

## Unit3 Model Code Description

The experiments in this unit are more involved than those of the last unit. The experiments are more complicated, and they involve collecting data and comparing it to existing experimental results. Many of the functions that were introduced in the last unit will be seen again (some of them always have to be there, like run) and there will be a few more introduced in this unit.

Because it is often necessary to run a model multiple times to understand its behavior and then to use the average and deviation for data comparison, running the model quickly can be important. One thing that can greatly improve the time it takes to run the model (i.e. the real time that passes not the simulated time which the model experiences) is to have it interact with a virtual window instead of interacting with a real window on the computer. Virtual windows are an abstraction of a window interface that is internal to ACT-R. From the model's perspective there is no difference between a virtual window and a real window, but there is much less overhead involved with virtual windows because they exist entirely within Lisp. The only down side to using a virtual window is that you cannot see it, which can make debugging the model more difficult. To help with that, the tools that were introduced in the last unit for building and manipulating windows work exactly the same for real windows and virtual windows. All that is necessary to switch between them is one parameter when the window is opened. Thus, you can build the experiment and debug the model using a window that you can see. Then with one small change make the window virtual and run the model quickly over many runs. How to do that will be described below.

Here is the experiment code from the Sperling model.

```
(defvar *responses* nil)
(defvar *show-responses* nil)

(defvar *sperling-exp-data* '(3.03 2.40 2.03 1.50))

(defun do-sperling-trial (onset-time)

  (reset)

  (let* ((lis (permute-list '("B" "C" "D" "F" "G" "H" "J"
                             "K" "L" "M" "N" "P" "Q" "R"
                             "S" "T" "V" "W" "X" "Y" "Z")))
         (answers nil)
         (tone (act-r-random 3))
         (window (open-exp-window "Sperling Experiment"
                                  :visible t
                                  :width 300
                                  :height 300)))

    (dotimes (i 3)
      (dotimes (j 4)
        (let ((txt (nth (+ j (* i 4)) lis)))
          (when (= i tone)
            (push txt answers))
          (add-text-to-exp-window :text txt
```

```

                                :width 40
                                :x (+ 75 (* j 50))
                                :y (+ 101 (* i 50))))))

(install-device window)
(new-tone-sound (case tone (0 2000) (1 1000) (2 500)) .5 onset-time)
(schedule-event-relative (+ .9 (act-r-random .2)) 'clear-screen)

(proc-display)
(setf *responses* nil)
(run 30 :real-time t)

(when *show-responses*
  (format t "~%-~%answers: ~S~%responses: ~S~%" answers *responses*))

(compute-score answers))

(defun compute-score (answers)
  (let ((score 0))
    (dolist (x answers score)
      (when (member x *responses* :test 'string-equal)
        (incf score)))))

(defun clear-screen ()
  (clear-exp-window)
  (proc-display))

(defmethod rpm-window-key-event-handler ((win rpm-window) key)
  (unless (string= key " ")
    (push (string key) *responses*)))

(defun report-data (data)
  (correlation data *sperling-exp-data*)
  (mean-deviation data *sperling-exp-data*)
  (print-results data))

(defun print-results (data)
  (format t "~%Condition      Current Participant      Original Experiment~%"
    (do ((condition '(0.00 0.15 0.30 1.00) (cdr condition))
        (temp1 data (cdr temp1))
        (temp2 *sperling-exp-data* (cdr temp2)))
      ((null temp1)
       (format t " ~4,2F sec.           ~6,2F           ~6,2F~%"
         (car condition) (car temp1) (car temp2)))))

(defun run-block ()
  (let ((times (permute-list '(0.0 .15 .30 1.0)))
        (result nil))
    (dolist (x times)
      (push (cons x (do-sperling-trial x)) result))
    (sort result '< :key 'car)))

(defun run-sperling (n)
  (let ((results (list 0 0 0 0)))
    (dotimes (i n)
      (setf results (mapcar '+ results (mapcar 'cdr (run-block))))))

