Tutorial #3: Procedures

This tutorial leads you through the process of building a complete model, built up in stages, with every step explained along the way.

Agents and procedures

In Tutorial #2, you learned how to use the command center and agent monitors to inspect and modify agents and make them do things. Now you're ready to learn about the real heart of a NetLogo model: the Code tab.

You've seen that agents in NetLogo are divided into patches, turtles, links, and the observer. Patches are stationary and arranged in a grid. Turtles move over that grid. Links connect two turtles. The observer oversees everything that's going on and does whatever the turtles, patches and links can't do for themselves.

All four types of agents can run NetLogo commands. All four can also run "procedures". A procedure combines a series of NetLogo commands into a single new command that you define.

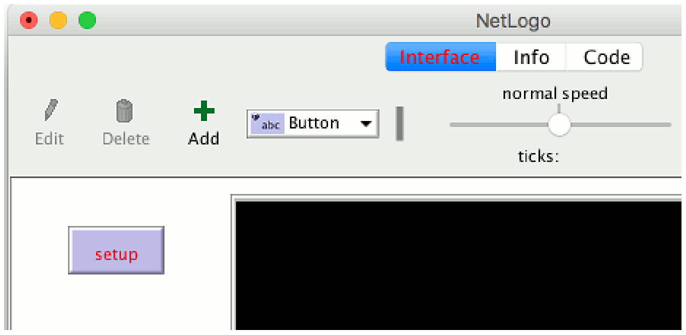
You will now learn to write procedures that make turtles move, eat, reproduce, and die. You will also learn how to make monitors, sliders, and plots. The model we'll build is a simple ecosystem model not unlike Wolf Sheep Predation from Tutorial #1.

Making the setup button

To start a new model, select "New" from the File menu. Then begin by creating a setup button:

- Click the "Add" icon in the toolbar at the top of the Interface tab.
- On the menu next to Add, select Button (if it isn't already selected).
- Click wherever you want the button to appear in the empty white area of the Interface tab.
- A dialog box for editing the button opens. Type `setup` in the box labeled "Commands".
- Press the OK button when you're done; the dialog box closes.

Now you have a setup button. Pressing the button runs a procedure called "setup". A procedure is a sequence of NetLogo commands that we assign a new name. We'll define that procedure soon, but we haven't yet. The button refers to a procedure that doesn't exist, so the button turns red:



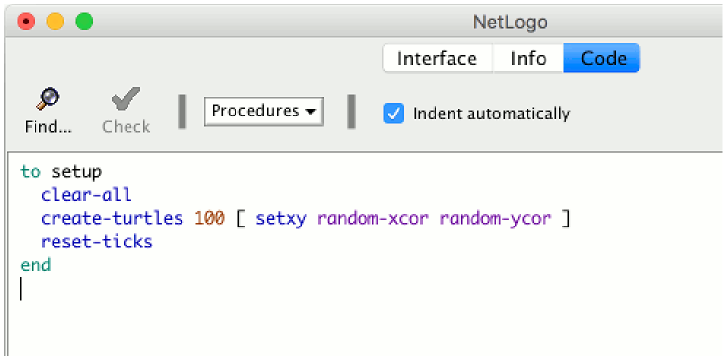
If you want to see the actual error message, click the button.

Now we'll create the "setup" procedure, so the error message will go away:

- Switch to the Code tab.
- Type the following:

```
to setup
  clear-all
  create-turtles 100 [ setxy random-xcor random-ycor ]
  reset-ticks
end
```

When you're done, the Code tab looks like this:



```
to setup
  clear-all
  create-turtles 100 [ setxy random-xcor random-ycor ]
  reset-ticks
end
```

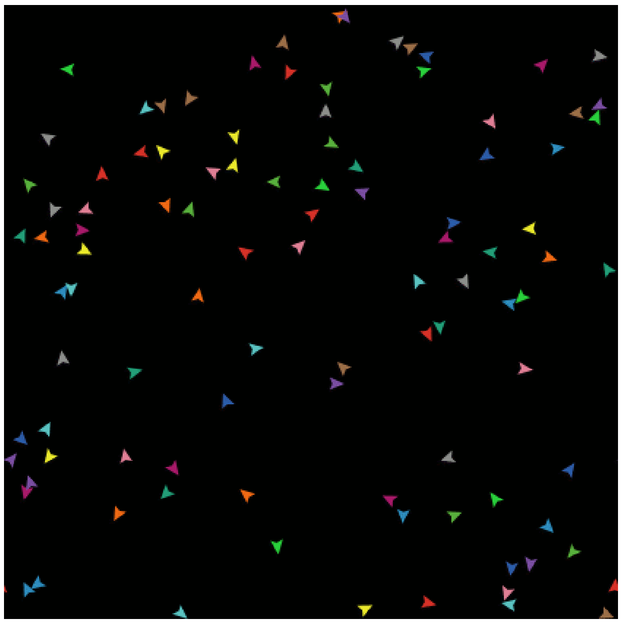
Note that some lines are indented. Most people find it helpful to indent their code. It isn't mandatory, but it makes the code easier to read and change.

