Programming Guide

NetLogo 6.0.1 User Manual

This section describes the NetLogo programming language in detail.

The Code Example models mentioned throughout can be found in the Code Examples section of the Models Library.

- Agents
- Procedures
- Variables
- Tick counter
- Colors
- Ask
- Agentsets
- Breeds
- Buttons
- Lists
- Math
- Random numbers
- Turtle shapes
- Link shapes
- View updates
- Plotting
- Strings
- Output
- File I/O
- Movies
- Perspective
- Drawing
- Topology
- Links
- Anonymous procedures
- Ask-Concurrent
- User Interaction Primitives
- Tie
- Multiple source files
- Syntax

Agents

The NetLogo world is made up of **agents**. Agents are beings that can follow instructions.

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 observer doesn't observe passively -- it gives instructions to the other agents.

When NetLogo starts up, there are no turtles. The observer can make new turtles. Patches can make new turtles too. (Patches can't move, but otherwise they're just as "alive" as turtles.)

Patches have coordinates. The patch at coordinates (0, 0) is called the origin and the coordinates of the other patches are the horizontal and vertical distances from this one. We call the patch's coordinates `pxcor` and `pycor`. Just like in the standard mathematical coordinate plane, `pxcor` increases as you move to the right and `pycor` increases as you move up.

The total number of patches is determined by the settings `min-pxcor`, `max-pxcor`, `min-pycor`, and `max-pycor` When NetLogo starts up, `min-pxcor`, `max-pxcor`, `min-pycor`, and `max-pycor` are -16, 16, -16, and 16 respectively. This means that `pxcor` and `pycor` both range from -16 to 16, so there are 33 times 33, or 1089 patches total. (You can change the number of patches with the Settings button.)

Turtles have coordinates too: `xcor` and `ycor`. A patch's coordinates are always integers, but a turtle's coordinates can have decimals. This means that a turtle can be positioned at any point within its patch; it doesn't have to be in the center of the patch.

Links do not have coordinates. Every link has two ends, and each end is a turtle. If either turtle dies, the link dies too. A link is represented visually as a line connecting the two turtles.

Procedures

In NetLogo, **commands** and **reporters** tell agents what to do. A command is an action for an agent to carry out, resulting in some effect. A reporter is instructions for computing a value, which the agent then "reports" to whoever asked it.

Typically, a command name begins with a verb, such as "create", "die", "jump", "inspect", or "clear". Most reporter names are nouns or noun phrases.

Commands and reporters built into NetLogo are called **primitives**. The NetLogo Dictionary has a complete list of built-in commands and reporters.

Commands and reporters you define yourself are called **procedures**. Each procedure has a name, preceded by the keyword `to` or `to-report`, depending on whether it is a command procedure or a reporter procedure. The keyword `end` marks the end of the commands in the procedure. Once you define a procedure, you can use it elsewhere in your program.

Many commands and reporters take **inputs** -- values that the command or reporter uses in carrying out its actions or computing its result.

Here are two command procedures:

```
to setup
  clear-all
  create-turtles 10
  reset-ticks
end

to go
  ask turtles [
    fd 1            ;; forward 1 step
    rt random 10    ;; turn right
    lt random 10    ;; turn left
  ]
  tick
end
```

Note the use of semicolons to add "comments" to the program. Comments can make your code easier to read and understand, but they don't affect its behavior.

In this program,

- `setup` and `go` are user-defined commands.
- `clear-all`, `create-turtles`, `reset-ticks`, `ask`, `lt` ("left turn"), `rt` ("right turn") and `tick`, are all primitive commands.
- `random` and `turtles` are primitive reporters. `random` takes a single number as an input and reports a random integer that is less than the input (in this case, between 0 and 9). `turtles` reports the agentset consisting of all the turtles. (We'll explain about agentsets later.)

`setup` and `go` can be called by other procedures, or by buttons, or from the Command Center.

Many NetLogo models have a once button that calls a procedure called `setup` and a forever button that calls a procedure called `go`.

In NetLogo, you may specify which agents -- turtles, patches, or links -- are to run each command. If you don't specify, the code is run by the observer. In the code above, the observer uses `ask` to make the set of all turtles run the commands between the square brackets.

`clear-all` and `create-turtles` can only be run by the observer. `fd`, on the other hand, can only be run by turtles. Some other commands and reporters, such as `set` and `ticks`, can be run by different agent types.

Here are some more advanced features you can take advantage of when defining your own procedures.

Procedures with inputs

Procedures can take inputs, just like many primitives do. To create a procedure that accepts inputs, put their names in square brackets after the procedure name. For example:

```
to draw-polygon [num-sides len]  ;; turtle procedure
  pen-down
  repeat num-sides [
    fd len
    rt 360 / num-sides
  ]
end
```

Elsewhere in the program, you might use the procedure by asking the turtles to each draw an octagon with a side length equal to its who number:

```
ask turtles [ draw-polygon 8 who ]
```

Reporter procedures

Just like you can define your own commands, you can define your own reporters. You must do two special things. First, use `to-report` instead of `to` to begin your procedure. Then, in the body of the procedure, use `report` to report the value you want to report.

```
to-report absolute-value [number]
  ifelse number >= 0
    [ report number ]
    [ report (- number) ]
end
```

Variables

Agent variables

Agent variables are places to store values (such as numbers) in an agent. An agent variable can be a global variable, a turtle variable, a patch variable, or a link variable.

If a variable is a global variable, there is only one value for the variable, and every agent can access it. You can think of global variables as belonging to the observer.

Turtle, patch, and link variables are different. Each turtle has its *own* value for every turtle variable. The same goes for patches and links.

Some variables are built into NetLogo. For example, all turtles and links have a `color` variable, and all patches have a `pcolor` variable. (The patch variable begins with "p" so it doesn't get confused with the turtle variable, since turtles have direct access to patch variables.) If you set the variable, the turtle or patch changes color. (See next section for details.)

Other built-in turtle variables including `xcor`, `ycor`, and `heading`. Other built-in patch variables include `pxcor` and `pycor`. (There is a complete list here.)

You can also define your own variables. You can make a global variable by adding a switch, slider, chooser, or input box to your model, or by using the `globals` keyword at the beginning of your code, like this:

```
globals [score]
```

You can also define new turtle, patch and link variables using the `turtles-own` , `patches-own` and `links-own` keywords, like this:

```
turtles-own [energy speed]
patches-own [friction]
links-own [strength]
```

These variables can then be used freely in your model. Use the `set` command to set them. (Any variable you don't set has a starting value of zero.)

Global variables can be read and set at any time by any agent. As well, a turtle can read and set patch variables of the patch it is standing on. For example, this code:

```
ask turtles [ set pcolor red ]
```

causes every turtle to make the patch it is standing on red. (Because patch variables are shared by turtles in this way, you can't have a turtle variable and a patch variable with the same name.)

In other situations where you want an agent to read a different agent's variable, you can use `of`. Example:

```
show [color] of turtle 5
;; prints current color of turtle with who number 5
```

You can also use `of` with a more complicated expression than just a variable name, for example:

```
show [xcor + ycor] of turtle 5
;; prints the sum of the x and y coordinates of
;; turtle with who number 5
```

Local variables

A local variable is defined and used only in the context of a particular procedure or part of a procedure. To create a local variable, use the `let` command. If you use `let` at the top of a procedure, the variable will exist throughout the procedure. If you use it inside a set of square brackets, for example inside an "ask", then it will exist only inside those brackets.

```
to swap-colors [turtle1 turtle2]
  let temp [color] of turtle1
  ask turtle1 [ set color [color] of turtle2 ]
  ask turtle2 [ set color temp ]
end
```

Tick counter

In many NetLogo models, time passes in discrete steps, called "ticks". NetLogo includes a built-in tick counter so you can keep track of how many ticks have passed.

The current value of the tick counter is shown above the view. (You can use the Settings button to hide the tick counter, or change the word "ticks" to something else.)

In code, to retrieve the current value of the tick counter, use the `ticks` reporter. The `tick` command advances the tick counter by 1. The `clear-all` command clears the tick counter along with everything else.

When the tick counter is clear, it's an error to try to read or modify it. Use the `reset-ticks` command when your model is done setting up, to start the tick counter.

If your model is set to use tick-based updates, then the `tick` command will usually also update the view. See the later section, View Updates.

When to tick

Use `reset-ticks` at the end of your setup procedure.

Use `tick` at the end of your go procedure.

```
to setup
  clear-all
  create-turtles 10
  reset-ticks
end

to go
  ask turtles [ fd 1 ]
  tick
end
```

Fractional ticks

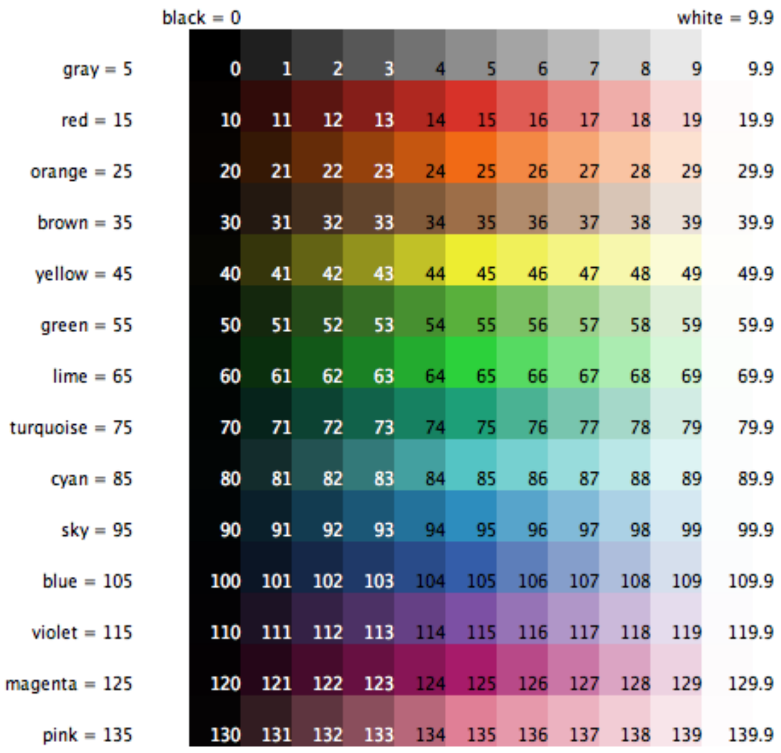
In most models, the tick counter starts at 0 and goes up 1 at a time, from integer to integer. But it's also possible for the tick counter to take on in-between floating point values.

To advance the tick counter by a fractional amount, use the `tick-advance` command. This command takes a numeric input specifying how far to advance the tick counter.

A typical use of fractional ticks is to approximate continuous or curved motion. See, for example, the GasLab models in the Models Library (under Chemistry & Physics). These models calculate the exact time at which a future event is to occur, then advance the tick counter to exactly that time.

Colors

NetLogo represents colors in different ways. A color can be number in the range 0 to 140, with the exception of 140 itself. Below is a chart showing the range of such colors you can use in NetLogo.



	black = 0										white = 9.9
gray = 5	0	1	2	3	4	5	6	7	8	9	9.9
red = 15	10	11	12	13	14	15	16	17	18	19	19.9
orange = 25	20	21	22	23	24	25	26	27	28	29	29.9
brown = 35	30	31	32	33	34	35	36	37	38	39	39.9
yellow = 45	40	41	42	43	44	45	46	47	48	49	49.9
green = 55	50	51	52	53	54	55	56	57	58	59	59.9
lime = 65	60	61	62	63	64	65	66	67	68	69	69.9
turquoise = 75	70	71	72	73	74	75	76	77	78	79	79.9
cyan = 85	80	81	82	83	84	85	86	87	88	89	89.9
sky = 95	90	91	92	93	94	95	96	97	98	99	99.9
blue = 105	100	101	102	103	104	105	106	107	108	109	109.9
violet = 115	110	111	112	113	114	115	116	117	118	119	119.9
magenta = 125	120	121	122	123	124	125	126	127	128	129	129.9
pink = 135	130	131	132	133	134	135	136	137	138	139	139.9

The chart shows that:

- Some of the colors have names. (You can use these names in your code.)
- Every named color except black and white has a number ending in 5.
- On either side of each named color are darker and lighter shades of the color.
- 0 is pure black. 9.9 is pure white.
- 10, 20, and so on are all so dark they are very nearly black.
- 19.9, 29.9 and so on are all so light they are very nearly white.

Code Example: The color chart was made in NetLogo with the Color Chart Example model.

If you use a number outside the 0 to 140 range, NetLogo will repeatedly add or subtract 140 from the number until it is in the 0 to 140 range. For example, 25 is orange, so 165, 305, 445, and so on are orange too, and so are -115, -255, -395, etc. This calculation is done automatically whenever you set the turtle variable `color` or the patch variable `pcolor`. Should you need to perform this calculation in some other context, use the `wrap-color` primitive.