```

```
(report-data (mapcar (lambda (x) (/ x n)) results))))
```

First, two global variables are defined. *\*responses\** will hold the list of keys pressed by the participant and *\*show-responses\** is used as a flag to indicate whether or not to print out the participant's responses every trial.

```
(defvar *responses* nil)
(defvar *show-responses* nil)
```

Next we define a global variable that holds the results of the original experiment so that the model's performance can be compared to it.

```
(defvar *sperling-exp-data* '(3.03 2.40 2.03 1.50))
```

The *do-sperling-trial* function takes one parameter which is the delay time at which to present the auditory cue in seconds. It presents the array of letters, waits for the responses, and returns the number of letters correctly recalled in the target row.

```
(defun do-sperling-trial (onset-time)
```

First it resets ACT-R and randomizes a list of letters

```
(reset)

(let* ((lis (permute-list '("B" "C" "D" "F" "G" "H" "J"
                          "K" "L" "M" "N" "P" "Q" "R"
                          "S" "T" "V" "W" "X" "Y" "Z"))))
```

then it creates a variable to hold the list of target letters,

```
(answers nil)
```

randomly chooses which row to be the target,

```
(tone (act-r-random 3))
```

and opens a window to do the task. The keyword parameters used when opening this window are new in this unit and will be described below in detail.

```
(window (open-exp-window "Sperling Experiment"
                          :visible t
                          :width 300
                          :height 300)))
```

Then it displays 3 rows of 4 letters recording the letters that are in the target row in the *answers* variable.

```
(dotimes (i 3)
  (dotimes (j 4)
    (let ((txt (nth (+ j (* i 4)) lis)))
      (when (= i tone)
        (push txt answers))
      (add-text-to-exp-window :text txt
                              :width 40
                              :x (+ 75 (* j 50))
                              :y (+ 101 (* i 50))))))
```

The model is told that the opened window is the one to interact with

```
(install-device window)
```

A tone is scheduled to occur for the model at the time specified which lasts for .5 seconds and has a frequency determined by which row is to be recalled.

```
(new-tone-sound (case tone (0 2000) (1 1000) (2 500)) .5 onset-time)
```

At a random time between .9 and 1.1 seconds the clear-screen function (which is defined below) will be called

```
(schedule-event-relative (+ .9 (act-r-random .2)) 'clear-screen)
```

The model is told to process the display

```
(proc-display)
```

The variable to hold the model's responses is cleared

```
(setf *responses* nil)
```

The model is run for up to 30 seconds in real time

```
(run 30 :real-time t)
```

If the `*show-responses*` variable is set it prints out the correct answers and the responses

```
(when *show-responses*
  (format t "~%-~%answers: ~S~%responses: ~S~%" answers *responses*))
```

Then it calls the compute-score function (defined below) to return the number of correct responses

```
(compute-score answers)))
```

The compute-score function takes one parameter which is a list of the letters in the target row. It returns the number of those items that were given by the participant.

```
(defun compute-score (answers)
  (let ((score 0))
    (dolist (x answers score)
      (when (member x *responses* :test 'string-equal)
        (incf score)))))
```

The clear-screen function is called at the appropriate time when the model is performing the task. It clears the screen and makes the model reprocess it.

```
(defun clear-screen ()
  (clear-exp-window)
  (proc-display))
```

The rpm-window-key-event-handler gets called automatically when a key is pressed and is passed the window in which the press occurred and the key that was pressed. For this task it pushes the keys onto the `*responses*` list unless the space bar is pressed.

```
(defmethod rpm-window-key-event-handler ((win rpm-window) key)
  (unless (string= key " ")
    (push (string key) *responses*)))
```

The report-data function takes one parameter which is a list that should represent average data of participants in the task. Those data are compared to the original experimental data and the correlation, mean deviation, and table of the results are printed.

```
(defun report-data (data)
  (correlation data *sperling-exp-data*)
  (mean-deviation data *sperling-exp-data*)
  (print-results data))
```

