbers

See the Mathematical category in the Dictionary. `random-float` is perhaps the most commonly used.

2.1.5 Turtles

See the Turtle category in the Dictionary. Turtles (which can move) and patches (which cannot move) are, with lists, the main data structures in

NetLogo. Here, we won't be using patches and our turtles won't move. Still, we have this:

```
turtles-own [Player
             PolicyOfPlay
             NextMove ; the player's next move, which is 0 or 1
             MyMoves ; a list of my moves, moves are 0 or 1
             CounterPartMoves ; a list of the counterpart's moves
             Payoffs ; a list of the payoffs received
             ]
```

What this does is to define new attributes that all turtles will have. We can define as many as we want. Our program will use this attributes as turtle-specific variables, which will be set perhaps many times during a run.

2.2 Understanding Simple2x2.nlogo

[OK, I'll handle this live.]

2.3 Exercises

1. Simple2x2.nlogo prints output messages to the command window at the end of a run. Change the program so that there is an output widget on the Interface tab and the messages at the end of the run are printed to it.

2. Simple2x2.nlogo comes with the game matrix set to a Prisoner's Dilemma. Add code an Interface widgets that let you choose (use a chooser) among a stated list of games. Add several interesting 2×2 games to the program and test it all out. You should have a chooser whose variable is `PickGameSetup`. You should add a button that calls the procedure `SetUpGame` and, obviously, you need to add a procedure named `SetUpGame` that resets the game matrix payoff sliders as appropriate.

3. Simple2x2.nlogo comes with two built-in straties: "Random" and "TitForTat". Add new strategies and explore their performances. Best to think up your own (be sure to document them!), but here are some suggestions.

   (a) “TitForTatComplement”. Defaults to 1, after that, like “TitForTat” it mimics the play of the counter-player in the previous round. (Also known as “SuspiciousTitForTat”.)
   (b) “2 Tits for OneTat”.
   (c) “Tit for Two Tats”.
   (d) All of the strategies used by Axelrod in his tournaments.

4. Add a feature to output the run information to a comma separated file. Such files are easily read by R, Excel, and other data analysis programs. See the Files category in the Dictionary. You should settle on a name for your file, such as Simple2x2Output.txt. When you go to write your data to your file for the first time, you will normally want to see if the file already exists. If it does and you want to start anew, then delete it.

   Don’t forget to close your file when you are done. Also, NetLogo really only lets you deal with one open file at a time.

5. Add a slider to the Interface tab, named `NumReplications`. Then make appropriate code changes so that that number of replications is run for any given setting. Preferably, make this work with the file logging feature so that results from each replication are stored (as rows) in a comma separated file.

6. Add features to the program so that you can run tournaments, say one strategy playing each strategy in a given list. Make sure the results are properly recorded a log file.

7. Add features to the program so that you can do multiple runs for sensitivity analysis. For example, you might vary the payoffs in a game systematically, undertake multiple runs, record the data, and see how the payoff changes affect the performance of a strategy.

Chapter 3

Exercise: Simple animation with turtles

In this exercise, or series of exercises, we will have one or more trucks move between two points, which we might think of as notional supply and delivery locations.

Since the trucks have to move, we use turtles to embody them. NetLogo comes, I shall assume, with a truck shape. Verify this by choosing Turtle Shapes Editor under the Tools menu in NetLogo. You should find a scrolling window displaying turtle shapes, with truck near the bottom. Note that you can also click on Import from Library... and see an even larger collection of turtle shapes. Select (click on) truck, then click on Duplicate. In the new window, type `truck-west` to name our new shape. Then click Flip Horizontal to head the truck to the west (left). Click OK. You should now see your new shape in the Shapes Editor scrolling window. Click the go-away button on the window and return to the main window of NetLogo.

Why did we do this? Our trucks will start in the west and head east to a specified point. After that, they will turn around and head west to a specified point, and so on. The truck shape is not symmetric, so rotating it (which is all NetLogo can do under program control) won't make it point west without being upside down. (Notice that in the Shapes Editor, the Rotatable check box is unchecked. You can check it and thereby allow your program to rotate the truck—e.g., with `right` or `rt`—but why would you want an upside-down truck?) So, we will use two shapes with the same turtle.

In the command center, test things out with:

```
observer> crt 1
observer> ask turtle 0 [set size 4]
observer> ask turtle 0 [set shape "truck-west"]
```

then

```
observer> ask turtle 0 [set shape "truck"]
```

OK. Now we'll do three exercises in which we move one or more trucks back and forth across the gridscape.

3.0.1 Exercise 1

We write two commands: `Setup` and `Go`. In `Setup`, create a single turtle, and give it a name, say `daTruck` which should be global. Position the truck at patch `-10 0`. Hint: Use `setxy`. Give the truck the shape `"truck"`, set its `size` to 4, and its `heading` to 90 (due east).

In `Go`, when the truck has the shape `"truck"` move it forward east one patch per run of `Go`, until the truck is on patch `10 0`. Then, set the shape to `"truck-west"` and the heading to 270 (due west). If the shape is `"truck-west"`, move the truck forward west one patch at a time, until the truck is on patch `-10 0`. Now, change its shape to `"truck"` again and its heading to due east.

Create buttons for `Setup` and `Go`, making `Go` a forever button. Exercise the code. Use the speed control slider at the top of the world window to control the speed of the truck. Experiment with the code a bit to add features, e.g., change the color of the truck depending on its direction.

3.0.2 Exercise 2

We write two commands: `SetupPlus` and `GoPlus`, and buttons to call them.

Now we declare `delivery-trucks` as a new breed with `breed [delivery-trucks delivery-truck]` and we add `loading-time` as a property of `delivery-trucks`. Do this with `delivery-trucks-own [ loading-time ]`. Our truck will take some time to load and unload.

Write `SetupPlus` much as you did `Setup`, but use `create-delivery-trucks` instead of `create-turtles` and set the `loading-time` of our truck to `-1`.

Write `GoTruckPlus` much as you did `GoTruck`, but when the truck arrives at the eastern terminus, set its `loading-time` to 4, then decrement `loading-time` by 1 each time step until it equals 0. At that time, set the shape and direction for heading west, and set `loading-time` to `-1` again.

When the truck arrives at the western terminus, it should be handled analogously to what was done at the eastern terminus.

Using buttons for `SetupPlus` and `GoPlus`, exercise the code and experiment with changing it.

3.0.3 Exercise 3

Now we'll create two delivery trucks and run them in parallel at different speeds. We write two commands: `SetupPlusArg` and `GoPlusArg`, and buttons to call them. We'll also write a command, `GoTruckPlusArg` that takes a delivery truck as its calling argument and processes its activities.

There are one or two important issues here. First, we want different trucks to do things at different, idiosyncratic speeds. We'll facilitate this by maintaining a global counter, `mytick`, which we increment each time `GoPlusArg` is called. A particular truck will do things based on the value of `mytick`. A truck that does something every 2 ticks, for example, will check for `mytick mod 2 = 0`. A slower truck might act when `mytick mod 5 = 0`.

Note well: Consider how to do all of this more elegantly using the reserved words in NetLogo, `tick` and `ticks`. **Note well**

The second important issue is that we want a single way to handle all of the delivery trucks, even though they behave differently. We do this by giving them different values for their properties and writing a command (here `GoTruckPlusArg`) that handles any delivery truck based on its property values.

So, `GoTruckPlusArg` is very like `GoTruckPlus` of exercise 2, except that it takes a delivery truck as an input argument.

Delivery trucks now have more properties: `delivery-trucks-own [ speed loading-time loading-flag loading-time-left]`.

In `SetupPlusArg` we create two delivery trucks. Call them `daTruck`, as before, and `daOtherTruck`. Make one of the truck green and the other yellow (or pick some other color scheme). Both trucks should have their `loading-flag` set at `-1`. Let one have a `speed` of 2 and give the other 3. Have one truck go between patch `-10 0` on the west to `10 0` on the east, while the other has a route from `-10 10` to `10 10`. Finally, give one a `loading-time` of 3 and give the other a 5.

The job of `GoPlusArg` is mainly to call `GoTruckPlusArg`. Here it is:

```
to GoPlusArg
  set mytick mytick + 1
  ask delivery-trucks [
    if mytick mod speed = 0
      [GoTruckPlusArg(self)]
  ]
end
```

The role of `self` is crucial in this quite elegant NetLogo approach to the problem. `ask delivery-trucks` iterates in random order through the agentset `delivery-trucks`. The agent it happens to be processing at a given time is called `self`, which name we use as the argument to `GoTruckPlusArg`. (Otherwise, how would we do this?)

Using buttons for `SetupPlusArg` and `GoPlusArg`, exercise the code and experiment with changing it.