Your procedure begins with `to` and ends with `end`. Every procedure begins and ends with these words.

Let's look at what you typed in and see what each line of your procedure does:

- `to setup` begins defining a procedure named "setup".
- `clear-all` resets the world to an initial, empty state. All the patches turn black and any turtles you might have created disappear. Basically, it wipes the slate clean for a new model run.
- `create-turtles 100` creates 100 turtles. They start out standing at the origin, that is, the center of patch 0,0.
- After `create-turtles` we can put commands for the new turtles to run, enclosed by square brackets.
- `setxy random-xcor random-ycor` is a command using "reporters". A reporter, as opposed to a command, reports a result. First each turtle runs the reporter `random-xcor` which will report a random number from the allowable range of turtle coordinates along the X axis. Then each turtle runs the reporter `random-ycor`, same for the Y axis. Finally each turtle runs the `setxy` command with those two numbers as inputs. That makes the turtle move to the point with those coordinates.
- `reset-ticks` starts the tick counter, now that setup is otherwise complete.
- `end` completes the definition of the "setup" procedure.

When you're done typing, switch to the Interface tab and press the setup button you made before. You will see the turtles scattered around the world:



Press setup a couple more times, and see how the arrangement of turtles is different each time. Note that some turtles may be right on top of each other.

Think a bit about what you needed to do to make this happen. You needed to make a button in the interface and make a procedure that the button uses. The button only worked once you completed both of these separate steps. In the remainder of this tutorial, you will often have to complete two or more similar steps to add another feature to the model. If something doesn't appear to work after you completed what you thought is the final step for that new feature, continue to read ahead to see if there is still more to do. After reading ahead for a couple of paragraphs, you should then go back over the directions to see if there is any step you might have missed.

Switching to tick-based view updates

Now that we're using the tick counter (with `reset-ticks`), we should tell NetLogo that it only needs to update the view once per tick, instead of continuously updating it.

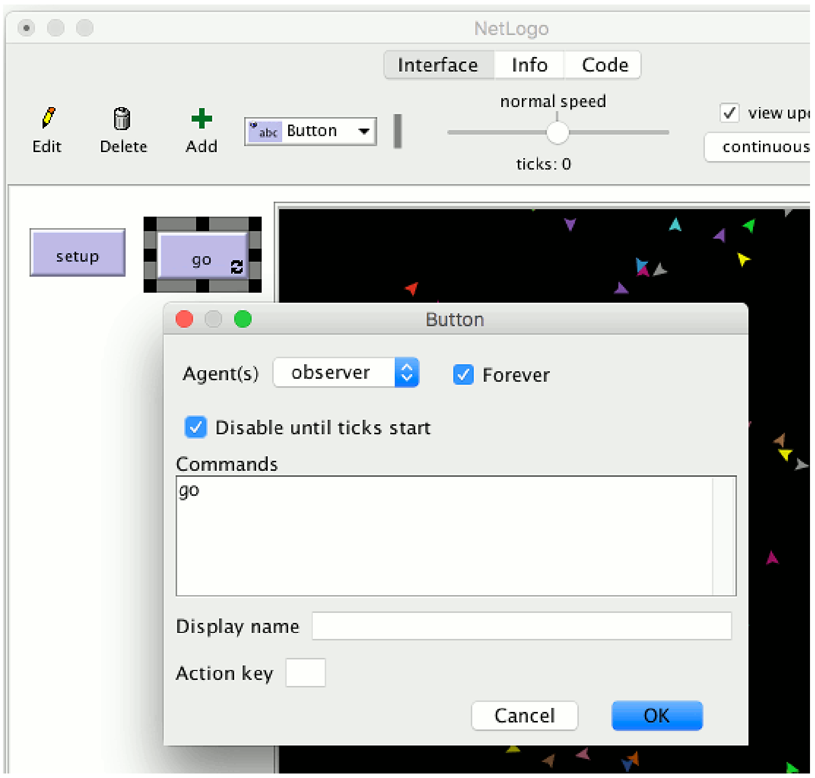
- Find the view updates menu. It's above the view and by default says "continuous".
- Choose "on ticks" instead.

This makes your model run faster and ensures a consistent appearance (since the updates will happen at consistent times). See the Programming Guide for a fuller discussion of view updates.

Making the go button

Now make a button called "go". Follow the same steps you used to make the setup button, except:

- For Commands enter `go` instead of `setup`.
- Check the "Forever" checkbox in the edit dialog.
- Check the "Disable until ticks start" checkbox too.



Agent(s) observer ✓ Forever

✓ Disable until ticks start

Commands

go

Display name

Action key

The "Forever" checkbox makes the button stay down once pressed, so its commands run over and over again, not just once.

The "Disable until ticks start" prevents you from pressing go before setup.