If you want a color that's not on the chart, more exist between the integers. For example, 26.5 is a shade of orange halfway between 26 and 27. This doesn't mean you can make any color in NetLogo; the NetLogo color space is only a subset of all possible colors. It contains only a fixed set of discrete hues (one hue per row of the chart). Starting from one of those hues, you can either decrease its brightness (darken it) or decrease its saturation (lighten it), but you cannot decrease both brightness and saturation. Also, only the first digit after the decimal point is significant. Thus, color values are rounded down to the next 0.1, so for example, there's no visible difference between 26.5 and 26.52 or 26.58.

Color primitives

There are a few primitives that are helpful for working with colors.

We have already mentioned the `wrap-color` primitive.

The `scale-color` primitive is useful for converting numeric data into colors.

`shade-of?` will tell you if two colors are both "shades" of the same basic hue. For example, `shade-of? orange 27` is true, because 27 is a lighter shade of orange.

Code Example: Scale-color Example demonstrates the scale-color reporter.

RGB and RGBA Colors

NetLogo also represents colors as RGB (red/green/blue) lists and RGBA (red/green/blue/alpha) lists. When using RGB colors the full range of colors is available to you. RGBA colors allow all the colors that RGB allows and you can also vary the transparency of a color. RGB and RGBA lists are made up of three or four integers, respectively, between 0 and 255 if a number is outside that range 255 is repeatedly subtracted until it is in the range. You can set any color variables in NetLogo (`color` for turtles and links and `pcolor` for patches) to an RGB list and that agent will be rendered appropriately. So you can set the color of patch 0 0 to pure red using the following code:

```
set pcolor [255 0 0]
```

Turtles, links, and labels can all contain RGBA lists as their color variables, however, patches cannot have RGBA `pcolors` You can set the color of a turtle to be approximately half transparent pure red with the following code:

```
set color [255 0 0 125]
```

You can convert from a NetLogo color to RGB or HSB (hue/saturation/brightness) using `extract-hsb` and `extract-rgb`. You can use `rgb` to generate rgb lists and `hsb` to convert from an HSB color to RGB.

Since many colors are missing from the NetLogo color space, `approximate-hsb` and `approximate-rgb` often can't give you the exact color you ask for, but they try to come as close as possible.

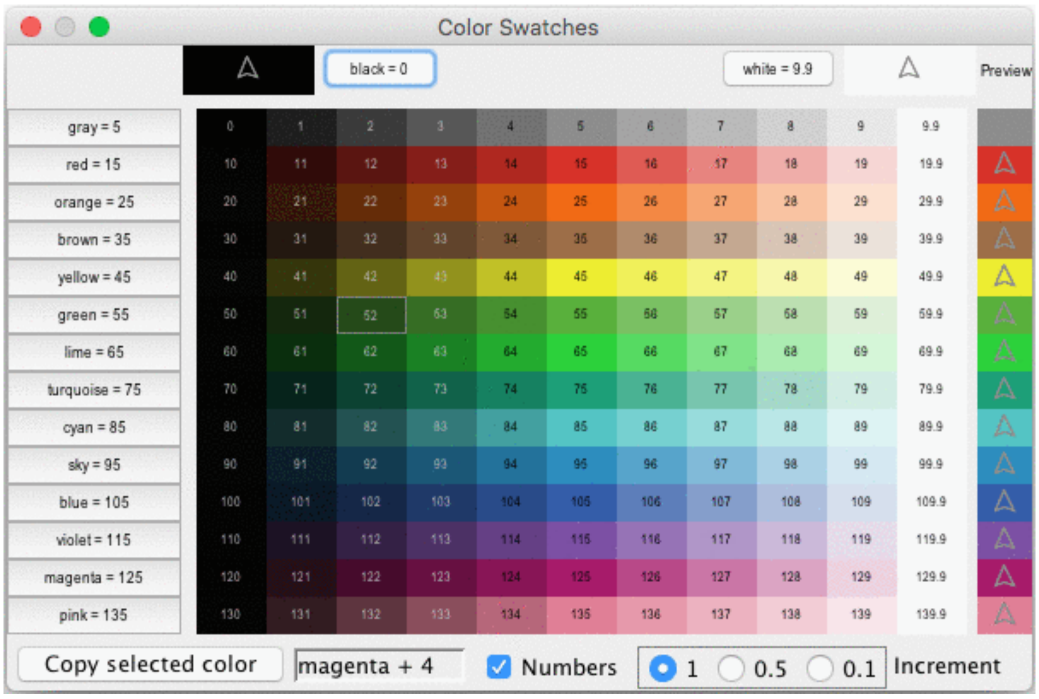
Example: you can change any turtle from it's existing NetLogo color to a half transparent version of that color using:

```
set color lput 125 extract-rgb color
```

Code Examples: HSB and RGB Example (lets you experiment with the HSB and RGB color systems), Transparency Example

Color Swatches dialog

The Color Swatches dialog helps you experiment with and choose colors. Open it by choosing Color Swatches on the Tools Menu.



gray = 5	0	1	2	3	4	5	6	7	8	9	9.9
red = 15	10	11	12	13	14	15	16	17	18	19	19.9
orange = 25	20	21	22	23	24	25	26	27	28	29	29.9
brown = 35	30	31	32	33	34	35	36	37	38	39	39.9
yellow = 45	40	41	42	43	44	45	46	47	48	49	49.9
green = 55	50	51	52	53	54	55	56	57	58	59	59.9
lime = 65	60	61	62	63	64	65	66	67	68	69	69.9
turquoise = 75	70	71	72	73	74	75	76	77	78	79	79.9
cyan = 85	80	81	82	83	84	85	86	87	88	89	89.9
sky = 95	90	91	92	93	94	95	96	97	98	99	99.9
blue = 105	100	101	102	103	104	105	106	107	108	109	109.9
violet = 115	110	111	112	113	114	115	116	117	118	119	119.9
magenta = 125	120	121	122	123	124	125	126	127	128	129	129.9
pink = 135	130	131	132	133	134	135	136	137	138	139	139.9

magenta + 4 [✓ Numbers] [✓ 1] 0.5 0.1 Increment

When you click on a color swatch (or a color button), that color will be shown against other colors. In the bottom left, the code for the currently selected color is displayed (for example, `red + 2`) so you can copy and paste it into your code. On the bottom right there are three increment options, 1, 0.5, and 0.1. These numbers indicate the difference between two adjacent swatches. When the increment is 1 there are 10 different shades in each row; when the increment is 0.1 there are 100 different shades in each row. 0.5 is an intermediate setting.

Ask

NetLogo uses the `ask` command to give commands to turtles, patches, and links. All code to be run by turtles *must* be located in a turtle "context". You can establish a turtle context in any of three ways:

- In a button, by choosing "Turtles" from the popup menu. Any code you put in the button will be run by all turtles.
- In the Command Center, by choosing "Turtles" from the popup menu. Any commands you enter will be run by all the turtles.
- By using `ask turtles`, `hatch`, or other commands which establish a turtle context.

The same goes for patches, links, and the observer, except that you cannot `ask` the observer. Any code that is not inside any `ask` is by default observer code.

Here's an example of the use of `ask` in a NetLogo procedure:

```
to setup
  clear-all
  create-turtles 100   ;; create 100 turtles with random headings
  ask turtles
    [ set color red    ;; turn them red
      fd 50 ]          ;; spread them around
  ask patches
    [ if pxcor > 0          ;; patches on the right side
        [ set pcolor green ] ]   ;; of the view turn green
  reset-ticks
end
```

The models in the Models Library are full of other examples. A good place to start looking is in the Code Examples section.

Usually, the observer uses `ask` to ask all turtles, all patches or all links to run commands. You can also use `ask` to have an individual turtle, patch or link run commands. The reporters `turtle`, `patch`, `link` and patch-at are useful for this technique. For example:

```
to setup
  clear-all
  crt 3                              ;; make 3 turtles
  ask turtle 0                       ;; tell the first one...
    [ fd 1 ]                         ;; ...to go forward
  ask turtle 1                       ;; tell the second one...
    [ set color green ]              ;; ...to become green
  ask turtle 2                       ;; tell the third one...
    [ rt 90 ]                        ;; ...to turn right
  ask patch 2 -2                     ;; ask the patch at (2,-2)
    [ set pcolor blue ]              ;; ...to become blue
  ask turtle 0                       ;; ask the first turtle
    [ ask patch-at 1 0               ;; ...to ask patch to the east
      [ set pcolor red ] ]           ;; ...to become red
  ask turtle 0                       ;; tell the first turtle...
    [ create-link-with turtle 1 ] ;; ...make a link with the second
  ask link 0 1                       ;; tell the link between turtle 0 and 1
    [ set color blue ]               ;; ...to become blue
  reset-ticks
end
```

Every turtle created has a who number. The first turtle created is number 0, the second turtle number 1, and so forth.

The turtle primitive reporter takes a who number as an input, and reports the turtle with that who number. The patch primitive reporter takes values for pxcor and pycor and reports the patch with those coordinates. The link primitive takes two inputs, the who numbers of the two turtles it connects. And the patch-at primitive reporter takes *offsets*: distances, in the x and y directions, *from* the first agent. In the example above, the turtle with who number 0 is asked to get the patch east (and no patches north) of itself.

You can also select a subset of turtles, or a subset of patches, or a subset of links and ask them to do something. This involves using **agentsets**. The next section explains them in detail.

When you ask a set of agents to run more than one command, each agent must finish before the next agent starts. One agent runs all of the commands, then the next agent runs all of them, and so on. For example, if you write:

```
ask turtles
  [ fd 1
    set color red ]
```

first one turtle moves and turns red, then another turtle moves and turns red, and so on.

But if you write it this way:

```
ask turtles [ fd 1 ]
ask turtles [ set color red ]
```

first all the turtles move, then they all turn red.

Agentsets

An agentset is exactly what its name implies, a set of agents. An agentset can contain either turtles, patches or links, but not more than one type at once.

An agentset is not in any particular order. In fact, it's always in a random order. And every time you use it, the agentset is in a *different* random order. This helps you keep your model from treating any particular turtles, patches or links differently from any others (unless you want them to be). Since the order is random every time, no one agent always gets to go first.

You've seen the `turtles` primitive, which reports the agentset of all turtles, the `patches` primitive, which reports the agentset of all patches and the `links` primitive which reports the agentset of all links.

But what's powerful about the agentset concept is that you can construct agentsets that contain only *some* turtles, *some* patches or *some* links. For example, all the red turtles, or the patches with pxcor evenly divisible by five, or the turtles in the first quadrant that are on a green patch or the links connected to turtle 0. These agentsets can then be used by `ask` or by various reporters that take agentsets as inputs.

One way is to use `turtles-here` or `turtles-at`, to make an agentset containing only the turtles on my patch, or only the turtles on some other patch at some x and y offsets. There's also `turtles-on` so you can get the set of turtles standing on a given patch or set of patches, or the set of turtles standing on the same patch as a given turtle or set of turtles.

Here are some more examples of how to make agentsets:

```
;; all other turtles:
other turtles
;; all other turtles on this patch:
other turtles-here
;; all red turtles:
turtles with [color = red]
;; all red turtles on my patch
turtles-here with [color = red]
;; patches on right side of view
patches with [pxcor > 0]
;; all turtles less than 3 patches away
turtles in-radius 3
;; the four patches to the east, north, west, and south
patches at-points [[1 0] [0 1] [-1 0] [0 -1]]
;; shorthand for those four patches
neighbors4
;; turtles in the first quadrant that are on a green patch
turtles with [(xcor > 0) and (ycor > 0)
              and (pcolor = green)]
;; turtles standing on my neighboring four patches
turtles-on neighbors4
;; all the links connected to turtle 0
[my-links] of turtle 0
```

Note the use of `other` to exclude this agent. This is common.

Once you have created an agentset, here are some simple things you can do:

- Use `ask` to make the agents in the agentset do something
- Use `any?` to see if the agentset is empty
- Use `all?` to see if every agent in an agentset satisfies a condition.
- Use `count` to find out exactly how many agents are in the set

And here are some more complex things you can do:

- Pick a random agent from the set using `one-of`. For example, we can make a randomly chosen turtle turn green:

  ```
  ask one-of turtles [ set color green ]
  ```

  Or tell a randomly chosen patch to `sprout` a new turtle:

  ```
  ask one-of patches [ sprout 1 ]
  ```

- Use the `max-one-of` or `min-one-of` reporters to find out which agent is the most or least along some scale. For example, to remove the richest turtle, you could say

  ```
  ask max-one-of turtles [sum assets] [ die ]
  ```

- Make a histogram of the agentset using the `histogram` command (in combination with `of`).
- Use `of` to make a list of values, one for each agent in the agentset. Then use one of NetLogo's list primitives to do something with the list. (See the "Lists" section below.) For example, to find out how rich turtles are on the average, you could say

```
show mean [sum assets] of turtles
```

- Use `turtle-set`, `patch-set` and `link-set` reporters to make new agentsets by gathering together agents from a variety of possible sources.
- Use `no-turtles`, `no-patches` and `no-links` reporters to make empty agentsets.
- Check whether two agentsets are equal using `=` or `!=`.
- Use `member?` to see whether a particular agent is a member of an agentset.

This only scratches the surface. See the Models Library for many more examples, and consult the NetLogo Dictionary for more information about all of the agentset primitives.