3.0.4 Solutions

The NetLogo program is `animation-1-truck.nlogo`. When all three exercises are implemented the leading declarations are:

```
globals [ daTruck mytick  daOtherTruck ]

breed [delivery-trucks delivery-truck]

delivery-trucks-own [ speed loading-time loading-flag loading-time-left]
```

3.0.4.1 Exercise 1

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;; Exercise 1 ;;;;;;;;;;;;
to Setup
clear-all
create-turtles 1
set daTruck turtle 0

ask daTruck
  [setxy -10 0
   set shape "truck"
   set size 4
   set heading 90]
end

to Go
ask daTruck [
if (shape = "truck") [
ifelse (xcor < 9)
  [fd 1]
  [fd 1
   set shape "truck-west"
   ; Note: the shape is defined in the library as "truck-west"
   ; Things don’t work properly if you change capitalization at all,
   ; e.g., "truck-west". It’s safest just to always use lower case.
   set heading 270]
] ; end of if shape = truck

if (shape = "truck-west") [
ifelse (xcor > -9)
  [fd 1]
  [fd 1
   set shape "truck"
   set heading 90]
]
] ; end of ask daTruck
end ; of Go
```

3.0.4.2 Exercise 2

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;; Exercise 2 ;;;;;;;;;;

to SetupPlus
clear-all
create-delivery-trucks 1
set daTruck delivery-truck 0


ask daTruck
  [setxy -10 0
   set shape "truck"
   set size 4
   set speed 3
   set heading 90
   set loading-time -1]
end
```

```
to GoTruckPlus
ask daTruck [
if (shape = "truck") [
ifelse (xcor < 9)
  [fd 1]
  [if (loading-time < 0) [
   set loading-time 4]
  if (loading-time > 0) [
   set loading-time loading-time - 1]
  if (loading-time = 0) [
   set shape "truck-west"
   ; Note: the shape is defined in the library as "truck-west"
   ; Things don't work properly if you change capitalization at all,
   ; e.g., "truck-west". It's safest just to always use lower case.
   set heading 270
   set loading-time -1]
   ]
] ; end of if shape = truck

if (shape = "truck-west") [
ifelse (xcor > -9)
  [fd 1]
  [if (loading-time < 0) [
   set loading-time 4]
  if (loading-time > 0) [
   set loading-time loading-time - 1]
  if (loading-time = 0) [
   set shape "truck"
   set heading 90
   set loading-time -1]
   ] ; end of else in ifelse
] ; end of if shape = truck-west
] ; end of ask daTruck
end ; of GoTruckPlus command

to GoPlus
  set mytick mytick + 1
  ask daTruck [
  if mytick mod speed = 0 [
   GoTruckPlus
  ]
  ] ; end of ask daTruck

end
```

3.0.4.3 Exercise 3

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;; Exercise 3 ;;;;;;;;;;

;;;;;;;;;;;;;;;;;;;;;
;;; SetupPlusArg ;;;;
;;;;;;;;;;;;;;;;;;;;;

to SetupPlusArg
clear-all
create-delivery-trucks 2
set daTruck turtle 0
set daOtherTruck turtle 1

ask daTruck
  [setxy -10 0
   set shape "truck"
   set size 4
   set speed 3
   set heading 90
   set color green
   set loading-flag -1
   set loading-time 3]


ask daOtherTruck
  [setxy -10 10
   set shape "truck"
   set size 4
   set speed 2
   set heading 90
   set color yellow
   set loading-flag -1
   set loading-time 5]
end

;;;;;;;;;;;;;;;;;;;;;
;;; GoPlusArg ;;;;;;;
;;;;;;;;;;;;;;;;;;;;;
to GoPlusArg
  set mytick mytick + 1
  ask delivery-trucks [
    if mytick mod speed = 0
      [GoTruckPlusArg(self)]
  ]
end

;;;;;;;;;;;;;;;;;;;;;;;
;;; GoTruckPlusArg ;;;;
;;;;;;;;;;;;;;;;;;;;;;;
to GoTruckPlusArg [daDeliveryTruck]

ask daDeliveryTruck [
if (shape = "truck") [
ifelse (xcor < 9)
  [fd 1]
  [if (loading-flag > 0) [
   set loading-time-left loading-time-left - 1
   ]
  if (loading-flag < 0) [
   set loading-time-left loading-time
   set loading-flag 1]

  if (loading-time-left <= 0 and loading-flag > 0) [
   set shape "truck-west"
   ; Note: the shape is defined in the library as "truck-west"
   ; Things don't work properly if you change capitalization at all,
   ; e.g., "truck-West". It's safest just to always use lower case.
   set heading 270
   set loading-flag -1
   set loading-time-left 0]
   ]
] ; end of if shape = truck
```

```
if (shape = "truck-west") [
ifelse (xcor > -9)
  [fd 1]
  [  if (loading-flag > 0) [
   set loading-time-left loading-time-left - 1]
  if (loading-flag < 0) [
   set loading-time-left loading-time
   set loading-flag 1]

  if (loading-time-left <= 0 and loading-flag > 0) [
   set shape "truck"
   set heading 90
   set loading-flag -1
   set loading-time-left 0]
   ] ; end of else in ifelse
] ; end of if shape = truck-west
] ; end of ask daTruck
end ; of GoTruckPlusArg command
```

Chapter 4

Working with Lists

See §1.4.8, page 22 for our first introduction to lists in NetLogo. Also, read the Dictionary under Lists.

4.1 Basics

You create lists using the `list` reporter:

```
globals [bob carol ted alice]

to setup
 set bob (list 1 2 3 4 5)
end
```

Qua list, `bob` may be operated on in a number of ways (see the Dictionary for the full. . . list).

```
observer> print bob
[1 2 3 4 5]
observer> print first bob
1
observer> print but-first bob
[2 3 4 5]
observer> print reverse bob
[5 4 3 2 1]
observer> print item 3 bob
4
```

Note that item counts in lists start with 0.

Sorting is often very useful. See `sort` and `sort-by`.

```
observer> print sort reverse bob
[1 2 3 4 5]
observer> print sort-by [?1 > ?2] bob
[5 4 3 2 1]
```

4.2 Exercise: `map` and data manipulation

NetLogo's `map` command—originating in the list processing language, Lisp—is extremely useful for iterating over lists. A basic format is:

```
map [< reporter >] <list>
```

For example,

```
print map [?  + 2] [1 2 3 4 5]
```

prints out the list `[3 4 5 6 7]`. The `?` refers to the current item in the list, as `map` iterates through the list.

One of the great features of lists is that they can be indefinitely long. In consequence, with `map` (and other list reporters) it is possible to write general procedures that work on lists of any size. This facilitates reuse of code.

Useful list reporters include: `length` for the number of items in a list and `sum` for the numerical sum of the items in the list.

4.2.1 Exercise 1

As an exercise, let us look at some elementary statistical number processing. Suppose our data are in a list. We'd like the mean, the sum of squared deviations from the mean, the variance, and so forth.

Do this: Declare a short list of numerical data and assign it a name, say `bob`, and print it out. Get the number of items in the list and print that out. Get the numerical sum of the elements in the list and print that out. Then, use `map` to get the sum of the squared deviations from the mean (ssdm) of the data in the list. That is, if x_i is the i^{th} data element of the list, then ssdm is

$$\sum (x_i - \overline{x})^2$$

where $\overline{x}$ is the average value of x in the list and the summation is over all the elements in the list. Do this directly in a procedure, then write a reporter that takes a list (presumably of numbers) as an argument and returns the list's ssdm.

4.2.2 Exercise 2

If your list contains elements other than numbers, for example strings or other lists, then numerical operations performed while iterating on the list (e.g., with `map` or `sum`) will cause an error condition.

The solution to this problem is to write a reporter that determines whether or not everything in the list is in fact a number. NetLogo has built-in reporters that find the types of objects. Specifically, `is-number?` reports `true` if the argument is a number, and false otherwise.

Write a reporter that accepts a list as its argument and returns `true` if every element is a number and `false` otherwise. Hint: `member? xx yy` reports `true` if `xx` is a member of list `yy` and `false` otherwise.

See NetLogo's manual for other `is-` reporters.

4.2.3 Solutions

4.2.3.1 Exercise 1

Here is code that does this. `list-processing.nlogo` contains this code.

```
to test
let bob []  ; empty list, but really anything would do
let carol []  ; empty list, but really anything would do
set bob [1 3 5 7 9]
print (word "bob = "  bob)
print (word "The length of bob is "  length bob)
print (word "The sum of the elements in bob is "  sum bob)
set carol map [? - sum bob / length bob] bob
print (word "The elements of bob minus the mean of bob is "  carol)
print (word "The sum of the mean squared deviations is "
                sum map [ ? * ? ] carol)
print (word "This again, with a reporter call: "  ssdm(bob))
end

; sum of squared deviations from the mean
to-report ssdm [ daDataList ]
  report sum map [(? - (sum daDataList / length daDataList)) ^ 2] daDataList
end
```

4.2.3.2 Exercise 2

```
to-report ListIsAllNumbers? [aList]
```

```
  dummy [] ; empty list, but really anything would do
  set dummy map [is-number? ?] aList
  ifelse (member? false dummy)
    [report false]
    [report true]
end
```

4.3 Exercise 3: Probe and Adjust

Lists are often useful for remembering things. The agent observes something, notes a value in a list (use `fput` for efficiency), ...

```
observer> set bob fput 6 bob
observer> print bob
[6 1 2 3 4 5]
```

. . . and after a time takes an action depending on the contents of the list, i.e., the data collected and remembered. Then, typically, the agent will reset the list, making it empty, `[]`.

In this exercise we model a form of learning I call Probe and Adjust. A source of data, puts out (to begin) a constant value. Our agent wants to learn what that value is. The agent has an initial guess, `currentValue`. In each tick, the agent uses its `currentValue` to make a guess. Specifically, the agent's guess is a uniformly random number between `currentValue - delta` and `currentValue + delta`, where `delta` is a global variable (think: slider) and is small compared to `currentValue`.

After the agent guesses, the data source returns to the agent the absolute value of the difference between the guess and the source's value. The agent maintains two lists: one for guesses above `currentValue` and one for guesses below `currentValue`. The agent records the source's responses in whichever list is appropriate. After a number of guesses, `epochLength`, another global variable, the agent adjusts its `currentValue`. If the high guesses on average produce smaller errors, then the agent adjust `currentValue` up by `epsilon`, another global variable or parameter, one that should be smaller than `delta`. And similarly if the low guesses do better.

You should plot both the source's value and the agent's guesses. What happens?

Now make the source's values a mild random walk. Can the agent track the changes? Under what conditions?

See Figure 4.1, page 47, for pseudocode presenting Probe and Adjust.

