ACT-R 6.0 Reference Manual

Working Draft

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Includes material adapted from the ACT-R 4.0 manual by Christian Lebiere, documentation on the perceptual motor components by Mike Byrne and the Introduction is a shortened version of the ACT-R description written by Raluca Budiu for the ACT-R web site.

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Preface

This document is still a work in progress. The content is accurate, but so far only covers the basic operations and the primary modules in detail. It contains references to sections on advanced materials, but most of those are not yet included. The hope is that although it is not yet complete, this working version will be of some use to ACT-R modelers.

Introduction

ACT-R is a cognitive architecture: a theory about how human cognition works. Its constructs reflect assumptions about human cognition which are based on numerous facts derived from psychology experiments. It is a hybrid cognitive architecture – it has both symbolic and subsymbolic components. Its symbolic structure is a production system and its subsymbolic structure is represented by a set of massively parallel processes that can be summarized by a number of mathematical equations. The subsymbolic equations control many of the symbolic processes, and are also responsible for most learning processes in ACT-R.

Using ACT-R, researchers can create models that incorporate ACT-R's view of cognition and their own assumptions about a particular task. These assumptions can be tested by comparing the results of the model performing the task with the results of people doing the same task. By "results" we mean the traditional measures of cognitive psychology: time to perform the task, accuracy in the task, and, (more recently) neurological data such as those obtained from fMRI.

One important feature of ACT-R that distinguishes it from other theories in the field is that it allows researchers to collect quantitative measures that can be directly compared with the quantitative measures obtained from human participants.

ACT-R has been used successfully to create models in domains such as learning and memory, problem solving and decision making, language and communication, perception and attention, cognitive development, or individual differences.

Beside its applications in cognitive psychology, ACT-R has also been used in other fields including:

- human-computer interaction to produce user models that can assess different computer interfaces
- education (cognitive tutoring systems) to "guess" the difficulties that students may have and provide focused help
- computer-generated forces to provide cognitive agents that inhabit training environments
- neuropsychology, to interpret fMRI data.

For more detailed information, please refer to the latest description of the ACT-R theory in the paper "An Integrated Theory of the Mind" (2004) which is available from the ACT-R web site at: http://act-r.psy.cmu.edu/papers/403/IntegratedTheory.pdf.

Document Overview

This manual is a guide and reference for the ACT-R 6.0 software implementation. It is not meant to be a tutorial or a textbook on the ACT-R theory or a "how to" on writing models using ACT-R. The ACT-R Tutorial, which accompanies the software, is designed to introduce the theory and techniques for modeling with ACT-R. This document is intended to be a compliment to the tutorial, and it describes the components of the implementation, how they are connected, the commands available to the user, and some recommended practices for use.

This manual is a reference for the ACT-R 6.0 implementation only. It does not describe mechanisms from older implementations nor does it thoroughly discuss how commands may differ from similar commands in previous versions.

General Software Description

ACT-R 6.0 (hereafter referred to as ACT-R, unless otherwise specified) is written in Common Lisp. It was implemented and tested using Allegro Common Lisp by Franz Inc. http://www.franz.com/, Macintosh Common Lisp by Digitool Inc http://www.digitool.com/, Clozure CL http://www.clozure.com/clozurecl.html, LispWorks by LispWorks Ltd http://www.lispworks.com, CMUCL http://www.cons.org/cmucl/, CLISP http://www.clisp.org, and SBCL http://sbcl.sourceforge.net/. It should run in any ANSI compliant implementation of Common Lisp, but has only been tested with those listed above. If you have problems loading or running ACT-R in any Lisp please contact Dan Bothell (db30@andrew.cmu.edu) with the details. We also make the ACT-R system available as a standalone application for those that do not have Lisp software, but the standalone versions are not as robust or as flexible as using ACT-R with a full Lisp implementation.

It is not necessary for one to be a Lisp programmer to be able to use ACT-R for basic modeling work. However, because ACT-R is running in Lisp, some basic understanding of how to program in Lisp can be helpful, and for those looking to extend the capabilities of a model it will be essential. An introduction to Lisp is beyond the scope of this document, but there are many introductory Lisp books available as well as many online resources. Two online resources where you can find additional information about Lisp are The Association of Lisp Users, http://www.alu.org/alu/home, and CLiki, the Common Lisp wiki, http://www.cliki.net/.

