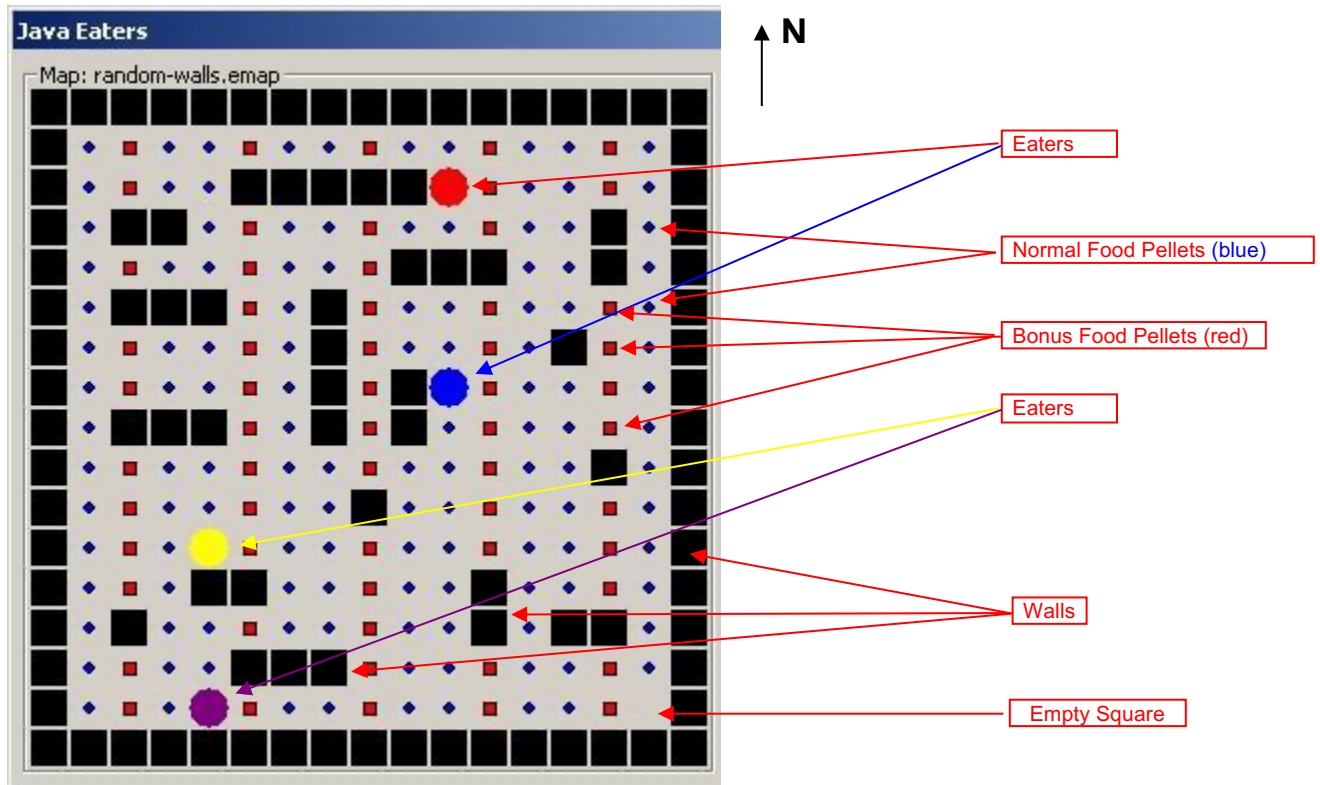


Part II: Simple External Interaction

1. The Eaters Game

The game used in this part is called “Eaters.” In Eaters, PACMAN-like eaters compete to consume food in a simple grid world. Below is the Eaters Playing Board near the beginning of a game with four eaters.



The Eaters world consists of a rectangular grid, 15 squares wide by 15 squares high. Walls bound all four sides. Interior wall sections are randomly generated for each new game. No two walls will touch, so there are no corners, except for exterior walls and no “dead ends” anywhere on the board. Each eater starts at a random location. Food pellets are in all other squares of the grid. There are two kinds of food: normal food (blue circles and worth 5 points) and bonus food (red squares and worth 10 points). An eater consumes food by moving into a square. When an eater moves out of a square it will be empty (unless another eater moves into it).

An eater can sense the contents of cells (eater, normal food, bonus food, and empty) up to 2 squares away in all directions. On each turn, an eater can move one square north, south, east, or west. An eater can also jump two squares north, south, east, or west. An eater can jump over a wall or another eater. An eater does not consume any food in the space it jumps over. A jump costs the eater 5 points.

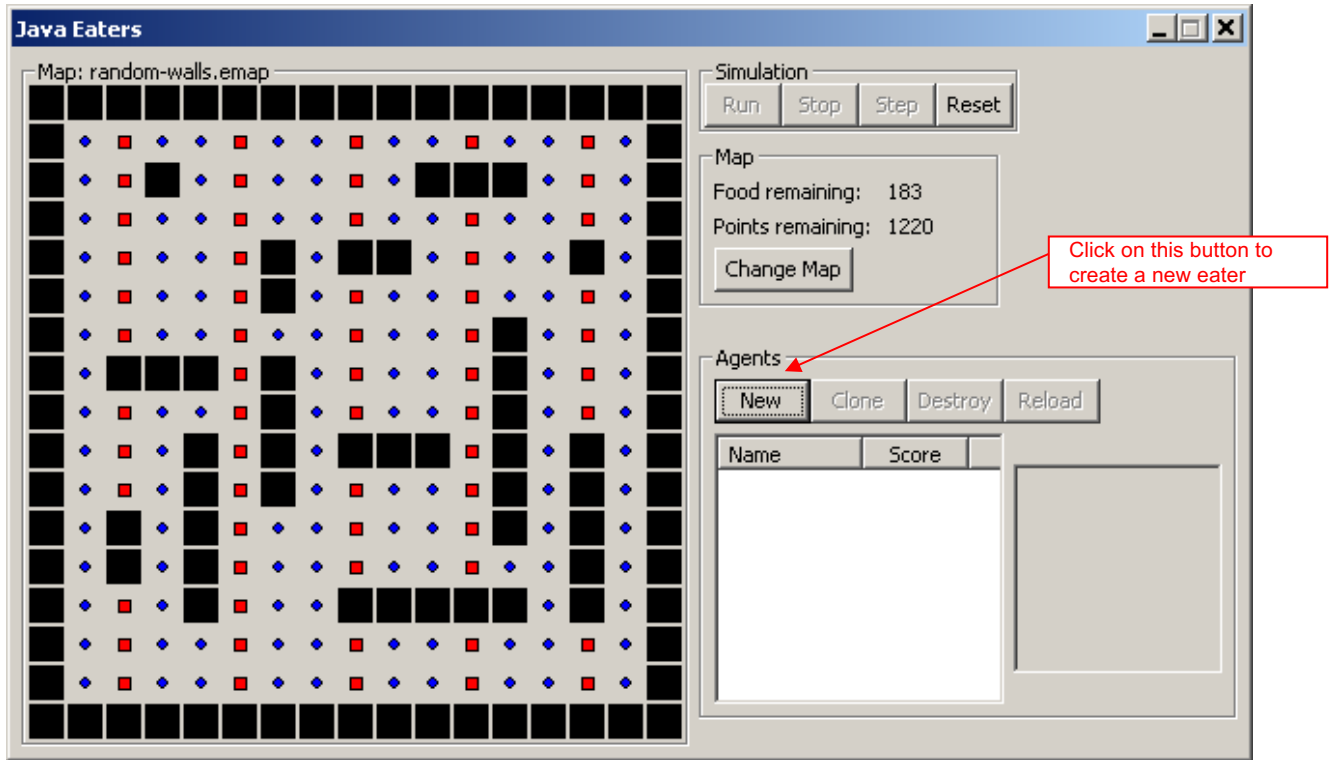
Whenever two eaters try to occupy the same cell at the same time, they collide. As a result of the collision, their scores are averaged and they are teleported to new, random locations on the board.

1.1 Creating an Eater

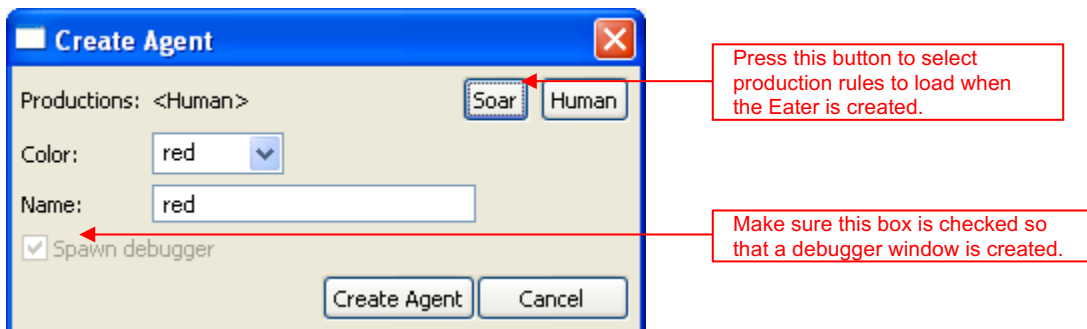
Start the Eaters environment:

Open the directory where you installed Eaters and launch the appropriate script file (Eaters.bat on Windows, Eaters.sh on Mac or Linux)

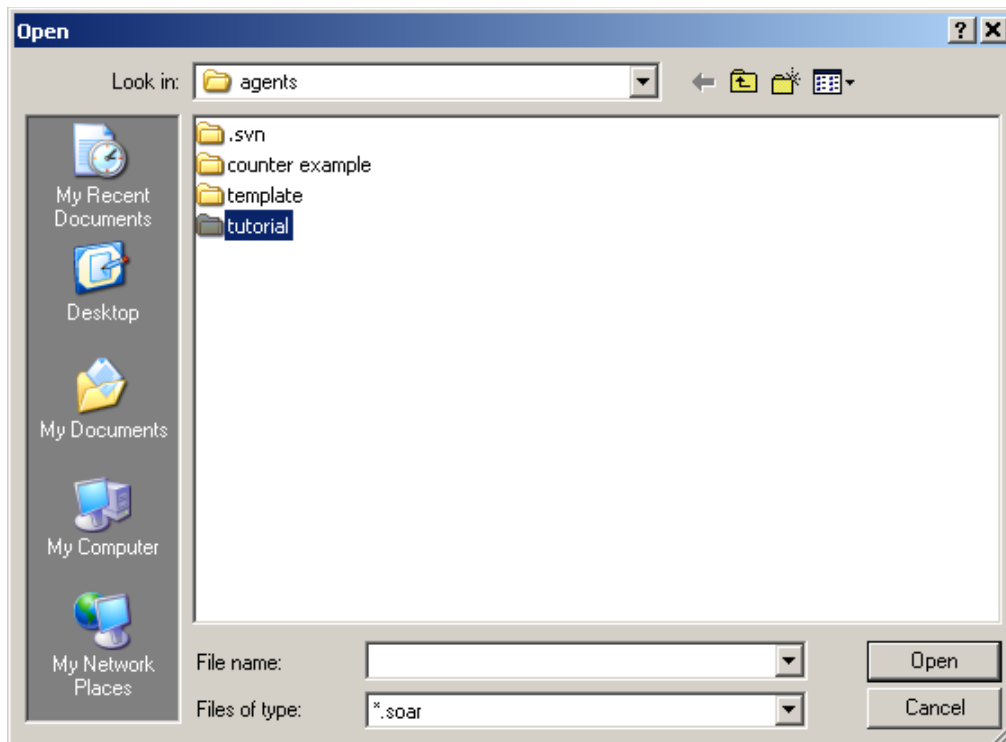
Once Eaters has started, you will have a new window on your computer screen. The configuration of the playing board, or map, may look different than shown. You will use this window to create and destroy eaters and run the game.



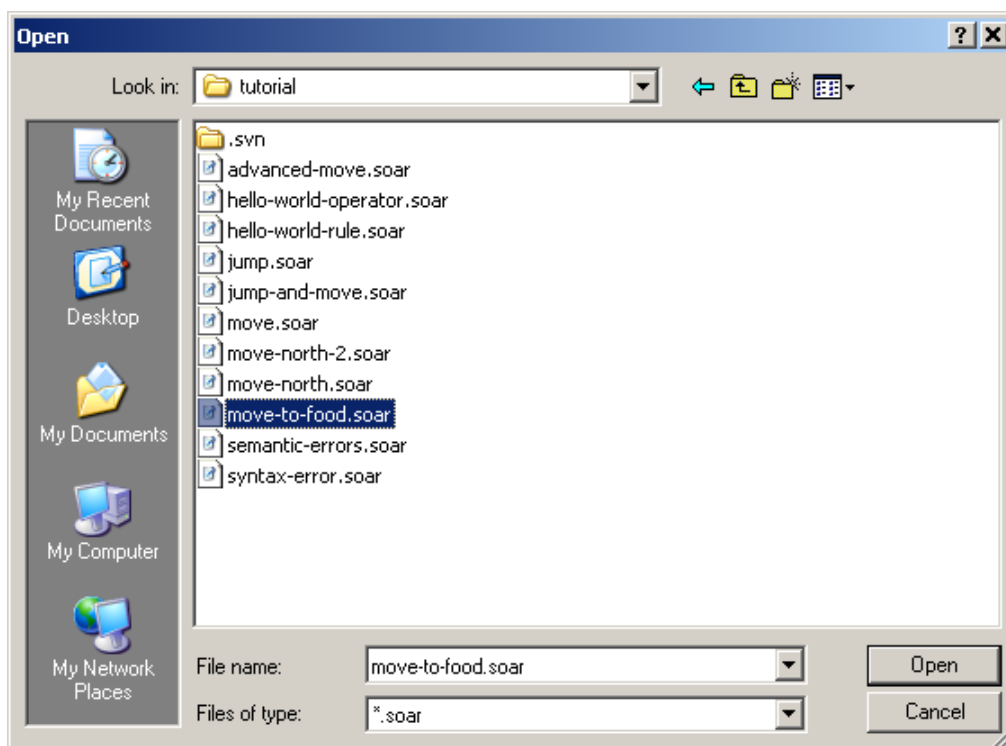
Individual Eaters are controlled by Soar programs, which are automatically loaded when an eater is created. Press the “New” button in the “Agents” area of the Eaters game. A dialog will pop up.