The print-results function takes one parameter which should be a list containing average data of participants in the task. Those data are printed in a table with the onset times and the original data.

```
(defun print-results (data)
  (format t "~%Condition      Current Participant      Original Experiment~%"
    (do ((condition '(0.00 0.15 0.30 1.00) (cdr condition))
        (temp1 data (cdr temp1))
        (temp2 *sperling-exp-data* (cdr temp2)))
      ((null temp1)
       (format t " ~4,2F sec.           ~6,2F           ~6,2F~%"
         (car condition) (car temp1) (car temp2))))))
```

The run-block function takes no parameters. It runs one trial of the task at each of the 4 onset times randomly ordered. It returns a list of conses ordered by onset time, with the car of each cons being the onset time and the cdr being the number of correct responses.

```
(defun run-block ()
  (let ((times (permute-list '(0.0 .15 .30 1.0)))
        (result nil))
    (dolist (x times)
      (push (cons x (do-trial x)) result))
    (sort result '< :key 'car)))
```

The run-sperling function takes one parameter which is the number of blocks of the experiment to run. A block is one trial at each of the 4 onset times. The results of those blocks are averaged together and then the comparison of that average data to the original experimental data is printed.

```
(defun run-sperling (n)
  (let ((results (list 0 0 0 0)))
    (dotimes (i n)
      (setf results (mapcar '+ results (mapcar 'cdr (run-block))))))
  (report-data (mapcar (lambda (x) (/ x n)) results))))
```

The new ACT-R and miscellaneous modeling functions that are used in this task are:

**Open-exp-window** – this was introduced in the last unit. Here we see it getting passed keyword parameters that were not used previously. :height and :width specify the size of the window in pixels. The :visible parameter is the flag that determines whether a real or a virtual window is used. If :visible is **t** (the default value if it is not specified) then a real

window is used. If `:visible` is **nil**, then a virtual window is used. There are two other parameters, `:x` and `:y` which can be used to specify the position of the upper left corner of the window on the main display.

**New-tone-sound** – This function takes 2 required parameters and a third optional parameter. The first parameter is the frequency of a tone to be presented to the model. The second is the duration of that tone in seconds. If the third parameter is specified then it indicates at what time the tone is to be presented, and if it is omitted then the tone is to be presented immediately. At the requested time a tone sound will be made available to the model’s auditory module using the requested frequency and duration.

**Schedule-event-relative** – This function takes 2 required parameters and a number of additional parameters. It is used to schedule functions to be called during the running of the model. The first parameter specifies an offset from the current time at which the function should be called. The second parameter is the function to call. By scheduling functions to be called during the running of the model it is possible to have the experiment change without stopping the model to do so. More information on the scheduling functions can be found in the ACT-R reference manual.

**Correlation** – this function takes 2 required parameters which must be equal length ‘sequences’ of numbers. The numbers can be in arrays or lists and they do not both need to be in the same format (one could be an array and the other a list). The only requirement is that they have the same number of numbers in them. This function then extracts those numbers and computes the correlation between the two sets of numbers. That correlation value is returned. There is a keyword parameter `:output` which defaults to `t`. When `:output` is `t` the correlation is printed to `*standard-output*`. If `:output` is a string, stream, or pathname then it is used to open a stream to which the results are written.

**Mean-deviation** – this function operates just like correlation, except that the calculation performed is the root mean square deviation between the data sets.