```
1. Set parameters $\delta$, $\varepsilon$, currentQuantity, epochLength
   (Typically, $\varepsilon < \delta \ll$ currentQuantity and epochLength $\approx 30$.)
2. episodeCounter $\leftarrow 0$
3. returnsUp $\leftarrow$ []    (Initialize returnsUp to an empty list.)
4. returnsDown $\leftarrow$ []    (Initialize returnsDown to an empty list.)
5. Do forever:
6. episodeCounter $\leftarrow$ episodeCounter $+ 1$
7. bidQuantity $\sim U[$currentQuantity $- \delta,$ currentQuantity $+ \delta]$
   (The agent's bidQuantity is drawn from the uniform distribution
   within the range currentQuantity $\pm\delta$.)
8. return $\leftarrow$ Return-of bidQuantity
   (The agent receives return from bidding bidQuantity.)
9. If (return $\geq$ currentQuantity) then:
   returnsUp $\leftarrow$ Append return to returnsUp
   else:
   returnsDown $\leftarrow$ Append return to returnsDown
10. If (episodeCounter mod epochLength $= 0$) then:
    (Epoch is over. Adjust episodeCounter and reset accumulators.)

    (a) If (mean-of returnsUp $\geq$ mean-of returnsDown) then:
        currentQuantity $\leftarrow$ currentQuantity $+ \varepsilon$
        else:
        currentQuantity $\leftarrow$ currentQuantity $- \varepsilon$
    (b) returnsUp $\leftarrow$ []
    (c) returnsDown $\leftarrow$ []
11. Loop back to step 5.
```

Figure 4.1: Pseudo code for basic PROBE AND ADJUST

4.4 Exercise 4: Genetic Operators

It is natural to represent a solution for a multi-variable optimization problem as a list of numbers. Perhaps the simplest case is the so-called Simple Knapsack problem in which we have to choose for each of n items whether it is in the knapsack (=1) or not (=0). In such a problem we might represent a solution as a list of n 0s and 1s:

```
let aSolution (list 1 1 0 1 1 0 0 0)
```

Here $n = 8$.

Genetic algorithms (GAs) are a popular and often appropriate kind of approach to treating such problems. Two important genetic operators on solutions that GAs typically employ are mutation and recombination.

4.4.1 Mutation

In mutation, a solution undergoes one or more changes of its "alleles" (for us, items in the list constituting a solution) at random. One way this might be done is to set a probability of mutation for an allele, say `ProbMutation` = 0.05, and to consider each allele in turn. For each allele, or item in the list, we draw a random number uniformly distributed between 0 and 1:

```
set mutation random-float 1
```

Then if `mutation` $\leq$ `ProbMutation` we randomly set the allele to 0 or 1. To do this, we draw another random number and set the allele accordingly.

```
set newValue random 0 2
```

Write a reporter that takes as arguments a solution in the form of a list of 0s and 1s and a mutation rate, and returns a possibly mutated solution.

4.4.2 Recombination

In recombination, two (or more, but we'll stick to two) solutions exchange genetic material, at least metaphorically. A simple way to this is with *single-point crossover*. Two solutions are identified as well as a crossover point. If our solutions are

```
[1 1 0 1 1 0 0 0]
```

and

```
[1 1 1 1 1 1 1 1]
```

and our crossover point is 3, then the two resulting solutions are

```
[1 1 0 1 1 1 1 1]
```

and

```
[1 1 1 1 1 0 0 0]
```

Write a reporter that accepts two solutions on input and a probability of crossover, and returns two solutions, appropriately, using single-point crossover.

The single-point crossover has a bias. It matters what the order is of the meaning of the alleles. This can be overcome with *two-point crossover*. Instead of one point of exchange, there are two. So, for example, if our previous two solutions were instead crossed over at points 3 and 6, we would get

```
[1 1 0 1 1 1 0 0]
```

and

```
[1 1 1 1 1 0 1 1]
```

Write a reporter that accepts two solutions on input and a probability of crossover, and returns two solutions, appropriately, using two-point crossover.

Chapter 5

Programming exercise: evo-dyna

In this chapter we present a programming exercise to develop a simple model in NetLogo that exercises an evolutionary dynamic ("evo-dyna") in a finite population of players playing a 2×2 game. Here is a schematic for the game:

	0	1
0	(row00, col00)	(row01, col01)
1	(row10, col10)	(row11, col11)

Each player, Row and Column, has two stage-game strategies, labeled 0 and 1. The payoffs are listed in the form rowXY and colXY. Row gets rowXY if Row plays its strategy 0 and Column plays its strategy Y.

This is a discrete (finite population) version of the *replicator dynamics*, which is modeled using differential equations. In our finite and discrete model, we have a population of players represented as patches in the NetLogo world. Each patch is a player and each player has a `playerType`.

We distinguish four types of players: `"type00"` players play strategy 0 as Row and 0 as Column; `"type10"` players play strategy 1 as Row and 0 as Column; `"type01"` players play strategy 0 as Row and 1 as Column; and `"type11"` players play strategy 1 as Row and 1 as Column.

A run is organized by distinct generations. Each generation consists of a number of rounds of play, that number being set by the `RoundsPerGeneration` slider/global variable. A generation is run the command `RunAGeneration`. At the heart of this command is the following mixture of code and pseudo-code (indicated by `< code goes here >`):

```
  repeat RoundsPerGeneration [
     ; Pick two players/patches at random
     < code goes here >
     ; Have the two players play one round, collecting appropriate statistics
     < code goes here >
  ]
```

We can sketch a simple version of `RoundsPerGeneration` as follows:

```
to RunAGeneration
  < declare local variables here using let >
  ; Reset accumulator variables to track performance by playerType
  ResetAccumulators
  repeat RoundsPerGeneration [
     ; Pick two players/patches at random
     < code goes here >
     ; Have the two players play one round, collecting appropriate statistics
     < code goes here >
   ] ; of repeat RoundsPerGeneration
  ; Set currentWeightTypeXY to how much return typeXY got in the round overall,
  ; divided by the total return in the round from all types.
  UpdateCurrentWeights
  ; Re-seed the patches according to the new distribution of types.
  ask patches [set playerType GetRandomType
      set pcolor TypeColor(playerType)]
  ; Compute (for display) the new actual number of types of each kind.
  UpdateTypeCounts
  ; Increment the generation counter
  set generationCounter generationCounter + 1
end ; of RunAGeneration
```

Your task is to fill in the blanks and create a basic evo-dyna program in NetLogo. See `finite-pop-2x2-evo-dyna-template.nlogo`, which provides the `Setup` command and considerable structure. You will find it at `http://opim-sky.wharton.upenn.edu/~sok/mandms/nlogocode/`.

Note on the Interface Tab:

1. There are two buttons. Setup calls the `Setup` command, which has been left more or less intact from the full working program. The RunAGeneration button calls the `RunAGeneration` command. When the program is fully working, this should be a forever button. The

`RunAGeneration` command needs to be developed as part of this exercise, although considerable structure is available for you there.

2. There are 8 sliders for setting the globals `row00`, `row01`, `row10`, `row11`, `col00`, `col01`, `col10`, and `col11`. These are the payoffs to the Row and Column players. So `rowXY` is the payoff to Row if Row plays strategy `X` and Column plays strategy `Y`.

   Note especially that this representation is quite general and in particular allows for non-symmetric 2×2 games.

   Payoffs should not be negative.

3. There are 4 slides for setting the globals `initialWeight00`, `initialWeight01`, `initialWeight10`, and `initialWeight11`. The program permits up to 4 types of players. Players of `typeXY` play strategy X when they are Row players and strategy Y when they are Column players.

   The expected percentage of the various types in each generation is determined from the weights. A type's percentage is just its current weight divided by the total weight of all the types. These four sliders initialize the four weights. After that, returns from play are accumulated during a generation and used to determine the percentages for the next generation.

4. There is a slider for the global variable `roundsPerGeneration`. During each generation the number of rounds of play is `roundsPerGeneration`. In a single round of play, two patches are randomly chosen, one to be the Row player, the other to be the Column player. They play as specified and the resulting payoffs are accumulated during the generation.

   Note that in the `Test` command there is some useful code for conducting a round of play:

   ```
   set rowPatch patch-at random-pxcor random-pycor
   set colPatch patch-at random-pxcor random-pycor
   set rowPlayerType [playerType] of rowPatch
   set colPlayerType [playerType] of colPatch
   ```

   `random-pxcor` finds a random x-coordinate for the patches. `patch-at` returns the patch at the coordinates specified by the two arguments that follow. This example illustrates setting a variable to have the value of a particular patch.

5. There are 6 monitors and an output window on the Interface Tab. These should have self-evident functionality.

Now, the best next step is probably to study `Setup` and understand how it works. After that, you should be able to begin designing and coding for this exercise.

Chapter 6

Diffusion and Hill Climbing

6.1 Diffusion

Use the `diffuse` command to create patches with different heights. Use