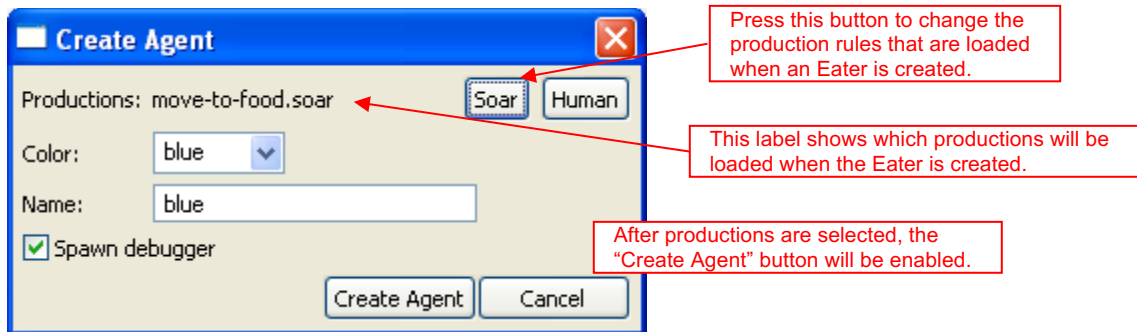
The first thing you must do is select the productions that will define the behavior of the Eater. Pressing the button “Soar” will pop up a file selection box:



Select the “Agents\Eaters\Tutorial” directory with the mouse, and then Choose “Open” (or dbl-click on “Tutorial”). The dialog will display the Soar production files that will be used in this tutorial. Each set of production rules defines specific behaviors for an Eater. Select the file “move-to-food.soar”

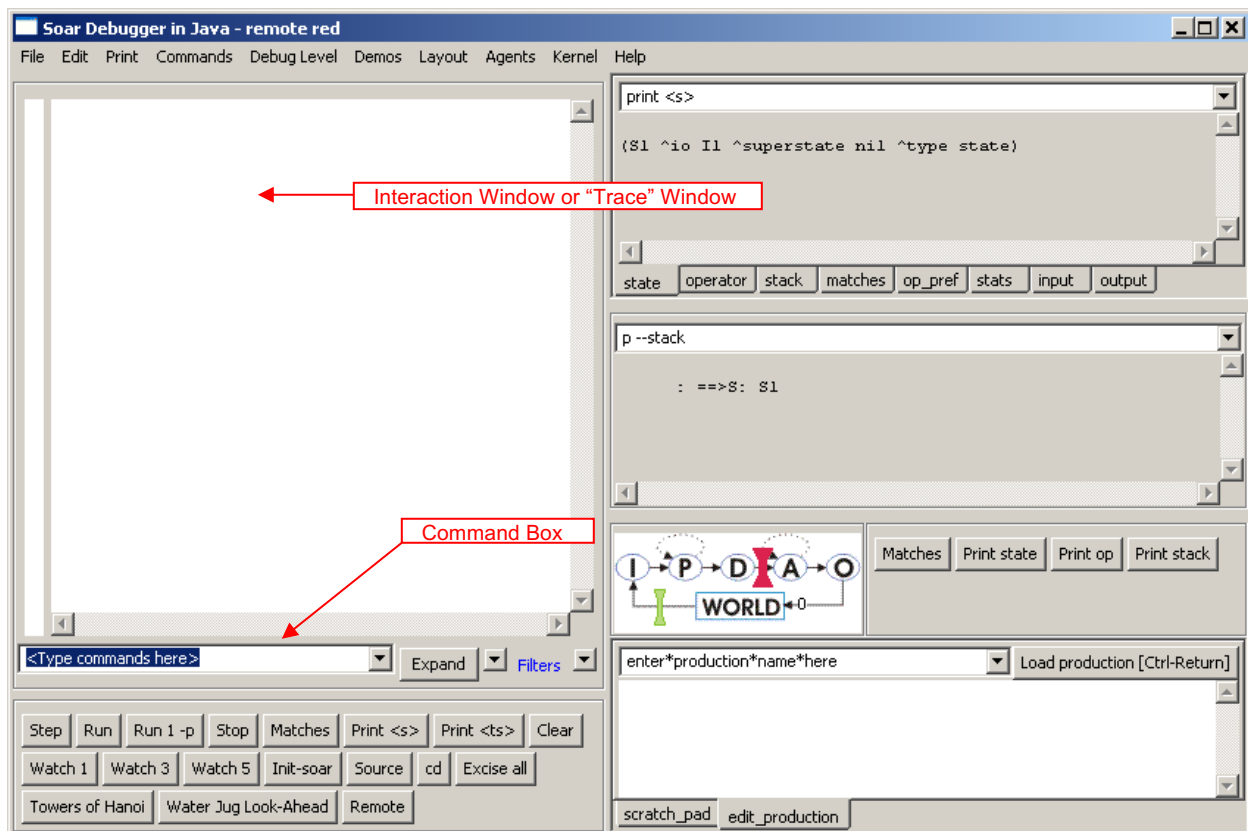


After you have selected the move-to-food eater, the Create Agent dialog should look as follows:



The productions in the file "move-to-food.soar" will now be loaded whenever the "Create Agent" button is pressed. The production set can be changed before creating another agent by pressing the "Soar" button to choose a different file.

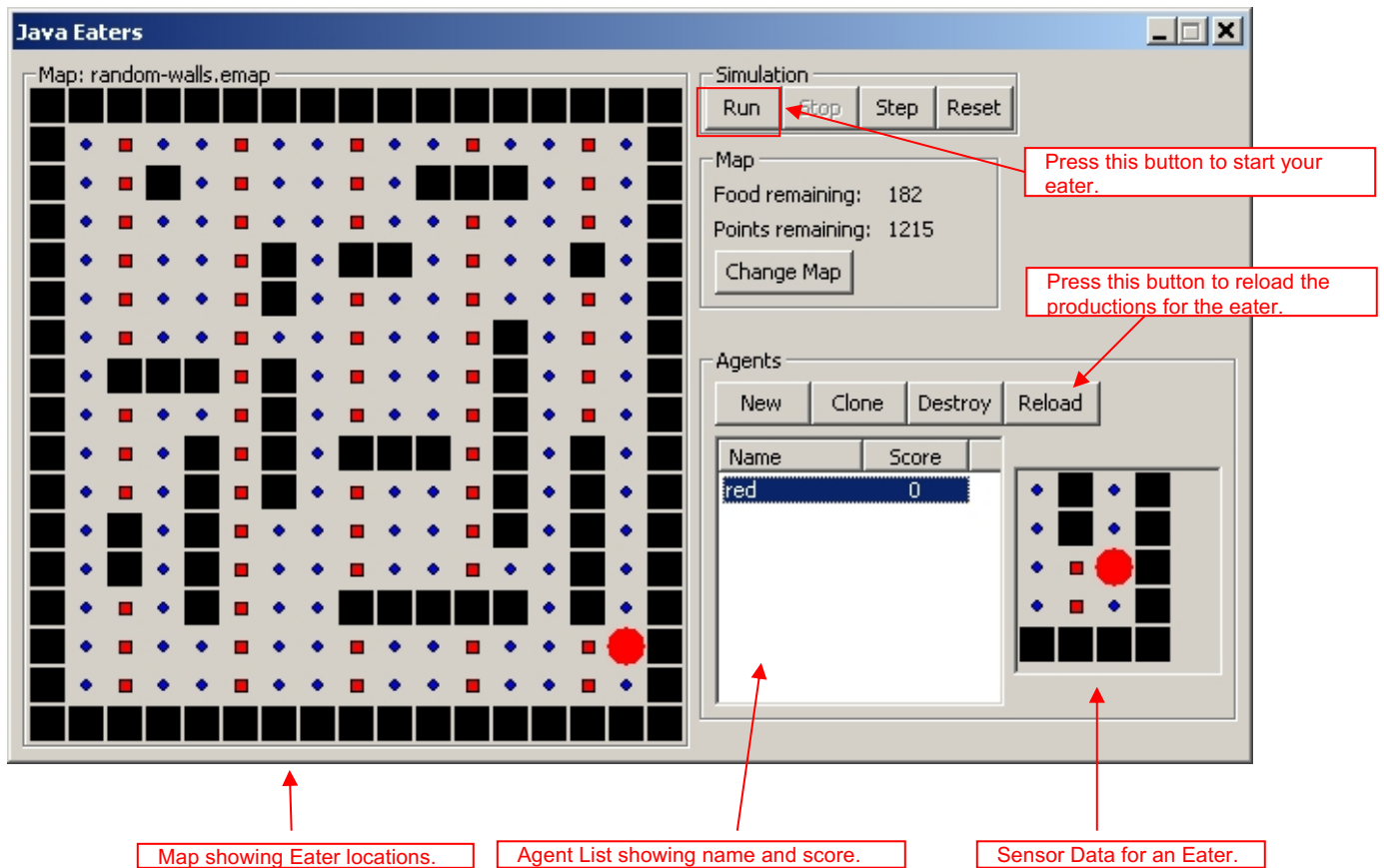
You can also pick a color for your eater by clicking on the button to the right of "Color:" labeled "red". The color does not affect on the eater's behavior, so pick your favorite color. Once you have selected the productions file, and a color, you are ready to create your eater by clicking on the Create Agent button.



After clicking on Create Agent, the agent's Soar Debugger window will appear. Arrange the Java Eaters window and the Soar Debugger windows so that they do not overlap. You might need to resize the Soar Debugger window to make it shorter. Don't make it too narrow or it will be difficult to view Soar's output.

The Soar Debugger Window will look as shown above, although it may be larger, and have additional panes. The eater is referred to by its color, which is listed in the window title (remote red). Once you are familiar with the Debugger, you can completely customize its appearance. Across the top are a series of pull down menus, which are described later. On the left side of the window is the Interaction Window where trace and debugging information will be displayed. Just below it is the Command Box where you can type in commands. The bottom of the window contains buttons for single stepping, running, or stopping the eater, setting Watch levels, and printing information. The layout of the buttons may change depending on the size of the window and user preferences. Features available in the Debugger will be described throughout this document as they are needed. More details are provided in "Intro to the Soar Debugger in Java.doc" at <https://soar.eecs.umich.edu/articles/articles/faqs-and-guides/69-intro-to-the-soar-debugger>.

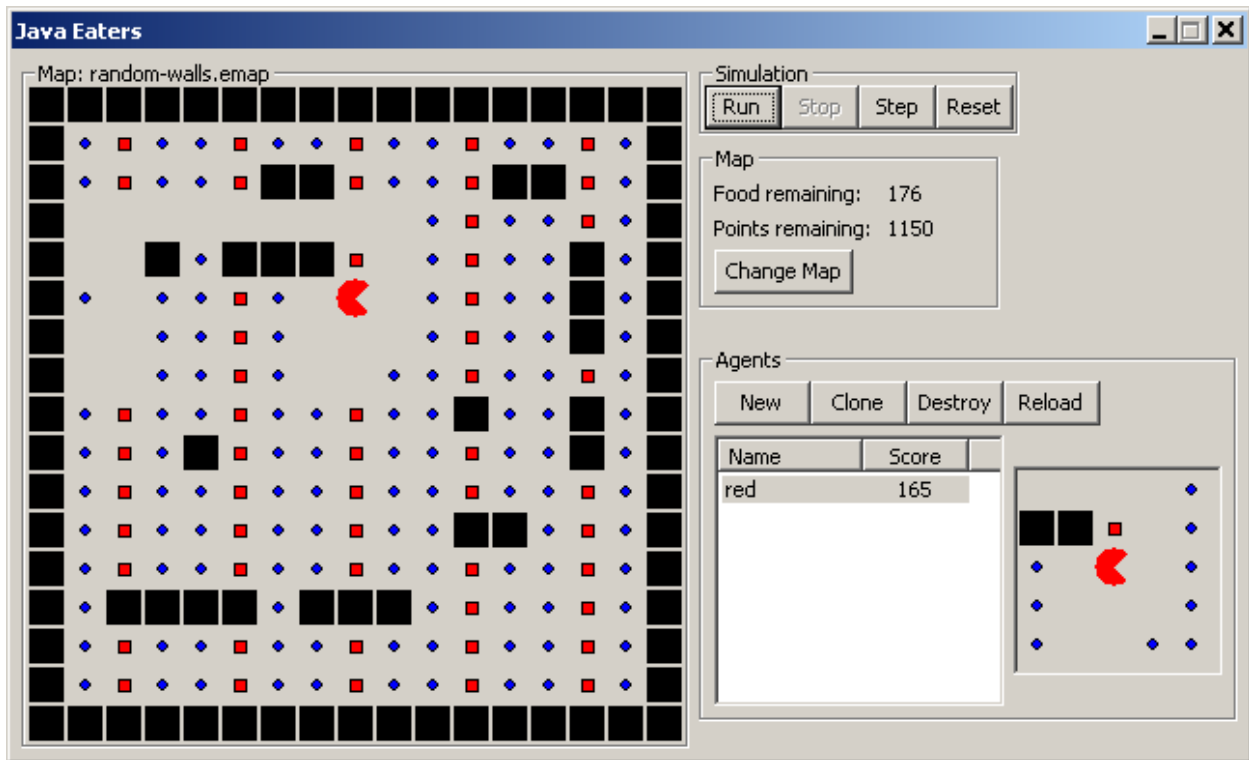
You should also see that the Java Eaters window has changed. The Red Eater is shown on the map, and the Eater name and score are shown in the Agent List. To the right of the Agent List is the sensor data for the Eater, showing the contents of the map cells that surround the Eater.



1.2 Running an Eater

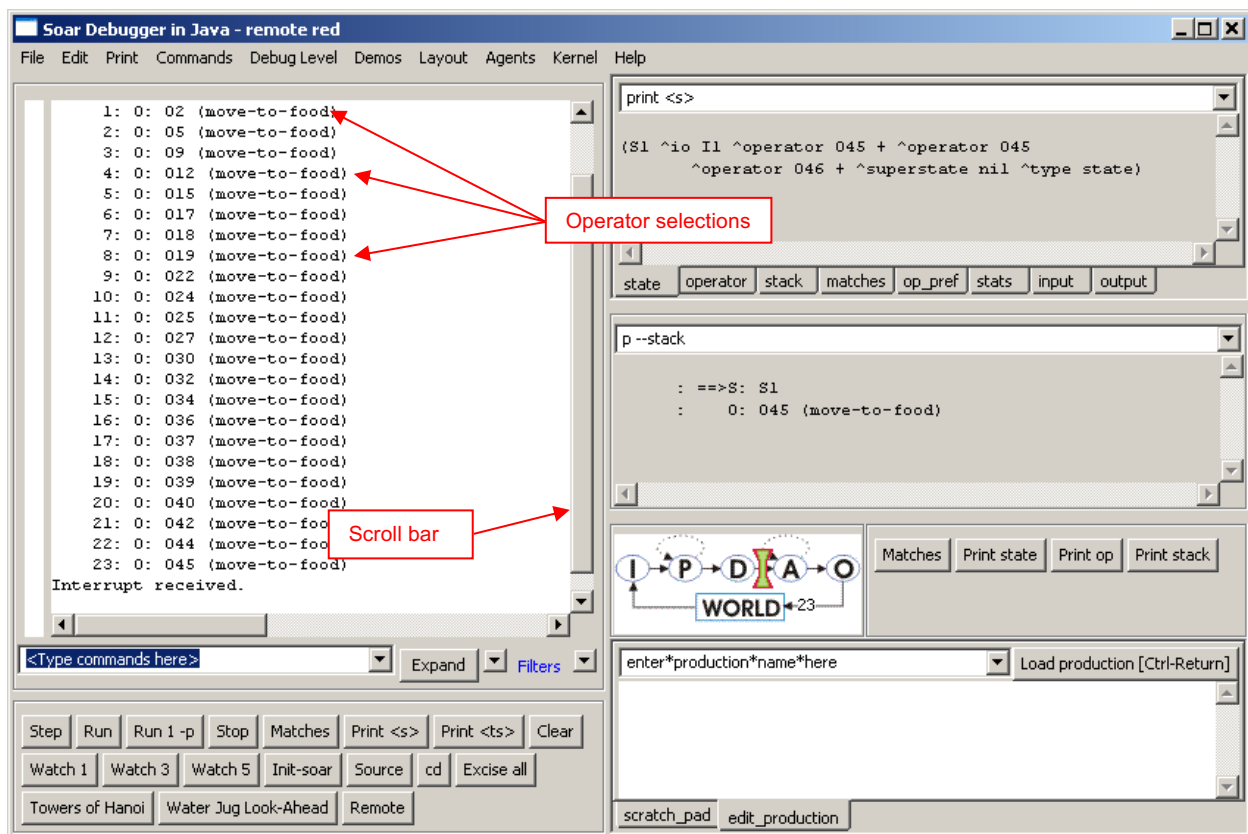
Your eater is now ready to start eating. Click the Run button on either the Eater Control Panel (highlighted above) or the Soar Debugger Window. The eater will start to move and consume food. After a few moves, click the Stop button on either the Eater Control Panel (next to the “Run” button) or the Interaction Window.

At this point, the Eaters Playing Board will look something like the one below. Your board will look different because the walls and eater starting position are different each time the game is played.



During the run, the Eaters Sensor window will change with each move, showing the food pellets, walls, and empty squares that the eater senses. As shown above, an eater can sense a 5x5 grid of cells, although the *move-to-food* rules consider only the four neighboring cells (north, south, east and west).

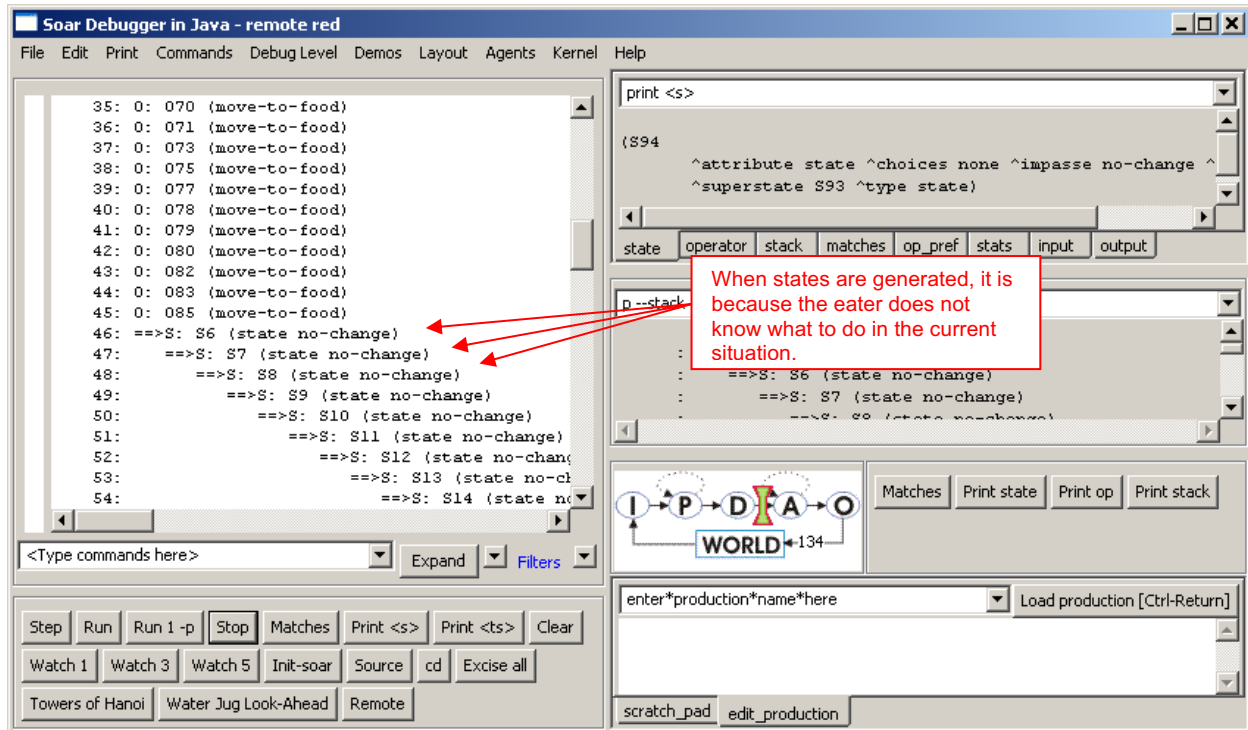
The Interaction window (shown below) displays a trace of the eater's decisions.