- Then add a go procedure to the Code tab:

```
to go
  move-turtles
  tick
end
```

`tick` is a primitive that advances the tick counter by one tick.

But what is `move-turtles`? Is it a primitive (in other words, built-in to NetLogo)? No, it's another procedure that you're about to add. So far, you have introduced two procedures that you added yourself: `setup` and `go`.

- Add the `move-turtles` procedure after the `go`procedure:

```
to go
  move-turtles
  tick
end

to move-turtles
  ask turtles [
    right random 360
    forward 1
  ]
end
```

Note there are no spaces around the hyphen in `move-turtles`. In Tutorial #2 we used `red - 2`, with spaces, in order to subtract two numbers, but here we want `move-turtles`, without spaces. The "-" combines "move" and "turtles" into a single name.

Here is what each command in the `move-turtles` procedure does:

- `ask turtles [ ... ]` says that each turtle should run the commands in the brackets.
- `right random 360` is another command that uses a reporter. First, each turtle picks a random whole number between 0 and 359. (`random` doesn't include the number you give it as a possible result.) Then the turtle turns right this number of degrees.
- `forward 1` makes the turtle move forward one step.

Why couldn't we have just written all of these commands in `go` instead of in a separate procedure? We could have, but during the course of building your project, it's likely that you'll add many other parts. We'd like to keep `go` as simple as possible, so that it is easy to understand. Eventually, it will include many other things you want to have happen as the model runs, such as calculating something or plotting the results. Each of these things to do will have its own procedure and each procedure will have its own unique name.

The 'go' button you made in the Interface tab is a forever button, meaning that it will continually run its commands until you shut it off (by clicking on it again). After you have pressed 'setup' once, to create the turtles, press the 'go' button. Watch what happens. Turn it off, and you'll see that all the turtles stop in their tracks.

Note that if a turtle moves off the edge of the world, it "wraps", that is, it appears on the other side. (This is the default behavior. It can be changed; see the Topology section of the Programming Guide for more information.)

Experimenting with commands

We suggest you start experimenting with other turtle commands.

Type commands into the Command Center (like `turtles> set color red`), or add commands to `setup`, `go`, or `move-turtles`.

Note that when you enter commands in the Command Center, you must choose `turtles>`, `patches>`, `links>`, or `observer>` in the popup menu on the left, depending on which agents are going to run the commands. It's just like using `ask turtles` or `ask patches`, but saves typing. You can also use the tab key to switch agent types, which you might find more convenient than using the menu.

You might try typing `turtles> pen-down` into the Command Center and then pressing the go button.

Also, inside the `move-turtles` procedure you can try changing `right random 360` to `right random 45`.

Play around. It's easy and the results are immediate and visible -- one of NetLogo's many strengths.

When you feel you've done enough experimenting for now, you're ready to continue improving the model you are building.

Patches and variables

Now we've got 100 turtles aimlessly moving around, completely unaware of anything else around them. Let's make things a little more interesting by giving these turtles a nice background against which to move.

- Go back to the `setup` procedure. We can rewrite it as follows:

```
to setup
  clear-all
  setup-patches
  setup-turtles
  reset-ticks
end
```

- The new definition of `setup` refers to two new procedures. To define `setup-patches`, add this:

```
to setup-patches
  ask patches [ set pcolor green ]
end
```

The `setup-patches` procedure sets the color of every patch to green to start with. (A turtle's color variable is `color`; a patch's is `pcolor`.)

The only part remaining in our new 'setup' that is still undefined is `setup-turtles`.

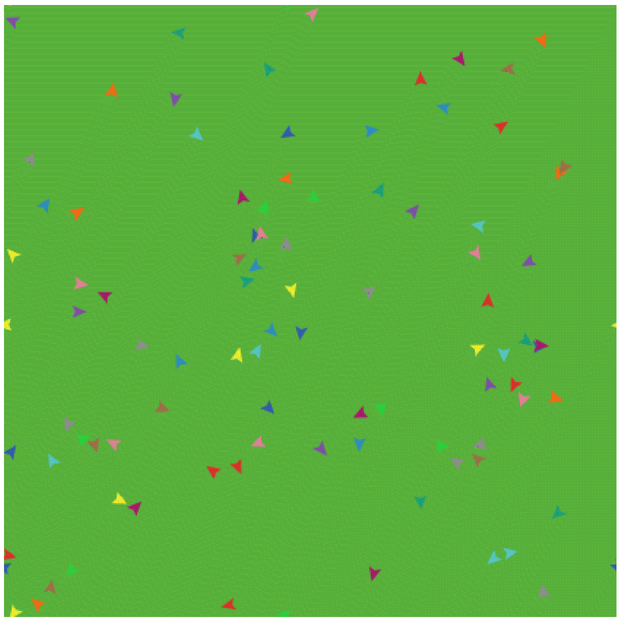
- Add this procedure too:

```
to setup-turtles
  create-turtles 100
  ask turtles [ setxy random-xcor random-ycor ]
end
```

Did you notice that the new `setup-turtles` procedure has most of the same commands as the old `setup` procedure?