The primary means of interacting with ACT-R is through the Lisp read-eval-print loop - a command line interface. All of the commands described in this manual are available through that interface, and the manual assumes that that is how one will be using the system. However, there is also a set of GUI tools available (included with the main distribution) called the ACT-R Environment. The ACT-R Environment provides an alternate interface to a subset of the commands and is described in its own manual. The ACT-R Environment is useful for beginners, and because it uses multiple windows to display the information, can be helpful to coordinate viewing model data for advanced users as well.

Commands and names in ACT-R are not case-sensitive. Also, many ACT-R user commands are implemented as macros so that one does not have to quote the arguments. That also means that the arguments to such commands are not evaluated. For most of the macro based commands, there is also a corresponding function which will have the same name, but with a –fct appended to it. The commands' descriptions and examples should make clear how each command is to be used.

Notations in the Documentation

When describing the commands' syntax the following conventions will be used:

- items appearing in **bold** are to be entered verbatim
- items appearing in *italics* take user-supplied values
- items enclosed in **{**curly braces**}** are optional
- * indicates that any number of items may be supplied
- $^{+}$ indicates that one or more items may be supplied
- | indicates a choice between options which are enclosed in [square brackets]
- (parentheses) denote that the enclosed items are to be in a list
- a pair of items enclosed in <angle brackets> denote a cons cell with the first the car and the second the cdr
- -> indicates that calling the command on the left of the "arrow" will return the item to the right of the "arrow"
- **::=** indicates that the item on the left of that symbol is of the form given by the expression on the right

When examples are provided for the commands they are shown as if they have been evaluated at a Lisp prompt. The prompt that is shown prior to the command indicates additional information about the examples. There are three types of prompts that are used in the examples:

- A prompt with just the character '>' indicates that it is an individual example – independent of those preceding or following it.
- A prompt with a number followed by '>', for example "2>" means that the example is part of a sequence of calls which were evaluated and the result depends on the preceding examples. For any given sequence of calls in an example the numbering will start at 1 and increase by 1 with each new example in the sequence.
- A prompt with the letter E preceding the '>', "E>", indicates that this is an example which is either incorrect or was evaluated in a context where the call results in an error or warning. This is done to show examples of the warnings and errors that can occur.

In the description of some commands it will describe a parameter or return value as a "generalized boolean". What that means is that the value is used to represent a truth value – either true/successful or false/failure. If the value is the symbol **nil** then it represents false and all other values represent true. When a generalized boolean is returned by one of the commands, one should not make any assumptions about the returned value for the true case. Sometimes the true value may look like it provides additional information, but if that is not specified in the command's description then it is not guaranteed to hold for all cases or across updates to the command.

ACT-R Software Distribution

There are two primary means of acquiring the ACT-R software. The first is from the ACT-R web site http://act-r.psy.cmu.edu. The web site has an archived copy of the most recently released version of ACT-R in zip and diskimage formats. The released versions have been tested with the tutorial models and are updated when there are any significant updates or bug fixes to the software. The other method for acquiring the distribution is via version control software called Subversion. More information on Subversion can be found at http://subversion.tigris.org. The ACT-R archive is located at svn://jordan.psy.cmu.edu/usr/local/svnroot/actr6. The Subversion archive contains the most up to date version of ACT-R, and often contains minor changes or bug fixes not yet available in the released version. Note however that the minor changes made to the sources available through subversion are not all tested thoroughly against the tutorial models and there may be discrepancies with respect to the tutorial documentation until the next released version.