The line starting with 1: 0: 02 shows the first selection of the *move-to-food operator*. This is followed by successive selections of *move-to-food operators*. The *move-to-food operator* causes the eater to move to a new cell. Some of the eaters will also jump; others will halt when they cannot sense any food.

If the trace gets longer than the window can hold, the printing will scroll up. You can look at decisions that scroll off the window by using the scroll bar to the right of the window. You can search for information in the trace by using the find function that is found under Edit at the top of the Interaction window.

In Soar, a program consists of rules, and move-to-food has only three simple rules that move the eater to a neighboring cell that contains food. As your eaters get more sophisticated, more rules will be loaded. If you let the eater run for a long time, it will eventually get to a place where there is no food directly next to it. The move-to-food eater does not have any rules to respond to this situation (although you could easily add some) so the eater will stop moving. The trace will look as follows:



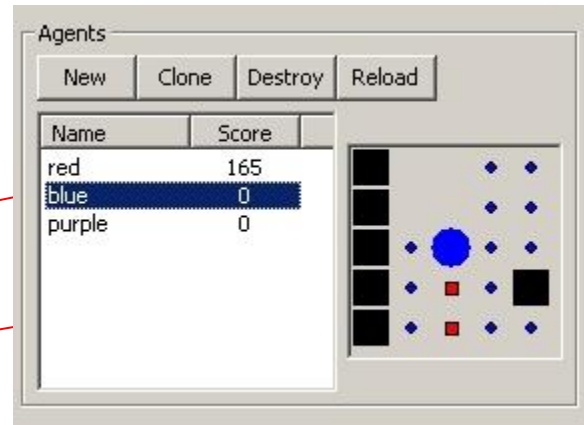
When an eater does not know how to respond to a situation, it will start generating new states, such as S6, S7, S8, ... in the above trace above. In later sections of the tutorial you will learn how to write rules that take advantage of these new states, but for now you just need to know that when they arise, the eater does not know what to do.

At anytime you can create more eaters. You can create additional eaters from the same or different files, so that you can create a set of identical eaters (except for color), or sets of different eaters. Each time a new eater is created, a new Interaction Window is created, and the Eaters Agent List is expanded to include the new eater. To make a new agent with the same set of rules as an existing agent, you can use the "Clone" button. To create an eater with a different set of rules, press "New" and use the dialog to select the desired rule set just as you did when creating your first move-to-food eater.

From the Agent List, you can select which eater's sensor data is displayed by selecting the eater color with the mouse. When an eater is highlighted, it can also be "cloned" or destroyed. To destroy an eater, click on the eater Name in the Agent List (highlight it) and press the "Destroy" button.

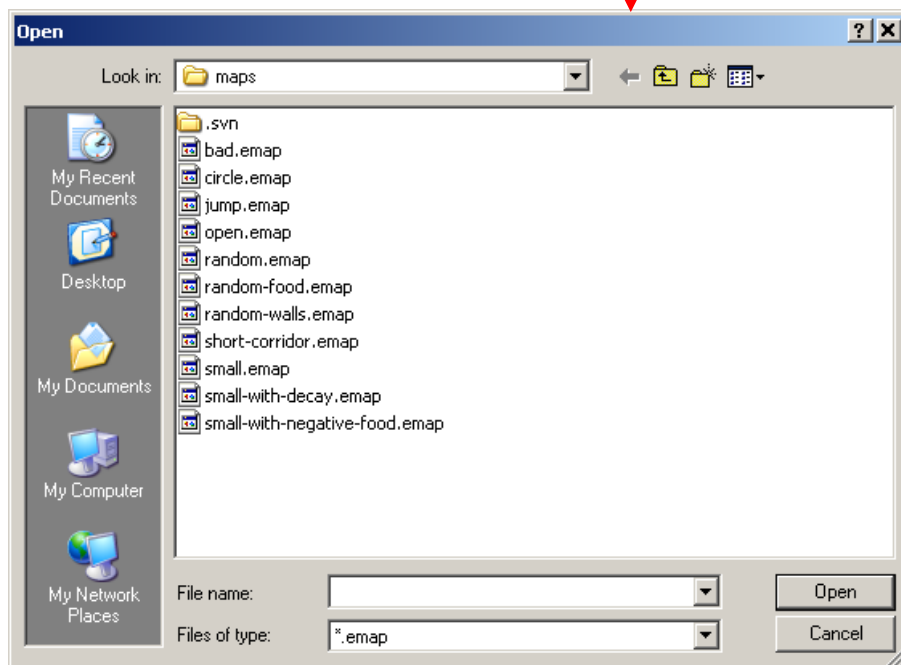
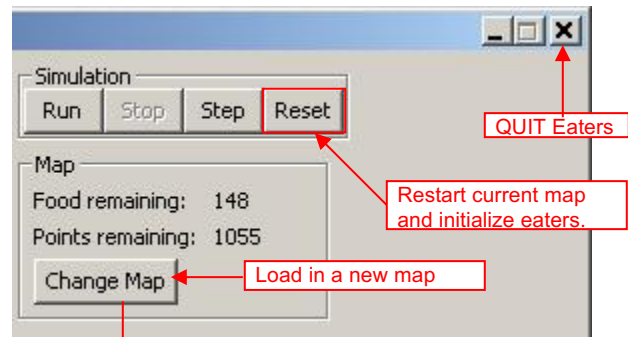
Highlight an eater in the Agent List...

...its current sensor data will be displayed



To reload the production rules for the eater, you should use the reload button (not implemented yet!), or if you create an Eater using VisualSoar you can use the runtime tab to reload the agent, reload a file, or change a single rule. Reloading is useful if you have found a bug, modified the rules in the file, and then wish to immediately test them on the current situation. Soar will replace existing rules with new versions (a '#' is printed in the Interaction Window whenever a rule is replaced), as well as adding any new rules. This can be done at any time as Soar will match new and modified rules against working memory.

The upper right portion of the JavaEaters window has options for controlling the Eaters "Simulation." If you click on the "Change Map" button, a dialog will appear listing the available map types that can be loaded. Select a map and press "Open" to see what the map looks like. Press "Cancel" to not change the current map. You can restart the eaters on the current map by clicking on the "Reset" button. The eaters will be placed randomly on the board and all of the food will be regenerated. To QUIT Eaters, press the "Close Application" X in the upper right corner of JavaEaters.



Spend some time creating, running and destroying different eaters. Notice how the eaters move around the board differently, some being much more efficient at consuming food.

2. Building a Simple Eater Using Rules

In contrast to the Water Jug, an Eater does not have to initialize the state with an operator – the Eater will start with information about its situation coming in through a structure called the input-link. We will keep the Eater very simple, so all we will do initially is create operators, which means creating operator proposal and application rules.

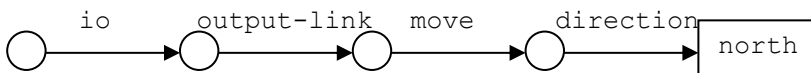
The first operator you will create moves an eater north one step. (It might not even do that if there is a wall to its north when it is created.)

2.1 English Version

Here is one possible version of the move-north operator.

```
##### Move-north operator #####
# Propose*move-north:
# If I exist, then propose the move-north operator.
#
# Apply*move-north:
# If the move-north operator is selected, then generate an output command to
# move north.
```

To write the Soar rule for apply*move-north, you have to know how to get an eater to move. All external actions are issued by creating working memory elements that are augmentations of the output-link. The output-link is an augmentation of the io object, which in turn is an augmentation of the state. In Eaters, a move command is issued by creating a “move” augmentation on the output-link object, which in turn has an augmentation called “direction” with a value of the direction to move: “north”, “south”, “east”, or “west”. For each task in Soar, a set of output commands is defined, and in Eaters there are two commands: move and jump.



You should now try to write the Soar rules for the move-north operator.

To create your own agent for eaters, use your favorite text editor, and save the file that you create with a .soar file extension. To create an agent that loads the production that you have written, create an agent as in section 1.1, but this time instead of loading “move-to-food.soar”, load the file that you just created.

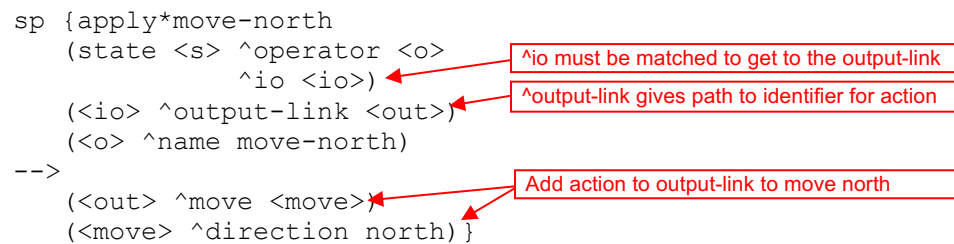
2.2 Soar Version

Below is the proposal rule I wrote. You can find this rule in the file “move-north.soar” in the “Agents\ \Eaters\Tutorial” directory where you found “move-to-food.soar”. The proposal rule is exactly the same as the proposal rule for hello-world, except that the names of the rule and the operator are changed.

```
sp {propose*move-north
  (state <s> ^type state)
-->
  (<s> ^operator <o> +)
  (<o> ^name move-north)}
```

The rule that applies the operator has more differences. Its action is to add a move command to the output-link. This command will cause the eater to move one cell to the north. In order to add the command to the output-link, the rule must match the output-link identifier in its conditions with a variable. Therefore, conditions are included that match the io (<io>) object, and then the output-link (<out>).

```
sp {apply*move-north
  (state <s> ^operator <o>
    ^io <io>)
  (<io> ^output-link <out>)
  (<o> ^name move-north)
-->
  (<out> ^move <move>)
  (<move> ^direction north)}
```

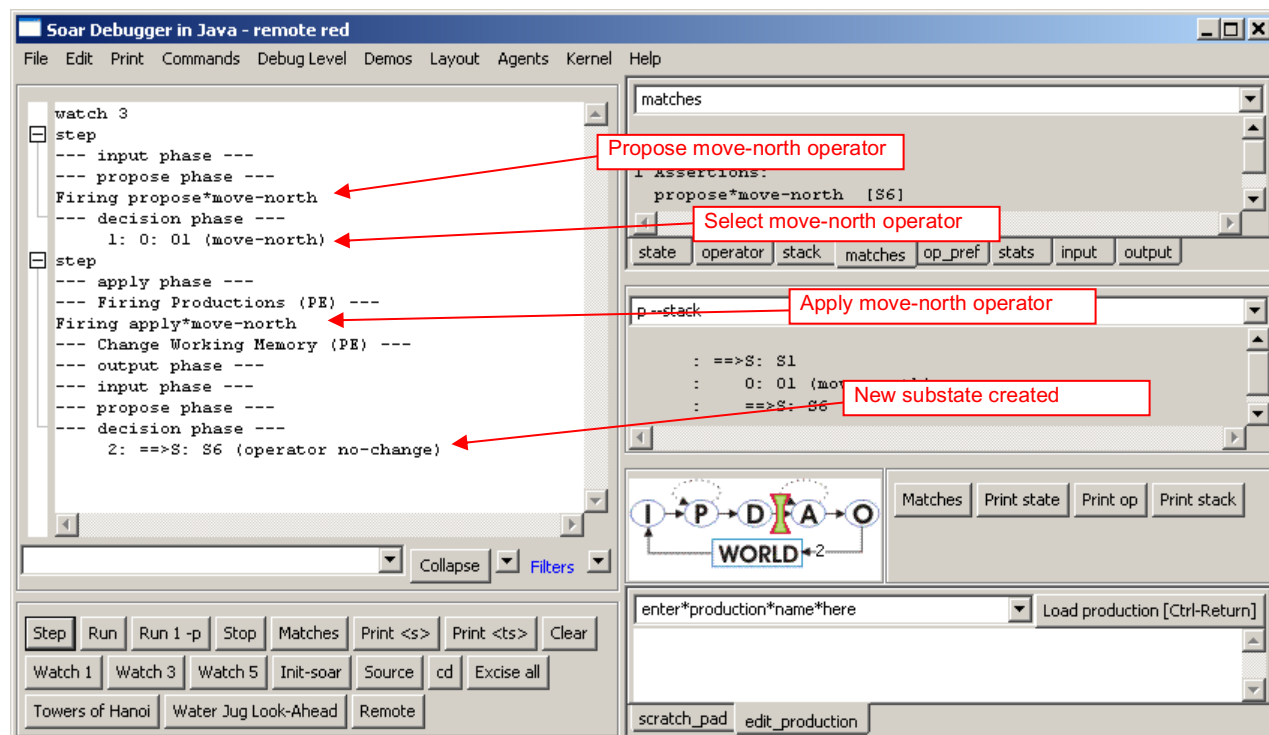


Annotations for the rule:

- “^io must be matched to get to the output-link” points to the `^io <io>` condition.
- “^output-link gives path to identifier for action” points to the `<out>` identifier in the `<io> ^output-link <out>` condition.
- “Add action to output-link to move north” points to the `<out> ^move <move>` action.

The exact order of the conditions (and actions) does not matter, except that the first condition must match the state identifier.

You should change your rules if they were significantly different than these. Then create a move-north eater and type “watch 3” on the command line so that you can watch the productions fire. Run the eater by clicking on the “Step” button until your eater moves north. If your eater doesn’t seem to be working, skip ahead to the Debugging Your Eater section. Once your eater has moved north, your interaction window should look like the following:



But what happened to your eater? After selecting move-north and taking one step, the eater had nothing more to do and a new state is created (`s6` in the above Figure). Unfortunately, the rules you wrote are not sufficient to get the eater to continually move north. In the next section, you will modify your eater so that it continues to move north.

2.3 Shortcuts

The `apply*move-north` rule has lots of variables in it whose sole purpose is to make connections between attributes. For example, `<o>` is used to later match the name of the operator and `<io>` is used to later match the output-link. Similarly, `<move>` is used in the action to connect the output-link to the final direction. None of these variables is used in both conditions and the actions.

```
sp {apply*move-north
  (state <s> ^operator <o>
    ^io <io>)
  (<io> ^output-link <out>)
  (<o> ^name move-north)
-->
  (<out> ^move <move>)
  (<move> ^direction north)}
```

To simplify the writing and reading of rules, Soar allows you to combine conditions that are linked by variables. To do this, you can just string together attributes, replacing the intermediate variables with a period, “.”, to separate the attributes. In Soar, we call this “dot” or “path” notation. Below is the same rule as before using dot notation.

```
sp {apply*move-north
  (state <s> ^operator.name move-north
    ^io.output-link <out>)
-->
  (<out> ^move.direction north)}
```

This rule is exactly the same as the original from Soar’s perspective.

One mistake you want to avoid making is to use dot notation in the action when you are creating multiple sub-attributes of a new object. This will create multiple objects, each with a single sub-attribute. For example, if you want create a second augmentation of the move object called speed (which is irrelevant in Eaters), you *do not* want to do the following:

```
-->
  (<out> ^move.direction north
    ^move.speed fast)
```

This is equivalent to:

```
-->
  (<out> ^move <move1>
    ^move <move2>)
  (<move1> ^speed fast)
  (<move2> ^direction north)
```

These actions will create *two* move augmentations on the output-link, each with a single attribute. The correct action is:

```
-->
  (<out> ^move <move>)
  (<move> ^speed fast
    ^direction north)
```

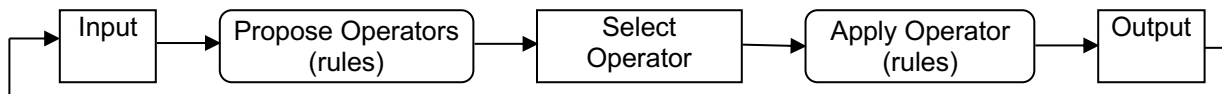
3. Move-North Operator: Multiple Moves

Although the move-north operator did move one step north, the eater never takes a second step. In this section, you are going to find out why it takes only one step and modify the eater so that it can take multiple steps. This is one of the most complex sections of the tutorial, so study it carefully.