Now we will look at the subitizing experiment code.

```
(defvar *key-time* nil)
(defvar *speak-time* nil)
(defvar *answer* nil)
(defvar *correct* nil)

(defvar *subitizing-exp-data* '(.6 .65 .7 .86 1.12 1.5 1.79 2.13 2.15 2.58))

(defun subitize-trial (n &optional who)
  (let ((points (generate-points n))
        (window (open-exp-window "Subitizing Experiment"
                                 :visible t
                                 :width 300
                                 :height 300
                                 :x 300
                                 :y 300)))
    (rt)))
```

```

(dolist (point points)
  (add-text-to-exp-window :text "x"
                        :width 10
                        :x (first point)
                        :y (second point)))

(setf *correct* nil)
(setf *speak-time* nil)
(setf *key-time* nil)

(reset)

(if (not (eq who 'human))
    (progn
      (setf *answer* (format nil "~r" n))
      (install-device window)
      (proc-display)
      (run 30 :real-time t)
      (setf rt (if (numberp *speak-time*)
                  *speak-time*
                  30000)))
    (progn
      (let ((start-time (get-time nil)))
        (setf *answer* (format nil "~d" (if (= n 10) 0 n)))
        (while (null *key-time*)
          (allow-event-manager window)
          (setf rt (- *key-time* start-time))))))
    (list (/ rt 1000.0) *correct*)))

(defun subitize (&optional who)
  (let (result)
    (dolist (items (permute-list '(10 9 8 7 6 5 4 3 2 1)))
      (push (list items (subitize-trial items who)) result))
    (report-data (mapcar 'second (sort result '< :key 'car)))))

(defun report-data (data)
  (let ((rts (mapcar 'first data)))
    (correlation rts *subitizing-exp-data*)
    (mean-deviation rts *subitizing-exp-data*)
    (print-results data)))

(defun print-results (predictions)
  (format t "Items      Current Participant      Original Experiment~%"
    (dotimes (i (length predictions))
      (format t "~3d          ~5,2f  (~3s)          ~5,2f~%"
        (1+ i) (car (nth i predictions)) (second (nth i predictions))
        (nth i *subitizing-exp-data*))))))

(defun generate-points (n)
  (let ((points nil))
    (dotimes (i n points)
      (push (new-distinct-point points) points))))

(defun new-distinct-point (points)
  (do ((new-point (list (+ (act-r-random 240) 20) (+ (act-r-random 240) 20)))
      (list (+ (act-r-random 240) 20) (+ (act-r-random 240) 20))))
    ((not (too-close new-point points)) new-point)))

(defun too-close (new-point points)
  (some (lambda (a) (and (< (abs (- (car new-point) (car a))) 40)
                        (< (abs (- (cadr new-point) (cadr a))) 40)))
    points))

```

```
(defmethod rpm-window-key-event-handler ((win rpm-window) key)
  (setf *correct* (string-equal (string key) *answer*))
  (setf *key-time* (get-time nil)))

(defmethod device-speak-string ((win rpm-window) text)
  (setf *correct* (string-equal text *answer*))
  (setf *speak-time* (get-time)))
```

First we define some global variables to hold the times for the possible responses, the expected answer for the current trial, and whether or not the response given was correct.

```
(defvar *key-time* nil)
(defvar *speak-time* nil)
(defvar *answer* nil)
(defvar *correct* nil)
```

Then we create a global variable that holds the data from the original experiment so that the participant's performance can be compared to it.

```
(defvar *subitizing-exp-data* '(.6 .65 .7 .86 1.12 1.5 1.79 2.13 2.15 2.58))
```

The subitize-trial function takes one parameter which is the number of items to present, and an optional parameter which can be used to run a person through the task. It presents one trial to either the model or a person as needed and then returns a list of two items. The first item is the response time in seconds and the second item indicates whether or not the response was correct (t) or incorrect (nil).

```
(defun subitize-trial (n &optional who)
```

First it builds a list of n points using the generate-points function (defined below), opens a window, and creates a local variable called rt.

```
(let ((points (generate-points n))
      (window (open-exp-window "Subitizing Experiment"
                               :visible t
                               :width 300
                               :height 300
                               :x 300
                               :y 300)))
  (rt))
```

Then it draws an x at each of those random points

```
(dolist (point points)
  (add-text-to-exp-window :text "x"
                          :width 10
                          :x (first point)
                          :y (second point)))
```

It clears the response variables and resets the model

```
(setf *correct* nil)
(setf *speak-time* nil)
(setf *key-time* nil)
```

```
(reset)
```