```
patches-own [height]
```

to give each patch a height. Pick one patch, say `patch 0 0`, to be the top of a hill. Set its height to some reasonably large number, say 100. Now set the `pcolor` of that patch to some extreme on the color table. See "Programming Guide" and "Colors" within it. For example height = 100 might map to 69.9, which is white. Height = 0 might map to 60, which is black, the default patch color. And heights in between to colors between would be various shades of green.

Now use `diffuse` to make neighboring patches have non-zero heights. Do all of this so it displays nicely and the hill is visually evident.

6.2 Hill Climbing

Create a turtle that is able to climb the hill you just built. See `uphill` (and `downhill`). You might also use `neighbors`.

These methods assume the agent, here a turtle, has a very short field of vision, i.e., that he can see only his immediate neighbors. Redo the procedures so that the turtle has a field of vision set by a parameter (≥ 1). Hint: Look at the documentation for `in-radius`.

Chapter 7

File I/O (Input & Output)

NetLogo has rudimentary file I/O capabilities. We'll focus here on file output, because we are primarily interested in writing data to files in a format convenient for subsequent analysis. For NetLogo documentation, see "File I/O" in the "Programming Guide," the "Files" category in the "NetLogo Dictionary," and the programs `FileOutputExample.nlogo` and `FileInputExample.nlogo` in the Code Examples folder of the Models Library.

7.1 File Output

To write data to a file, you must do three things, in order:

1. Open the file.
2. Write to the file.
3. Close the file.

You open a file in the current directory with the Netlogo command `file-open`, followed by the name of the file as a string (in quotes, if literal). See line 6 in Figure 7.1 on page 60, reproduced here:

```
file-open "data-dump-example.txt"
```

If the file you name doesn't exist, executing the `file-open` command causes an empty file to be created. If the file already exists it is opened as is, and anything you write to it will be appended, preserving what is already there.

Often, the file will exist, but you no longer want the data, you want to write new data to an empty file. In that case, you need to check whether the file exists and if so, delete it. Lines 2–4 from Figure 7.1 on page 60 show how to do this:

```
; Delete the existing file if there is one.
if (file-exists? "data-dump-example.txt")
  [file-delete "data-dump-example.txt"]
```

Now that the file is open, you can write to it. Line 7 from Figure 7.1 on page 60 shows how to do this:

```
file-print "Bob,Carol,Ted,Alice"
```

`file-print` prints strings (as here) as well as numbers and even agents, and then terminates the line, so that the next thing you output begins the next line of the file. If you don't want to start a new line, use `file-write`.

To close a file, use `file-close`. It's important to do this, if only because you can't open and opened file. Error!

7.2 Output format

Under the Tools menu in NetLogo you will find the BehaviorSpace option. It is for "parameter sweeping," that is, running a model multiple times with different parameter values, and recording data. This is a fine thing to do and we shall do it. But we'll do it without BehaviorSpace. Still, it's worth looking into.

The format for data from BehaviorSpace is idiosyncratic spreadsheet. Much better is what I'll call "R-tabular" format (after R, the statistical analysis package, `http://www.r-project.org/`, and what it likes), which I define as follows.

1. The (text) file consists of rows of one or more items (or fields), with each row having the same number of items.

2. The items are separated by a common symbol, which I shall take to be the comma, ",".

3. The first row in the file contains headers for each of the columns, that is, names for the data fields under them.

4. After the first row, all rows at data records. The records may mix data types; specifically, they may include integers, floating point numbers, and text. The text items should not have spaces in them; use a dash or underscore if you want to preserve the appearance of a space.

The NetLogo code in Figure 7.1 on page 60 produces output files in R-tabular format. Here is the top portion of one such file:

```
Bob,Carol,Ted,Alice
2,3,4,100
2,3,4,101
2,3,5,100
2,3,5,101
2,5,4,100
2,5,4,101
2,5,5,100
2,5,5,101
2,7,4,100
2,7,4,101
2,7,5,100
2,7,5,101
4,3,4,100
4,3,4,101
4,3,5,100
```

Note well: Although NetLogo has a `file-close-all` command, only one file at a time can be available for writing (or for reading). So, if you open a file, close it as soon as you are done writing. Don't rely on the `file-close-all` command.

Study Figure 7.1 on page 60 to make sure you understand how it works.

```
 1 to dump-em
 2 ; Delete the existing file if there is one.
 3 if (file-exists? "data-dump-example.txt")
 4   [file-delete "data-dump-example.txt"]
 5 ; Print the headers for the file. Assume CSV.
 6 file-open "data-dump-example.txt"
 7 file-print "Bob,Carol,Ted,Alice"
 8 file-close
 9 let firstLoopCounter 0
10 let secondLoopCounter 0
11 let thirdLoopCounter 0
12 let fourthLoopCounter 0
13 foreach [2 4 6] [
14  set firstLoopCounter ?
15  foreach [3 5 7] [
16   set secondLoopCounter ?
17   foreach [4 5] [
18    set thirdLoopCounter ?
19    foreach [100 101] [
20     set fourthLoopCounter ?
21     ; Print the records to the file. Assume CSV.
22     file-open "data-dump-example.txt"
23     file-print (word firstLoopCounter "," secondLoopCounter ","
24                      thirdLoopCounter "," fourthLoopCounter)
25     file-close
26    ] ; end of fourth loop
27   ] ; end of third loop
28  ] ; end of second loop
29 ] ; end of first loop
30 end ; end of to dump-em
```

Figure 7.1: Example procedure to write data to a file. Line numbers added. Code is from Example-data-writing.nlogo.

7.3 Exercises

7.3.1 Modify m1-symmetric-2x2-wID.nlogo to record data

Save `m1-symmetric-2x2-wID.html`, which you may find at `http://opim-sky.wharton.upenn.edu/~sok/age/nlogo/`, to a new file name and modify it to record data in R-tabular format. Specifically,

1. In the present version the program runs (after setup) using a forever button to call the `go` procedure. Add a slider for `NumberOfGenerations` and modify the program so that `go` is executed `NumberOfGenerations` times.

2. Having done this, further modify the code so that `NumRuns` replications are run with the same parameter input values.

3. Having done this, modify the code to record in a file, in R-tabular form, key output values from each run. Your file should have 20 columns, whose headers are as follows:

   `total-0s,total1s,total2s,total3s,total4s,total5s,total6s,`

   followed by

   `total7s,zero-weight,one-weight,two-weight,three-weight,`

   followed by

   `four-weight,five-weight,six-weight,seven-weight,`

   followed by

   `A-value-cc-to-row,B-value-cd-to-row,C-value-dc-to-row,`

   followed by

   `D-value-dd-to-row`

   Each subsequent row should record data for one run.

   (Notice the principle: record both the output data and the run parameters for each run. Full information)

4. Having done this add parameter sweeping by changing one parameter, setting it at three distinct levels. So, we have the starting parameter settings, which we run `NumRuns` times, then we modify the value of one parameter and run another `NumRuns` times, then we modify the parameter once more and do another `NumRuns` runs. All the while, we record the data at the end of each run.

5. Having done all this, conduct the runs, creating the output file with the data.

6. Then launch R, use the `read.table` command to load in the data, creating an R data frame. Now explore.

Chapter 8

Example: A Simple Queuing System

See: SimpleQueuingModel.nlogo. SinmpleQueuingModel.nlogo embodies a simple model of a simple queuing system. There is one server and one type of customer. The customers arrive randomly, go to the end of the line (a first-in-first-out queue). When it is their turn, they are served, for random lengths of time, by the single server.

Analytic solutions to this model have long been known. The purpose of this implementation is to illustrate basic techniques in NetLogo and to serve as a template for more complex models, which cannot be solved analytically.

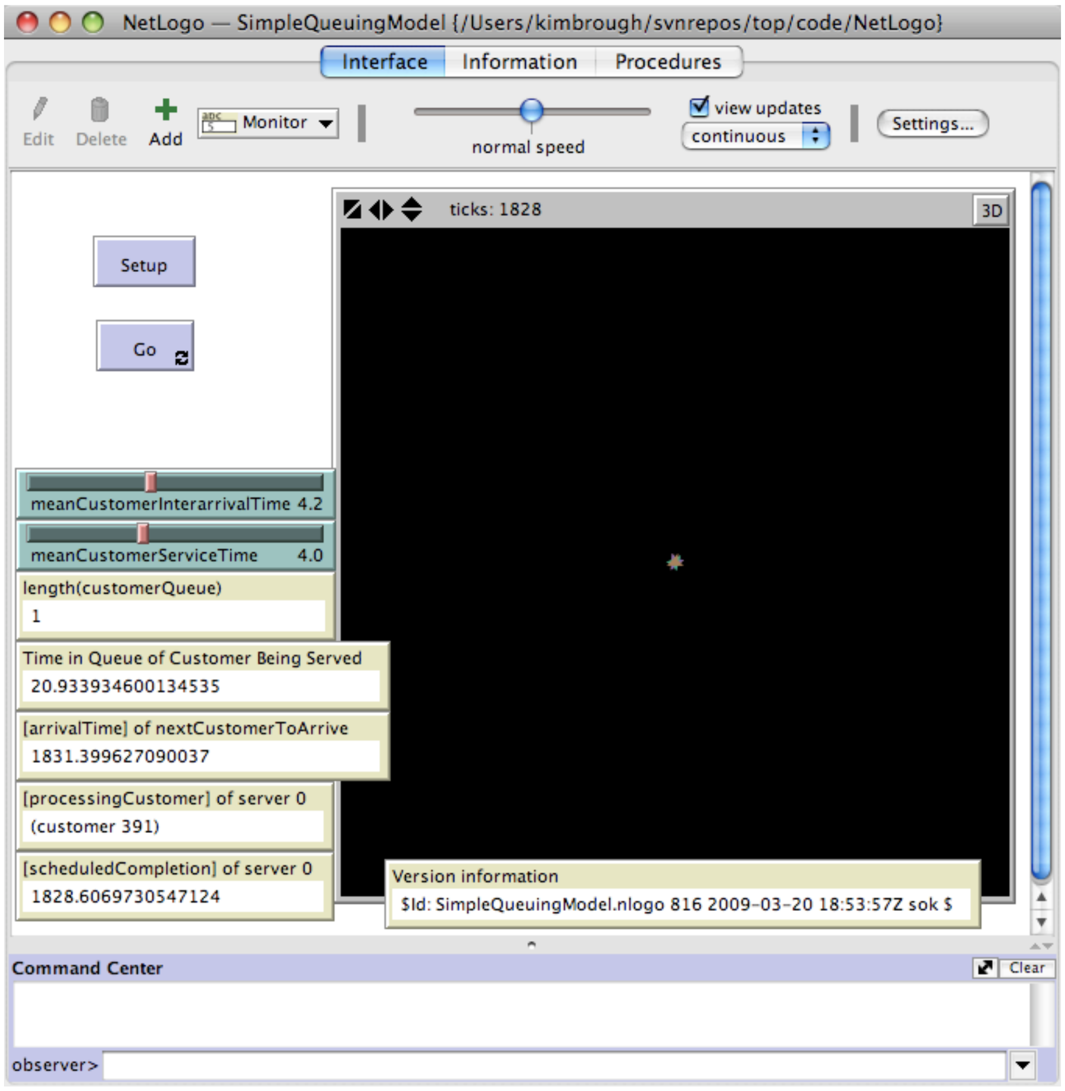
8.1 How It Works

There are two procedures: Setup and Go. Both have buttons on the Interface tab, with Go being a forever button. You initialize the system by clicking on the Setup button. You then run the system by clicking on the Go button. You stop the run by clicking on the Go button again.

0. Time proceeds discretely by ticks (of the clock; tick in NetLogo).

1. The queue is represented by a list of turtles waiting to be served. Its name in the program is customerQueue, a global variable. When a new turtle arrives it is put at the end of the queue (under a presumed first-come-first-served regime). In NetLogo

   ```
   set customerQueue lput nextCustomerToArrive customerQueue
   ```



meanCustomerInterarrivalTime 4.2

meanCustomerServiceTime 4.0

length(customerQueue)
1

Time in Queue of Customer Being Served
20.933934600134535

[arrivalTime] of nextCustomerToArrive
1831.399627090037

[processingCustomer] of server 0
(customer 391)

[scheduledCompletion] of server 0
1828.6069730547124

Version information
$Id: SimpleQueuingModel.nlogo 816 2009-03-20 18:53:57Z sok $

Figure 8.1: SimpleQueuingModel.nlogo, Interface tab

2. Turtles arrive randomly with exponential interarrival times (in this simple model). The mean of the interarrival times is set by the program variable

   ```
   meanCustomerInterarrivalTime
   ```

   which itself is set by a slider on the Interface tab.

   At initialization (in the Setup procedure), a single turtle is scheduled for arrival, but it is not put in the queue yet, because it hasn't arrived. This is because its arrival time is after 0, which is the time (tick) now, at initialization. Instead, the turtle assigned to a program variable:

   ```
   nextCustomerToArrive
   ```

3. There are two breeds of turtles: servers and customers.

   ```
   breed [servers server]
   breed [customers customer]
   ```

   The program assumes that all of the servers are created before any customer is created. (NetLogo numbers turtles consecutively, regardless of specific breed. The program uses these numbers to identify customers.)

4. Servers have three distinctive properties:

   ```
   servers-own [idle scheduledCompletion processingCustomer]
   ```

   The variable idle may be true or false; it is used to indicate whether a given (here, the only) server is busy or not. scheduledCompletion is the time at which the currently-processed customer is scheduled to be finished. processingCustomer, when not empty, actually holds a copy of the customer/turtle that the server is processing.

5. Customers have two distinctive properties:

   ```
   customers-own [arrivalTime dequeueTime]
   ```

   arrivalTime records the time of scheduled arrival to the queue, and dequeueTime is the time (in ticks) that the customer was removed from the queue and begun to be processed by the server.

6. At initialization, the customerQueue is empty:

   ```
    set customerQueue []
   ```

7. In Go,

(a) The clock is advanced: `tick`

(b) The turtle/customer assigned to nextCustomerToArrive is checked. If its arrival time is greater than now (the current value of ticks), nothing is done. If its arrival time is at for before now, then:

   i. The turtle/customer is placed at the end of the customerQueue.

   ii. The next arriving customer/turtle is created, scheduled for arrival, and assigned to nextCustomerToArrive.

(c) The server(s) is(are) checked. If a server is busy and the completion time of the job is after now, nothing is done.

   If a server is busy and the completion time of the job is at or before now, the job is terminated and the server is made idle.

   If the server is idle, and there is a job is the queue, the frontmost job is removed, the server is made busy, and the completion time of the job is scheduled (using an exponential distribution with mean

   `meanCustomerServiceTime`

   a global variable set in a slider on the Interface tab).

At this point, the end of Go, statistics, plots etc. may be updated. Monitors on the Interface tab presently handle what is done directly.