3.1 Operator Selection: Multiple Instances

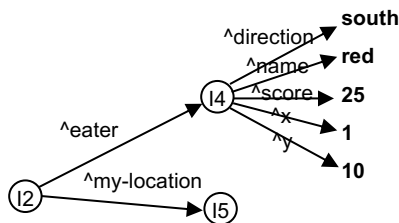
In Soar, each action in the world, such as moving an eater, should be performed by a separate operator *instance*. An operator instance is a separate operator in working memory element created by the firing of an operator proposal rule. Thus, each action should test for the creation of a new operator object in working memory. Different instances of the same operator will have the same name, and sometimes will have the same augmentations, but a given instance will be used for only one move. Some operator instances may include many actions, but they will be selected and applied only once.

Therefore, new instances of the move-north operator should be created in working memory for each new move. You should not attempt to have the move-north operator selected once, and have it move an eater multiple times. Instead, you should design your eater so that a new instance of the move-north operator is created for each move. You can do this by having the operator proposal rule fire each time the eater is to move. How can you change propose*move-north so that it fires after each move? As the rule is currently written, it will fire only once because it only tests `^type state`, which stays in working memory forever. Your rule needs to test working memory elements that change each time the eater moves – those working memory elements that correspond to the eater's senses on the input-link. Soar is designed so that changes to the input-link are made following output, just in time to affect operator proposals.



The information that comes in on the input-link consists of objects with attributes and values.

```
(I2 ^eater I4 ^my-location I5)
(I4 ^direction south ^name red ^score 25 ^x 1 ^y 10)
```



The input-link object, I2, has two augmentations. The first, `^eater`, has information about the eater: its current direction, its name, its current score, and its x, y coordinates. The second, `^my-location`, has additional substructure (not shown) that includes the eater's sensing of nearby cells. Some of the `^eater` information changes during the game:

- The x location will change when the eater moves east or west.
- The y location will change when the eater moves north or south.

Thus, whenever the eater moves, either the x or y location will change. We can modify the conditions of our proposal rule to test both of these working memory elements, and eliminate the test for `^type state`.

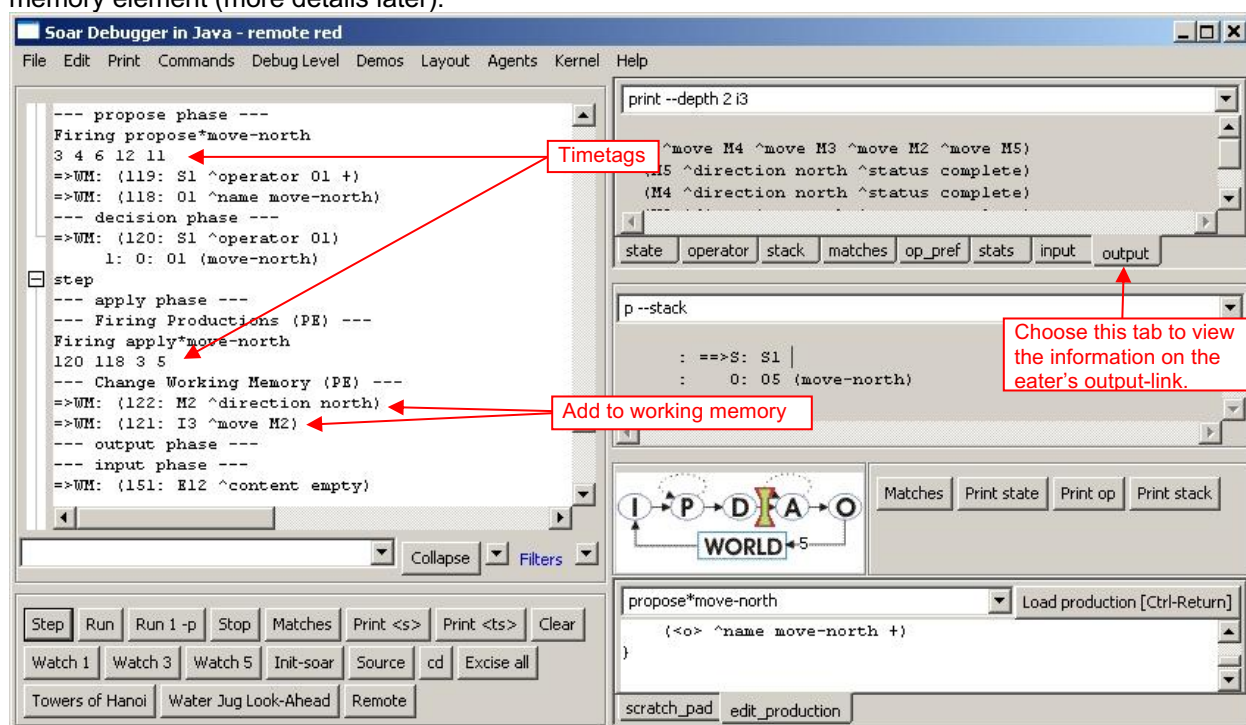
```
sp {propose*move-north
  (state <s> ^io.input-link.eater <e>)
  (<e> ^x <x> ^y <y>)
-->
  (<s> ^operator <o> +)
  (<o> ^name move-north) }
```

Matches current position of eater,
which changes after each move.

What will happen? First, when the original working memory elements for x and y are removed from working memory, the original move-north operator will be removed from working memory because the rule instantiation that created it no longer matches – some of the working memory elements responsible for the match are gone. We call this *retracting* the rule firing. Rules such as propose*move-north maintain their actions in working memory only as long as they match exactly the same working memory elements.

Second, a new instance of the move-north operator will be created because propose*move-north will match the new values of x and y and fire. To see these changes, modify your move-north operator as above and then rerun it. This time, we are going to increase the tracing so that we can see the individual changes to working memory. To do this, type “watch 4 --timetags” in the interaction window.

The figure below shows the end of the trace. The trace is long because it includes the addition and removal of all of the sensory data that changes during a move (not shown below). In the trace, an addition to working memory is shown preceded by an “=>”, while a removal from working memory is preceded by an “<=>”. Each working memory element also contains a number, such as 119 for the top element in the trace below. This is the *timetag* of the working memory element – a unique number generated when a working element is created. Soar sometimes displays only timetags instead of the full working memory element, and the timetag can be used in the print and wmes commands for displaying the full working memory element (more details later).



Your eater will now move north a second time (and a third, etc, if not blocked) because the proposal matches against a new set of x and y coordinates, apply*move fires again, and a second move command is created. But there are still problems. Step the eater a few more times and then choose the “output” tab on the upper right section of the eater Debugger window to see the eater’s ^output-link. You will notice that the original move command (I3 ^move M2) is not removed from the output-link, and the output-link will gradually accumulate stale commands. The old move command is not removed because it is the action of an operator application rule. Such actions are not automatically removed when the rule no longer matches.

3.2 Operator Application: Persistence

As noted above, proposing and selecting a second operator makes the eater move a second time, but the accumulation of more and more move commands will eventually become a problem. Why aren't these commands automatically removed like the preferences for operators? The reason is that the rule that creates them is part of the application of an operator, and operator applications create *persistent* working memory elements.

Persistence is necessary for creating memories of prior events, such as the memory of something sensed in the environment. For example, if an eater needed to remember the location of uneaten food so that it could return to it later, the eater would have to create a persistent structure in its working memory. Otherwise, as soon as it stopped sensing the food, it would forget about it. In Soar, all working memory elements created by an operator application rule are persistent. A rule is an operator application rule if it tests a selected operator and modifies the state. Persistent working memory elements are said to be *operator-supported*, or *o-supported*, because they are created by operators. For example, `apply*move-north` is an operator application rule and creates o-supported working memory elements.

```
sp {apply*move-north
  (state <s> ^operator.name move-north
    ^io.output-link <out>)
-->
(<out> ^move.direction north) }
```

← Tests selected operator

← Actions are o-supported

Just as it is important to have persistent memories, it is also important to have structures that are removed automatically when the reason for creating them goes away. Actions of rules that test only the state, or that test the operator and elaborate only the operator create non-persistent preferences or working memory elements. Obvious examples of non-persistent structures are the preferences for operators. These are created by operator proposal rules, which retract the operators when the proposal conditions change. Other examples include state elaboration rules and operator elaboration rules. Non-persistent working memory elements and preferences are called *instantiation-supported*, or *i-supported*, because they only persist as long as the rule instantiation that created them. For example, `propose*move-north` is not an operator application rule because it does not test a selected operator. All of its actions are i-supported and they will be removed from working memory when `propose*move-north` no longer matches.

```
sp {propose*move-north
  (state <s> ^io.input-link.eater <e>)
  (<e> ^x <x> ^y <y>)
-->
(<s> ^operator <o> +)
(<o> ^name move-north) }
```

← i-supported actions

Returning to the problem of moving the eater, you need to add a rule that removes old move commands from the output-link after the move is finished. In Eaters, the output system creates an augmentation on the move object after the action has executed: `^status complete`. To remove a structure from working memory, a rule “rejects” a working memory element in its action. A reject must be part of an operator application rule because it is a persistent change to working memory. Therefore, the removal must test the move-north operator so that it is an operator application rule. In English, the rule is:

```
# Apply*move-north*remove-move:
# If the move-north operator is selected,
#   and there is a completed move command on the output link,
#   then remove that command.
```

In Soar, the action of a rule can remove a working memory element by following it by a reject preference, which is designated with a minus sign (“-”). The above rule is translated in to Soar as follows:

```
sp {apply*move-north*remove-move
  (state <s> ^operator.name move-north
    ^io.output-link <out>)}
  (<out> ^move <move>)
  (<move> ^status complete)
-->
  (<out> ^move <move> -) }
```

Cannot use dot notation for <out> and <move> because they are needed in the action

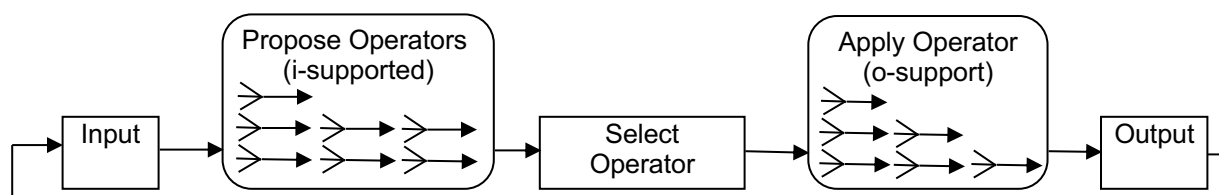
Created by the output system when the move action is completed

- means remove from working memory

The action of this rule removes the working memory element specified by `(<out> ^move <move>)`, which would be something like `(i3 ^move m1)`. When this working memory element is removed, all of the augmentations of `m1` are automatically removed because they are no longer *linked* to the rest of working memory. In this case, `(m1 ^direction north)` and `(m1 ^status complete)` are removed. These would not be removed if they remained linked via another working memory element that had `m1` as a value.

This is an operator application rule, so it will not fire during the following operator proposal phase. Instead, it will fire during the next operator application phase, after a new move-north operator has been selected. It will not interfere with other operator application rules because rules fire (and retract) in *parallel* as a wave. The parallelism is only simulated, but the effect is as if all the rules fire or retract at the same time. Once a wave of rules has fired, their actions may cause additional rules to match or retract. Soar will continue to fire or retract additional waves of rules until no more rules match. Thus, within the phases of proposing and applying operators, Soar fires all rules that match until *quiescence*, that is, until no more rules match. During the propose phase, only rules that have i-supported actions will fire. During the apply phase, both o-supported and i-supported rules fire.

Returning to our diagram of the phases of Soar, both the propose operator and apply operator phases can be expanded to show that multiple rules fire and retract in parallel until quiescence.



3.3 Running and Tracing

When running your new eater, it will go north until it hits a wall or the border. When it can no longer move, it will start generating states because it cannot successfully apply and terminate the move-north operator. Below is a sample trace, with the “watch 3 --timetags” in use, of the interaction window for the first two moves to the north by an eater.

The screenshot shows the Soar Debugger in Java - remote red interface. The main window displays a trace of an eater's movement. The trace includes phases like propose, decision, apply, and retracting. Red arrows point to specific lines in the trace with callouts: "One rule firing and one rule retracting at the same time" and "Two rules firing in parallel". The interface also shows a command window, a stack window, a diagram of the world state, and a production rule editor.

Trace Log:

```

--- propose phase ---
Firing propose*move-north
3 4 6 12 11
--- decision phase ---
1: 0: 01 (move-north)
--- apply phase ---
--- Firing Productions (PE) ---
Firing apply*move-north
120 118 3 5
--- Change Working Memory (PE) ---
--- output phase ---
--- input phase ---
--- propose phase ---
Firing propose*move-north
3 4 6 126 125
Retracting propose*move-north
3 4 6 12 11
--- decision phase ---
2: 0: 02 (move-north)
--- apply phase ---
--- Firing Productions (PE) ---
Firing apply*move-north
154 152 3 5
Firing apply*move-north*remove-move
154 152 3 5 121 123

```

Command Window:

```

print --depth 2 i3
(i3 ^move M3)
(M3 ^direction north ^status complete)

```

Stack Window:

```

p --stack
: ==>S: S1
: 0: 03 (move-north)

```

Diagram: A diagram showing the flow of information between the World and the Eater. The World is represented by a box labeled "WORLD" with a "3" next to it. The Eater is represented by a box labeled "E" with a "3" next to it. The flow is indicated by arrows: "I" (Input) from the World to the Eater, "P" (Propose) from the Eater to the World, "D" (Decision) from the World to the Eater, "A" (Apply) from the Eater to the World, and "O" (Output) from the Eater to the World.

Production Rule Editor:

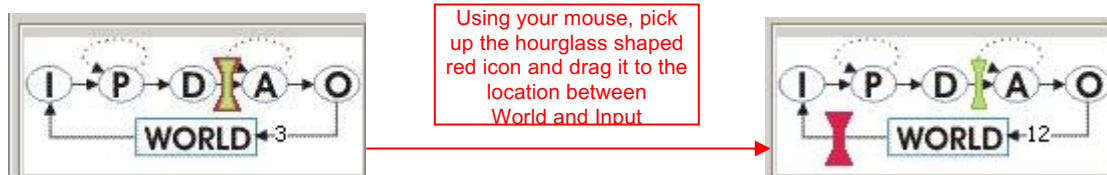
```

sp {apply*move-north*remove-move
  (state <s> ^operator <o*1> ^io <i*1>)
  (<o*1> ^name move-north)
  (<i*1> ^output-link <ol>)
  (<ol> ^move <move>)}

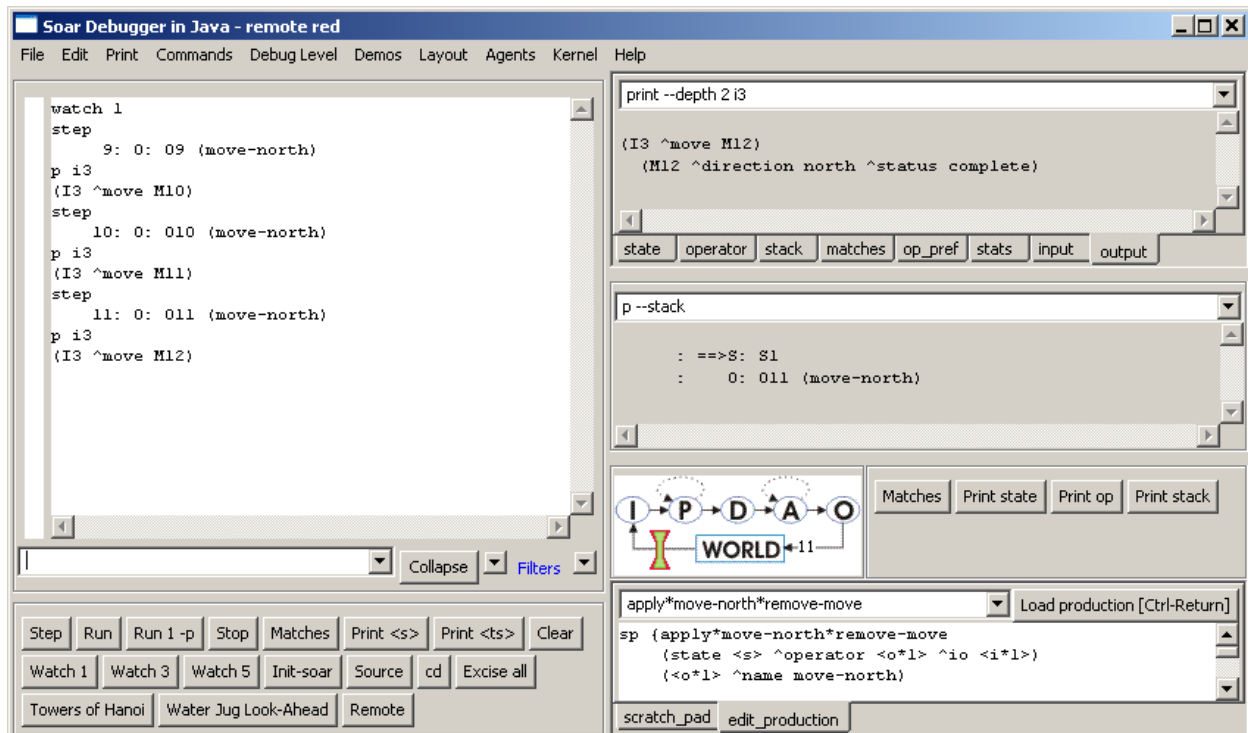
```

If you look closely at this trace, you see that two rules are firing at the same time: apply*move-north, and apply*move-north*remove-move. One is adding the new move command to the output-link at the same time that the other is removing the previous move command. There are also examples of rules firing and retracting at the same time where an operator is being removed from working memory at the same time that a new operator is being created.