- Switch back to the Interface tab.
- Press the setup button.

Voila! A lush NetLogo landscape complete with turtles and green patches appears:



After seeing the new `setup` procedure work a few times, you may find it helpful to read through the procedure definitions again.

Turtle variables

So we have some turtles running around on a landscape, but they aren't doing anything with it. Let's add some interaction between the turtles and the patches.

We'll make the turtles eat "grass" (the green patches), reproduce, and die. The grass will gradually grow back after it is eaten.

We'll need a way of controlling when a turtle reproduces and dies. We'll determine that by keeping track of how much "energy" each turtle has. To do that we need to add a new turtle variable.

You've already seen built-in turtle variables like `color`. To make a new turtle variable, we add a `turtles-own` declaration at the top of the Code tab, before all the procedures. Call it `energy`:

```
turtles-own [energy]

to go
  move-turtles
  eat-grass
  tick
end
```

Let's use this newly defined variable (`energy`) to allow the turtles to eat.

- Switch to the Code tab.
- Rewrite the `go` procedure as follows:

```
to go
  move-turtles
  eat-grass
  tick
end
```

- Add a new `eat-grass` procedure:

```
to eat-grass
  ask turtles [
    if pcolor = green [
      set pcolor black
      set energy energy + 10
    ]
  ]
end
```

We are using the `if` command for the first time. Look at the code carefully. Each turtle, when it runs these commands, compares the value of the patch color it is on (`pcolor`) to the value for `green`. (A turtle has direct access to the variables of the patch it is standing on.) If the patch color is green, the comparison reports `true`, and only then will the turtle run the commands inside the brackets (otherwise it skips them). The commands make the turtle change the patch color to black and increase its own energy by 10. The patch turns black to signify that the grass at that spot has been eaten. And the turtle is given more energy, from having just eaten.

Next, let's make the movement of turtles use up some of the turtle's energy.

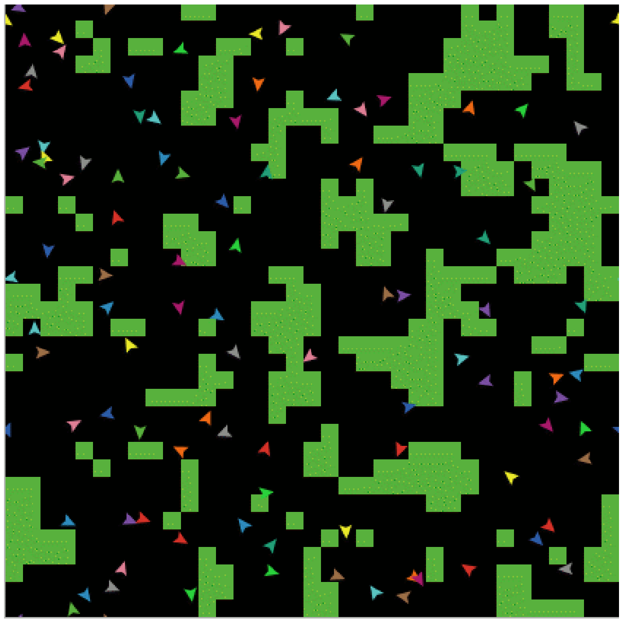
- Rewrite `move-turtles` as follows:

```
to move-turtles
  ask turtles [
    right random 360
    forward 1
    set energy energy - 1
  ]
end
```

As each turtle wanders, it will lose one unit of energy at each step.

- Switch to the Interface tab now and press the setup button and the go button.

You'll see the patches turn black as turtles travel over them.



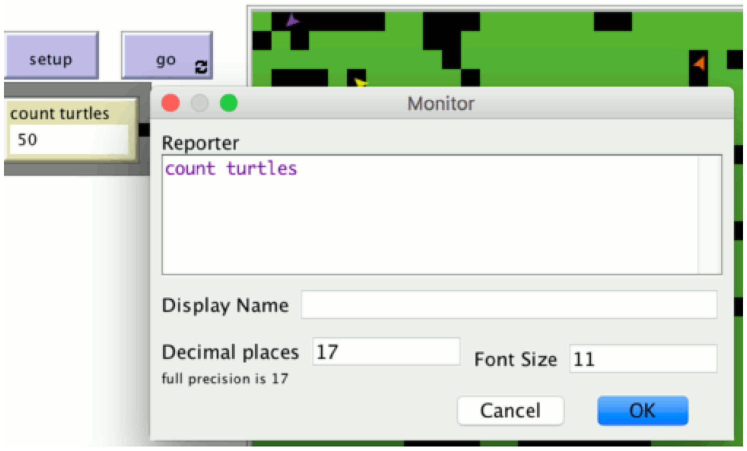
Monitors

Next you will create two monitors in the Interface tab with the toolbar. (You make them just like buttons and sliders, using the Add icon on the toolbar.) Let's make the first monitor now.