More examples of using agentsets are provided in the individual entries for these primitives in the NetLogo Dictionary.

Special agentsets

The agentsets `turtles` and `links` have special behavior because they always hold the sets of *all* turtles and *all* links. Therefore, these agentsets can grow.

The following interaction shows the special behavior. Assume the Code tab has `globals [g]`. Then:

```
observer> clear-all
observer> create-turtles 5
observer> set g turtles
observer> print count g
5
observer> create-turtles 5
observer> print count g
10
observer> set g turtle-set turtles
observer> print count g
10
observer> create-turtles 5
observer> print count g
10
observer> print count turtles
15
```

The `turtles` agentset grows when new turtles are born, but other agentsets don't grow. If I write `turtle-set turtles`, I get a new, normal agentset containing just the turtles that *currently* exist. New turtles don't join when they're born.

Breed agentsets are special in the same way as `turtles` and `links`. Breeds are introduced and explained below.

Agentsets and lists

Earlier, we said that agentsets are always in random order, a different random order every time. If you need your agents to do something in a fixed order, you need to make a list of the agents instead. See the Lists section below.

Code Example: Ask Ordering Example

Breeds

NetLogo allows you to define different "breeds" of turtles and breeds of links. Once you have defined breeds, you can go on and make the different breeds behave differently. For example, you could have breeds called `sheep` and `wolves`, and have the wolves try to eat the sheep or you could have link breeds called `streets` and `sidewalks` where foot traffic is routed on sidewalks and car traffic is routed on streets.

You define turtle breeds using the `breed` keyword, at the top of the Code tab, before any procedures:

```
breed [wolves wolf]
breed [sheep a-sheep]
```

You can refer to a member of the breed using the singular form, just like the `turtle` reporter. When printed, members of the breed will be labeled with the singular name.

Some commands and reporters have the plural name of the breed in them, such as `create-<breeds>`. Others have the singular name of the breed in them, such as `<breed>`

The order in which breeds are declared is also the order in which they are layered in the view. So breeds defined later will appear on top of breeds defined earlier; in this example, sheep will be drawn over wolves.

When you define a breed such as `sheep`, an agentset for that breed is automatically created, so that all of the agentset capabilities described above are immediately available with the `sheep` agentset.

The following new primitives are also automatically available once you define a breed: `create-sheep`, `hatch-sheep`, `sprout-sheep`, `sheep-here`, `sheep-at`, `sheep-on`, and `is-a-sheep?`.

Also, you can use `sheep-own` to define new turtle variables that only turtles of the given breed have. (It's allowed for more than one breed to own the same variable.)

A turtle's breed agentset is stored in the `breed` turtle variable. So you can test a turtle's breed, like this:

```
if breed = wolves [ ... ]
```

Note also that turtles can change breeds. A wolf doesn't have to remain a wolf its whole life. Let's change a random wolf into a sheep:

```
ask one-of wolves [ set breed sheep ]
```

The `set-default-shape` primitive is useful for associating certain turtle shapes with certain breeds. See the section on shapes below.

Who numbers are assigned irrespective of breeds. If you already have a `frog 0`, then the first mouse will be `mouse 1`, not `mouse 0`, since the who number 0 is already taken.

Here is a quick example of using breeds:

```
breed [mice mouse]
breed [frogs frog]
mice-own [cheese]
to setup
  clear-all
  create-mice 50
    [ set color white
      set cheese random 10 ]
  create-frogs 50
    [ set color green ]
  reset-ticks
end
```

Code Example: Breeds and Shapes Example

Link breeds

Link breeds are very similar to turtle breeds, however, there are a few differences.

When you declare a link breed you must declare whether it is a breed of directed or undirected links by using the `directed-link-breed` and `undirected-link-breed` keywords.

```
directed-link-breed [streets street]
undirected-link-breed [friendships friendship]
```

Once you have created a breeded link you cannot create unbreeded links and vice versa. (You can, however, have directed and undirected links in the same world, just not in the same breed)

Unlike with turtle breeds the singular breed name is required for link breeds, as many of the link commands and reports use the singular name, such as `<link-breed>-neighbor?`.

The following primitives are also automatically available once you define a directed link breed: `create-street-from` `create-streets-from` `create-street-to` `create-streets-to` `in-street-neighbor?` `in-street-neighbors` `in-street-from` `my-in-streets` `my-out-streets` `out-street-neighbor?` `out-street-neighbors` `out-street-to`

And the following are automatically available when you define an undirected link breed: `create-friendship-with` `create-friendships-with` `friendship-neighbor?` `friendship-neighbors` `friendship-with` `my-friendships`

Multiple link breeds may declare the same `-own` variable, but a variable may not be shared between a turtle breed and a link breed.

Just as with turtle breeds the order in which link breeds are declared defines the order in which the links are drawn, so the friendships will always be on top of streets (if for some reason these breeds were in the same model). You can also use `<link-breeds>-own` to declare variables of each link breed separately.

You can change the breed of a link with `set breed`. (However, you cannot change a breeded link to an unbreeded one, to prevent having breeded and unbreeded links in the same world.)

```
ask one-of friendships [ set breed streets ]
ask one-of friendships [ set breed links ] ;; produces a runtime error
```

`set-default-shape` may also be used with link breeds to associate it with a particular link shape.

Code Example: Link Breeds Example

Buttons

Buttons in the interface tab provide an easy way to control the model. Typically a model will have at least a "setup" button, to set up the initial state of the world, and a "go" button to make the model run continuously. Some models will have additional buttons that perform other actions.

A button contains some NetLogo code. That code is run when you press the button.

A button may be either a "once button", or a "forever button". You can control this by editing the button and checking or unchecking the "Forever" checkbox. Once buttons run their code once, then stop and pop back up. Forever buttons keep running their code over and over again.

A forever button stops if the user presses the button again to stop it. The button waits until the current iteration has finished, then pops up.

A forever button can also be stopped from code. If the forever button directly calls a procedure, then when that procedure stops, the button stops. (In a turtle or patch forever button, the button won't stop until every turtle or patch stops -- a single turtle or patch doesn't have the power to stop the whole button.)

Normally, a button is labeled with the code that it runs. For example, a button that says "go" on it usually contains the code "go", which means "run the go procedure". (Procedures are defined in the Code tab; see below.) But you can also edit a button and enter a "display name" for the button, which is a text that appears on the button instead of the code. You might use this feature if you think the actual code would be confusing to your users.

When you put code in a button, you must also specify which agents you want to run that code. You can choose to have the observer run the code, or all turtles, or all patches, or all links. (If you want the code to be run by only some turtles or some patches, you could make an observer button, and then have the observer use the `ask` command to ask only some of the turtles or patches to do something.)

When you edit a button, you have the option to assign an "action key". This makes that key on the keyboard behave just like a button press. If the button is a forever button, it will stay down until the key is pressed again (or the button is clicked). Action keys are particularly useful for games or any model where rapid triggering of buttons is needed.

Buttons take turns

More than one button can be pressed at a time. If this happens, the buttons "take turns", which means that only one button runs at a time. Each button runs its code all the way through once while the other buttons wait, then the next button gets its turn.

In the following examples, "setup" is a once button and "go" is a forever button.

Example #1: The user presses "setup", then presses "go" immediately, before the "setup" has popped back up. Result: "setup" finishes before "go" starts.

Example #2: While the "go" button is down, the user presses "setup". Result: the "go" button finishes its current iteration. Then the "setup" button runs. Then "go" starts running again.

Example #3: The user has two forever buttons down at the same time. Result: first one button runs its code all the way through, then the other runs its code all the way through, and so on, alternating.

Note that if one button gets stuck in an infinite loop, then no other buttons will run.

Turtle, patch, and link forever buttons

There is a subtle difference between putting commands in a turtle, patch or link forever button, and putting the same commands in an observer button that does `ask turtles`, `ask patches` or `ask links`. An "ask" doesn't complete until all of the agents have finished running all of the commands in the "ask". So the agents, as they all run the commands concurrently, can be out of sync with each other, but they all sync up again at the end of the ask. The same isn't true of turtle, patch and link forever buttons. Since `ask` was not used, each turtle or patch runs the given code over and over again, so they can become (and remain) out of sync with each other.

At present, this capability is very rarely used in the models in our Models Library. A model that does use the capability is the Termites model, in the Biology section of Sample Models. The "go" button is a turtle forever button, so each termite proceeds independently of every other termite, and the observer is not involved at all. This means that if, for example, you wanted to add ticks and/or a plot to the model, you would need to add a second forever button (an observer forever button), and run both forever buttons at the same time. Note also that a model like this cannot be used with BehaviorSpace.

Code Example: State Machine Example shows how Termites can be recoded in a tick-based way, without using a turtle forever button.

At present, NetLogo has no way for one forever button to start another. Buttons are only started when you press them.

Lists

In the simplest models, each variable holds only one piece of information, usually a number or a string. Lists let you store multiple pieces of information in a single value by collecting that information in a list. Each value in the list can be any type of value: a number, or a string, an agent or agentset, or even another list.

Lists allow for the convenient packaging of information in NetLogo. If your agents carry out a repetitive calculation on multiple variables, it might be easier to have a list variable, instead of multiple number variables. Several primitives simplify the process of performing the same computation on each value in a list.

The NetLogo Dictionary has a section that lists all of the list-related primitives.

Constant lists

You can make a list by simply putting the values you want in the list between brackets, like this: `set mylist [2 4 6 8]`. Note that the individual values are separated by spaces. You can make lists that contain numbers and strings this way, as well as lists within lists, for example `[[2 4] [3 5]]`.

The empty list is written by putting nothing between the brackets, like this: `[]`.

Building lists on the fly

If you want to make a list in which the values are determined by reporters, as opposed to being a series of constants, use the `list` reporter. The `list` reporter accepts two other reporters, runs them, and reports the results as a list.

If I wanted a list to contain two random values, I might use the following code:

```
set random-list list (random 10) (random 20)
```

This will set `random-list` to a new list of two random integers each time it runs.

To make longer or shorter lists, you can use the `list` reporter with fewer or more than two inputs, but in order to do so, you must enclose the entire call in parentheses, e.g.:

```
(list random 10)
(list random 10 random 20 random 30)
```

For more information, see Varying number of inputs.

Some kinds of lists are most easily built using the `n-values` reporter, which allows you to construct a list of a specific length by repeatedly running a given reporter. You can make a list of the same value repeated, or all the numbers in a range, or a lot of random numbers, or many other possibilities. See dictionary entry for details and examples.

The `of` primitive lets you construct a list from an agentset. It reports a list containing each agent's value for the given reporter. (The reporter could be a simple variable name, or a more complex expression -- even a call to a procedure defined using `to-report`.) A common idiom is

```
max [...] of turtles
sum [...] of turtles
```

and so on.

You can combine two or more lists using the `sentence` reporter, which concatenates lists by combining their contents into a single, larger list. Like `list`, `sentence` normally takes two inputs, but can accept any number of inputs if the call is surrounded by parentheses.

Changing list items

Technically, lists can't be modified, but you can construct new lists based on old lists. If you want the new list to replace the old list, use set. For example:

```
set mylist [2 7 5 Bob [3 0 -2]]
; mylist is now [2 7 5 Bob [3 0 -2]]
set mylist replace-item 2 mylist 10
; mylist is now [2 7 10 Bob [3 0 -2]]
```

The replace-item reporter takes three inputs. The first input specifies which item in the list is to be changed. 0 means the first item, 1 means the second item, and so forth.

To add an item, say 42, to the end of a list, use the lput reporter. (fput adds an item to the beginning of a list.)

```
set mylist lput 42 mylist
; mylist is now [2 7 10 Bob [3 0 -2] 42]
```

But what if you changed your mind? The but-last (bl for short) reporter reports all the list items but the last.

```
set mylist but-last mylist
; mylist is now [2 7 10 Bob [3 0 -2]]
```

Suppose you want to get rid of item 0, the 2 at the beginning of the list.

```
set mylist but-first mylist
; mylist is now [7 10 Bob [3 0 -2]]
```

Suppose you wanted to change the third item that's nested inside item 3 from -2 to 9? The key is to realize that the name that can be used to call the nested list [3 0 -2] is `item 3 mylist`. Then the replace-item reporter can be nested to change the list-within-a-list. The parentheses are added for clarity.

```
set mylist (replace-item 3 mylist
                  (replace-item 2 (item 3 mylist) 9))
; mylist is now [7 10 Bob [3 0 9]]
```

Iterating over lists

If you want to do some operation on each item in a list in turn, the foreach command and the map reporter may be helpful.

foreach is used to run a command or commands on each item in a list. It takes an input list and a command name or block of commands, like this:

```
foreach [1 2 3] show
=> 1
=> 2
=> 3
foreach [2 4 6]
  [ n -> crt n
    show (word "created " n " turtles") ]
=> created 2 turtles
=> created 4 turtles
=> created 6 turtles
```

In the block, the variable `n` holds the current value from the input list.