Instead of letting Soar run free, you can step Soar through each decision using the “Step” button on either the Soar Debugger or the Java Eaters window. The default will stop each step before the application phase, right after Soar has made an operator selection (decision phase). It’s possible to change the location where Soar will stop when stepping, using the Soar Cycle widget in the Debugger.



The red icon in the diagram shows the point where Soar will stop when the Step button is used. The green icon shows where Soar is in its execution cycle. Move the Stop Point to the location between “World” and “Input” as shown above. This is just after the output commands have been added to the output-link and just before the eaters are about to move. In the following trace, the Watch level is 1, the step button has been used, and then the output-link is examined. This is repeated twice.



From prior runs, you know that I3 is the identifier of the output-link. Although Soar does not guarantee that I3 will always be the identifier of the output-link, it always is, just as I1 is the identifier of the io object, I2 is the identifier of the input-link, and S1 is the identifier of the first state.

When you print I3, you see that the move command is correctly added to the output-link. You can see more than one level of augmentation by using the -d flag on the print command as shown in the upper right monitoring window.

You can also step through one phase at a time by using the `run 1 -p` command.

4. Move-To-Food Operator

In this section you will create an eater that greedily moves to any food it senses. You will use the lessons you learned from the move-north operator, and learn more about the structure of the input-link and operator preferences.

Each eater can sense the food and walls that surround it, two steps in each direction. The Eaters Info window shows what an eater can sense. For this eater, you will write an operator that moves the eater to one of the neighboring cells (north, east, south, or west) that contains normalfood or bonusfood. Since food can be in more than one of the neighboring cells, more than one operator may be proposed. Soar does not automatically select randomly from among a set of proposed operators – it will get a *tie impasse* if there are multiple operators with only acceptable preferences. To avoid ties, Soar has additional preferences. For this exercise, it does not matter which food an eater consumes first, so you can use a preference that makes the decision procedure arbitrarily select one of the proposed operators.

Based on the above discussion, you will need four rules for the move-to-food operator.

- You need one rule to propose the operator when there is normal-food in a neighboring cell and a second rule to propose the operator when bonus-food is in a neighboring cell. Unlike the move-north operator, these proposal rules do not have to test the coordinates of the eater because the contents of the neighboring cells will change when the eater moves. The contents will change (the working memory elements for contents of all of the sensed cells are removed and re-added to working memory) even if the sensed object is the same type. The operator proposal rules can also create the indifferent preferences that lead to a random selection.
- You need a third rule to apply the operator and move the eater in the correct direction.
- You need a fourth rule to remove the move command from the output-link.

Now try to write English versions of the move-to-food operator. Use the English versions of the move-north operator as a guide:

```
##### Move-north operator #####
# Propose*move-north:
# If I am at a specific location, then propose the move-north operator.
#
# Apply*move-north:
# If the move-north operator is selected,
#   generate an output command to move north.
#
# Apply*move-north*remove-move:
# If the move-north operator is selected,
#   and there is a completed move command on the output link,
#   then remove that command.
```

4.1 English Version

Here is one possible set of rules for the move-to-food operator.

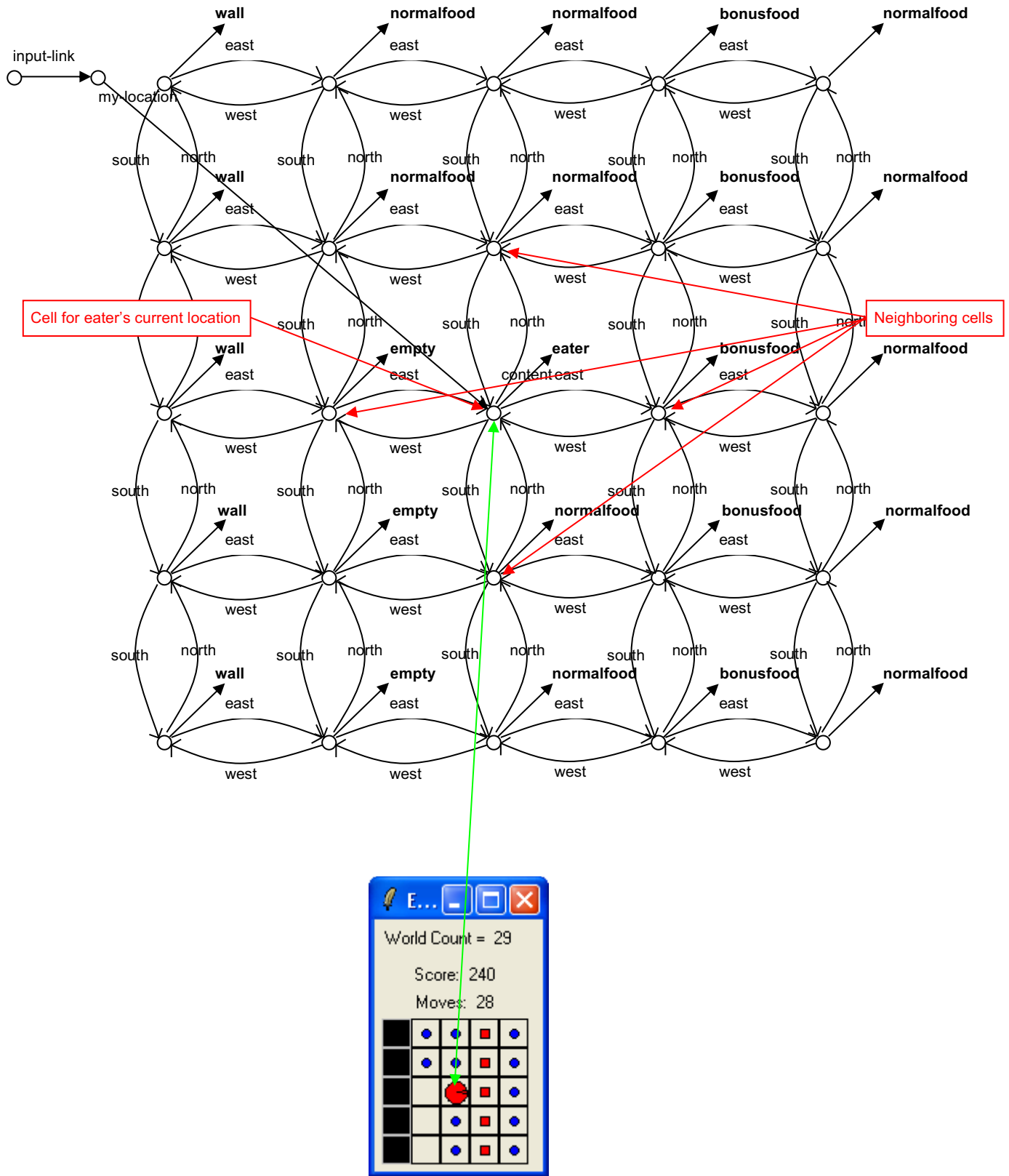
```
##### Move-to-food operator #####
# Propose*move-to-food*normalfood
# If there is normalfood in an adjacent cell,
#   propose move-to-food in the direction of that cell
#   and indicate that this operator can be selected randomly.
#
# Propose*move-to-food*bonusfood
# If there is bonusfood in an adjacent cell,
#   propose move-to-food in the direction of that cell
#   and indicate that this operator can be selected randomly.
#
# Apply*move-to-food
# If the move-to-food operator for a direction is selected,
#   generate an output command to move in that direction.
#
# Apply*move-to-food*remove-move:
# If the move-to-food operator is selected,
#   and there is a completed move command on the output link,
#   then remove that command.
```

Converting these rules to Soar requires a more detailed examination of preferences and the input-link.

- **Preferences.** To select randomly among the proposed operators, Soar has a preference called *indifferent*. The equal sign, “=”, is used to signify an indifferent preference for an operator, just as “+” signifies acceptable. The indifferent preference means that the decision procedure can randomly select among all operators with indifferent preferences, so it is important that all proposed operators have indifferent preferences. Even though we will create an indifferent preference for these operators, the acceptable preference is still necessary and an operator will not be selected if it does not have an acceptable preference.
- **Input-link representation.** The input-link has two augmentations: eater and my-location. Remember that the value of the my-location augmentation is the eater’s current position and is a cell in middle of the 5x5 Eaters Info sensory field. On the next page there is a graphic depiction of this cell and all of the other cells in the sensory field. Adjacent cells are augmentations labeled *north*, *east*, *south*, and *west*. Every cell also has a *^content* augmentation, whose value can be *wall*, *empty*, *eater*, *normalfood*, or *bonusfood*. If the cell has an eater in it, there will be additional augmentations (not shown in the figure) for the color of the eater (*^eater-color*), and the eater’s current score (*^eater-score*). Below the figure for the input-link structure is the corresponding Eaters Info window.

Based on the information in those figures, you should try to write a Soar rule for propose*move-to-normalfood. Two hints:

1. Write down the sequence of attributes that go from the state to the value of the content of a cell, separating each attribute with a “.”.
2. Use a variable to match the direction augmentations to a neighboring cell and then test that the content is *normalfood*. That variable in the attribute position will match any direction augmentation between cell: *north*, *east*, *south*, or *west*. You can write it: *^<variable>*



4.2 Soar Version

Below is the proposal rule I wrote without dot notation so that it is clear which working memory elements are being matched. The proposal rule tests a sequence of linked identifier-attribute-values, and includes a variable for the attribute that leads to an adjacent cell. The variable will match north, east, south, or west if the final condition matches an adjacent cell containing (has “^content”) normalfood.

```

sp {propose*move-to-normalfood
  (state <s> ^io <io>)
  (<io> ^input-link <input-link>)
  (<input-link> ^my-location <my-loc>)
  (<my-loc> ^<direction> <cell>*)
  (<cell> ^content normalfood)
-->
  (<s> ^operator <o> +)
  (<s> ^operator <o> =)
  (<o> ^name move-to-food
    ^direction <direction>*)}

```

Matches any attribute

Matches an adjacent cell

Matches cell with normalfood

= signifies indifferent/random

Use matched direction in action

The indifferent preference tells Soar that a random selection can be made between proposed operators. The <direction> in the action augments the operator with the direction of an adjacent cell containing normalfood. When an eater is surrounded by food, the <direction> variable will match all directions, leading to four matches of the rule. In Soar, all new matches fire in parallel, creating new operators, each with a different ^direction augmentation. For example, if there was normalfood to the south and west, two operators would be created, one with ^direction south and one with ^direction west.

This rule can be written much more concisely using dot notation, and a short cut for the preferences.

```

sp {propose*move-to-normalfood
  (state <s> ^io.input-link.my-location.<dir>.content normalfood)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move-to-food
    ^direction <dir>*)}

```

+ = means two preferences are created: acceptable and indifferent

The rule that proposes the operator to move to consume bonusfood is very similar.

```

sp {propose*move-to-bonusfood
  (state <s> ^io.input-link.my-location.<dir>.content bonusfood)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move-to-food
    ^direction <dir>*)}

```

The rule to create the move command on the output link is very similar to the one used in move-north. The only difference is that instead of always using “north” as the direction, it uses the direction created by the operator proposal rule and matched by variable <dir>.

```

sp {apply*move-to-food
  (state <s> ^io.output-link <out>
    ^operator <o>)
  (<o> ^name move-to-food
    ^direction <dir>)
-->
  (<out> ^move.direction <dir>*)}

```

The final rule removes the move command from the output-link when it has completed.

```

sp {apply*move-to-food*remove-move
  (state <s> ^io.output-link <out>
    ^operator.name move-to-food)
  (<out> ^move <move>)
  (<move> ^status complete)
-->
  (<out> ^move <move> -)}

```


4.3 Shortcuts and Extensions

The rules `propose*move-to-normalfood` and `propose*move-to-bonusfood` differ only in the tests for `normalfood` and `bonusfood`. Instead of writing an individual rule for each of those values, it is possible to write a single rule that tests for any one of a set of alternative values. The alternative values are written in the same position as a single value, but are surrounded by double angle brackets: `<< normalfood bonusfood >>`. Any number of different values can be included, but none of them can be a variable. Using this notation, the two rules can be rewritten as the following rule:

```
sp {propose*move-to-food
  (state <s> ^io.input-link.my-location.<dir>.content
    << normalfood bonusfood >>)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move-to-food
    ^direction <dir>)}
```

Make sure there is a space between the <<, >>, and the values

This notation can also be used for testing alternative values of attributes.

Soar supports another shortcut, similar in spirit to dot notation that allows you to eliminate variables in conditions whose sole purpose is to link conditions. Dot notation works if there is a single augmentation. However, if there are multiple augmentations, dot notation doesn't help. Grouping, using parentheses, handles this case. In place of where a variable would go as an action, you can insert the augmentations of the value. For example, the original `apply*move-to-food` was:

```
sp {apply*move-to-food
  (state <s> ^io.output-link <out>
    ^operator <o>)
  (<o> ^name move-to-food
    ^direction <dir>)
-->
  (<out> ^move.direction <dir>))
```

This can be replaced by

```
sp {apply*move-to-food
  (state <s> ^io.output-link <out>
    ^operator (^name move-to-food
      ^direction <dir>))
-->
  (<out> ^move.direction <dir>))
```

Although this does eliminate unnecessary variables, it often makes the rules more difficult to read, so this notation will not be used in the rest of the tutorial.

One more thing you might want to add is the ability to trace the direction of the selected operator. You can do this with a rule that tests that the operator is selected and uses the write action.

```
sp {monitor*move-to-food
  (state <s> ^operator <o>)
  (<o> ^name move-to-food
    ^direction <direction>)
-->
  (write |Direction: | <direction>))
```

This rule will fire in parallel with `apply*move-to-food` because it matches a selected operator.

4.4 Example Trace

The screenshot shows the Soar Debugger interface with a blue title bar and a menu bar (File, Edit, Print, Commands, Debug Level, Demos, Layout, Agents, Kernel). The main window is divided into three panes:

- Left Pane (Trace):** Displays a list of events with expandable sections.
 - watch -P:** Contains several "Firing propose*move-to-normalfood" events with timestamps like "3 4 12 29 112".
 - 1: 0: 01 (move-to-food):** Contains "Firing monitor*move-to-food" and "Direction: east" events.
 - 2: 0: 05 (move-to-food):** Contains "Firing monitor*move-to-food" and "Direction: south" events.
 - 3: 0: 07 (move-to-food):** Contains "Firing monitor*move-to-food" events.
- Right Pane (Top):** Shows a command "print <s>" and its output:


```
(S1 ^io I1 ^oper
07 +
    ^supersta
```
- Right Pane (Bottom):** Shows a command "p --stack" and its output:


```
: ==>S: S1
:      0: 07
```

At the bottom of the window, there is a search bar, an "Expand" button, and a "Filters" dropdown menu.

5. Debugging Soar Programs

In trying to write the operators in the previous section, you may have made some mistakes. In this section, you will learn techniques for finding and fixing bugs in Soar programs. The techniques are separated based on the cause of the error:

- When the rules for an eater are read into Soar, Soar checks to make sure that the rules are legal and displays messages when it finds errors. These types of errors are called *syntax errors*. Visual-Soar will also check for syntax errors in rules. I recommend using Visual-Soar to check for errors first.
- If your rules load into Soar without any error messages, there can still be mistakes in the underlying logic of the rules. These are *semantic errors*.