Now, if the model is doing the task it sets the correct answer to the text of the number of items, tells the model which window to look at, makes it process the display, run for up to 30 seconds, and sets the `rt` variable to the time at which the model spoke the answer or 30000 if it did not speak an answer.

```
(if (not (eq who 'human))
  (progn
    (setf *answer* (format nil "~r" n))
    (install-device window)
    (proc-display)
    (run 30 :real-time t)
    (setf rt (if (numberp *speak-time*)
                *speak-time*
                30000)))
```

If a person is doing the task record the time that the trial starts

```
(progn
  (let ((start-time (get-time nil)))
```

Set the correct answer to a string of the number or 0 if it's 10 items

```
(setf *answer* (format nil "~d" (if (= n 10) 0 n)))
```

Wait for a response

```
(while (null *key-time*)
  (allow-event-manager window))
```

Set the `rt` variable to the difference between the start time and the time the key press was recorded

```
(setf rt (- *key-time* start-time))))
```

Then for either participant the return list is generated. The response time is converted into seconds from milliseconds and put into a list with the variable which indicates if the correct answer was produced.

```
(list (/ rt 1000.0) *correct*))
```

The `subitize` function takes one optional parameter which can be specified as `human` to run a person. It presents each of the 10 possible conditions once in random order collecting the data. It then prints out the data and the comparison to the experimental results.

```
(defun subitize (&optional who)
  (let (result)
    (dolist (items (permute-list '(10 9 8 7 6 5 4 3 2 1)))
      (push (list items (subitize-trial items who)) result))
    (report-data (mapcar 'second (sort result '< :key 'car)))))
```

The `report-data` function takes one parameter which is a list of response lists as are returned by the `subitize-trial` function. It prints the comparison of the response times to the experimental data and then prints a table of the response times and correctness.

```
(defun report-data (data)
  (let ((rts (mapcar 'first data)))
    (correlation rts *subitizing-exp-data*)
    (mean-deviation rts *subitizing-exp-data*)
    (print-results data)))
```

The `print-results` function takes one parameter which is a list of response lists as are returned by the `subitize-trial` function. It prints a table of the response times and correctness along with the original data.

```
(defun print-results (predictions)
  (format t "Items      Current Participant      Original Experiment-%")
  (dotimes (i (length predictions))
    (format t "~3d          ~5,2f  (~3s)              ~5,2f-%"
      (1+ i) (car (nth i predictions)) (second (nth i predictions))
      (nth i *subitizing-exp-data*))))
```

The `generate-points` function takes 1 parameter which specifies how many points to generate. It returns a list of `n` randomly generated points (lists of `x` and `y` coordinates) to use for displaying the items. The points are generated such that they are not too close to each other and within the default experiment window size.

```
(defun generate-points (n)
  (let ((points nil))
    (dotimes (i n points)
      (push (new-distinct-point points) points))))
```

The `new-distinct-point` function takes one parameter which is a list of points. It returns a new point that is randomly generated within the default experiment window boundary and which is not too close to any of the points on the list provided.

```
(defun new-distinct-point (points)
  (do ((new-point (list (+ (act-r-random 240) 20) (+ (act-r-random 240) 20)))
      (list (+ (act-r-random 240) 20) (+ (act-r-random 240) 20))))
    ((not (too-close new-point points)) new-point)))
```

The `too-close` function takes two parameters. The first is a point and the second is a list of points. It returns `t` if the first point is within 40 pixels in either the `x` or `y` direction of any of the points on the list, otherwise it returns `nil`.

```
(defun too-close (new-point points)
  (some (lambda (a) (and (< (abs (- (car new-point) (car a))) 40)
                        (< (abs (- (cadr new-point) (cadr a))) 40)))
    points))
```

The `rpm-window-key-event-handler` method is called automatically when a key is pressed. In this task that will be collecting the response from a person doing the task. It

sets the correct variable to t if the key which was pressed matches the correct answer for this trial and sets the key-time variable to the current time for a person.