Here are some more examples of `foreach`:

```
foreach [1 2 3] [ steps -> ask turtles [ fd steps ] ]
;; turtles move forward 6 patches
foreach [true false true true] [ should-move? -> ask turtles [ if should-move? [ fd 1 ] ] ]
;; turtles move forward 3 patches
```

`map` is similar to `foreach`, but it is a reporter. It takes an input list and a reporter name or reporter block. Note that unlike `foreach`, the reporter comes first, like this:

```
show map round [1.2 2.2 2.7]
;; prints [1 2 3]
```

`map` reports a list containing the results of applying the reporter to each item in the input list. Again, use the variable named in the anonymous procedure (`x` in the examples below) to refer to the current item in the list.

Here are a couple more examples of `map`:

```
show map [ x -> x < 0 ] [1 -1 3 4 -2 -10]
;; prints [false true false false true true]
show map [ x -> x * x ] [1 2 3]
;; prints [1 4 9]
```

Besides `map` and `foreach`, other primitives for processing whole lists in a configurable way include `filter`, `reduce`, and `sort-by`.

These primitives aren't always the solution for every situation in which you want to operate on an entire list. In some situations, you may need to use some other technique such as a loop using `repeat` or `while`, or a recursive procedure.

The blocks of code we're giving to `map` and `foreach` in these examples are actually **anonymous procedures**. Anonymous procedures are explained in more detail in Anonymous procedures, below.

Varying number of inputs

Some commands and reporters involving lists and strings may take a varying number of inputs. In these cases, in order to pass them a number of inputs other than their default, the primitive and its inputs must be surrounded by parentheses. Here are some examples:

```
show list 1 2
=> [1 2]
show (list 1 2 3 4)
=> [1 2 3 4]
show (list)
=> []
```

Note that each of these special primitives has a default number of inputs for which no parentheses are required. The primitives which have this capability are `list`, `word`, `sentence`, `map`, `foreach`, `run`, and `runresult`.

Lists of agents

Earlier, we said that agentsets are always in random order, a different random order every time. If you need your agents to do something in a fixed order, you need to make a list of the agents instead.

There are two primitives that help you do this, `sort` and `sort-by`.

Both `sort` and `sort-by` can take an agentset as input. The result is always a new list, containing the same agents as the agentset did, but in a particular order.

If you use `sort` on an agentset of turtles, the result is a list of turtles sorted in ascending order by `who` number.

If you use `sort` on an agentset of patches, the result is a list of patches sorted left-to-right, top-to-bottom.

If you use `sort` on an agentset of links, the result is a list of links, sorted in ascending order first by `end1` then by `end2` any remaining ties are resolved by breed in the order they are declared in the Code tab.

If you need descending order instead, you can combine `reverse` with `sort`, for example `reverse sort turtles`.

If you want your agents to be ordered by some other criterion than the standard ones `sort` uses, you'll need to use `sort-by` instead.

Here's an example:

```
sort-by [ [a b] -> [size] of a < [size] of b ] turtles
```

This returns a list of turtles sorted in ascending order by their turtle variable `size`.

There's a common pattern to get a list of agents in a random order, using a combination of `of` and `self`, in the rare case that you cannot just use `ask`:

```
[self] of my-agentset
```

Asking a list of agents

Once you have a list of agents, you might want to ask them each to do something. To do this, use the `foreach` and `ask` commands in combination, like this:

```
foreach sort turtles [ the-turtle ->
  ask the-turtle [
    ...
  ]
]
```

This will ask each turtle in ascending order by who number. Substitute "patches" for "turtles" to ask patches in left-to-right, top-to-bottom order.

Note that you can't use `ask` directly on a list of turtles. `ask` only works with agentsets and single agents.

Performance of lists

The data structure underlying NetLogo's lists is a sophisticated tree-based data structure on which most operations run in near-constant time. That includes `fput`, `lput`, `butfirst`, `butlast`, `length`, `item`, and `replace-item`.

One exception to the fast-performance rule is that concatenating two lists with `sentence` requires traversing and copying the whole second list. (This may be fixed in a future version.)

Technically, "near-constant time" is actually logarithmic time, proportional to the depth of the underlying tree, but these trees have large nodes and a high branching factor, so they are never more than a few levels deep. This means that changes can be made in at most a few steps. The trees are immutable, but they share structure with each other, so the whole tree doesn't need to be copied to make a changed version.

The actual data structure used is the immutable Vector class from the Scala collections library. These are 32-wide hash array mapped tries, as implemented by Tiark Rompf, based in part on work by Phil Bagwell and Rich Hickey.

Math

All numbers in NetLogo are stored internally as double precision floating point numbers, as defined in the IEEE 754 standard. They are 64 bit numbers consisting of one sign bit, an 11-bit exponent, and a 52-bit mantissa. See the IEEE 754 standard for details.

An "integer" in NetLogo is simply a number that happens to have no fractional part. No distinction is made between 3 and 3.0; they are the same number. (This is the same as how most people use numbers in everyday contexts, but different from some programming languages. Some languages treat integers and floating point numbers as distinct types.)

Integers are always printed by NetLogo without the trailing ".0":

```
show 1.5 + 1.5
observer: 3
```

If a number with a fractional part is supplied in a context where an integer is expected, the fractional part is simply discarded. So for example, `crt 3.5` creates three turtles; the extra 0.5 is ignored.

The range of integers is +/-9007199254740992 (2^53, about 9 quadrillion). Calculations that exceed this range will not cause runtime errors, but precision will be lost when the least significant (binary) digits are rounded off in order fit the number into 64 bits. With very large numbers, this rounding can result in imprecise answers which may be surprising:

```
show 2 ^ 60 + 1 = 2 ^ 60
=> true
```

Calculations with smaller numbers can also produce surprising results if they involve fractional quantities, since not all fractions can be precisely represented and roundoff may occur. For example:

```
show 1 / 6 + 1 / 6 + 1 / 6 + 1 / 6 + 1 / 6 + 1 / 6
=> 0.9999999999999999
show 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9 + 1 / 9
=> 1.0000000000000002
```

Any operation which produces the special quantities "infinity" or "not a number" will cause a runtime error.

Scientific notation

Very large or very small floating point numbers are displayed by NetLogo using "scientific notation". Examples:

```
show 0.000000000001
=> 1.0E-12
show 50000000000000000000
=> 5.0E19
```

Numbers in scientific notation are distinguished by the presence of the letter E (for "exponent"). It means "times ten to the power of", so for example, 1.0E-12 means 1.0 times 10 to the -12 power:

```
show 1.0 * 10 ^ -12
=> 1.0E-12
```

You can also use scientific notation yourself in NetLogo code:

```
show 3.0E6
=> 3000000
```

```
show 8.123456789E6
=> 8123456.789
show 8.123456789E7
=> 8.123456789E7
show 3.0E16
=> 3.0E16
show 8.0E-3
=> 0.0080
show 8.0E-4
=> 8.0E-4
```

These examples show that numbers with fractional parts are displayed using scientific notation if the exponent is less than -3 or greater than 6. Numbers outside of NetLogo's integer range of -9007199254740992 to 9007199254740992 (+/-2^53) are also always shown in scientific notation:

```
show 2 ^ 60
=> 1.15292150460684698E18
```

When entering a number, the letter E may be either upper or lowercase. When printing a number, NetLogo always uses an uppercase E:

```
show 4.5e20
=> 4.5E20
```

Floating point accuracy

Because numbers in NetLogo are subject to the limitations of how floating point numbers are represented in binary, you may get answers that are slightly inaccurate. For example:

```
show 0.1 + 0.1 + 0.1
=> 0.30000000000000004
show cos 90
=> 6.123233995736766E-17
```

This is an inherent issue with floating point arithmetic; it occurs in all programming languages that use floating point numbers.

If you are dealing with fixed precision quantities, for example dollars and cents, a common technique is to use only integers (cents) internally, then divide by 100 to get a result in dollars for display.

If you must use floating point numbers, then in some situations you may need to replace a straightforward equality test such as `if x = 1 [ ... ]` with a test that tolerates slight imprecision, for example `if abs (x - 1) < 0.0001 [ ... ]`.

Also, the `precision` primitive is handy for rounding off numbers for display purposes. NetLogo monitors round the numbers they display to a configurable number of decimal places, too.

Random numbers

The random numbers used by NetLogo are what is called "pseudo-random". (This is typical in computer programming.) That means they appear random, but are in fact generated by a deterministic process. "Deterministic" means that you get the same results every time, if you start with the same random "seed". We'll explain in a minute what we mean by "seed".

In the context of scientific modeling, pseudo-random numbers are actually desirable. That's because it's important that a scientific experiment be reproducible -- so anyone can try it themselves and get the same result that you got. Since NetLogo uses pseudo-random numbers, the "experiments" that you do with it can be reproduced by others.

Here's how it works. NetLogo's random number generator can be started with a certain seed value, which must be an integer in the range -2147483648 to 2147483647. Once the generator has been "seeded" with the `random-seed` command, it always generates the same sequence of random numbers from then on. For example, if you run these commands:

```
random-seed 137
show random 100
show random 100
show random 100
```

You will always get the numbers 79, 89, and 61 in that order.

Note, however, that you're only guaranteed to get those same numbers if you're using the same version of NetLogo. Sometimes when we make a new version of NetLogo the random number generator changes. (Presently, we use a generator known as the Mersenne Twister.)

To create a number suitable for seeding the random number generator, use the `new-seed` reporter. `new-seed` creates a seed, evenly distributed over the space of possible seeds, based on the current date and time. It never reports the same seed twice in a row.

Code Example: Random Seed Example

If you don't set the random seed yourself, NetLogo sets it to a value based on the current date and time. There is no way to find out what random seed it chose, so if you want your model run to be reproducible, you must set the random seed yourself ahead of time.

The NetLogo primitives with "random" in their names (random, random-float, and so on) aren't the only ones that use pseudo-random numbers. Many other operations also make random choices. For example, agentsets are always in random order, `one-of` and `n-of` choose agents randomly, the `sprout` command creates turtles with random colors and headings, and the `downhill` reporter chooses a random patch when there's a tie. All of these random choices are governed by the random seed as well, so model runs can be reproducible.

In addition to the uniformly distributed random integers and floating point numbers generated by `random` and `random-float`, NetLogo also offers several other random distributions. See the dictionary entries for `random-normal`, `random-poisson`, `random-exponential`, and `random-gamma`.

Auxiliary generator

Code run by buttons or from the command center uses the main random number generator.

Code in monitors uses an auxiliary random generator, so even if a monitor does a calculation that uses random numbers, the outcome of the model is not affected. The same is true of code in sliders.

Local randomness

You may want to explicitly specify that a section of code does not affect the state of the main random generator, so the outcome of the model is not affected. The `with-local-randomness` command is provided for this purpose. See its entry in the NetLogo Dictionary for more information.

Turtle shapes

In NetLogo, turtle shapes are vector shapes. They are built up from basic geometric shapes; squares, circles, and lines, rather than a grid of pixels. Vector shapes are fully scalable and rotatable. NetLogo caches bitmap images of vector shapes size 1, 1.5, and 2 in order to speed up execution.

A turtle's shape is stored in its `shape` variable and can be set using the `set` command.

New turtles have a shape of "default". The `set-default-shape` primitive is useful for changing the default turtle shape to a different shape, or having a different default turtle shape for each breed of turtle.

The `shapes` primitive reports a list of currently available turtle shapes in the model. This is useful if, for example, you want to assign a random shape to a turtle:

```
ask turtles [ set shape one-of shapes ]
```

Use the Turtle Shapes Editor to create your own turtle shapes, or to add shapes to your model from our shapes library, or to transfer shapes between models. For more information, see the Shapes Editor section of this manual.

The thickness of the lines used to draw the vector shapes can be controlled by the `set-line-thickness` primitive.

Code Examples: Breeds and Shapes Example, Shape Animation Example

Link shapes

Link Shapes are similar to turtle shapes, only you use the Link Shape Editor to create and edit them. Link shapes consist of between 0 and 3 lines which can have different patterns and a direction indicator that is composed of the same elements as turtle shapes. Links also have a `shape` variable that can be set to any link shape that is in the model. By default links have the "default" shape, though you can change that using `set-default-shape`. The `link-shapes` reporter reports all the link shapes included in the current model.

The thickness of the lines in the link shape is controlled by the `thickness` link variable.

View updates

The "view" in NetLogo lets you see the agents in your model on your computer's screen. As your agents move and change, you see them moving and changing in the view.

Of course, you can't really see your agents directly. The view is a picture that NetLogo paints, showing you how your agents look at a particular instant. Once that instant passes and your agents move and change some more, that picture needs to be repainted to reflect the new state of the world. Repainting the picture is called "updating" the view.

When does the view get updated? This section discusses how NetLogo decides when to update the view, and how you can influence when it gets updated.

NetLogo offers two updates modes, "continuous" updates and "tick-based" updates. You can switch between NetLogo's two view update modes using a popup menu at the top of the Interface tab.

Continuous updates are the default when you start up NetLogo or start a new model. Nearly every model in our Models Library, however, uses tick-based updates.

Continuous updates are simplest, but tick-based updates give you more control over when and how often updates happen.

It's important exactly when an update happens, because when updates happen determines what you see on the screen. If an update comes at an unexpected time, you may see something unexpected -- perhaps something confusing or misleading.