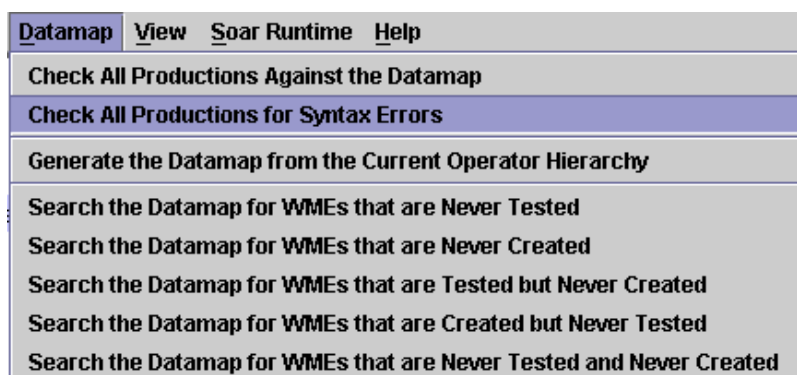
This section starts with a subsection on Syntax Errors. Subsections follow this on different techniques for monitoring and examining your program while it is running. The last subsection is a walk through of using these techniques to debug a program.

5.1 Syntax Errors

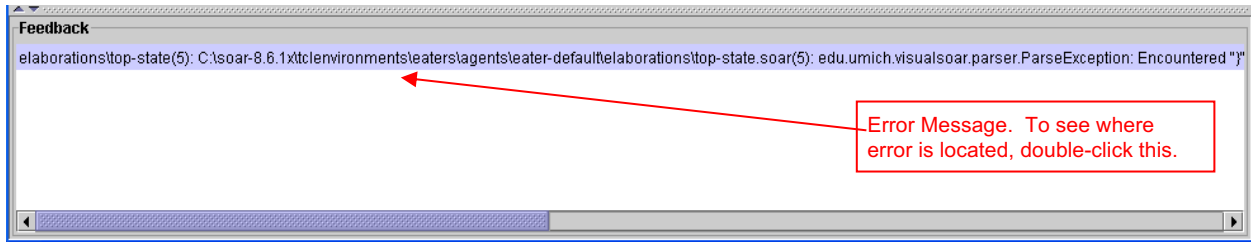
There are many different types of syntactic errors that you can have in your programs. The eight most common errors are:

1. Missing comment character
2. Missing {
3. Missing)
4. Extra)
5. Missing }
6. Missing state
7. Missing ^
8. Disconnected rhs action variable.

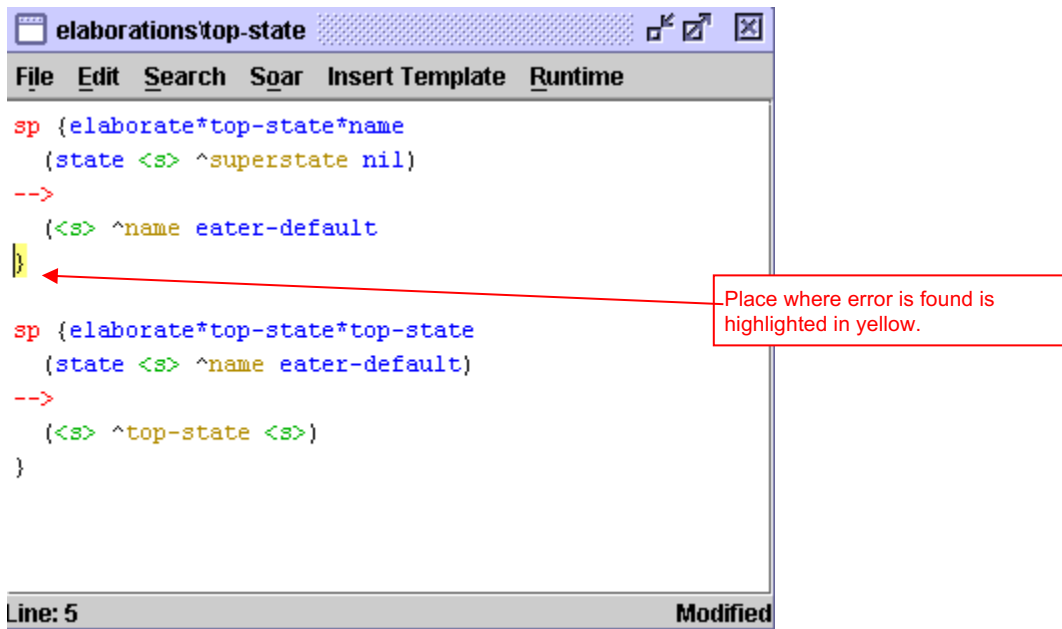
Fortunately, with the development of VisualSoar, locating and fixing syntax errors in Soar productions has become relatively easy. Before loading rules into the debugger to execute a Soar program, check for syntax errors using VisualSoar. To do this, click Datamap | Check All Productions for Syntax Errors.



VisualSoar will check all of your productions to make sure that they conform to the standard syntax rules. The results of this check will appear in the feedback window (which is located at the bottom of the VisualSoar window). If an error is found, an informative error message will appear in blue. The first part of the error message will be the name of the file where the error was found and its line number in the format <file-name>(line number): This is then followed by more output which will include the specific path of the file the error was found in, and why VisualSoar considers it a syntax error:



One of the best features of VisualSoar is that double-clicking on an error message allows you to see exactly where the error occurred. Double-clicking an error message automatically opens the window in which the error was found, and highlights the illegal area in yellow. For instance, double-clicking this error message would cause this window to pop-up:



If no errors are found, "There were no errors detected in this project" will be printed in the feedback window.

We suggest playing around with this tool. Delete brackets and braces, # signs and -->'s to see what errors VisualSoar gives you so that you are able to quickly recognize what types of messages certain errors give. This will make future debugging much easier.

5.2 Write Statements

One of the oldest debugging techniques in traditional programming languages is to add print statements throughout the program. Although not the most effective technique, it can be easily used in Soar by adding write statements in the action of rules. To make the output readable, you want to have a linefeed before writing out any text, using the (crlf) command, which stands for carriage-return and linefeed.

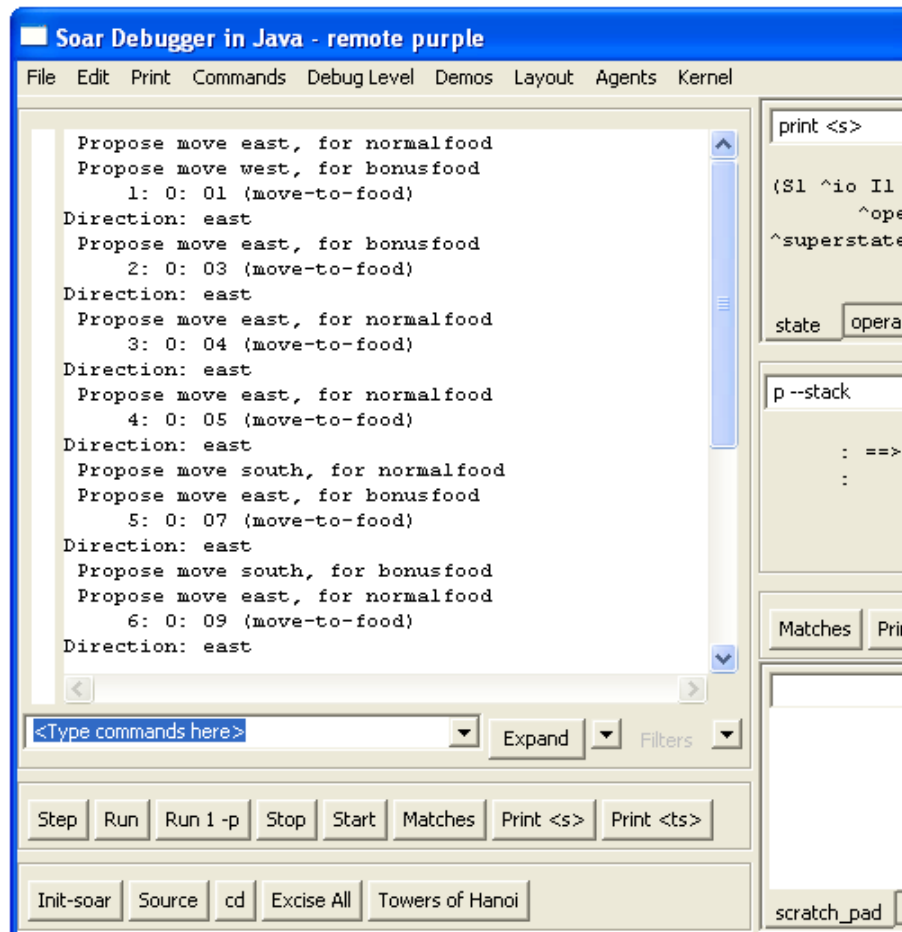
For example, if you want to keep track of all of the move-to-food operators that are proposed, including their direction and expected food, you could take the original rule given below:

```
sp {propose*move-to-food
  (state <s> ^io.input-link.my-location.<dir>.content
    << normalfood bonusfood >>)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move-to-food
    ^direction <dir>)}
```

and modify it by adding a write statement. To get the right values in the action requires a variable for the food type in the condition.

```
sp {propose*move-to-food
  (state <s> ^io.input-link.my-location.<dir>.content
    { <type> << normalfood bonusfood >> })
-->
  (write (crlf) | Propose move | <dir> |, for | <type>)
  (<s> ^operator <o> + =)
  (<o> ^name move-to-food
    ^direction <dir>)}
```

The write command concatenates all of its arguments, which can include constants and variables.



5.3 Runtime Debugging Commands

While Soar is running, there are many commands you can use to get information on what the current state of the system is, what happened in the past, and what is about to happen. This subsection is organized by the different commands. To learn the details of all of these commands, you should check the Soar User's Manual.

print

You have already seen the print command, which is used to print out working memory structures. Print can take a variety of arguments. One of the most useful is to print to a given depth. This prints not only the current identifier and all of its augmentations, but also all of their augmentations recursively to a given depth. For example, you can print out the current state to a depth of 2 by using the following command:

```
red> print --depth 2 s1
```

The order is important and s1 must come at the end of the print statement. The result is:

```
(S1 ^type state ^superstate nil ^io I1 ^operator O2 ^operator O4 +
  ^operator O3 + ^operator O2 + ^operator O1 +)
(I1 ^input-link I2 ^output-link I3)
(O2 ^name move-to-food ^direction south)
(O4 ^name move-to-food ^direction west)
(O3 ^name move-to-food ^direction north)
(O1 ^name move-to-food ^direction east)
```

You can also use the mouse to print working memory objects by right clicking on an identifier. If you select the print option, you will see that there are many other options for printing objects in working memory.

wmes

The wmes command can also be used to print out individual working memory elements instead of complete objects. This command also prints out the *timetag* of an individual working memory element. This is a unique number that Soar uses to keep track of each working memory element.

```
red> wmes o1
(120: o1 ^name move-to-food)
(121: o1 ^direction east)
```

Timetags can also be used as arguments in the print and wmes commands. Print will display all of the working memory elements that have the given timetag as their identifier, while wmes will display only the specified working memory element.

```
red> print 120
(O1 ^name move-to-food ^direction east)

red> wmes 120
(120: o1 ^name move-to-food)
```

matches

One of the questions you will frequently want to ask is, “What rules are about to fire?” The matches command will return a list of all rules that are ready to fire, separated into those that will be operator applications (O Assertions), those that will create I-support augmentations (I Assertions), and those that will remove I-supported augmentations (Retractions).

```
red> matches
O Assertions:
I Assertions:
Retractions:
```

Matches also can be invoked through the “show” item on the menu list, or by right clicking on the interaction window, then selecting the production item on the menu that appears. Note; matches will not show rules that completely match, but have *already fired*. Thus, if you stop Soar after a rule has fired, matches alone will not show it.

Matches can also take as an argument the name of a rule. It will then print out the rule, condition by condition, with information on how many working memory elements match that condition and are consistent with all of the variables in the previous conditions. When Soar loads in a rule, it automatically reorders the conditions of the rule so that it can efficiently match it, so the ordering of the conditions from matches will not be the same as the ordering of the rule when you wrote it.

If a rule completely matches, then it has either already fired, or is about to fire.

```
red> matches propose*move-to-food
1 (state <s> ^io <i*1>)
1 (<i*1> ^input-link <i*2>)
1 (<i*2> ^my-location <m*1>)
7 (<m*1> ^<dir> <d*1>)
3 (<d*1> ^content { << normalfood bonusfood >> <c*1> })
```

3 complete matches.

In this example, the first three conditions have a single match, and then the fourth condition matches seven different working memory elements. These are all of the augmentations of my-location. The final condition then restricts the matches to be only those that have content normalfood or bonusfood.

If a rule does not completely match, the condition that failed to match will be preceded by “>>>>” as in:

```
red> matches apply*move-to-food*remove-move
1 (state <s> ^operator <o*1>)
1 (<o*1> ^name move-to-food)
1 (<s> ^io <i*1>)
1 (<i*1> ^output-link <out>)
1 (<out> ^move <move>)
>>>> (<move> ^status complete)
```

0 complete matches.

Matches can also print out working memory elements that match the conditions by using the -timetags (for just the timetags) or -wmes (for complete working memory elements) arguments. Matches can be invoked by clicking with the right mouse button on the name of a production and then selecting “production” from the menu that appears.

preferences

There is a special command to print out the preferences for selecting an operator. This command also works for any working memory element (prior versions of Soar allowed preferences for all working memory elements and there are still vestiges of them in the current version). To use the preference command, you give an identifier and an attribute. Soar will then print out all of the preferences for all values of that identifier attribute pair. For example, to print out all of the preferences for the operator attribute:

```
red> preferences s1 operator
Preferences for S1 ^operator:
acceptables:
  O7 (move-to-food) +
  O8 (move-to-food) +
  O9 (move-to-food) +
unary indifferents:
  O7 (move-to-food) =
  O8 (move-to-food) =
  O9 (move-to-food) =
```

This example shows that there are three operators proposed (O7, O8, O9), and each one has an acceptable and indifferent preference.

The preferences command has another feature that makes it extremely useful. Using the -name argument, it will tell you the name of the production that created the preference. For example, if you want to discover why there is the working memory element (I3 move m3), you can type:

```
red> preferences I3 move --names
Preferences for I3 ^move:
acceptables:
  M3 +
    From apply*move-to-food
```

This tells you that apply*move-to-food creates this working memory element. If you want to find out what working memory elements matched apply*move-to-food when it created (I3 move m3), you can type:

```
red> preferences I3 move --wmes
Preferences for I3 ^move:
acceptables:
  M3 +
    From apply*move-to-food
  (212: S1 ^operator O8)
  (205: O8 ^name move-to-food)
  (206: O8 ^direction north)
  (3: S1 ^io I1)
  (5: I1 ^output-link I3)
```

You can also invoke preferences by clicking with the right mouse button on an attribute of a working memory element in the interaction window. Select the preferences command from the menu that appears and then select the appropriate preferences command.

5.4 Semantic Errors

In this section you will use the techniques from the prior section to fix semantic errors. In a rule-based system, semantic errors have three general results:

1. A rule does not fire when it should.
2. A rule fires when it shouldn't.
3. The action of the rule is incorrect.

Unfortunately, when you have an error, you don't know which type it is. Luckily, there are general techniques for finding all types of semantic errors.

The first, and most important, step in finding semantic errors is knowing what you think the program should be doing at each step. Only by knowing what the program should do, will you be able to detect when it does something wrong. Usually you will notice that the wrong operator is selected, or that no operator is selected (a substate is created).

I've created a file called "semantic-errors.soar" in the "Agents\Eaters\Tutorial" directory for move-to-food that has some bugs. Create an eater with this file and also open the file in a text editor so you can modify as we go along. You should expect that propose*move-to-food to fire during the first step, so be bold and click on the step button and see what happens. You should get a trace like:

```
red> ***
      0: ==>S: S1
      1:      ==>S: S2 (state no-change)
```

This clearly indicates that propose*move-to-food did not fire. To find out why, try matches propose*move-to-food.

```
red> matches propose*move-to-food
      1 (state <s> ^io <i*1>)
      1 (<i*1> ^input-link <i*2>)
      1 (<i*2> ^my-location <m*1>)
      7 (<m*1> ^<dir> <d*1>)
>>>> (<d*1> ^contant { << normalfood bonusfood >> <c*1> })

      0 complete matches.
```

There is a problem with the last condition. You can examine working memory to find out what it should be matching and after some examination, you should realize that the name of the attribute should be "content", not "contant". Change the rule in the file. If you have been using Visual-Soar, it would have found this error while you were creating the Eater. To avoid destroying and creating a new eater, you can just reload the rules by clicking on the Commands menu of the Interaction Window and selecting "Reload Productions". Now you can try going one step again. You should have the following in your interaction window:

```
red> ***
      0: ==>S: S1
      1:      O: O1 (move-to-food)
```

At this point, you can check which rules are about to fire by using the matches command.

```
red> matches
      0 Assertions:
        apply*move-to-food
      1 Assertions:
      Retractions:
```

That looks fine, so take one more step. Unfortunately, the eater doesn't move. What's the problem? You should examine the output-link to see if the move command was correctly created:

```
red> print --depth 2 i3
      (I3 ^moves M1)
        (M1 ^direction east)
```

Unfortunately, you have to inspect this structure and realize that the command it creates is "moves" not "move". Correct this, reload, and take another step. Now the eater moves and runs appropriately.