```
globals [ nextCustomerToArrive ; the who/ID of the customer that is
           ; scheduled to be the next arrival
          customerQueue ; the queue of arrived and waiting customers
           ]
; We'll have two breeds of turtles/agents:
; servers and customers.
breed [servers server]
servers-own [idle scheduledCompletion processingCustomer]
breed [customers customer]
customers-own [arrivalTime dequeueTime]
to Setup
clear-all ; For a fresh start.
; We'll have one server
create-servers 1
; Declare the server(s) to be idle
; and set the scheduled completion times
; for their jobs to -1.
; Notice that we could do without the idle
; field, but having it arguably makes things
; clearer.
ask servers [
    set idle true
    set scheduledCompletion -1
    set processingCustomer []
    ]
create-customers 1
ask customers [
    set arrivalTime random-exponential meanCustomerInterarrivaltime
    set dequeueTime -1
    ]
; Now we assign the customer, a turtle, to a program variable:
set nextCustomerToArrive customer max [who] of customers
set customerQueue []
end
```

Figure 8.2: Initialization of SimpleQueuingModel.nlogo

```
to Go
tick
if [arrivalTime] of nextCustomerToArrive <= ticks
  [set customerQueue lput nextCustomerToArrive customerQueue
   create-customers 1
   ask customer max [who] of customers
     [set arrivalTime (ticks + random-exponential
                     meanCustomerInterarrivaltime)]
   set nextCustomerToArrive customer max [who] of customers
  ]
ask servers [
  if idle = false and scheduledCompletion <= ticks
    [let toDie [who] of processingCustomer
     ask customer toDie [die]
     set idle true
     set scheduledCompletion -1
     set processingCustomer []
    ]
  ; If you are idle and there is a customer to serve,
  ; dequeue it and start processing it.
  if idle = true and length(customerQueue) > 0
    [set processingCustomer first customerQueue
     set customerQueue but-first customerQueue
     set scheduledCompletion (ticks + random-exponential
              meanCustomerServiceTime)
     set idle false
     set [deQueueTime] of processingCustomer ticks
     ]
]
end
```

Figure 8.3: Go procedure of SimpleQueuingModel.nlogo

Chapter 9

Doing Experiments

It is appropriate to think of an ABM, or indeed any computational model, as calculating one or more functions. Given a setting of the parameters, or more generally a configuration of the model, the model is executed and produces results. We may—indeed should—think of the configuration of the model as fixing predictor (exogenous) variables and the results produced as response (exogenous) variables. The function computed is from the predictor variables to the response variables. To understand or investigate the computational model is to understand or investigate this function.

At bottom, we investigate a computational model because we want to describe it partially or in summary form, because we find this valuable. We summarize the model with certain findings of interest or with a simpler model, for example a low-order polynomial model, as would be generated by a regression study.

Directly or indirectly we are presented with a number of issues associated with any attempt to understand or investigate a computational model.

1. **Model setup**. Setting up, possibly reprogramming, the computational model so that it can be run in a way that collects the data we wish to have.

2. **Variable construction**. Constructing, arranging to generate, the appropriate response variables.

3. **Response point estimation**. Estimating the response variables for a given configuration. Every ABM (or very nearly so) is a stochastic computational model, so its outputs, the particular realizations of its response variables, will vary from run to run. The results from any single run are not likely to be credible unless supported by adequate

replication. Experimentation is about doing the replications and interpreting them. That is the main subject of this chapter.

4. **Response surface estimation**. Estimating the response of the response variables to changes in the model's configuration. The problem of response point estimation is compounded by the fact that we are normally interested understanding the response variables

5. **Response discovery**. Searching for predictor settings that will generate a response of a particular sort. For example, in seeking to optimize a function, we see to find settings of the decision (predictor; exogenous) variables that maximize (or minimize) a specified response variable. Response discovery is central to the use of models for decision making and design.

In this chapter I aim to illustrate the *basics* of, the first steps in, experimental investigation of computational models. There is very much more to the subject. Here we have only a beginning, but a useful one.

In addressing the issues, above, I shall work with a single example in this chapter, the SimpleQueuingModel.nlogo, discussed in the previous chapter. Readers should first be familiar with it. Here, we shall work with a descendant of that model, called SimpleQueuingModelExp.nlogo.

9.1 Model Setup

SimpleQueuingModel.nlogo is typical of NetLogo models in having `Setup` and `Go` command procedures, run by buttons on the Interface tab, with `Go` being run as a forever button. There are two initial problems with how SimpleQueuingModel.nlogo is written (and with how other NetLogo models are typically written).

First, the `Go` command procedure should be run not forever but until a specified stopping condition is met. We solve this problem by using a slider on the Interface tab to define the program variable `maxTicks`. So in all we do this:

1. Convert the Go button by unchecking the forever option.

2. Add a slider to the Interface tab to introduce the new program variable `maxTicks`.

3. Modify the `Go` command procedure. Formerly it began

```
to Go
tick
```

Now it begins

```
to Go
while [ticks < maxTicks]
[
tick
```

and ends with an added `]` to match the one added in line 3 of the procedure. The former code is completely encompassed within the body of this added while-loop.

Finally, we need to take care to clear or reset all of the *appropriate* variables in `globals`. When we do this, `Setup` now begins as follows:

```
to Setup
clear-all-except-globals ; For a fresh start.
; Now clear the globals we need cleared:
set nextCustomerToArrive nobody
set customerQueue []
```

There is a third variable in `globals`, `daVersion`, which we do not need to reset here. This solves our first problem.

Our second problem is that the `Setup` command procedure contains, indeed begins with, the command `clear-all`, which (from the NetLogo manual)

> Resets all global variables to zero, and calls reset-ticks, clear-turtles, clear-patches, clear-drawing, clear-all-plots, and clear-output.

We want to do this *sort* of thing because we want a fresh start with every run. If we didn't do it then, for example, we might begin a run with unwanted stuff left over from the previous run. The problem with keeping `clear-all` in `Setup` is that we want to do multiple runs and store the results. How may runs? Where do the results go? This information is stored in program variables which would be wiped out if we called `clear-all` for each new run.

The solution to this problem is to eliminate the use of `clear-all` in `Setup`, but clear everything *except* the global variables at the start of `Setup`. To do that, we write a new command procedure, called `clear-all-except-globals`, and substitute it for `clear-all` in `Setup`. Here it is.