- Create a monitor by clicking the Add icon on the toolbar, selecting Monitor next to it, and clicking on an open spot in the Interface.

A dialog box will appear.

- In the dialog type: `count turtles` (see image below).
- Press the OK button to close the dialog.



Reporter
```
count turtles
```
Display Name

Decimal places 17
full precision is 17

Font Size 11

`turtles` is an "agentset", the set of all turtles. `count` tells us how many agents are in that set.

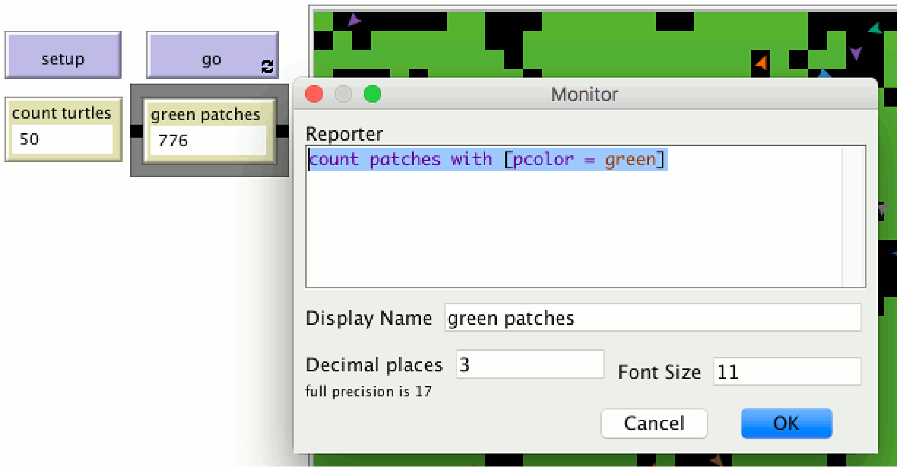
Let's make the second monitor now:

- Create a monitor by clicking the Add icon on the toolbar, selecting Monitor next to it, and clicking on an open spot in the Interface.

A dialog box will appear.

- In the Reporter section of the dialog box type: `count patches with [pcolor = green]` (see image below).
- In the Display name section of the dialog box type: `green patches`

- Press the OK button to close the dialog box.



Reporter

```
count patches with [pcolor = green]
```

Display Name: green patches

Decimal places: 3 (full precision is 17)

Font Size: 11

Here we're using `count` again to see how many agents are in an agentset. `patches` is the set of all the patches, but we don't just want to know how many patches there are total, we want to know how many of them are green. That's what `with` does; it makes a smaller agentset of just those agents for whom the condition in the brackets is true. The condition is `pcolor = green`, so that gives us just the green patches.

Now we have two monitors that will report how many turtles and green patches we have, to help us track what's going on in our model. As the model runs, the numbers in the monitors will automatically change.

- Use the setup and go buttons and watch the numbers in the monitors change.

Switches and labels

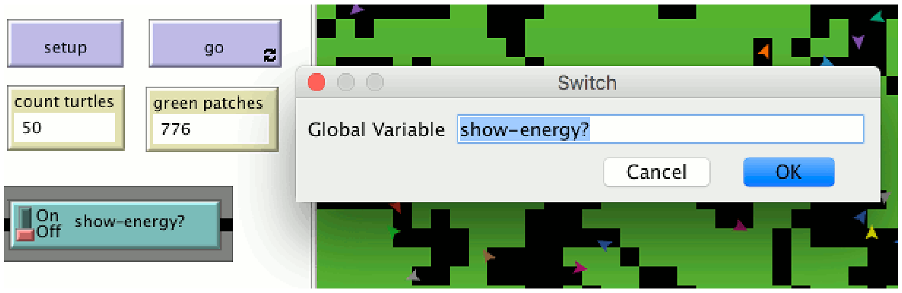
The turtles aren't just turning the patches black. They're also gaining and losing energy. As the model runs, try using a turtle monitor to watch one turtle's energy go up and down.

It would be nicer if we could see every turtle's energy all the time. We will now do exactly that, and add a switch so we can turn the extra visual information on and off.

- Click on the Add icon on the toolbar (in the Interface tab).
- Select Switch from the menu next to Add.
- Click on an open spot in the interface.

A dialog will appear.

- Into the Global variable field, type `show-energy?` Don't forget to include the question mark in the name. (See image below.)



Global Variable: show-energy?