6. Generalized Move Operator

The move-to-food operator you created in the last section would get stuck when there was no food in the cells adjacent to the eater. It also did not prefer bonusfood to normalfood. In this section, you will generalize the move-to-food operator to be an operator that can move to a cell with any type of content. Once you have created such a generalized move operator, we will introduce additional preferences that allow you to create a greedy eater that never gets stuck.

6.1 Move Operator Proposal

The proposal for the move operator needs to test that there is an adjacent square that it can move into. It should not propose moving into a wall. There are two possible approaches to write this test. The first is to test all of the content values that are ok to move into: normalfood, bonusfood, eater, or empty. The second is to test that the content does not equal wall. Taking the first approach gives us the following English version of the proposal:

```
# Propose*move*1:
# If there is normalfood, bonusfood, eater, or empty in an adjacent cell,
#   propose move in the direction of that cell
#   and indicate that this operator can be selected randomly.
```

It is straightforward to translate this into Soar based on the move-to-food operator proposal:

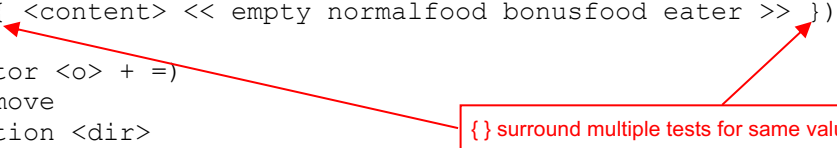
```
sp {propose*move*1
  (state <s> ^io.input-link.my-location.<dir>.content
    << empty normalfood bonusfood eater >>)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move
    ^direction <dir>)}
```

Although this is adequate, it will make future selection rules simpler if the operator also contains the contents of the cell. Thus, an alternative version is:

```
# Propose*move*1a:
# If there is normalfood, bonusfood, eater, or empty in an adjacent cell,
#   propose move in the direction of that cell, with the cell's content,
#   and indicate that this operator can be selected randomly.
```

To translate this into Soar requires matching the cell's content to a variable and then using that variable in the action as an augmentation of the operator, such as ^content <content>. However, the value is already matched by << empty normalfood bonusfood eater >>. What is needed is a way to match both a variable and the list at the same time. In Soar this is done by surrounding the two (or more) things to match against the same item with curly braces: "{ }". Thus, the Soar version of the proposal becomes:

```
sp {propose*move*1a
  (state <s> ^io.input-link.my-location.<dir>.content
    { <content> << empty normalfood bonusfood eater >> })
-->
  (<s> ^operator <o> + =)
  (<o> ^name move
    ^direction <dir>
    ^content <content>)}
```



{ } surround multiple tests for same value

Although this rule is adequate, it forces you to list all of the contents except walls. This rule will have to be changed if we ever add other types of food (e.g., superbonusfood). It might be better to write a rule that tests that the content is *not equal* to wall. This can be done in Soar by using “<>”. The not equal test can also be combined with the variable as in propose*move*1a, giving the following rule:

```
sp {propose*move*2a
  (state <s> ^io.input-link.my-location.<dir>.content
    { <content> <> wall })
-->
  (<s> ^operator <o> + =)
  (<o> ^name move
    ^direction <dir>
    ^content <content>)}
```

Will match any value except wall.

The “<>” must be placed directly *before* the value it compares, and in the example above, it is correctly before wall. The rule can also be written with the variable *after* the test that the content is not equal to wall:

```
sp {propose*move*2a
  (state <s> ^io.input-link.my-location.<dir>.content
    { <> wall <content> })
-->
  (<s> ^operator <o> + =)
  (<o> ^name move
    ^direction <dir>
    ^content <content>)}
```

The order of tests in {} does not matter.

The not equal test can also be used with variables. For example, if you want to test that the content of the cells to the north and south of the eater are not equal, you could use the following conditions:

```
(state <s> ^io.input-link.my-location <my-loc>)
(<my-loc> ^north.content <north>
  ^south.content <> <north>)
```

If you wanted to match the contents of both the north and south cells for use in the action, you could use the following conditions:

```
(state <s> ^io.input-link.my-location <my-loc>)
(<my-loc> ^north.content <north>
  ^south.content { <south> <> <north> })
```

Remember, the not equal test, “<>”, must directly precede the symbol or variable it refers to. Soar also has tests for greater than (>), less than (<), greater than or equal to (>=), and less than or equal to (<=). These can be used when matching numbers and also precede the value they refer to. For example, to test that the eater’s score is greater than 25, the following condition can be used.

```
(state <s> ^io.input-link.eater.score > 25)
```

6.2 Move Operator Application

This application rule for the move operator is a copy of the move-to-food operator application. The English and Soar versions are the same except for the name of the operator:

```
# Apply*move
# If the move operator for a direction is selected,
#   generate an output command to move in that direction.

    sp {apply*move
      (state <s> ^io.output-link <out>
        ^operator <o>)
      (<o> ^name move
        ^direction <dir>)
    -->
      (<out> ^move.direction <dir>)}

# Apply*move*remove-move:
# If the move operator is selected,
#   and there is a completed move command on the output link,
#   then remove that command.
.
    sp {apply*move*remove-move
      (state <s> ^io.output-link <out>
        ^operator.name move)
      (<out> ^move <direction>)
      (<direction> ^status complete)
    -->
      (<out> ^move <direction> -)}
```

The proposal rule together with these two rules will give you an eater that randomly moves around, avoiding walls. We can greatly improve its behavior by using more preferences.

6.3 Move Operator Selection

To improve the performance of the eater, we can add rules that prefer moving to bonusfood over normalfood or an empty cell and prefer moving to normalfood over moving into an empty cell or a cell with another eater. The preference language in Soar is rich enough to support a variety of ways of ordering the choices and we will explore different possibilities in this section.

To get started, you need to create a rule to prefer bonusfood to normalfood or empty or an eater. The condition part of the rule must match against operator proposals, while the action part must prefer the operator that moves to the bonusfood. In English this would be:

```
# Select*move*bonusfood-better-than-normalfood
# If there is a proposed operator to move to a cell with bonusfood and
#   there is a second proposed operator to move to a cell that is empty or
#   has normalfood or another eater
#   prefer the first operator.
```

The conditions of this operator must match against proposed operators before they have been selected. A proposed operator can be matched by matching the acceptable preference for the operator, which is written in the condition as the `^operator` augmentation of the state, with a value for the operator identifier, followed by a plus sign, “+”.

```
(state <s> ^operator <o> +)
```

Acceptable preferences are the only preferences that are added to working memory. All of the other preferences (better, best, worse, worst, and reject) are not added to working memory. They are held in preference memory and persist as long as the rule instantiations that created them still match. They are not in working memory because there is little advantage to having them available for other rules to match against, whereas the acceptable preferences must be in working memory because they define what operators are candidates for selection.

An operator can be preferred by creating a *better* than preference and the decision procedure will use that preference in determining which operator to select – it will never select an operator if it is worse than another candidate operator, unless that candidate is rejected. In addition to the better preference, there is a *worse* preference that is exactly the opposite. In an action, the better preference is the greater than sign: “>”. It is used in the same place as an acceptable or indifferent preference, except that a variable that matched the identifier of the better operator is put before the greater than sign, and the variable that matched the identifier of the worse operator is put after the greater than sign. Therefore, the Soar rule is as follows:

```
sp {select*move*bonusfood-better-than-normalfood-empty-eater
  (state <s> ^operator <o1> +
    ^operator <o2> +)
  (<o1> ^name move
    ^content bonusfood)
  (<o2> ^name move
    ^content << normalfood empty eater >>)
-->
  (<s> ^operator <o1> > <o2> )}
```

This rule will match two different proposed operators (operators with acceptable preferences), `<o1>` and `<o2>`. Both have name `move`, while one matches operators that move to bonusfood while the other will match operators that move to normalfood, empty squares, or squares with another eater.

If there are adjacent cells with both bonusfood and normalfood, this rule will fire right after `propose*move` creates acceptable preferences, but during the same proposal phase so that it will influence the next operator selection. It will fire multiple times if there are multiple cells with bonusfood or normalfood. After these preferences are created, the decision procedure will gather them up to make a decision.

You can use exactly the same approach to prefer moving to cells with normalfood over moving to empty cells or cells with eaters. Soar provides an alternative with the *worst* preference, which means don't select the operator unless there are no other choices. In this case, you can create worse preferences for operators that move the eater into an empty cell or a cell with another eater. With these additional preferences, operators that move into cells with bonusfood or normalfood will always be selected if they exist, and otherwise the eater will randomly select between moving into an empty cell or into a cell with another eater. The new selection rule can be written in English as:

```
# Select*move*avoid-empty-eater
# If there is a proposed operator to move to an empty cell or a cell with
#   another eater,
#   then avoid that operator.
```

Here we use the word avoid to mean that the operator will only be selected if there is nothing worse. A worst preference is written as a less than sign: "<". This is similar to a worse preference, except that there is no second variable that the first variable is compared to.

```
sp {select*move*avoid-empty-eater
  (state <s> ^operator <o> +)
  (<o> ^name move
    ^content << empty eater >>)
-->
  (<s> ^operator <o> <)> }
```

+ signifies acceptable preference

< signifies the worst preference

Just as there is a worst preference, there is also a *best* preference. The best preference means that an operator should be selected as long as there is no other operator better than it (or it is not worse than another operator is). Thus the meaning of best is a bit odd in that better preferences are more important than the best preferences and an operator with a best preference will not be selected if another operator is better than it.

You could have used a best preference for a move into a cell with normalfood instead of using the worst preference. The move to normalfood would then be selected over a move to an empty cell or a cell with an eater. Select*move*bonusfood-better-than-normalfood-empty-eater will ensure that bonusfood is preferred to normalfood.

```
# Select*move*prefer-normalfood
# If there is a proposed operator to move to a cell with normalfood,
#   prefer that operator.
sp {select*move*prefer-normalfood
  (state <s> ^operator <o> +)
  (<o> ^name move
    ^content normalfood)
-->
  (<s> ^operator <o> >)> }
```

> signifies the best preference

6.4 Summary of Preferences

This section summarizes the meaning of the preferences presented earlier. There are two additional preferences (require and prohibit) that are only rarely used and are not covered in this tutorial, but are described in the Soar 8 Manual. The preferences can be thought of as a sequence of filters, processed in the following order.

- **Acceptable (+)** An acceptable preference states that a value is a candidate for selection. Only values with an acceptable preference have the potential of being selected. If there is only one value with an acceptable preference, that value will be selected if it does not also have a reject preference.
- **Reject (-)** A reject preference states that the value is not a candidate for selection. A value will not be selected if it has a reject preference.
- **Better (>), Worse (<)** These preferences state that a value should not be selected if the better value is a candidate. If the better value does not have an acceptable preference, or is rejected, the better/worse preference is ignored. Otherwise, the worse value is removed from consideration. Better and worse are simple inverses of each other, so that A better than B is equivalent to B worse than A.
- **Best (>)** A best preference states that the value should be selected if it is not rejected, or if there is no other value better than it. If a value is best (and not rejected, or worse than another), it will be selected over any other value that is not also best. If two values are best, then the remaining preferences (worst, indifferent) will be examined to determine the selection. If a value (that is not rejected) is better than a best value, the better value will be selected. (This result is counter-intuitive, but allows explicit knowledge about the relative worth of two values to dominate knowledge of only a single value.)
- **Worst (<)** A worst preference states that the value should be selected only if there are no alternatives. A worst will only be considered if the above preferences have not filtered the choices to a single choice. In this case, any value with a worst preference will be discarded, unless all of the values have worst preferences.
- **Indifferent (=)** An indifferent preference states that there is positive knowledge that it does not matter which value is selected. This may be a binary preference, to say that two values are mutually indifferent, or a unary preference, to say that a single value is as good or as bad a choice as other expected alternatives. Indifferent preferences are used to signal that it does not matter which operator is selected, which results in a random selection is made from among the alternatives.

6.5 Example Run

The following trace shows how Soar fires and retracts many rules in parallel, with operator proposals following selections.

The screenshot shows the Soar Debugger in Java - remote red interface. The main window displays a trace of rule firings and retractions. The trace starts with a selection of rule 6: 0: 016 (move). This is followed by a series of firings and retractions of rules, including apply*move, apply*move*remove-move, propose*move*2a, and select*move*prefer-normalfood. The trace ends with a selection of rule 6: 0: 016 (move). The right-hand pane shows the current state of the system, including the state of the stack and the current operator.

```

6: 0: 016 (move)
Firing apply*move
351 342 343 3 5
Firing apply*move*remove-move
351 342 3 5 307 338
Firing propose*move*2a
3 4 12 19 363
Firing propose*move*2a
3 4 12 13 367
Firing propose*move*2a
3 4 12 15 370
Firing propose*move*2a
3 4 12 29 374
Retracting propose*move*2a
3 4 12 13 323
Retracting propose*move*2a
3 4 12 15 326
Retracting propose*move*2a
3 4 12 29 330
Firing select*move*prefer-normalfood
395 385 383
Firing select*move*avoid-empty-eater
396 386 388
Firing select*move*prefer-normalfood
397 391 389
Firing select*move*avoid-empty-eater
398 392 394
Retracting select*move*avoid-empty-eater
350 345 347
Retracting select*move*prefer-normalfood
349 344 342
Retracting select*move*avoid-empty-eater
  
```

The right-hand pane shows the current state of the system, including the state of the stack and the current operator.

```

print <s>
(S1 ^io I1 ^
^oper
^type state)
state operator
p --stack
: ==>S
: 0
  
```

At the bottom of the window, there are buttons for "Expand" and "Filters".

7. Advanced Move Operator

The eater you created in the last section will greedily consume food and never get stuck. However, its behavior doesn't always appear to be very intelligent, especially if it is surrounded by empty cells. The specific problem addressed in this section is that the eater will sometimes move randomly back and forth when it is surrounded by empty cells. That is clearly wasted effort and the eater should at least move to a cell different from the one it just came from. There are other approaches to improving the eater, such as having it test for food two spaces away, but the point of this section is to avoid moving back to the same cell, which will give you experience with creating persistent structures in working memory.

In order for the eater to avoid moving back to the cell it just came from, the eater must remember which direction it moved to get to the current cell. That information is available as an augmentation of the move operator while the eater is moving, but it disappears, along with the operator, once the move is completed. What is needed is a persistent augmentation of the state that records the direction of the last operator. This direction can then be used to avoid moving in the opposite direction. You will need to change the operator proposal to avoid moving back to the prior cell and the operator application to record the direction of the prior cell. A further change is needed to initialize some data structures in working memory that will make it easy to determine the opposite of each direction, which is needed to avoid moving back to the last cell.

In this section we start with the initialization rules, and then cover the operator application rules and operator proposals.

7.1 Initialization: Opposite Directions

The rules that you will write for operator application and selection need to determine the opposite of the direction the eater moved last, because that is the direction that needs to be avoided. The easiest way to do this is to create a structure in working memory that contains each direction, and each direction has an attribute that is its opposite direction. This structure can be on the state and the following rule creates one possible structure that encodes this information:

```
sp {initialize*state*directions
  (state <ss> ^type state)
  -->
  (<ss> ^directions <n> <e> <s> <w>)
  (<n> ^value north ^opposite south)
  (<e> ^value east ^opposite west)
  (<s> ^value south ^opposite north)
  (<w> ^value west ^opposite east)}
```

Multiple values for a single attribute can be listed following the attribute.

This is the first rule you've seen where there is an action with multiple values (<n> <e> <s> <w>) for a single attribute (^direction). Each value can be written as individual actions; however, as a shortcut, all of the values can be listed following their common attribute.

One might be tempted to have the values of ^direction be the symbols north, east, south, and west. However, these values cannot be further augmented with their opposites; only identifiers can have augmentations. It is not legal to have augmentations of the form: (north ^opposite south).