```
to clear-all-except-globals
  reset-ticks
  clear-turtles
  clear-patches
  clear-drawing
  clear-all-plots
  clear-output
end
```

This doesn't quite give us the capability of doing multiple runs and recording the data, but we're getting close. We need a master setup procedure. It will call `Setup` and `Go` for us and won't forget why. Here's a first version of `MasterSetup`, after declaring `endingNumInQueue` in `globals`. We'll call it `MasterSetup #1`.

MasterSetup #1

```
to MasterSetup
  ; MasterSetup #1
  clear-all
  let endingNumInQueue []
  foreach n-values numRunsToRun [?]
    [set currentRunNumber ?
     Setup
     Go
     set endingNumInQueue
        lput length(customerQueue) endingNumInQueue
    ]
  print (word "Mean=" mean(endingNumInQueue) ". "
         "Variance=" variance(endingNumInQueue) ". Full list:"
         endingNumInQueue ".")
  print "All done."
end
```

And so our second problem is solved, at least tentatively.

9.2 Variable construction

We engaged in response variable construction in creating `MasterSetup #1`. The response variables were the number in the queue at the end of the run (`endingNumInQueue`), plus its mean and variance. Other variables are possible and there is reason not to construct several if we want to. It's our system and we can assess it with as many measures of performance (MOP's) as we find useful. The program already displays the length of the customer queue and the time in queue of the customer being served.

Comparing running averages, say of the last 100 customers, is a way to smooth the data and arguably affords better comparison. However, for the sake of simplicity, I'll stick here to non-averaged data and use lots of replications.

9.3 Response Point Estimation

The system as it is affords experimentation. Here is the output from a trial consisting of 100 runs in which the maximum number of ticks was 100. The mean of the customer interarrival times was 4.0, while the mean of the customer service times was 4.4, so customers are arriving on average faster than they are being processed.

```
Mean=4.35. Variance=14.512626262626256. Full list:[
7 13 0 0 0 0 0 8 0 5 12 11 8 4 2 4 3 5 2 7 4 6 5 7 2 0 3 6 0
13 2 0 3 8 0 1 16 1 3 11 6 7 12 0 0 8 4 0 7 8 3 8 4 1 8 5 6
0 11 0 2 2 1 6 2 7 3 4 1 4 0 8 1 8 6 3 9 8 0 5 0 0 3 7 2 0 3
2 5 7 14 3 5 2 3 0 9 6 3 1].
All done.
```

We see that the queue lengths are not unduly long. What happens if we run for more ticks? Here are the results when `maxTicks` = 1,000.

```
Mean=21.9. Variance=190.01010101010093. Full list:[
45 8 34 28 19 6 15 14 20 48 15 19 5 24 12 0 52 21 21 1 0
12 20 53 26 1 61 9 34 57 30 14 22 33 39 34 23 12 20 5 15
11 32 23 19 29 20 27 31 5 7 16 22 12 55 35 39 10 28 17 5
2 30 0 25 26 29 12 5 12 32 28 30 10 17 12 14 48 24 28 1
24 22 17 33 29 22 17 33 17 16 46 32 13 9 22 39 3 28 13].
All done.
```

And here 10,000:

```
Mean=185.69. Variance=2826.923131313131. Full list:[
145 210 201 219 175 189 177 224 115 189 210 216 57
104 126 109 169 274 322 234 211 103 181 150 186 180
199 186 128 199 122 139 170 150 201 164 211 267 170
191 295 167 182 212 303 174 196 176 192 232 195 139
293 184 231 170 199 94 131 266 127 197 265 185 168
208 201 188 146 138 150 290 186 286 90 190 154 244
150 191 151 176 152 81 187 116 214 98 182 283 169
110 147 169 221 221 194 287 191 262].
All done.
```

With these settings it is evident that the queue length will grow without limit unless the system is stopped. What is perhaps most interesting is how long it takes, how many customer arrivals it takes, starting from an empty system (Good morning!) to have intolerable degradation of service. This is something that simulation is well suited to investigate.

As we extend and deepening our investigations, however, it makes sense to write the data to files, and then explore the data with a good statistical analysis package, such as R, our tool of choice. To do that we begin with version #2 of `MasterSetup`.

`MasterSetup #2`

```
to MasterSetup
  ; MasterSetup #2
  clear-all
  ; Delete the existing output file, if it exists.
  if file-exists? "runsOutput.txt"
    [file-delete "runsOutput.txt"]
  ; Print the data column headers to the output file,
  ; separated by commas.
  file-open "runsOutput.txt"
  file-print (word "runNumber,meanCustomerInterarrivalTime,"
    "meanCustomerServiceTime,maxTicks,numInQueueAtEnd")
  file-close
  foreach n-values numRunsToRun [?]
    [set currentRunNumber ?
     Setup
     Go
     file-open "runsOutput.txt"
     file-print (word currentRunNumber "," meanCustomerInterarrivalTime ","
       meanCustomerServiceTime "," maxTicks "," length(customerQueue))
     file-close
    ]
  print "All done."
end
```

Here is what the top of the resulting file, runsOutput.txt, characteristically looks like. We have a *comma-separated values* or csv file, in which each column of data is headed by the variable's name and each row (after the first) is a distinct data record. Let's call this the *headed csv format*.

headed csv format

```
runNumber,meanCustomerInterarrivalTime,meanCustomerServiceTime,
maxTicks,numInQueueAtEnd
0,4,4.4,10000,163
1,4,4.4,10000,286
2,4,4.4,10000,135
3,4,4.4,10000,83
4,4,4.4,10000,225
5,4,4.4,10000,191
```

Now, into R. R likes data files in headed csv format (and so do all statistical packages, as well as spreadsheets). At the R prompt we navigate to the directory of our output file. On my machine:

`getwd()` is also helpful. Type `help(getwd)` for help.

```
> dir()
 [1] "BibDesk.app" "Desktop"     "Documents"   "Downloads"
 [5] "Library"     "Movies"      "Music"       "Pictures"
 [9] "Public"      "Sites"       "diary"       "fos"
[13] "hellobob.py" "skycvs"      "svnrepos"    "yobob.bash"
> setwd('svnrepos/top/code/NetLogo/')
> dir()
 [1] "March1.nlogo"
 [2] "MarriageMatching-1.nlogo"
 [3] "MarriageMatching-1a.nlogo"
 [4] "MarriageMatching-1b.nlogo"
 [5] "NetLogoLite.jar"
 [6] "ReplicatorDynamicsWithBalking.html"
 [7] "ReplicatorDynamicsWithBalking.nlogo"
 [8] "SimpleMarriageMatching.nlogo"
 [9] "SimpleQueuingModel.nlogo"
[10] "SimpleQueuingModelExp.nlogo"
[11] "VectorMatchSelection.nlogo"
[12] "runsOutput.txt"
[13] "templateElectricityBidPrices.nlogo"
```

Now we read the file as a table into our R variable, `bob`, which becomes an R *dataframe,* and then we ask for a summary of the data table resulting.

```
> bob <- read.table('runsOutput.txt',header=T,sep=",")
> summary(bob)
   runNumber     meanCustomerInterarrivalTime meanCustomerServiceTime
 Min.   : 0.00   Min.   :4                    Min.   :4.4
 1st Qu.:24.75   1st Qu.:4                    1st Qu.:4.4
 Median :49.50   Median :4                    Median :4.4
 Mean   :49.50   Mean   :4                    Mean   :4.4
 3rd Qu.:74.25   3rd Qu.:4                    3rd Qu.:4.4
 Max.   :99.00   Max.   :4                    Max.   :4.4
    maxTicks     numInQueueAtEnd
 Min.   :10000   Min.   : 73.0
 1st Qu.:10000   1st Qu.:146.8
 Median :10000   Median :186.5
 Mean   :10000   Mean   :186.1
 3rd Qu.:10000   3rd Qu.:226.2
 Max.   :10000   Max.   :316.0
```

Here, only the last column is interesting. We can ask for it explicitly:

```
> summary(bob$numInQueueAtEnd)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   73.0   146.8   186.5   186.1   226.2   316.0
```

OK, now let's repeat the experiment with only 20,000 ticks, instead of 10,000.