- Now go back to the 'go' procedure using the Code tab with the Toolbar.
- Rewrite the `eat-grass` procedure as follows:

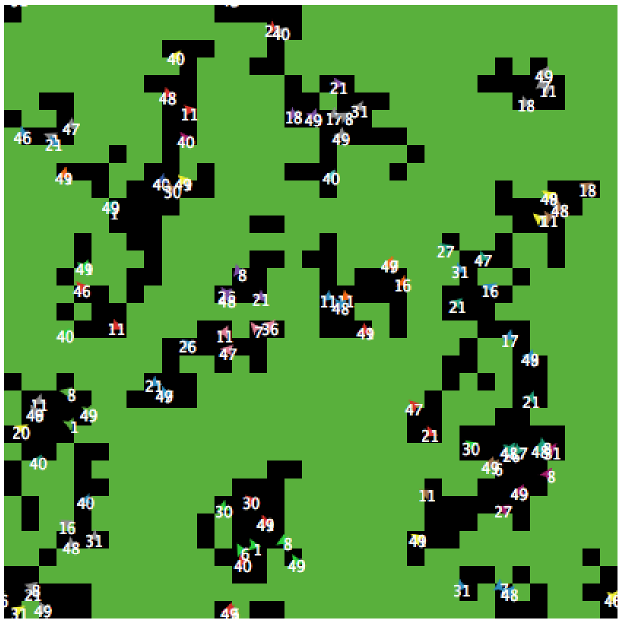
```
to eat-grass
  ask turtles [
    if pcolor = green [
      set pcolor black
      set energy energy + 10
    ]
  ifelse show-energy?
    [ set label energy ]
    [ set label "" ]
  ]
end
```

The `eat-grass` procedure introduces the `ifelse` command. Look at the code carefully. Each turtle, when it runs these new commands, checks the value of `show-energy?` (determined by the switch). If the switch is on, comparison is true and the turtle will run the commands inside the first set of brackets. In this case, it assigns the value for the energy to the label of the turtle. If the comparison is false (the switch is off) then the turtle runs the commands inside the second set of brackets. In this case, it removes the text labels (by setting the label of the turtle to be nothing).

(In NetLogo, a piece of text is called a "string", short for string of characters. A string is a sequence of letters or other characters, written between double quotes. Here we have two double quotes right next to each other, with nothing in between them. That's an empty string. If a turtle's label is an empty string, no text is attached to the turtle.)

- Test this in the Interface tab, by running the model (using the setup and go buttons) switching the `show-energy?` switch back and forth.

When the switch is on, you'll see the energy of each turtle go up each time it eats grass. You'll also see its energy going down whenever it moves.



More procedures

Now our turtles are eating. Let's make them reproduce and die, too. And let's make the grass grow back. We'll add all three of these of these behaviors now, by making three separate procedures, one for each behavior.

- Go to the Code tab.
- Rewrite the `go` procedure as follows:

```
to go
  move-turtles
  eat-grass
  reproduce
  check-death
  regrow-grass
  tick
end
```

- Add the procedures for `reproduce`, `check-death`, and `regrow-grass` as shown below:

```
to reproduce
  ask turtles [
    if energy > 50 [
      set energy energy - 50
      hatch 1 [ set energy 50 ]
    ]
  ]
end

to check-death
  ask turtles [
    if energy <= 0 [ die ]
  ]
end

to regrow-grass
  ask patches [
    if random 100 < 3 [ set pcolor green ]
  ]
end
```

Each of these procedures uses the `if` command. Each turtle, when it runs `check-death` it will check to see if its energy is less or equal to 0. If this is true, then the turtle is told to `die` (die is a NetLogo primitive).

When each turtle runs `reproduce`, it checks the value of the turtle's `energy` variable. If it is greater than 50, then the turtle runs the commands inside the first set of brackets. In this case, it decreases the turtle's energy by 50, then 'hatches' a new turtle with an energy of 50. The `hatch` command is a NetLogo primitive which looks like this: `hatch` *number* [*commands*]. This turtle creates *number* new turtles, each identical to its parent, and asks the new turtle(s) that have been hatched to run *commands*. You can use the commands to give the new turtles different colors, headings, or whatever. In our case we run one command. We set the energy for the newly hatched turtle to be 50.

When each patch runs `regrow-grass` it will check to see if a random integer from 0 to 99 is less than 3. If so, the patch color is set to green. This will happen 3% of the time (on average) for each patch, since there are three numbers (0, 1, and 2) out of 100 possible that are less than 3.

- Switch to the Interface tab now and press the setup and go buttons.

You should see some interesting behavior in your model now. Some turtles die off, some new turtles are created (hatched), and some grass grows back. This is exactly what we set out to do.

If you continue to watch your monitors in your model, you will see that the **count turtles** and **green patches** monitors both fluctuate. Is this pattern of fluctuation predictable? Is there a relationship between the variables?

It'd be nice if we had a easier way to track the changes in the model behavior over time. NetLogo allows us to plot data as we go along. That will be our next step.