It's also important how often updates happen, because updates take time. The more time NetLogo spends updating the view, the slower your model will run. With fewer updates, your model runs faster.

Continuous updates

Continuous updates are very simple. With continuous updates, NetLogo updates the view a certain number of times per second -- by default, 30 times a second when the speed slider is in the default, middle setting.

If you move the speed slider to a slower setting, NetLogo will update more than 30 times a second, effectively slowing down the model. On a faster setting, NetLogo will update less than 30 times a second. On the fastest setting, updates will be separated by several seconds.

At extremely slow settings, NetLogo will be updating so often that you will see your agents moving (or changing color, etc.) one at a time.

If you need to temporarily shut off continuous updates, use the `no-display` command. The `display` command turns updates back on, and also forces an immediate update (unless the user is fast-forwarding the model using the speed slider).

Tick-based updates

As discussed above in the Tick Counter section, in many NetLogo models, time passes in discrete steps, called "ticks". Typically, you want the view to update once per tick, between ticks. That's the default behavior with tick-based updates.

If you want additional view updates, you can force an update using the `display` command. (The update may be skipped if the user is fast-forwarding the model using the speed slider.)

You don't have to use the tick counter to use tick-based updates. If the tick counter never advances, the view will update only when you use the `display` command.

If you move the speed slider to a fast enough setting, eventually NetLogo will skip some of the updates that would ordinarily have happened. Moving the speed slider to a slower setting doesn't cause additional updates; rather, it makes NetLogo pause after each update. The slower the setting, the longer the pause.

Even under tick-based updates, the view also updates whenever a button in the interface pops up (both once and forever buttons) and when a command entered in the Command Center finishes. So it's not necessary to add the `display` command to once buttons that don't advance the tick counter. Many forever buttons that don't advance the tick counter do need to use the `display` command. An example in the Models Library is the Life model (under Computer Science -> Cellular Automata). The forever buttons that let the user draw in the view use the `display` command so the user can see what they are drawing, even though the tick counter is not advancing.

Choosing a mode

Advantages of tick-based updates over continuous updates include:

1. Consistent, predictable view update behavior which does not vary from computer to computer or from run to run.
2. Continuous updates can confuse the user of your model by letting them see model states they aren't supposed to see, which may be misleading.
3. Increased speed. Updating the view takes time, so if one update per tick is enough, then enforcing there is only one update per tick will make your model faster.
4. Since `setup` buttons don't advance the tick counter, they are unaffected by the speed slider; this is normally the desired behavior.

Nearly every model in our Models Library uses tick-based updates.

Continuous updates are occasionally useful for those rare models in which execution is not divided into short, discrete phases. An example in the Models Library is Termites. (See also, however, the State Machine Example model, which shows how to re-code Termites using ticks.)

Even for models that would normally be set to tick-based updates, it may be useful to switch to continuous updates temporarily for debugging purposes. Seeing what's going on within a tick, instead of only seeing the end result of a tick, could help with troubleshooting. After switching to continuous updates, you may want to use the speed slider to slow the model down until you see your agents moving one at a time. Don't forget to change back to tick-based updates when you are done, as the choice of update mode is saved with the model.

Frame rate

One of the model settings in NetLogo's "Settings..." dialog is "Frame rate" which defaults to 30 frames per second.

The frame rate setting affects both continuous updates and tick-based updates.

With continuous updates, the setting directly determines the frequency of updates.

With tick-based updates, the setting is a *ceiling* on how many updates per second you get. If the frame rate is 30, then NetLogo will ensure that the model never runs faster than that when the speed slider is in the default position. If any frame takes less than 1/30 of a second to compute and display, NetLogo will pause and wait until the full 1/30 of a second has passed before continuing.

The frame rate settings lets you set what you consider to be a normal speed for your model. Then you, or the user of your model, can use the speed slider to temporarily get a faster or slower speed.

Plotting

NetLogo's plotting features let you create plots to help you understand what's going on in your model.

Before you can plot, you need to create one or more plots in the Interface tab. For more information on using and editing plots in the Interface tab, see the Interface Guide.

Plotting points

The two basic commands for actually plotting things are `plot` and `plotxy`.

With `plot` you need only specify the y value you want plotted. The x value will automatically be 0 for the first point you plot, 1 for the second, and so on. (That's if the plot pen's "interval" is the default value of 1; you can change the interval.)

The `plot` command is especially handy when you want your model to plot a new point at every time step. Example:

```
plot count turtles
```

If you need to specify both the x and y values of the point you want plotted, then use `plotxy` instead. This example assumes that a global variable called `time` exists:

```
plotxy time count-turtles
```

Plot commands

Each plot and its pens have setup and update code fields that may contain commands (usually containing `plot` or `plotxy`). These commands are run automatically triggered by other commands in NetLogo.

Plot setup commands and pen setup commands are run when the either `reset-ticks` or `setup-plots` commands are run. If the `stop` command is run in the body of the plot setup commands then the pen setup commands will not run.

Plot update commands and pen update commands are run when the either `reset-ticks`, `tick` or `update-plots` commands are run. If the `stop` command is run in the body of the plot update commands then the pen update commands will not run.

Here are the four commands that trigger plotting explained in more detail.

- `setup-plots` executes commands for one plot at a time. For each plot, the plot's setup commands are executed. If the stop command is not encountered while running those commands, then each of the plot's pens will have their setup code executed.
- `update-plots` is very similar to `setup-plots`. For each plot, the plot's update commands are executed. If the stop command is not encountered while running those commands, then each of the plot's pens will have their update code executed.
- `tick` is exactly the same as `update-plots` except that the tick counter is incremented before the plot commands are executed.
- `reset-ticks` first resets the tick counter to 0, and then does the equivalent of `setup-plots` followed by `update-plots`.

A typical model will use `reset-ticks` and `tick` like so:

```
to setup
  clear-all
  ...
  reset-ticks
end

to go
  ...
  tick
end
```

Note that in this example we plot from both the `setup` and `go` procedures (because `reset-ticks` runs plot setup and plot update commands). We do this because we want our plot to include the initial state of the system at the end of `setup`. We plot at the end of the `go` procedure, not the beginning, because we want the plot always to be up to date after the go button stops.

Models that don't use ticks but still want to do plotting will instead use `setup-plots` and `update-plots`. In the previous code, replace `reset-ticks` with `setup-plots update-plots` and replace tick with `update-plots`.

Code Example: Plotting Example

Other kinds of plots

By default, NetLogo plot pens plot in line mode, so that the points you plot are connected by a line.

If you want to move the pen without plotting, you can use the `plot-pen-up` command. After this command is issued, the `plot` and `plotxy` commands move the pen but do not actually draw anything. Once the pen is where you want it, use `plot-pen-down` to put the pen back down.

If you want to plot individual points instead of lines, or you want to draw bars instead of lines or points, you need to change the plot pen's "mode". Three modes are available: line, bar, and point. Line is the default mode.

Normally, you change a pen's mode by editing the plot. This changes the pen's default mode. It's also possible to change the pen's mode temporarily using the `set-plot-pen-mode command`. That command takes a number as input: 0 for line, 1 for bar, 2 for point.

Histograms

A histogram is a special kind of plot that measures how frequently certain values, or values in certain ranges, occur in a collection of numbers that arise in your model.

For example, suppose the turtles in your model have an age variable. You could create a histogram of the distribution of ages among your turtles with the histogram command, like this:

```
histogram [age] of turtles
```

The numbers you want to histogram don't have to come from an agentset; they could be any list of numbers.

Note that using the histogram command doesn't automatically switch the current plot pen to bar mode. If you want bars, you have to set the plot pen to bar mode yourself. (As we said before, you can change a pen's default mode by editing the plot in the Interface tab.)

Like other types of plots, histograms can be set to auto scale. However, auto scaled histograms do not automatically resize themselves horizontally like other plot types do. To set the range programmatically, you can use the `set-plot-x-range` primitive.

The width of the bars in a histogram is controlled by the plot pen's interval. You can set a plot pen's default interval by editing the plot in the Interface tab. You can also change the interval temporarily with the `set-plot-pen-interval` command or the `set-histogram-num-bars`. If you use the latter command, NetLogo will set the interval appropriately so as to fit the specified number of bars within the plot's current x range.

Code Example: Histogram Example

Clearing and resetting

You can clear the current plot with the `clear-plot` command, or clear every plot in your model with `clear-all-plots`. The `clear-all command` also clears all plots, in addition to clearing everything else in your model.

If you want to remove only the points that a particular pen has drawn, use `plot-pen-reset`.

When a whole plot is cleared, or when a pen is reset, that doesn't just remove the data that has been plotted. It also restores the plot or pen to its default settings, as they were specified in the Interface tab when the plot was created or last edited. Therefore, the effects of such commands as `set-plot-x-range` and `set-plot-pen-color` are only temporary.

Ranges and auto scaling

The default x and y ranges for a plot are fixed numbers, but they can be changed at setup time or as the model runs.

To change the ranges at any time, use `set-plot-x-range` and `set-plot-y-range`. Or, you can let the ranges grow automatically. Either way, when the plot is cleared the ranges will return to their default values.

By default, all NetLogo plots have the auto scaling feature enabled. This means that if the model tries to plot a point which is outside the current displayed range, the range of the plot will grow along one or both axes so that the new point is visible. Histogram plots, however, do not auto scale horizontally.

In the hope that the ranges won't have to change every time a new point is added, when the ranges grow they leave some extra room: 25% if growing horizontally, 10% if growing vertically.

If you want to turn off this feature, edit the plot and uncheck the Auto Scale? checkbox. At present, it is not possible to enable or disable this feature only on one axis; it always applies to both axes.

Using a Legend

You can show the legend of a plot by checking the "Show legend" checkbox in the edit dialog. If you don't want a particular pen to show up in the legend you can uncheck the "Show in Legend" checkbox for that pen also in the advanced plot pen settings (the advanced plot pen settings can be opened by clicking the pencil button for that pen in the plot pens table in the plot edit dialog).

Temporary plot pens

Most plots can get along with a fixed number of pens. But some plots have more complex needs; they may need to have the number of pens vary depending on conditions. In such cases, you can make "temporary" plot pens from code and then plot with them. These pens are called "temporary" because they vanish when the plot is cleared (by the `clear-plot`, `clear-all-plots`, or `clear-all` commands).

To create a temporary plot pen, use the `create-temporary-plot-pen` command. Typically, this would be done in the Code tab, but it is also possible to use this command from plot setup or plot update code (in the edit dialog). By default, the new pen is down, is black in color, has an interval of 1, and plots in line mode. Commands are available to change all of these settings; see the Plotting section of the NetLogo Dictionary.

Before you can use the pen, you'll have to use the use the `set-current-plot` and `set-current-plot-pen` commands. These are explained in the next section.

set-current-plot and set-current-plot-pen

Before NetLogo 5, it was not possible to put plot commands in the plot itself. All of the plot code was written in the Code tab with the rest of the code. For backwards compatibility, and for temporary plot pens, this is still supported. Models in previous versions of NetLogo (and those using temporary plot pens) have to explicitly state which plot is the current plot with the `set-current-plot` command and which pen is the current pen with the `set-current-plot-pen` command.

To set the current plot use the `set-current-plot` command with the name of the plot enclosed in double quotes, like this:

```
set-current-plot "Distance vs. Time"
```

The name of the plot must be exactly as you typed it when you created the plot. Note that later if you change the name of the plot, you'll also have to update the `set-current-plot` calls in your model to use the new name. (Copy and paste can be helpful here.)

For a plot with multiple pens, you can manually specify which pen you want to plot with. If you don't specify a pen, plotting will take place with the first pen in the plot. To plot with a different pen, the `set-current-plot-pen` command was used with the name of the pen enclosed in double quotes, like this:

```
set-current-plot-pen "distance"
```

Once the current pen is set, then commands like `plot count turtles` can be executed for that pen.

Older models with plots usually had their own `do-plotting` procedure that looked something like this:

```
to do-plotting
  set-current-plot "populations"
  set-current-plot-pen "sheep"
  plot count sheep
  set-current-plot-pen "wolves"
  plot count wolves

  set-current-plot "next plot"
  ...
end
```

Once again, this is no longer necessary in NetLogo 5, unless you are using temporary plot pens.

Conclusion

Not every aspect of NetLogo's plotting system has been explained here. See the Plotting section of the NetLogo Dictionary for information on additional commands and reporters related to plotting.

Many of the Sample Models in the Models Library illustrate various advanced plotting techniques. Also check out the following code examples:

Code Examples: Plot Axis Example, Plot Smoothing Example, Rolling Plot Example

Strings

Strings may contain any Unicode characters.

To input a constant string in NetLogo, surround it with double quotes.

The empty string is written by putting nothing between the quotes, like this: `""`.

Most of the list primitives work on strings as well:

```
but-first "string" => "tring"
but-last "string" => "strin"
empty? "" => true
empty? "string" => false
first "string" => "s"
item 2 "string" => "r"
last "string" => "g"
length "string" => 6
member? "s" "string" => true
member? "rin" "string" => true
member? "ron" "string" => false
position "s" "string" => 0
position "rin" "string" => 2
position "ron" "string" => false
remove "r" "string" => "sting"
remove "s" "strings" => "tring"
replace-item 3 "string" "o" => "strong"
reverse "string" => "gnirts"
```

A few primitives are specific to strings, such as `is-string?`, `substring`, and `word`:

```
is-string? "string" => true
is-string? 37 => false
substring "string" 2 5 => "rin"
word "tur" "tle" => "turtle"
```

Strings can be compared using the =, !=, <, >, <=, and >= operators.