Rules such as initialize*state*directions are quite common in Soar program because they create fixed working memory structures. These structures simplify operators by making it possible to directly match relations such as opposite instead of having to write rules that are specific to each of the directions. This rule will fire during the first cycle when (s1 ^type state) is added to working memory. The structures it creates will have i-support because the rule conditions do not test an operator. However, the structures will never be removed because the conditions match throughout the life of the eater.

7.2 Advanced Move Operator Application

Our planned extension to the move operator does not require any changes to the existing application rules. However, you must add two rules to maintain a memory of the last direction moved. One of the rules must create the memory by adding the persistent (o-supported) structure when an operator is applied, and one must remove the old value when the next operator is selected. (You may think that you could write a single rule that both creates the last-direction and removes any old value for last-direction, but then a second rule would have to be written to cover the initial situation when there is no existing last-direction.) Try to write the English and Soar versions of these two rules.

```
# Apply*move*create*last-direction
# If the move operator for a direction is selected,
#   create an augmentation called last-direction with that direction.

sp {apply*move*create*last-direction
  (state <s> ^operator <o>)
  (<o> ^name move
    ^direction <direction>)
-->
  (<s> ^last-direction <direction>)}

# Apply*move*remove*last-direction
# If the move operator for a direction is selected,
#   and the last-direction is not equal to that direction,
#   then remove the last-direction.

sp {apply*move*remove*last-direction
  (state <s> ^operator <o>
    ^last-direction <direction>)
  (<o> ^direction <> <direction>
    ^name move)
-->
  (<s> ^last-direction <direction> -)}
```

Since both of these rules test the current operator, their actions are persistent. The first rule creates an augmentation of the state with attribute `^last-direction`. This augmentation will always contain the direction of the last operator applied by copying the direction from the move operator. The next rule removes the `^last-direction` attribute if it does not equal the direction on the current operator by using a reject preference. These rules will fire during the operator application phase.

Why can't you use an i-supported rule? Conceptually, you need the `^last-direction` augmentation to persist after the operator is no longer selected because it is going to be tested to select and apply the next operator. More pragmatically, Soar will automatically make the augmentation o-supported because it is created as part of an operator application.

This section and the previous one demonstrate two different ways to create persistent structures in working memory. If the structure can persist throughout the life of the eater, you can use a rule that tests that the state exists and then creates the structure in working memory in the action. Whenever the structure must change during the life of the eater, you must use a pair of rules that are part of the application of an operator - one to add the structure when appropriate, and one to remove the structure when it is no longer appropriate.

7.3 Advanced Move Operator Proposal

There are two ways to modify the proposal and selection rules so that the eater does not move backward. One requires modifying the proposal rule so that the operator is never proposed, and the second is to create a new selection rule that creates a preference that prevents the operator from being selected. We will look at both possibilities.

In order to modify the proposal rule, recall the final move proposal:

```
# Propose*move:
# If the content of an adjacent cell is not a wall,
#   propose move in the direction of that cell, with the cell's content,
#   and indicate that this operator can be selected randomly.
```

A condition can easily be added that tests that the direction of the adjacent cell (<d>) is not equal to the opposite of the direction of the last move. However, this will not work for the first move when there is no direction for the last move because no operator has applied to create the memory of a previous move. An alternative is test that there does not exist an opposite of last direction that is equal to the direction of the adjacent cell. How is that different? The first tests that there does exist in working memory an augmentation of the state, but its value is not equal. The second tests that there does not exist in working memory an augmentation that is equal. The second one will be correct for the first move. Thus the revised English description is:

```
# Propose*move*no-backward:
# If there is normalfood, bonusfood, eater, or empty in an adjacent cell,
#   and there is no last direction equal to the opposite direction for that
#   cell,
#   propose move in the direction of that cell, with the cell's content,
#   and indicate that this operator can be selected randomly.
```

To test for the absence of an augmentation, Soar uses a dash, “-“. The dash, called negation, precedes the augmentation that must not be in working memory for the rule to match. The new proposal rule is as follows:

```
sp {propose*move*no-backward
  (state <s> ^io.input-link.my-location.<dir>.content { <co> <> wall }
    ^directions <d>
    - ^last-direction <o-dir>)
  (<d> ^value <dir>
    ^opposite <o-dir>)
-->
  (<s> ^operator <o> + =)
  (<o> ^name move
    ^direction <dir>
    ^content <co> ) }
```

- means that this rule will match only if no working memory elements match this attribute value.

<dir> matches the direction of the adjacent cell that is not a wall.

<o-dir> matches the opposite of direction of the adjacent cell that is not a wall.

A negation can also precede a complete object, where the identifier is followed by multiple attribute-values. In that case, its is a test that there is no object with all of those attributes in working memory. The semantics of using negation can be a bit tricky and the details of it are spelled out in the manual.

7.4 Advanced Move Operator Selection

The alternative to modifying the proposal rule is to add a rule that eliminates from consideration any operator that moves opposite to the last direction. This requires a new preference, called reject, represented by a dash, "-". This is different from the operator application action that is also called rejection because that rejection removes a working memory element. When a reject preference is created for an operator, the decision procedure will not select that operator, no matter which other preferences have been created. However, the reject preference will be retracted when the rule that creates it no longer fires, allowing the rejected operator to be selected when the situation changes. Reject is used when an operator should not be selected for the current situation even if there are no other options. In contrast, a worst preference is used when an operator can be selected, but only if there are no better options.

One side effect of reject is that it disables better/worse preferences where the rejected operator is better than some other operator. Normally, that other operator would not be selected, but if the better operator is rejected, the better/worse preference is ignored.

Try writing both English and Soar versions of this rule.

```
# Select*move*reject*backward
# If there is a proposed operator to move in the direction
#   opposite the last move,
#   reject that operator.
```

```
sp {select*move*reject*backward
  (state <s> ^operator <o> +
    ^directions <d>
    ^last-direction <dir>)
  (<d> ^value <dir>
    ^opposite <o-dir>)
  (<o> ^name move
    ^direction <o-dir>)
-->
  (<s> ^operator <o> -) }
```

Uses <dir> from operator to match <dir> in directions and then match opposite

<odir> must match opposite of last-direction and direction of proposed operator

- means reject so that this operator will not be selected.

Note that this rule will not reject the proposed operator for the first move because the attribute ^last-direction will not initially exist.

8. Jump Operator

All of the eaters you've created so far have a single type of operator: move. In many situations, more than one instance of the operator is created, but still, there was only one operator. Adding operators does not change the way Soar operates, but it does give you a chance to use what you've learned on a slightly different problem. In this section, you are going to write the jump operator. An eater can jump over a cell to a cell two moves away; however, a jump costs the eater 5 points (the same as it gains from a normal food). The eater can jump over a wall, but it cannot jump into a cell with a wall.

In writing the jump operator, you should write and test the proposal and application rules without including the move operator. This will let you debug the jump rules first, without getting things mixed up with the rules for the move operator. You should then write operator selection rules and combine your jump operator with the move operator. In writing the jump operator, you will want to use the initialization rule for directions from the previous section, so you will want to copy that to your file in which you are writing the jump operator.

The rest of this section goes through the rules for jump. If you feel confident in your knowledge of the aspects of Soar that have been presented so far, you should try to write your own jump operator before reading this section. As you are writing your own jump operator, you should try to reuse or generalize some of the rules you wrote for the move operator. You might find it is a bit tricky for your eater to correctly keep track of the previous direction it moved or jumped. If you get stuck, or are unsure about what to do, you should read these sections.

After you finish this section, you can try your own strategies by creating different eaters with different control knowledge. You can even have contests between them to see which strategies work best.

8.1 Jump Operator Proposal

There are only two differences between the proposal for the move operator and the jump operator.

- The first difference is that the name of the operator should be jump, not move.
- The second is that instead of testing that an adjacent cell does not contain a wall, the jump operator needs to test that a cell two moves away in a direction does not contain a wall. This is easy to add because every cell has the same four directional pointers, so the desired cell can be tested via the direction augmentation on the adjacent cell: instead of just <dir> use <dir>.<dir> which tests two steps in the same direction because the same directional pointer must match both uses of <dir>.

In these examples, we will use the proposal that does not test for the absence of backward moves. We will include that in the selection knowledge. Thus the English version is:

```
# Propose*jump:
# If the content of a cell two steps away in a direction is not a wall,
#   propose jump in the direction of that cell, with the cell's content,
#   and indicate that this operator can be selected randomly.
```

```
sp {propose*jump
  (state <s> ^io.input-link.my-location.<dir>.<dir>.content
    { <content> <> wall })
-->
  (<s> ^operator <o> + =)
  (<o> ^name jump
    ^direction <dir>
    ^content <content>)}
```

The first <dir> leads to an adjacent cell.

The second <dir> leads to a cell two away from the eater in the same direction.

8.2 Jump Operator Application

The application of jump is exactly the same as the application of move, except that the jump name must be issued instead of a move. Instead of creating a new rule for each operator, you can reuse and generalize the original operator application rules by allowing them to match an operator named either move or jump, and then copying the operator name to the output link.

```
# Apply*move*jump
# If the move or jump operator for a direction is selected,
#   generate an output name to move in that direction.

sp {apply*move
  (state <s> ^io.output-link <out>
    ^operator <o>)
  (<o> ^name { <name> << move jump >> }
    ^direction <dir>)
-->
  (<out> ^<name>.direction <dir>)}

# Apply*move*jump*remove-name:
# If the move or jump operator is selected,
#   and there is a completed action (<name>) on the output link,
#   then remove that name.

sp {apply*move*remove-move
  (state <s> ^io.output-link <out>
    ^operator.name <name>)
  (<out> ^<name> <<direction>)
  (<direction> ^status complete)
-->
  (<out> ^<name> <direction> -)}
```

<name> will match move or jump

<name> be move or jump as matched in condition

<name> will match move or jump

8.3 Simplified Operators

In writing the operator application rules for the jump operator, you have probably noticed that both operators include a rule to create the action command (move or jump) on the output-link, and then remove that command when it has completed. You can simplify the writing of future operators by writing two general rules that perform these functions for every operator that performs external actions.

The first rule creates the action command on the output-link. To make this a completely general rule, you need to have a standard way of representing action commands on operators so that a single rule can create the commands on the output-link. The simplest convention is to have the action command be an augmentation of the operator, such as: ^jump.direction <direction>. Another possibility would be to have a specific augmentation on the operator, say ^actions, that had the commands as subobjects:

```
(<o> ^actions.jump.direction <direction1>)
```

You probably want to adopt this second approach because it makes it possible to write a single rule that copies the action commands to the output-link without risk of copying other augmentations. Under that convention, the general command creation rule is:

```
sp {apply*operator*create-action-command
    (state <s> ^operator.actions.<att> <value>
        ^io.output-link <out>)
    -->
    (<out> ^<att> <value>) }
```

The <att> variable will match jump and the value will match the identifier of the object that has direction as an augmentation. It copies ^jump and that identifier on to the output-link.

The second general rule removes a completed action command.

```
sp {apply*operator*remove-command
    (state <s> ^operator.actions
        ^io.output-link <out>)
    (<out> ^<att> <value>)
    (<value> ^status complete)
    -->
    (<out> ^<att> <value> -) }
```

Included so action has
o-support.

With these rules included in an Eater, both the move and the jump operator require only proposals (except when other actions are performed, such as remembering prior moves). To use both of these rules, you need to modify the proposal rules so that they create the actions structure. Below is an example of the jump operator proposal.

```
sp {propose*jump
    (state <s> ^io.input-link.my-location.<dir>.<dir>.content
        { <content> <> wall })
    -->
    (<s> ^operator <o> + =)
    (<o> ^name jump
        ^actions.jump.direction <dir>
        ^content <content>) }
```

Replaced ^direction
<dir> with this.

Rules like this simplify the writing of Soar programs by creating conventions; however these conventions also restrict what can be written in a Soar program. For example, if this rule is used in a Soar program, then the status complete augmentation will always be removed and will not be available for other rules to test. For this domain, it doesn't seem like that will be a problem, and it might not be for others as well. It is just that before creating a rule that applies to all operators, you should be careful. Throughout this tutorial you will see additional rules that are used to simplify the writing of programs. We have tried to be careful in selecting these types of rules.

8.4 Jump Operator Selection

There are many strategies for selecting jump operators. One simple strategy is to prefer operators that jump into cells with bonusfood to operators that move into empty cells, while rejecting operators that jump into empty cells. We can generalize some of the rules for move to cover both jump and move.

```

sp {select*move*bonusfood-better-than-normalfood-empty-eater
  (state <s> ^operator <o1> +
    ^operator <o2> +)
  (<o1> ^name { << jump move >> <name> }
    ^content bonusfood)
  (<o2> ^name <name>
    ^content << normalfood empty eater >>)
-->
  (<s> ^operator <o1> > <o2>)}

sp {select*jump*bonusfood-better-than*move*empty
  (state <s> ^operator <o1> +
    ^operator <o2> +)
  (<o1> ^name jump
    ^content bonusfood)
  (<o2> ^name move
    ^content empty)
-->
  (<s> ^operator <o1> > <o2>)}

```

8.5 Jump and Move Operator Selection

In order to cover all of the cases of move and jump operators for all of the different cell contents, you would need to write lots of rules. Is there an easier way? One way is to translate the different names and contents into numbers that correspond to the number of points the eater will get. A rule could then compare the numbers and create better preferences for operators with higher numbers. You can translate the names and contents into numbers by writing one rule for each name and content pair; however, it is much easier to create a structure in working memory with the information and have a general rule match against it and do the translation. This is similar to the way opposite directions were computed.

The first rule to write is the one that creates the structure in working memory. It needs to include an object for each pair of name and content, and for each pair, the expected value to the eater.

```
sp {init*elaborate*name-content-value
  (state <s> ^type state)
-->
  (<s> ^name-content-value <c1> <c2> <c3> <c4>
                                <c5> <c6> <c7> <c8>)
  (<c1> ^name move ^content empty ^value 0)
  (<c2> ^name move ^content eater ^value 0)
  (<c3> ^name move ^content normalfood ^value 5)
  (<c4> ^name move ^content bonusfood ^value 10)
  (<c5> ^name jump ^content empty ^value -5)
  (<c6> ^name jump ^content eater ^value -5)
  (<c7> ^name jump ^content normalfood ^value 0)
  (<c8> ^name jump ^content bonusfood ^value 5)}
```

To compare two operators, you can write a rule that matches the operators and the name-content-value structure, but it is easier to understand the reasoning if you break it into two rules. The first rule matches each operator and the appropriate name-content-value and copies the value onto the operator.

```
sp {elaborate*operator*value
  (state <s> ^operator <o> +
    ^name-content-value <ccv>)
  (<o> ^name <name> ^content <content>)
  (<ccv> ^name <name> ^content <content> ^value <value>)
-->
  (<o> ^value <value>)}
```

Now you can write a rule that compares the values associated with each operator and then creates a better preference for the operators with higher values.

```
sp {select*compare*best*value
  (state <s> ^operator <o1> +
    ^operator <o2> +)
  (<o1> ^value <v>)
  (<o2> ^value <v>)
-->
  (<s> ^operator <o1> > <o2>)}
```

During a run, the first rule will fire for every proposed operator, and the second rule will fire for every pair of operators with different values. All of these firings, including the proposals of the operators, happen during the proposal phase.

9. Advanced Eaters

If you want to build more complex eaters, here are a few ideas. You will find it easier to build some of these after you complete the next part of the tutorial.

1. An eater that chases another eater.
2. An eater that tries to stay away from other eaters.
3. An eater that systematically searches for food when empty cells surround it.
4. An eater that looks ahead to see what move would be better based on what surrounds the cell it is going to move into.
5. An eater that takes advantage of the fact that bonus food comes in vertical lines, each 4 cells apart.

10. Top-state Structure

This page has a summary of the structure of the top-state for every eater. It is a useful reference when you build your own eaters and you will probably want to make a copy of it. All of the attributes of an object appear below it in outline form, with indentation used to signify sub-objects. Possible values are listed on the same line as the attribute.

```

^io
  ^input-link
    ^eater
      ^direction east/north/south/west
      ^name red/blue/yellow/green/purple/black
      ^score 0-1000
      ^x 1-15
      ^y 1-15
    ^my-location
      ^content bonusfood/normalfood/eater/empty/wall
      ^east
        ^content bonusfood/normalfood/eater/empty/wall
        ...
      ^north
        ^content bonusfood/normalfood/eater/empty/wall
        ...
      ^south
        ^content bonusfood/normalfood/eater/empty/wall
        ...
      ^west
        ^content bonusfood/normalfood/eater/empty/wall
        ...
    ^output-link
      ^move
        ^direction east/north/south/west
        ^status complete - created by Soar as feedback
      ^jump
        ^direction east/north/south/west
        ^status complete - created by Soar as feedback
  ^superstate nil
  ^type state

```