```
> carol <- read.table('runsOutput.txt',header=T,sep=",")
> summary(carol$numInQueueAtEnd)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  199.0   316.5   355.0   357.5   401.8   645.0
> summary(carol)
   runNumber     meanCustomerInterarrivalTime meanCustomerServiceTime
 Min.   : 0.00   Min.   :4                    Min.   :4.4
 1st Qu.:24.75   1st Qu.:4                    1st Qu.:4.4
 Median :49.50   Median :4                    Median :4.4
 Mean   :49.50   Mean   :4                    Mean   :4.4
 3rd Qu.:74.25   3rd Qu.:4                    3rd Qu.:4.4
 Max.   :99.00   Max.   :4                    Max.   :4.4
    maxTicks     numInQueueAtEnd
 Min.   :20000   Min.   :199.0
 1st Qu.:20000   1st Qu.:316.5
 Median :20000   Median :355.0
 Mean   :20000   Mean   :357.5
 3rd Qu.:20000   3rd Qu.:401.8
 Max.   :20000   Max.   :645.0
```

As we can see, the queue is lengthening, the server is falling farther and farther behind. Of course, we can do statistical tests. We'll use Wilcoxon's signed-rank test, which is non-parametric and does not require any assumption of a normal distribution. (See `help(wilcox.test)`.)

```
> wilcox.test(bob$numInQueueAtEnd,carol$numInQueueAtEnd)

Wilcoxon rank sum test with continuity correction

data:  bob$numInQueueAtEnd and carol$numInQueueAtEnd
W = 256, p-value < 2.2e-16
alternative hypothesis: true location shift is not equal to 0
```

We feel very safe in rejecting the null hypothesis that the means of these two data sets are identical. And we can see it even better with

```
> boxplot(bob$numInQueueAtEnd,carol$numInQueueAtEnd)
```

See Figure 9.1 for the results.

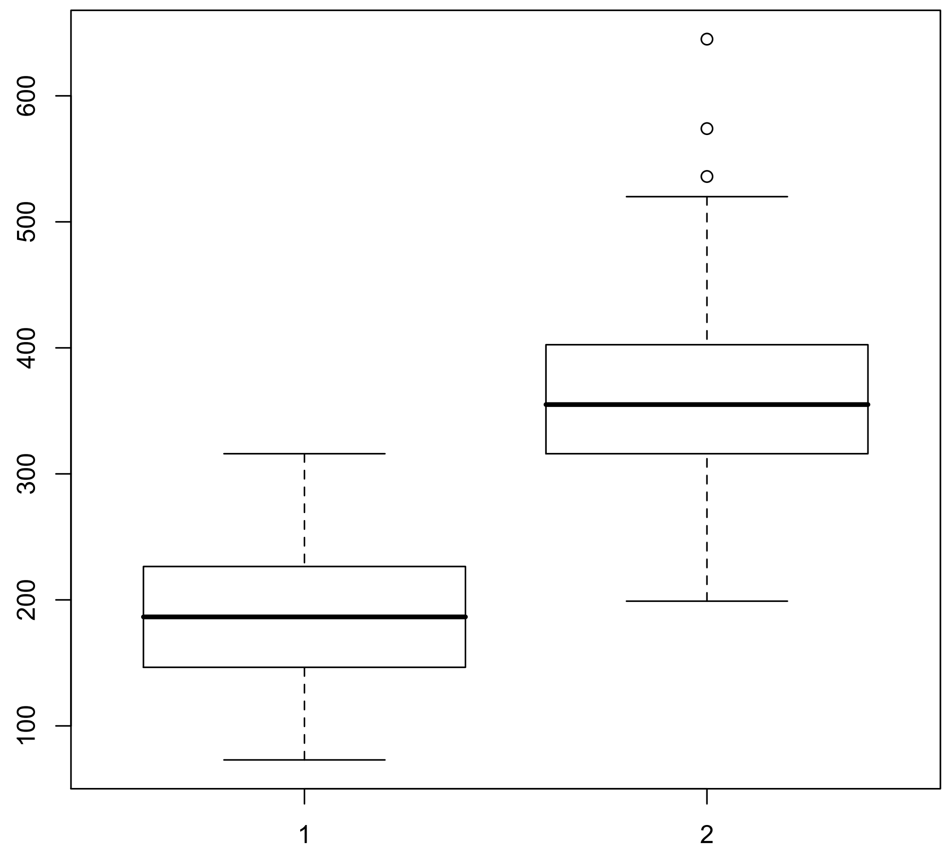


Figure 9.1: Box plots of queue lengths. 1) 10,000 ticks. 2) 20,000 ticks.

9.4 Response Surface Estimation

So far we've had one setting of the predictor variables per data file, with multiple runs in order to estimate a response variable. This is all well and good, and it can take us far. R's `summary` command (see above) is in fact very useful and can often settle issues to hand.

But we want more. In particular it is very often important to understand the joint effects of several predictor (exogenous) variables on a response variable. So first we have to get the data, generate it and write it to a file, then we need to analyze it. We'll start with what needs to be done first. To do that we begin with version #3 of `MasterSetup`. `MasterSetup #3`

With `maxTicks` = 1000 and `numRunsToRun`=100, we get 900 data records. As usual, `summary` is helpful, although not very on the overall data:

```
> ted <- read.table("runsOutput.txt",header=T,sep=",")
> summary(ted)
   runNumber     meanCustomerInterarrivalTime meanCustomerServiceTime
 Min.   :  1.0   Min.   :4                    Min.   :4
 1st Qu.:225.8   1st Qu.:4                    1st Qu.:4
 Median :450.5   Median :5                    Median :5
 Mean   :450.5   Mean   :5                    Mean   :5
 3rd Qu.:675.2   3rd Qu.:6                    3rd Qu.:6
 Max.   :900.0   Max.   :6                    Max.   :6
    maxTicks    numInQueueAtEnd
 Min.   :1000   Min.   :  0.00
 1st Qu.:1000   1st Qu.:  2.00
 Median :1000   Median : 10.50
 Mean   :1000   Mean   : 21.06
 3rd Qu.:1000   3rd Qu.: 36.00
 Max.   :1000   Max.   :116.00
```

We need to simplify. Our first and fourth columns contain data we do not need for the present, so we extract the needed columns into `a`:

```
 > a <- ted[,c(2,3,5)]
> summary(a)
 meanCustomerInterarrivalTime meanCustomerServiceTime numInQueueAtEnd
 Min.   :4                    Min.   :4               Min.   :  0.00
 1st Qu.:4                    1st Qu.:4               1st Qu.:  2.00
 Median :5                    Median :5               Median : 10.50
```

```
to MasterSetup
  ; MasterSetup #3
  clear-all
  set currentRunNumber 0
  ; Delete the existing output file, if it exists.
  if file-exists? "runsOutput.txt"
    [file-delete "runsOutput.txt"]
  ; Print the data column headers to the output file,
  ; separated by commas.
  file-open "runsOutput.txt"
  file-print (word "runNumber,meanCustomerInterarrivalTime,"
    "meanCustomerServiceTime,maxTicks,numInQueueAtEnd")
  file-close
  foreach [4.0 5.0 6.0]
   [set meanCustomerInterarrivalTime ?
    foreach [4.0 5.0 6.0]
    [set meanCustomerServiceTime ?
     foreach n-values numRunsToRun [?]
       [set currentRunNumber (currentRunNumber + 1)
        Setup
        Go
        file-open "runsOutput.txt"
        file-print (word currentRunNumber ","
              meanCustomerInterarrivalTime ","
          meanCustomerServiceTime "," maxTicks ","
              length(customerQueue))
        file-close
    ] ; end of foreach n-values numRunsToRun [?]
    ] ; end of the second foreach
    ] ; end of the first (the outer-most) foreach
  print "All done."
end
```

Figure 9.2: MasterSetup #3. Nested `for` loops for a factorial data collection.

```
 Mean   :5                     Mean   :5                Mean   : 21.06
 3rd Qu.:6                     3rd Qu.:6                3rd Qu.: 36.00
 Max.   :6                     Max.   :6                Max.   :116.00
```

Let us further restrict our attention to those records for which the `meanCustomerServiceTime` is 6.0.

```
> b <- a[a$meanCustomerServiceTime == 6,]
> summary(b)
 meanCustomerInterarrivalTime meanCustomerServiceTime numInQueueAtEnd
 Min.   :4                     Min.   :6                Min.   :  0.0
 1st Qu.:4                     1st Qu.:6                1st Qu.: 13.0
 Median :5                     Median :6                Median : 30.0
 Mean   :5                     Mean   :6                Mean   : 37.4
 3rd Qu.:6                     3rd Qu.:6                3rd Qu.: 60.0
 Max.   :6                     Max.   :6                Max.   :116.0
```

Now let's look at the mean of `numInQueueAtEnd` when `meanCustomerInterarrivalTime` is 4, 5, and 6:

```
> mean(b[b$meanCustomerInterarrivalTime == 4,3])
[1] 69.6
> mean(b[b$meanCustomerInterarrivalTime == 5,3])
[1] 32.25
> mean(b[b$meanCustomerInterarrivalTime == 6,3])
[1] 10.34
```

And what do we find when the arrival rates are lower than the service rates? Back to `a`, doing it only slightly differently.