If you need to embed a special character in a string, use the following escape sequences:

- `\n` = newline
- `\t` = tab
- `\"` = double quote
- `\\` = backslash

Output

This section is about output to the screen. Output to the screen can also be later saved to a file using the `export-output` command. If you need a more flexible method of writing data to external files, see the next section, File I/O.

The basic commands for generating output to the screen in NetLogo are `print`, `show`, `type`, and `write`. These commands send their output to the Command Center.

For full details on these four commands, see their entries in the NetLogo Dictionary. Here is how they are typically used:

- `print` is useful in most situations.
- `show` lets you see which agent is printing what.
- `type` lets you print several things on the same line.
- `write` lets you print values in a format which can be read back in using `file-read`.

A NetLogo model may optionally have an "output area" in its Interface tab, separate from the Command Center. To send output there instead of the Command Center, use the `output-print`, `output-show`, `output-type`, and `output-write` commands.

The output area can be cleared with the `clear-output` command and saved to a file with `export-output`. The contents of the output area will be saved by the `export-world` command. The `import-world` command will clear the output area and set its contents to the value in imported world file. It should be noted that large amounts of data being sent to the output area can increase the size of your exported worlds.

If you use `output-print`, `output-show`, `output-type`, `output-write`, `clear-output`, or `export-output` in a model which does not have a separate output area, then the commands apply to the output portion of the Command Center.

File I/O

In NetLogo, there is a set of primitives that give you the power to interact with outside files. They all begin with the prefix **file-**.

There are two main modes when dealing with files: reading and writing. The difference is the direction of the flow of data. When you are reading in information from a file, data that is stored in the file flows into your model. On the other hand, writing allows data to flow out of your model and into a file.

When working with files, always begin by using the primitive `file-open`. This specifies which file you will be interacting with. None of the other primitives work unless you open a file first.

The next **file-** primitive you use dictates which mode the file will be in until the file is closed, reading or writing. To switch modes, close and then reopen the file.

The reading primitives include `file-read`, `file-read-line`, `file-read-characters`, and `file-at-end?` Note that the file must exist already before you can open it for reading.

Code Examples: File Input Example

The primitives for writing are similar to the primitives that print things in the Command Center, except that the output gets saved to a file. They include `file-print`, `file-show`, `file-type`, and `file-write`. Note that you can never "overwrite" data. In other words, if you attempt to write to a file with existing data, all new data will be appended to the end of the file. (If you want to overwrite a file, use `file-delete` to delete it, then open it for writing.)

Code Examples: File Output Example

When you are finished using a file, you can use the command `file-close` to end your session with the file. If you wish to remove the file afterwards, use the primitive `file-delete` to delete it. To close multiple opened files, one needs to first select the file by using `file-open` before closing it.

```
;; Open 3 files
file-open "myfile1.txt"
file-open "myfile2.txt"
file-open "myfile3.txt"

;; Now close the 3 files
file-close
file-open "myfile2.txt"
file-close
file-open "myfile1.txt"
file-close
```

Or, if you know you just want to close every file, you can use `file-close-all`.

Two primitives worth noting are `file-write` and `file-read` . These primitives are designed to easily save and retrieve NetLogo constants such as numbers, lists, booleans, and strings. file-write will always output the variable in such a manner that file-read will be able to interpret it correctly.

```
file-open "myfile.txt"  ;; Opening file for writing
ask turtles
  [ file-write xcor file-write ycor ]
file-close

file-open "myfile.txt"  ;; Opening file for reading
ask turtles
  [ setxy file-read file-read ]
file-close
```

Code Examples: File Input Example and File Output Example

Letting the user choose

The `user-directory`, `user-file`, and `user-new-file` primitives are useful when you want the user to choose a file or directory for your code to operate on.

Movies

This section describes how to capture an ".mp4" movie of a NetLogo model.

First, use the `vid:start-recorder` command to start the video recorder.

To add a frame to your movie, use either `vid:record-view` or `vid:record-interface`, depending on whether you want the movie to show just the current view, or the entire Interface tab. In a single movie, the resolution will be one of the following:

- the resolution specified in the call to `vid:start-recorder` *`width height`* if you specified the resolution. These are optional parameters.
- The resolution of the view if you did not specify a resolution in the call to `vid:start-recorder` and call `vid:record-view` before calling `vid:record-interface`
- The resolution of the interface if you did not specify a resolution in the call to `vid:start-recorder` and call `vid:record-interface` before calling `vid:record-view`

Note that if the resolution of a recorded image doesn't match the resolution of the recording it will be scaled to fit which can result in images which look blurry or out-of-focus.

When you're done adding frames, use `vid:save-recording`. The filename you provide should end with `.mp4`, the extension for MP4-encoded movies (playable in QuickTime and other programs).

```
;; export a 30 frame movie of the view
extensions [vid]

;...
```

```
setup
vid:start-recorder
vid:record-view ;; show the initial state
repeat 30
[ go
  vid:record-view ]
vid:save-recording "out.mp4"
```

A movie will play back at 25 frames per second. To make the movie playback faster or slower, consider using a video postprocessing tool.

To check whether or not you are recording, call `vid:recorder-status`, which reports a string that describes the state of the current recorder.

To throw away the movie currently being recorded, call `vid:reset-recorder`.

Code Example: Movie Example

Movies generated when running headless, or by background runs in a parallel BehaviorSpace experiment may use only `vid:record-view` primitive. Movies generated in NetLogo GUI may also use `vid:record-interface` and `vid:record-source`.

NetLogo movies are exported as H.264-encoded MP4 files. To play an MP4 movie, you can use the VLC Player, a free download from the VideoLAN organization.

Movies can take up a lot of disk space. You will probably want to compress your movies with third-party software. The software may give you a choice of different kinds of compression. Some kinds of compression are lossless, while others are lossy. "Lossy" means that in order to make the files smaller, some of the detail in the movie is lost. Depending on the nature of your model, you may want to avoid using lossy compression, for example if the view contains fine pixel-level detail.

Perspective

The 2D and the 3D view show the world from the perspective of the observer. By default the observer is looking down on the world from the positive z-axis at the origin. You can change the perspective of the observer by using the `follow`, `ride` and `watch` observer commands and `follow-me`, `ride-me` and `watch-me` turtle commands. When in follow or ride mode the observer moves with the subject agent around the world. The difference between follow and ride is only visible in the 3D view. In the 3D view the user can change the distance behind the agent using the mouse. When the observer is following at zero distance from the agent it is actually riding the agent. When the observer is in watch mode it tracks the movements of one turtle without moving. In both views you will see a spotlight appear on the subject and in the 3D view the observer will turn to face the subject. To determine which agent is the focus you can use the `subject` reporter.

Code Example: Perspective Example

Drawing

The drawing is a layer where turtles can make visible marks.

In the view, the drawing appears on top of the patches but underneath the turtles. Initially, the drawing is empty and transparent.

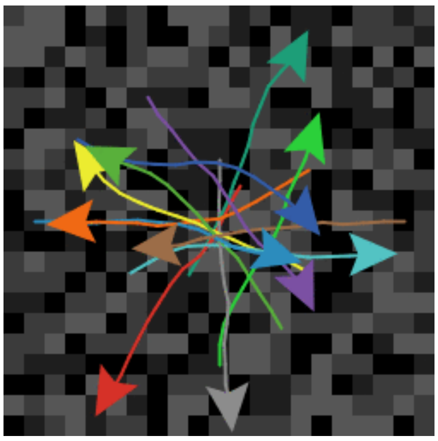
You can see the drawing, but the turtles (and patches) can't. They can't sense the drawing or react to it. The drawing is just for people to look at.

Turtles can draw and erase lines in the drawing using the `pen-down` and `pen-erase` commands. When a turtle's pen is down (or erasing), the turtle draws (or erases) a line behind it whenever it moves. The lines are the same color as the turtle. To stop drawing (or erasing), use `pen-up`.

Lines drawn by turtles are normally one pixel thick. If you want a different thickness, set the `pen-size` turtle variable to a different number before drawing (or erasing). In new turtles, the variable is set to 1.

Lines made when a turtle moves in a way that doesn't fix a direction, such as with `setxy` or `move-to`, the shortest path line that obeys the topology will be drawn.

Here's some turtles which have made a drawing over a grid of randomly shaded patches. Notice how the turtles cover the lines and the lines cover the patch colors. The `pen-size` used here was 2:



The `stamp` command lets a turtle leave an image of itself behind in the drawing and `stamp-erase` lets it remove the pixels below it in the drawing.

To erase the whole drawing, use the observer commmand `clear-drawing`. (You can also use `clear-all`, which clears everything else too.)

Importing an image

The observer command `import-drawing` command allows you to import an image file from disk into the drawing.

`import-drawing` is useful only for providing a backdrop for people to look at. If you want turtles and patches to react to the image, you should use `import-pcolors` or `import-pcolors-rgb` instead.

Comparison to other Logos

Drawing works somewhat differently in NetLogo than some other Logos.

Notable differences include:

- New turtles' pens are up, not down.
- Instead of using a `fence` command to confine the turtle inside boundaries, in NetLogo you edit the world and turn wrapping off.
- There is no `screen-color`, `bgcolor`, or `setbg`. You can make a solid background by coloring the patches, e.g. `ask patches [ set pcolor blue ]`.

Drawing features not supported by NetLogo:

- There is no `window` command. This is used in some other Logos to let the turtle roam over an infinite plane.
- There is no `flood` or `fill` command to fill an enclosed area with color.

Topology

The way the world of patches is connected can change. By default the world is a torus which means it isn't bounded, but "wraps" -- so when a turtle moves past the edge of the world, it disappears and reappears on the opposite edge and every patch has the same number of "neighbor" patches. If you're a patch on the edge of the world, some of your "neighbors" are on the opposite edge.

However, you can change the wrap settings with the Settings button. If wrapping is not allowed in a given direction then in that direction (x or y) the world is bounded. Patches along that boundary will have fewer than 8 neighbors and turtles will not move beyond the edge of the world.

The topology of the NetLogo world has four potential values, torus, box, vertical cylinder, or horizontal cylinder. The topology is controlled by enabling or disabling wrapping in the x or y directions. The default world is a torus.

A torus wraps in both directions, meaning that the top and bottom edges of the world are connected and the left and right edges are connected. So if a turtle moves beyond the right edge of the world it appears again on the left and the same for the top and bottom.

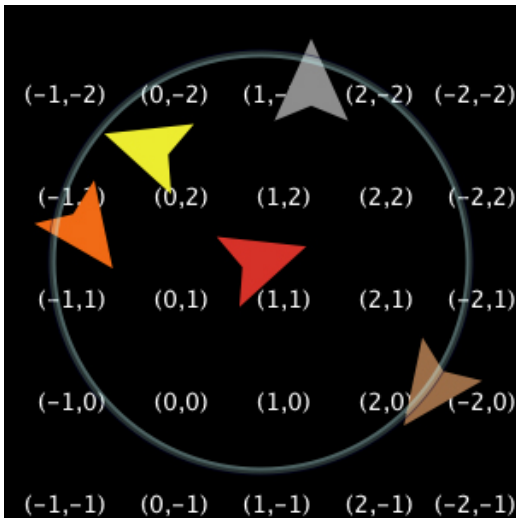
A box does not wrap in either direction. The world is bounded so turtles that try to move off the edge of the world cannot. Note that the patches around edge of the world have fewer than eight neighbors; the corners have three and the rest have five.

Horizontal and vertical cylinders wrap in one direction but not the other. A horizontal cylinder wraps vertically, so the top of the world is connected to the bottom. but the left and right edges are bounded. A vertical cylinder is the opposite; it wraps horizontally so the left and right edges are connected, but the top and bottom edges are bounded.

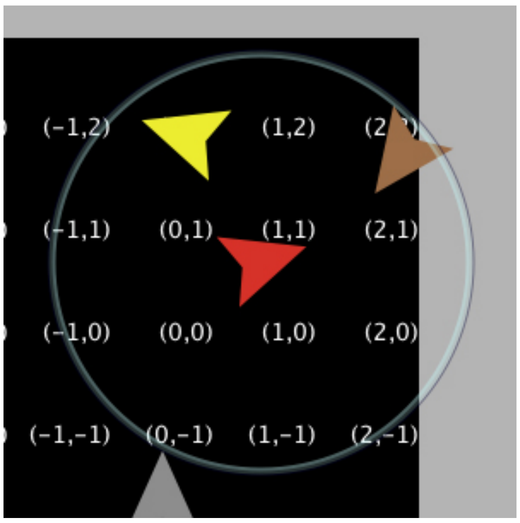
Code Example: Neighbors Example

When coordinates wrap, turtles and links wrap visually in the view, too. If a turtle shape or link extends past an edge, part of it will appear at the other edge. (Turtles themselves are points that take up no space, so they cannot be on both sides of the world at once, but in the view, they appear to take up space because they have a shape.)