There is one important thing to note about this function. The subitize-trial function is looping until the key-time variable is set when a person does the task. Because this function gets called by the system asynchronously, it is important to set the variable which is being used as the flag to indicate that it is finished last. If it were to set the variables in the opposite order then the subitize-trial function might try to use the value of the correct variable before it was actually set.

```
(defmethod rpm-window-key-event-handler ((win rpm-window) key)
  (setf *correct* (string-equal (string key) *answer*))
  (setf *key-time* (get-time nil)))
```

The device-speak-string method is very similar to the rpm-window-key-event-handler. It is called automatically whenever the model speaks. It is passed two parameters which are the current experiment window for the model and the text the model is speaking. In this experiment it is setting the variables to indicate if the response spoken was correct and the time at which that speech output occurred.

```
(defmethod device-speak-string ((win rpm-window) text)
  (setf *correct* (string-equal text *answer*))
  (setf *speak-time* (get-time)))
```

The only new ACT-R function used in this task is get-time.

**get-time** – this function takes an optional parameter and it returns the current time in milliseconds. If the optional parameter is not specified, then the model’s simulated time is returned. If the optional parameter is specified as true then the time returned is again the model’s simulated time. If the optional parameter is specified as **nil** then the time is taken from the internal Lisp timer using the command get-internal-real-time.

### Buffer stuffing

The buffer stuffing mechanism was introduced in this unit text. It mentioned that one can change the default conditions that are checked to determine which item (if any) will be stuffed into the visual-location buffer. The function which does that is called **set-visloc-default**. The parameters that you pass to it are essentially the same as you would specify in a request to the visual-location buffer. Here are a couple of examples:

```
(set-visloc-default isa visual-location :attended new screen-x lowest)
(set-visloc-default screen-x current > screen-y 100 < screen-y 230)
(set-visloc-default kind text color red width highest)
```

**set-visloc-default** – This command sets the conditions that will be used to select the visual-location that gets buffer stuffed. When the screen is processed by the model (proc-display is called) if the visual-location buffer is empty a visual-location that matches the

conditions specified by this command will be placed into the visual-location buffer. Effectively, what happens is that when `proc-display` gets called, if the visual-location buffer is empty, a visual-location request is automatically executed using the slot tests set with `set-visloc-default`.

### Speeding up the experiments

The experiment code provided for both of the tasks in this unit uses a real window for interaction and thus the model must be run in real time to interact with that window. In the main unit text it mentions that it is possible to instead use a virtual window for the model and then it does not have to be run in real time. To make the experiment window virtual the `:visible` keyword parameter provided to `open-exp-window` must be specified as **nil** instead of **t**. In the `sperling` task that call occurs in the `do-sperling-trial` function:

```
(defun do-sperling-trial (onset-time)
  (reset)
  (let* ((lis (permute-list '("B" "C" "D" "F" "G" "H" "J"
                             "K" "L" "M" "N" "P" "Q" "R"
                             "S" "T" "V" "W" "X" "Y" "Z"))))
    (answers nil)
    (tone (act-r-random 3))
    (window (open-exp-window "Sperling Experiment"
                             :visible t
                             :width 300
                             :height 300)))
```

and in the `subitizing` task it is in the `subitize-trial` function:

```
(defun subitize-trial (n &optional who)
  (let ((points (generate-points n))
        (window (open-exp-window "Subitizing Experiment"
                                  :visible t
                                  :width 300
                                  :height 300
                                  :x 300
                                  :y 300)))
```

Changing the highlighted **t** to **nil** in those functions will make them virtual windows.

After doing that, the call to run the model in those same functions can be changed to not run the model in real time. Like the `:visible` flag those calls to run include a keyword parameter `:real-time` which is specified as **t** as shown in this call which is used in both experiments:

```
(run 30 :real-time t)
```

Changing that **t** to **nil** will allow the model simulation to run without being constrained by real time. Alternatively, the real-time parameter could be removed entirely because the default operation of the run command is to run in simulated time:

(run 30)

After making those changes to the experiment code you will have to save the file and then load it before they will take effect.