```
> mean(a[a$meanCustomerInterarrivalTime == 4 & a$meanCustomerServiceTime == 4,3])
[1] 12.81
> mean(a[a$meanCustomerInterarrivalTime == 5 & a$meanCustomerServiceTime == 4,3])
[1] 3.19
> mean(a[a$meanCustomerInterarrivalTime == 6 & a$meanCustomerServiceTime == 4,3])
[1] 1.23
```

Well, there are much fancier things to do and more elegant ways of looking at this, but for starters I can only commend the KISS principle. (The obvious thing is to write a program to handle this sort of thing and indeed that can be done, but it's beyond the scope of these introductory notes.)

And here, FYI, is how we can do linear regression—

```
> tedregressed <- lm(numInQueueAtEnd ~
meanCustomerInterarrivalTime*meanCustomerServiceTime,data=ted)
> summary(tedregressed)

Call:
lm(formula = numInQueueAtEnd ~ meanCustomerInterarrivalTime *
    meanCustomerServiceTime, data = ted)

Residuals:
    Min      1Q  Median      3Q     Max
-48.437  -5.943  -0.280   5.507  50.310

Coefficients:
                                                      Estimate
(Intercept)                                          -262.9100
meanCustomerInterarrivalTime                           40.9667
meanCustomerServiceTime                                75.4267
meanCustomerInterarrivalTime:meanCustomerServiceTime  -11.9200
                                                     Std. Error t value
(Intercept)                                             15.6866  -16.76
meanCustomerInterarrivalTime                             3.0963   13.23
meanCustomerServiceTime                                  3.0963   24.36
meanCustomerInterarrivalTime:meanCustomerServiceTime     0.6112  -19.50
                                                     Pr(>|t|)
(Intercept)                                            <2e-16 ***
meanCustomerInterarrivalTime                           <2e-16 ***
meanCustomerServiceTime                                <2e-16 ***
meanCustomerInterarrivalTime:meanCustomerServiceTime   <2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1

Residual standard error: 12.22 on 896 degrees of freedom
Multiple R-squared: 0.7563,Adjusted R-squared: 0.7555
F-statistic: 926.9 on 3 and 896 DF,  p-value: < 2.2e-16
```

—which I think is not very helpful in this case.

Average of numInQueueAtEnd	meanCustomerServiceTime			
meanCustomerInterarrivalTime	4	5	6	Grand Total
4	14.4	43.71	71.65	43.25333333
5	2.98	11.25	31.39	15.20666667
6	1.08	3.14	10.11	4.776666667
Grand Total	6.153	19.366	37.716	21.079

Figure 9.3: Excel PivotTable report; data generated from `MasterSetup #3`

9.4.1 Cross-tabulation and PivotTables

Cross-tabulation is probably the most useful technique with factorial data, such as are produced by `MasterSetup #3`. It is, at the least, something to try early on in your analysis. Figure 9.3 shows a PivotTable report generated from data produced from `MasterSetup #3`. To generate this report, and similar reports, in Excel:

`MasterSetup #3`

1. Generate data, as in `runsOutput.txt` produced by `MasterSetup #3`.
2. In Excel, choose Data | Get External Data | Import Text File . . . , and import the file.
3. In Excel, choose Date | PivotTable Report . . . .
4. Run the Wizard and complete building the PivotTable.

Here is a nice, slightly dated, tutorial on PivotTables in Excel: `http://www.microsoft.com/dynamics/using/excel_pivot_tables_collins.mspx`

What Microsoft Excel calls a *PivotTable report* the rest of the world calls a *cross-tabulation* or *crosstab* (report). R has two built-in functions for this, `table` and `xtabs`.

9.5 Response Discovery

Just a word. This is a much larger topic and a difficult one. In a nutshell, this is a kind of optimization problem: define an outcome region of interest, then select decision variables in order to minimize the difference between the response variable and the outcome region of interest.

9.6 Back to the Code

We'll now take a look at version #4 of `MasterSetup`. Having seen something

`MasterSetup #4`

of the difficulties above, we'll do more in the code by way of collecting statistics.

Here's our example. Let's fix `meanCustomerServiceTime` at say 5.0. Then let's vary `meanCustomerInterarrivalTime` from say 2.0 to 8.0 in increments of 0.1. For each setting of `meanCustomerInterarrivalTime` let us estimate with 100 replications the value of `numInQueueAtEnd` when ending at 1,000 ticks. Here goes.

```
to MasterSetup
  ; MasterSetup #4
  clear-all
  ;set meanLengthOfQueueAtEndList []
  set currentRunNumber 0
  let holdingList []
  ; Delete the existing output file, if it exists.
  if file-exists? "runsOutput.txt"
    [file-delete "runsOutput.txt"]
  ; Print the data column headers to the output file,
  ; separated by commas.
  file-open "runsOutput.txt"
  file-print (word "meanLengthOfQueueAtEnd")
  set meanCustomerServiceTime 5.0
  foreach [2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9
           3.0 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9
           4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9
           5.0 5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 5.9
           6.0 6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9
           7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9
           8.0]
   [set meanCustomerInterarrivalTime ?
    set holdingList []
     foreach n-values numRunsToRun [?]
       [set currentRunNumber (currentRunNumber + 1)
        Setup
        Go
        set holdingList lput length(customerQueue) holdingList
    ] ; end of foreach n-values numRunsToRun [?]
    file-print mean(holdingList)
    ] ; end of the first (the outer-most) foreach
  file-close
  print "All done."
end
```

Now in R we do this

```
> alice <- read.table("runsOutput.txt",header=T,sep=",")
> summary(alice)
 meanLengthOfQueueAtEnd
 Min.   :  0.77
 1st Qu.:  2.49
 Median : 13.17
 Mean   : 44.16
 3rd Qu.: 73.79
 Max.   :212.55
> plot(alice$meanLengthOfQueueAtEnd)
```

and Figure 9.4 results.

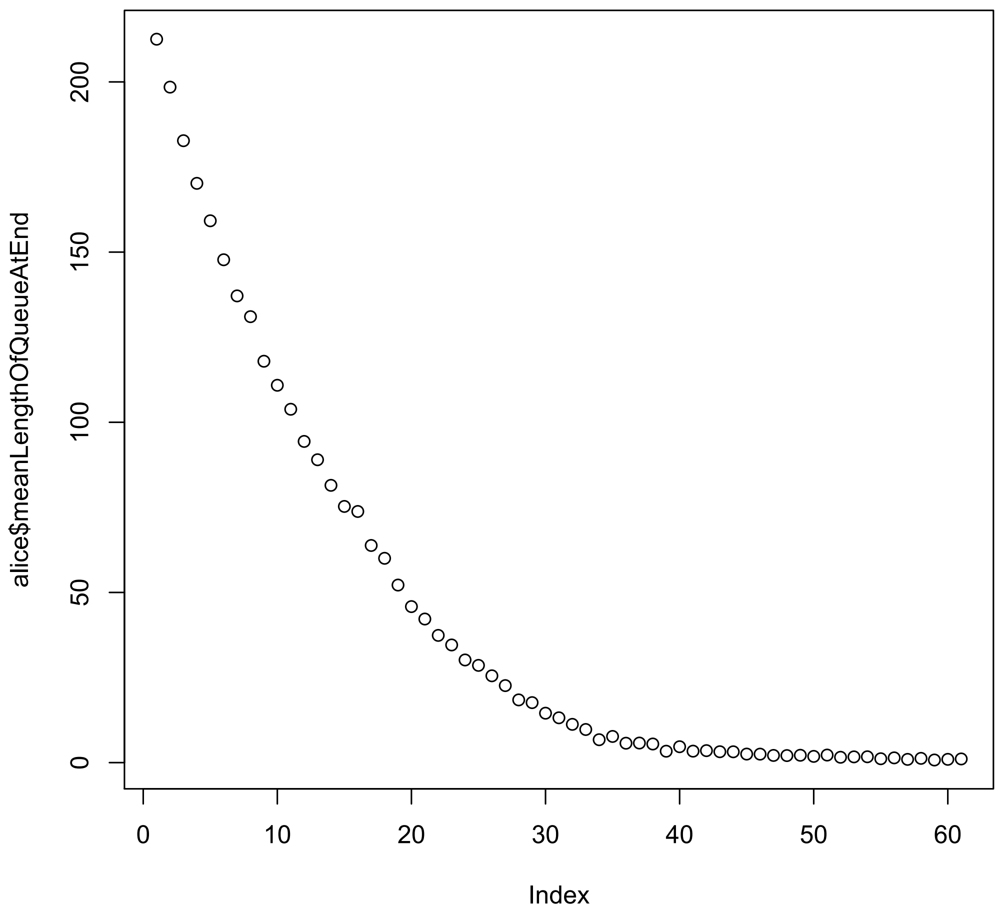


Figure 9.4: Queue length increases rapidly at 1000 ticks when arrival rate exceeds service rate

`$Id: doing-experiments.tex 3684 2013-09-09 20:37:28Z sok $`

Chapter 10

How To's

10.1 Collect Agents in a Neighborhood

`neighbors` and `neighbors4` return AgentSets of turtles on the immediately-adjacent patches. With `in-radius` we can collect (now in a list, not an AgentSet) the turtles (breeds) within a given radius from the calling turtle.

See MatingGame.nlogo.

```
to-report ListNeighboringBreed[daBreed daRadius]
  let toReturn []
  ask daBreed in-radius daRadius [set toReturn fput who toReturn]
  report toReturn
end
```

See also `in-cone`.

But, but, but . . .

The above reporter produces a list of neighbors. Generally better is to have an AgentSet. Here's how:

```
let myNeighbors daBreed in-radius daRadius
```

Simple and elegant! That's how to do it.

Both approaches assume that they are being called by some turtle.

10.2 Breeds Other than Me

See MatingGame.nlogo. `XXs` and `XYs` are declared as breeds.

```
to-report OppositeGender[MyBreed]
  let toReturn XXs
  if MyBreed = XYs [set toReturn XXs]
  if MyBreed = XXs [set toReturn XYs]
  report toReturn
end
```

Chapter 11

Development Notes

Creates a list and assigns it to bob.

```
let bob read-from-string (word "[" "1 2 3" "]")
print length bob
```

Bibliography

[Railsback and Grimm, 2012] Railsback, S. F. and Grimm, V. (2012). *Agent-Based and Individual-Based Modeling.* Princeton University Press, Princeton, NJ.

Index