Wrapping also affects how the view looks when you are following a turtle. On a torus, wherever the turtle goes, you will always see the whole world around it:



Whereas in a box or cylinder the world has edges, so the areas past those edges show up in the view as gray:



Code Example: Termites Perspective Demo (torus), Ants Perspective Demo (box)

The topology settings also control the behavior of the distance(xy), in-radius, in-cone, face(xy), and towards(xy) primitives. The topology controls whether the primitives wrap or not. They always use the shortest path allowed by the topology. For example, the distance from the center of the patches in the bottom right corner (min-pxcor, min-pycor) and the upper left corner (max-pxcor, max-pycor) will be as follows for each topology given that the min and max pxcor and pycor are +/-2:

- Torus - sqrt(2) ~ 1.414 (this will be the same for all world sizes since the patches are directly diagonal to each other in a torus.)
- Box - sqrt(world-width^2 + world-height^2) ~ 7.07
- Vertical Cylinder - sqrt(world-height^2 + 1) ~ 5.099
- Horizontal Cylinder - sqrt(world-width^2 + 1) ~ 5.099

All the other primitives will act similarly to distance. If you formerly used `-nowrap` primitives in your model we recommend removing them and changing the topology of the world instead.

If your model has turtles that move around you'll need to think about what happens to them when they reach the edge of the world, if the topology you're using has some non-wrapping edges. There are a few common options: the turtle is reflected back into the world (either systematically or randomly), the turtle exits the system (dies), or the turtle is hidden. It is no longer necessary to check the bounds using turtle coordinates, instead we can just ask NetLogo if a turtle is at the edge of the world. There are a couple ways of doing this, the simplest is to use the `can-move?` primitive.

```
if not can-move? distance [ rt 180 ]
```

can-move? merely returns true if the position *distance* in front of the turtle is inside the NetLogo world, false otherwise. In this case, if the turtle is at the edge of the world it simple goes back the way it came. You can also use `patch-ahead 1 != nobody` in place of `can-move?`. If you need to do something smarter that simply turning around it may be useful to use `patch-at` with `dx` and `dy`.

```
if patch-at dx 0 = nobody [
  set heading (- heading)
]
if patch-at 0 dy = nobody [
  set heading (180 - heading)
]
```

This tests whether the turtle is hitting a horizontal or vertical wall and bounces off that wall.

In some models if a turtle can't move forward it simply dies (exits the system, like in Conductor or Mousetraps).

```
if not can-move? distance[ die ]
```

If you are moving turtles using `setxy` rather than `forward` you should test to make sure the patch you are about to move to exists since `setxy` throws a runtime error if it is given coordinates outside the world. This is a common situation when the model is simulating an infinite plane and turtles outside the view should simply be hidden.

```
let new-x new-value-of-xcor
let new-y new-value-of-ycor

ifelse patch-at (new-x - xcor) (new-y - ycor) = nobody
  [ hide-turtle ]
  [ setxy new-x new-y
    show-turtle ]
```

Several models in the Models Library use this technique, Gravitation, N-Bodies, and Electrostatics are good examples.

The `diffuse` and `diffuse4` commands behave correctly in all topologies. Each patch diffuses and equal amount of the diffuse variable to each of its neighbors, if it has fewer than 8 neighbors (or 4 if you are using `diffuse4`), the remainder stays on the diffusing patch. This means that the overall sum of patch-variable across the world remains constant. However, if you want the diffuse matter to still fall off the edges of the world as it would on an infinite plane you still need to clear the edges each step as in the Diffuse Off Edges Example.

Links

A link is an agent that connects two turtles. These turtles are sometimes also called nodes.

The link is always drawn as a line between the two turtles. Links do not have a location as turtles do, they are not considered to be on any patch and you cannot find the distance from a link to another point.

There are two link designations: undirected and directed. A directed link is *out* of, or *from*, one node and *in*to, or *to*, another node. The relationship of a parent to a child could be modeled as a directed link. An undirected link appears the same to both nodes, each node has a link *with* another node. The relationship between spouses, or siblings, could be modeled as an undirected link.

There is a global agentset of all links, just as with turtles and patches. You can create undirected links using the `create-link-with` and `create-links-with` commands; and directed links using the `create-link-to`, `create-links-to`, `create-link-from`, and `create-links-from` commands. Once the first link has been created directed or undirected, all unbreeded links must match (links also support breeds, much like turtles, which will be discussed shortly); it's impossible to have two unbreeded links where one is directed and the other is undirected. A runtime error occurs if you try to do it. (If all unbreeded links die, then you can create links of that breed that are different in designation from the previous links.)

In general, link primitive names indicate what kind of links they deal with:

- Primitives that have "out" in their name utilize outgoing and undirected links. You can think of these as "the links I can use to get *from* the current node *to* other nodes." In general, these are probably the primitives you want to use.
- Primitives that have "in" in their name utilize incoming and undirected links. You can think of these as "the links I can use to get *to* the current node *from* other nodes."
- Primtives that do not specify "in" or "out", or have "with" in their name utilize *all* links, both undirected and directed, incoming and outgoing.

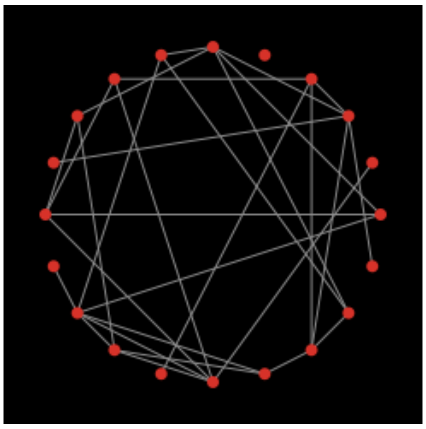
A link's `end1` and `end2` variables contain the two turtles the link connects. If the link is directed, it goes from end1 to end2. If the link is undirected, end1 is always the older of the two turtles, that is, the turtle with the smaller who number.

Link breeds, like turtle breeds, allow you to define different types of links in your model. Link breeds must either be directed or undirected, unlike unbreeded links this is defined at compile time rather than run time. You declare link breeds using the keywords `undirected-link-breed` and `directed-link-breed`. Breeded links can be created using the commands `create-<breed>-with` and `create-<breeds>-with` for undirected breeds and the commands `create-<breed>-to`, `create-<breeds>-to`, `create-<breed>-from`, and `create-<breeds>-from` for directed links.

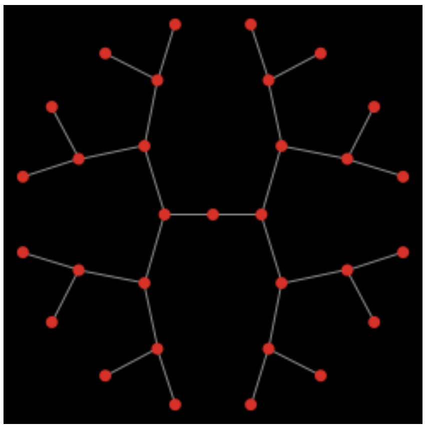
There cannot be more than one undirected link of the same breed (or more than one unbreeded undirected link) between a pair of agents, nor more than one directed link of the same breed in the same direction between a pair of agents. You can have two directed links of the same breed (or two unbreeded directed links) between a pair if they are in opposite directions.

Layouts

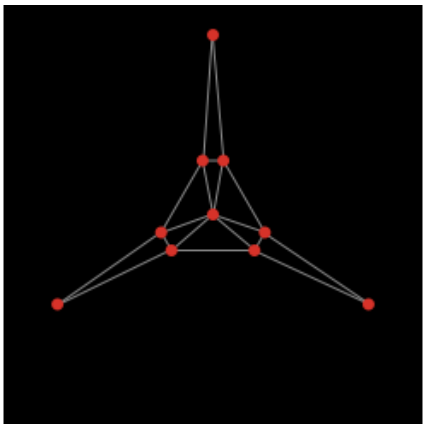
As part of our network support we have also added several different primitives that will help you to visualize the networks. The simplest is `layout-circle` which evenly spaces the agents around the center of the world given a radius.



`layout-radial` is a good layout if you have something like a tree structure, though even if there are some cycles in the tree it will still work, though as there are more and more cycles it will probably not look as good. `layout-radial` takes a root agent to be the central node places it at (0,0) and arranges the nodes connected to it in a concentric pattern. Nodes one degree away from the root will be arranged in a circular pattern around the central node and the next level around those nodes and so on. `layout-radial` will attempt to account for asymmetrical graphs and give more space to branches that are wider. `layout-radial` also takes a breed as an input so you use one breed of links to layout the network and not another.



Given a set of anchor nodes `layout-tutte` places all the other nodes at the center of mass of the nodes it is linked to. The anchor set is automatically arranged in a circle layout with a user defined radius and the other nodes will converge into place (this of course means that you may have to run it several times before the layout is stable.)



`layout-spring` is useful for many kinds of networks. The drawback is that is relatively slow since it takes many iterations to converge. In this layout the links act as springs that pull the nodes they connect toward each other and the nodes repel each other. The strength of the forces is controlled by inputs to the primitives. These inputs will always have a value between 0 and 1; keep in mind that very small changes can still affect the appearance of the network. The springs also have a length (in patch units), however, because of all the forces involved the nodes will not end up exactly that distance from each other.

Code Examples: Network Example, Network Import Example, Giant Component, Small Worlds, Preferential Attachment

Anonymous procedures

Anonymous procedures let you store code to be run later. Just like regular NetLogo procedures, an anonymous procedures can be either a command (anonymous command) or a reporter (anonymous reporter).

Anonymous procedures are values, which means they may be passed as input, reported as a result, or stored in a variable.

An anonymous procedure might be run once, multiple times, or not at all.

In other programming languages anonymous procedures are known as first-class functions, closures, or lambda.

Anonymous procedure primitives

Primitives specific to anonymous procedures are `->`, `is-anonymous-command?`, and `is-anonymous-reporter?`.

The `->` creates an anonymous procedure. The anonymous procedure it reports might be a command or a reporter, depending on what kind of block you pass it. For example `[ -> fd 1 ]` reports an anonymous command, because `fd` is a command, while `[ -> count turtles ]` reports an anonymous reporter, because `count` is a reporter.

These primitives require anonymous procedures as input: `foreach`, `map`, `reduce`, `filter`, `n-values`, `sort-by`. When calling these primitives, using an `->` is optional if your anonymous procedure takes no arguments. For example one may write simply `foreach mylist [ print ]` instead of `foreach mylist [ [x] -> print x ]`, though the latter is also accepted. Additionally, while brackets around argument names are required for anonymous procedures of two or more arguments, they may be omitted for anonymous procedures of one or zero arguments. So `foreach mylist [ x -> print x ]` is equivalent to `foreach mylist [ [x] -> print x ]`.

Note: brackets around arguments were **always required** in NetLogo 6.0.0. If you copy and paste code into NetLogo 6.0.0 using anonymous procedures with unbracketed arguments, the code will not compile until you have added the brackets.

The `run` command accepts anonymous commands as well as strings.

The `runresult` reporter accepts anonymous reporters as well as strings.

`run` and `runresult` allow passing inputs to an anonymous procedure. As with all primitives accepting varying number of inputs, the whole call must be surrounded with parentheses, so for example `(run my-anonymous-command 5)` or `(runresult my-anonymous-reporter "foo" 2)`. When not passing input, no parentheses are required.

Anonymous procedure inputs

An anonymous procedure may take zero or more inputs. The inputs are referenced the variables declared before the arrow. For instance, in the anonymous reporter `[ [a b] -> a + b ]`, `a` and `b` are inputs.

Anonymous procedures and strings

Creating and running anonymous procedures is fast. To use `run` or `runresult` on a new string for the first time is about 100x slower than running an anonymous procedure. Modelers should normally use anonymous procedures instead of running strings, except when running strings entered by the user.

Concise syntax

Simple uses of `foreach`, `map`, `reduce`, `filter`, `n-values`, and `sort-by` can be written with an especially concise syntax. You can write:

```
map abs [1 -2 3 -4] => [1 2 3 4]
reduce + [1 2 3 4] => 10
filter is-number? [1 "x" 3] => [1 3]
foreach [1 2 3 4] print
```

In older NetLogo versions (4 and earlier), these had to be written:

```
map [abs ?] [1 -2 3 -4] => [1 2 3 4]
reduce [?1 + ?2] [1 2 3 4] => 10
filter [is-number? ?] [1 "x" 3] => [1 3]
foreach [1 2 3 4] [ print ? ]
```

Anonymous procedures as closures

Anonymous procedures are "closures"; that means they capture or "close over" the bindings (not just the current values) of local variables and procedure inputs. They do not capture agent variables and do not capture the identity (or even the agent type) of the current agent.

Nonlocal exits

The `stop` and `report` commands exit from the dynamically enclosing procedure, not the enclosing anonymous procedure. (This is backward-compatible with older NetLogo versions.)

Anonymous procedures and extensions

The extensions API supports writing primitives that accept anonymous procedures as input. Write us for sample code.