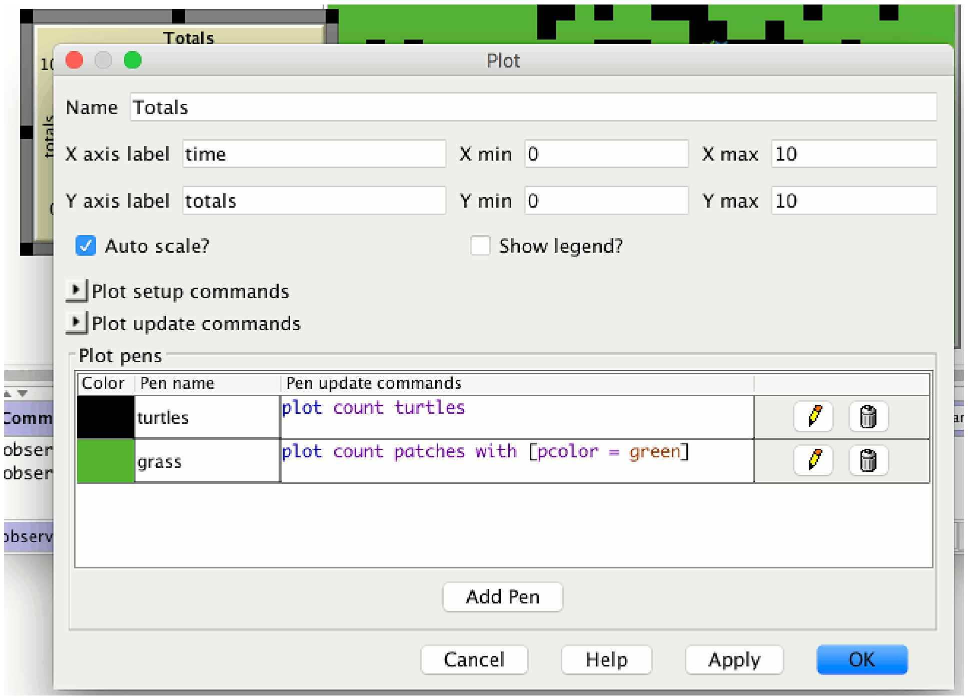
Plotting

To make plotting work, we'll need to create a plot in the Interface tab and put some commands inside it.

The commands we put in the plots will run automatically when our `setup` procedure calls `reset-ticks` and when our `go` procedure calls `tick`.

- Create a plot by clicking the Add icon on the toolbar, selecting Plot next to it, and clicking on an open spot in the Interface.
- Set its Name to "Totals" (see image below)
- Set the X axis label to "time"
- Set the Y axis label to "totals"
- Change the name of the "default" pen to "turtles".
- Enter `plot count turtles` under Pen Update Commands.
- Press the "Add Pen" button.
- Change the name of the new pen to "grass".
- Enter `plot count patches with [pcolor = green]` under Pen Update Commands.

When you're done, the dialog should look like this:



Name: Totals

X axis label: time X min: 0 X max: 10

Y axis label: totals Y min: 0 Y max: 10

Auto scale? ✓ Show legend? ☐

Color	Pen name	Pen update commands
⬛	turtles	`plot count turtles`
🟩	grass	`plot count patches with [pcolor = green]`

- Press OK in the Plot dialog to finish editing.

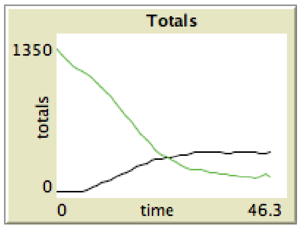
Note that when you create the plot you can also set the minimum and maximum values on the X and Y axes. You'll want to leave the "Auto Scale" checkbox checked, so that if anything you plot exceeds the minimum and maximum values for the axes, the axes will automatically grow so you can see all the data.

Note that we used the `plot` command to add the next point to a plot. This command moves the current plot pen to the point that has an X coordinate equal to 1 greater than the previously plotted X coordinate and a Y coordinate equal to the value given in the plot command (in the first case, the number of turtles, and in the second case, the number of green patches). As the pens move they each draw a line.

- Setup and run the model again.

You can now watch the plot being drawn as the model is running. Your plot should have the general shape of the one below, though your plot might not look exactly the same.

Remember that we left "Auto Scale?" on. This allows the plot to readjust itself when it runs out of room.



If you forget which pen is which, you can edit the plot and check the "Show legend?" checkbox.

You might try running the model several times to see what aspects of the plot are the same and which are different from run to run.

Tick counter

To make comparisons between plots from one model run and another, it is often useful to do the comparison for the same length of model run. Learning how to stop or start an action at a specific time can help make this happen by stopping the model at the same point each model run. Keeping track of how many times the `go` procedure is run is a useful way to cue these actions. That's what the tick counter does.

You're already using the tick counter in your model, with the `reset-ticks` and `tick` commands, which also trigger plotting.

You can also use the tick counter for other things, such as to set a limit on the total length of a run.

- Change the `go` procedure:

```
to go
  if ticks >= 500 [ stop ]
  move-turtles
  eat-grass
  check-death
  reproduce
  regrow-grass
  tick
end
```

- Now setup and run the model.

The graph and model won't keep running forever. They should stop automatically when the tick counter in the Interface tab's toolbar reaches 500.

The `tick` command advances the tick counter by 1. `ticks` is a reporter which reports the current value of the tick counter. `reset-ticks`, in your `setup` procedure, takes care of restarting the tick counter at 0 when a new run is set up and ready to begin.