Limitations

We hope to address at least some of the following limitations in future NetLogo versions:

- `import-world` does not support anonymous procedures.
- Anonymous procedures can't be variadic (accept a varying number of inputs).
- Anonymous reporters can't contain commands, only a single reporter expression. So for example you must use `ifelse-value` not `if`, and you don't use `report` at all. If your code is too complex to be written as one reporter, you'll need to move the code to a separate reporter procedure, and then call that procedure from your anonymous reporter, passing it any needed inputs.
- Anonymous procedures are not interchangeable with command blocks and reporter blocks. Only the primitives listed above accept anonymous procedures as input. Control primitives such as `ifelse` and `while` and agent primitives such as `of` and `with` don't accept anonymous procedures. So for example if I have an anonymous reporter `let r [ -> if random 2 == 0 ]` and two anonymous commands `let c1 [ -> tick ]` and `let c2 [ -> stop ]`, I can't write `ifelse r c1 c2`, I must write `ifelse runresult r [ run c1 ] [ run c2 ]`.
- The concise syntax where `->` may be omitted is only available to primitives and extension primitives, not ordinary procedures. So for example if I have a procedure `p` that accepts an anonymous procedure as input, it must be called as e.g. `p [ -> ... ]` not `p [ ... ]`.

Code example

Code Example: State Machine Example

Ask-Concurrent

NOTE: The following information is included only for backwards compatibility. We don't recommend using the `ask-concurrent` primitive at all in new models.

In very old versions of NetLogo, `ask` had simulated concurrent behavior by default. Since NetLogo 4.0 (2007), `ask` is serial, that is, the agents run the commands inside the ask one at a time.

The following information describes the behavior of the `ask-concurrent` command, which behaves the way the old `ask` behaved.

`ask-concurrent` produces simulated concurrency via a mechanism of turn-taking. The first agent takes a turn, then the second agent takes a turn, and so on until every agent in the asked agentset has had a turn. Then we go back to the first agent. This continues until all of the agents have finished running all of the commands.

An agent's "turn" ends when it performs an action that affects the state of the world, such as moving, or creating a turtle, or changing the value of a global, turtle, patch, or link variable. (Setting a local variable doesn't count.)

The `forward` (`fd`) and `back` (`bk`) commands are treated specially. When used inside `ask-concurrent`, these commands can take multiple turns to execute. During its turn, the turtle can only move by one step. Thus, for example, `fd 20` is equivalent to `repeat 20 [ fd 1 ]`, where the turtle's turn ends after each run of `fd`. If the distance specified isn't an integer, the last fraction of step takes a full turn. So for example `fd 20.3` is equivalent to `repeat 20 [ fd 1 ] fd 0.3`.

The `jump` command always takes exactly one turn, regardless of distance.

To understand the difference between `ask` and `ask-concurrent`, consider the following two commands:

```
ask turtles [ fd 5 ]
ask-concurrent turtles [ fd 5 ]
```

With `ask`, the first turtle takes five steps forward, then the second turtle takes five steps forward, and so on.

With `ask-concurrent`, all of the turtles take one step forward. Then they all take a second step, and so on. Thus, the latter command is equivalent to:

```
repeat 5 [ ask turtles [ fd 1 ] ]
```

Code Example: Ask-Concurrent Example shows the difference between `ask` and `ask-concurrent`.

The behavior of `ask-concurrent` cannot always be so simply reproduced using `ask`, as in this example. Consider this command:

```
ask-concurrent turtles [ fd random 10 ]
```

In order to get the same behavior using `ask`, we would have to write:

```
turtles-own [steps]
ask turtles [ set steps random 10 ]
while [any? turtles with [steps > 0]] [
  ask turtles with [steps > 0] [
    fd 1
    set steps steps - 1
  ]
]
```

To prolong an agent's "turn", use the `without-interruption` command. (The command blocks inside some commands, such as `create-turtles` and `hatch`, have an implied `without-interruption` around them.)

Note that the behavior of `ask-concurrent` is completely deterministic. Given the same code and the same initial conditions, the same thing will always happen (if you are using the same version of NetLogo and begin your model run with the same random seed).

In general, we suggest you not use `ask-concurrent` at all. If you do, we suggest you write your model so that it does not depend on the exact details of how `ask-concurrent` works. We make no guarantees that its semantics will remain the same in future versions of NetLogo, or that it will continue to be supported at all.

User Interaction Primitives

NetLogo features several primitives which allow a model to interact with the user. These primitives include user-directory, user-file, user-new-file, user-input, user-message, user-one-of, and user-yes-or-no?.

These primitives differ in precisely what interaction they take with the user. `user-directory`, `user-file`, and `user-new-file` are all reporters which prompt the user to select an item from the file system and report the path of the selected item to NetLogo. `user-yes-or-no?`, `user-one-of`, and `user-input` all prompt the user to provide input in the form of text or a selection. `user-message` simply presents a message to the user.

Note that all active forever buttons will pause when one of these primitives is used and will resume only when the user completes the interaction with the button.

What does "Halt" mean?

The primitives which prompt the user for input, as well as `user-message` all provide a "Halt" button. The effect of this button is the same for all of these primitives - it halts the model. When the model is halted all running code is stopped, including buttons and the command center. Since halting stops code in the middle of whatever it happened to be doing at the time it was halted, you may see strange results if you continue to run the model after a halt without setting it up again.

Tie

Tie connects two turtles so that the movement of one turtles affects the location and heading of another. Tie is a property of links so there must be a link between two turtles to create a tie relationship.

When a link's `tie-mode` is set to "fixed" or "free" `end1` and `end2` are tied together. If the link is directed `end1` is the "root agent" and `end2` is the "leaf agent". That is when `end1` moves (using `fd`, `jump`, `setxy`, etc.) `end2` also moves the same distance and direction. However when `end2` moves it does not affect `end1`.

If the link is undirected it is a reciprocal tie relationship, meaning, if either turtle moves the other turtle will also move. So depending on which turtle is moving either turtle can be considered the root or the leaf. The root turtle is always the turtle that initiates the movement.

When the root turtle turns right or left, the leaf turtle rotates around the root turtle the same amount as if a stiff were attaching the turtles. When `tie-mode` is set to "fixed" the heading of the leaf turtle changes by the same amount. If the `tie-mode` is set to "free" the heading of the leaf turtle is unchanged.

The `tie-mode` of a link can be set to "fixed" using the `tie` command and set to "none" (meaning the turtles are no longer tied) using `untie` to set the mode to "free" you need to: `set tie-mode "free"`.

Code Example: Tie System Example

Multiple source files

The `__includes` keyword allows you to use multiple source files in a single NetLogo model.

The keyword begins with two underscores to indicate that the feature is experimental and may change in future NetLogo releases.

When you open a model that uses the `__includes` keyword, or if you add it to the top of a model and hit the Check button, the includes menu will appear in the toolbar. From the includes menu you can select from the files included in this model.

When you open included files they appear in additional tabs. See the Interface Guide for more details.

You can have anything in external source files (`.nls`) that you would normally put in the Code tab: `globals`, `breed`, `turtles-own`, `patches-own`, `breeds-own`, procedure definitions, etc. Note though that these declarations all share the same namespace. That is, if you declare a global `my-global` in the Code tab you cannot declare a global (or anything else) with the name `my-global` in any file that is included in the model. `my-global` will be accessible from all the included files. The same would be true if `my-global` were declared in one of the included files.

Syntax

Colors

In the Code tab and elsewhere in the NetLogo user interface, program code is color-coded by the following scheme:

- Keywords are green
- Constants are orange

- Comments are gray
- Primitive commands are blue
- Primitive reporters are purple
- Everything else is black

Notice

The remainder of this section contains technical terminology which will be unfamiliar to some readers.

Keywords

The only keywords in the language are `globals`, `breed`, `turtles-own`, `patches-own`, `to`, `to-report`, and `end`, plus `extensions` and the experimental `__includes` keyword. (Built-in primitive names may not be shadowed or redefined, so they are effectively a kind of keyword as well.)

Identifiers

All primitives, global and agent variable names, and procedure names share a single global case-insensitive namespace; local names (`let` variables and the names of procedure inputs) may not shadow global names or each other. Identifiers may contain any Unicode letter or digit and the following ASCII characters:

```
.?=*!<>:#+/%$_^'&-
```

Some primitive names begin with two underscores to indicate that they are experimental and are especially likely to change or be removed in future NetLogo releases.

Scope

NetLogo is lexically scoped. Local variables (including inputs to procedures) are accessible within the block of commands in which they are declared, but not accessible by procedures called by those commands.

Comments

The semicolon character introduces a comment, which lasts until the end of the line. There is no multi-line comment syntax.

Structure

A program consists of optional declarations (`globals`, `breed`, `turtles-own`, `patches-own`, `<BREED>-own`, `extensions`) in any order, followed by zero or more procedure definitions. Multiple breeds may be declared with separate `breed` declarations; the other declarations may appear once only.

Every procedure definition begins with `to` or `to-report`, the procedure name, and an optional bracketed list of input names. Every procedure definition ends with `end`. In between are zero or more commands.

Commands and reporters

Commands take zero or more inputs; the inputs are reporters, which may also take zero or more inputs. No punctuation separates or terminates commands; no punctuation separates inputs. Identifiers must be separated by whitespace or by parentheses or square brackets. (So for example, `a+b` is a single identifier, but `a(b[c]d)e` contains five identifiers.)

All commands are prefix. All user-defined reporters are prefix. Most primitive reporters are prefix, but some (arithmetic operators, boolean operators, and some agentset operators like with and in-points) are infix.

All commands and reporters, both primitive and user-defined, take a fixed number of inputs by default. (That's why the language can be parsed though there is no punctuation to separate or terminate commands and/or inputs.) Some primitives are variadic, that is, may optionally take a different number of inputs than the default; parentheses are used to indicate this, e.g. `(list 1 2 3)` (since the `list` primitive only takes two inputs by default). Parentheses are also used to override the default operator precedence, e.g. `(1 + 2) * 3`, as in other programming languages.

Sometimes an input to a primitive is a command block (zero or more commands inside square brackets) or a reporter block (a single reporter expression inside square brackets). User-defined procedures may not take a command or reporter block as input.

Operator precedences are as follows, high to low:

- `with`, `at-points`, `in-radius`, `in-cone`
- (all other primitives and user-defined procedures)
- `^`
- `*`, `/`, `mod`
- `+`, `-`
- `<`, `>`, `<=`, `>=`
- `=`, `!=`
- `and`, `or`, `xor`

Compared to other Logos

There is no agreed-upon standard definition of Logo; it is a loose family of languages. We believe that NetLogo has enough in common with other Logos to earn the Logo name. Still, NetLogo differs in some respects from most other Logos. The most important differences are as follows.

Surface differences

- The precedence of mathematical operators is different. Infix math operators (like `+`, `*`, etc.) have lower precedence than reporters with names. For example, in many Logos, if you write `sin x + 1`, it will be interpreted as `sin (x + 1)`. NetLogo, on the other hand, interprets it the way most other programming languages would, and the way the same expression would be interpreted in standard mathematical notation, namely as `(sin x) + 1`.
- The `and` and `or` reporters are special forms, not ordinary functions, and they "short circuit", that is, they only evaluate their second input if necessary.
- Procedures can only be defined in the Code tab, not interactively in the Command Center.
- Reporter procedures, that is, procedures that "report" (return) a value, must be defined with `to-report` instead of `to`. The command to report a value from a reporter procedure is `report`, not `output`.
- When defining a procedure, the inputs to the procedure must be enclosed in square brackets, e.g. `to square [x]`.
- Variable names are always used without any punctuation: always `foo`, never `:foo` or `"foo`. (To make this work, instead of a `make` command taking a quoted argument we supply a `set` special form which does not evaluate its first input.) As a result, procedures and variables occupy a single shared namespace.

The last three differences are illustrated in the following procedure definitions:

most Logos	NetLogo

`to square :x`
`output :x * :x`
`end`
	`to-report square [x]`
	`report x * x`
	`end`

Deeper differences

- NetLogo's local variables and inputs to procedures are lexically scoped, not dynamically scoped.
- NetLogo has no "word" data type (what Lisp calls "symbols"). Eventually, we may add one, but since it is seldom requested, it may be that the need doesn't arise much in agent-based modeling. We do have strings. In most situations where traditional Logo would use words, we simply use strings instead. For example in Logo you could write `[see spot run]` (a list of words), but in NetLogo you must write `"see spot run"` (a string) or `["see" "spot" "run"]` (a list of strings) instead.
- NetLogo's `run` command works on anonymous procedures and strings, not lists (since we have no "word" data type), and does not permit the definition or redefinition of procedures.
- Control structures such as `if` and `while` are special forms, not ordinary functions. You can't define your own special forms, so you can't define your own control structures. (You can do something similar using anonymous procedures, but you must use the `->`, `run`, and `runresult` primitives for that, you cannot make them implicit.)
- Anonymous procedures (aka function values or lambda) are true lexically-scoped closures. This feature is available in NetLogo and in modern Lisps, but not in standard Logo.

Of course, the NetLogo language also contains other features not found in most Logos, most importantly agents and agentsets.