Some more details

First, instead of always using 100 turtles, you can have a varying number of turtles.

- Create a slider named "number": click the Add icon on the toolbar, select Slider next to it, and click on an open spot in the interface.
- Try changing the minimum and maximum values in the slider.
- Then inside of `setup-turtles`, instead of `create-turtles 100` you can type:

```
to setup-turtles
  create-turtles number [ setxy random-xcor random-ycor ]
end
```

Test this change and compare how having more or fewer turtles initially affect the plots over time.

Second, wouldn't it be nice to adjust the energy the turtles gain and lose as they eat grass and reproduce?

- Make a slider called `energy-from-grass`.
- Make another slider called `birth-energy`.
- Then, inside of `eat-grass`, make this change:

```
to eat-grass
  ask turtles [
    if pcolor = green [
      set pcolor black
      set energy (energy + energy-from-grass)
    ]
    ifelse show-energy?
      [ set label energy ]
      [ set label "" ]
  ]
end
```

- And, inside of `reproduce`, make this change:

```
to reproduce
  ask turtles [
    if energy > birth-energy [
      set energy energy - birth-energy
      hatch 1 [ set energy birth-energy ]
    ]
  ]
end
```

Finally, what other slider could you add to vary how often grass grows back? Are there rules you can add to the movement of the turtles or to the newly hatched turtles that happen only at certain times? Try writing them.

What's next?

So now you have a simple model of an ecosystem. Patches grow grass. Turtles wander, eat the grass, reproduce, and die.

You have created an interface containing buttons, sliders, switches, monitors, and a plot. You've even written a series of procedures to give the turtles something to do.

That's where this tutorial leaves off.

If you'd like to look at some more documentation about NetLogo, the Interface Guide section of the manual walks you through every element of the NetLogo interface in order and explains its function. For a detailed description and specifics about writing procedures, refer to the Programming Guide. All of the primitives are listed and described in the NetLogo Dictionary.

Also, you can continue experimenting with and expanding this model if you'd like, experimenting with different variables and behaviors for the agents.

Alternatively, you may want to revisit the first model in the tutorial, Wolf Sheep Predation. This is the model you used in `Tutorial #1`. In the Wolf Sheep Predation model, you saw sheep move around, consume resources that are replenished occasionally (grass), reproduce under certain conditions, and die if they ran out of resources. But that model had another type of creature moving around -- wolves. The addition of wolves requires some additional procedures and some new primitives. Wolves and sheep are two different "breeds" of turtle. To see how to use breeds, study Wolf Sheep Predation.

Alternatively, you can look at other models (including the many models in the Code Examples section of the Models Library) or even go ahead and build your own model. You don't even have to model anything. It can be interesting just to watch patches and turtles forming patterns, to try to create a game to play, or whatever.

Hopefully you have learned some things, both in terms of the NetLogo language and about how to go about building a model. The entire set of procedures that was created above is shown below.

Appendix: Complete code

The complete model is also available in NetLogo's Models Library, in the Code Examples section. It's called "Tutorial 3".

Notice that this listing is full of "comments", which begin with semicolons. Comments let you mix an explanation the code right in with the code itself. You might use comments to help others understand your model, or you might use them as notes to yourself.

In the Code tab, comments are gray, so your eyes can pick them out easily.

```
turtles-own [energy] ;; for keeping track of when the turtle is ready
                     ;; to reproduce and when it will die

to setup
  clear-all
  setup-patches
  setup-turtles
  reset-ticks
end

to setup-patches
  ask patches [ set pcolor green ]
end

to setup-turtles
  create-turtles number    ;; uses the value of the number slider to create turtles
  ask turtles [ setxy random-xcor random-ycor ]
end

to go
  if ticks >= 500 [ stop ]  ;; stop after 500 ticks
  move-turtles
  eat-grass
  check-death
  reproduce
  regrow-grass
  tick                    ;; increase the tick counter by 1 each time through
end

to move-turtles
  ask turtles [
    right random 360
    forward 1
    set energy energy - 1  ;; when the turtle moves it looses one unit of energy
  ]
```

```
end

to eat-grass
  ask turtles [
    if pcolor = green [
      set pcolor black
           ;; the value of energy-from-grass slider is added to energy
      set energy energy + energy-from-grass
    ]
  ifelse show-energy?
    [ set label energy ] ;; the label is set to be the value of the energy
    [ set label "" ]     ;; the label is set to an empty text value
  ]
end

to reproduce
  ask turtles [
    if energy > birth-energy [
      set energy energy - birth-energy  ;; take away birth-energy to give birth
      hatch 1 [ set energy birth-energy ] ;; give this birth-energy to the offspring
    ]
  ]
end

to check-death
  ask turtles [
    if energy <= 0 [ die ] ;; removes the turtle if it has no energy left
  ]
end

to regrow-grass
  ask patches [ ;; 3 out of 100 times, the patch color is set to green
    if random 100 < 3 [ set pcolor green ]
  ]
end
```