Distribution Contents

The primary components of the ACT-R distribution are the Lisp source code files. It also includes the ACT-R Environment application (a GUI for inspecting and debugging ACT-R models), the Tutorial units and models for learning ACT-R modeling, and additional documentation. All of the files are distributed in a single directory, called actr6, which contains one file and several subdirectories. The file is named load-act-r-6.lisp. When that file is loaded it will load all of the other components of the system. Here is a listing of the subdirectories along with a general description of their purpose and some of their specific contents:

commands

This directory contains code for user commands for some of the central modules. One feature of this directory is that any file with a .lisp extension placed into this folder will be compiled and loaded with the rest of the system.

core-modules

This directory contains the code that defines the modules which instantiate the main ACT-R system described in the theory. They are assumed to always be available, but are not absolutely required. The base modules are Procedural, Declarative, Goal, Vision, Auditory, Motor, Speech and Imaginal and are all described in this manual.

devices

This directory contains subdirectories which each contain two files that control the interaction between the ACT-R device and a specific Lisp and the corresponding AGI (ACT-R Graphical Interface) functions for that Lisp. There is also a generic (virtual) system that is available for all Lisps. The device and the AGI are described in later sections of this manual.

docs

This directory contains the documentation files for ACT-R. They include details on using the system, as well as documents describing particular features. Here are descriptions of some of the files found there:

- reference-manual.doc
  - This document.
- compilation.xls
  - An Excel Spreadsheet that is used to define the operation of the production compilation mechanism.
- compilation.doc
  - A document describing the design and theory of the production compilation mechanism.
- differences.txt
  - Some notes about differences between ACT-R 5.0 and ACT-R 6.0.
- framework-API.doc

    - A document that describes the internal system upon which ACT-R is built along with the API of the functions it provides. It is being replaced as a reference by this document and it has not been maintained with the most recent changes. It is still included as a reference for those interested in the design of the software.
- LGPL.txt
    - The Lesser Gnu Public License text. That is the license under which the ACT-R software is distributed.
- template.lisp
    - This is a lisp file that is the recommended starting point for any new modules or additions which are for general use with ACT-R. The author and contact information at the top should be changed, and then the remaining pieces filled in appropriately.
- extending-actr.ppt
    - A power point presentation which was given during the ACT-R advanced tutorial at ICCM in 2007. It describes the basics of creating new devices and adding new modules.
- EnvironmentManual.doc
    - The reference manual for the ACT-R Environment.

environment

The environment directory contains all of the files necessary for using the ACT-R GUI tools, called the ACT-R Environment. There are several items in this directory: lisp files that define the tools and the communication between ACT-R and the Environment, the Environment applications for both Windows and Mac OS X, and a GUI directory that contains the files used by the Environment application.

extras

The extras directory contains additional modules and other files that have been contributed to the distribution, but which are not part of the default ACT-R system. Directions for using those files should be found within the files themselves or the documentation which accompanies them. They are not loaded by default.

framework

The framework directory contains the Lisp files that define the software framework upon which the ACT-R system is based. The software framework is a basic discrete event simulation system that was designed to implement ACT-R, but is not based on the theory of the ACT-R.

modules

The modules directory contains additional modules that are not part of the core system. As with the commands directory, any files with a .lisp name placed into this directory will be loaded automatically when ACT-R is loaded.

other-files

This directory contains some files that add tools for viewing BOLD response data and graphic traces in the ACT-R Environment. Like the commands and modules directories, any file with a .lisp extension placed into this directory will be automatically loaded with the system.

support

The support directory contains files that may be needed for certain Lisp implementations, for certain modules of the system, or for possible user support. These files are loaded when required by other files.

examples

The examples directory contains source files that provide examples of some advanced components or techniques available to modelers. Currently, it has examples showing multiple models being run together, creation of new devices and a simple example of creating a new module.

tools

The tools directory contains source files that define user functions and modeling tools for ACT-R. Like the commands and modules directories, all files with a .lisp name placed into this folder will be automatically loaded.

tutorial

The tutorial directory contains several subdirectories. Each one holds the files for a unit of the ACT-R Tutorial. Each unit consists of a text on a particular aspect of ACT-R, one or more demonstration models, a partial model which provides a starting point for an assignment, and a text describing the Lisp code in the provided models.

user-loads

The user-loads directory contains no files in the distribution. It is provided as a place for users to add files which will be loaded automatically after ACT-R has finished loading and initializing. All of the files in the user-loads directory with a .lisp name will be compiled and loaded in order based on the file names sorted using the Lisp string< function. Because this occurs after the system has been initialized it is safe to put a model file into this directory.

Loading and Running the ACT-R System

To start ACT-R all one needs to do is load the load-act-r-6.lisp file into a supported Lisp system. That will load all of the necessary files for ACT-R. The file should only be loaded into a given Lisp session once.

The files are compiled before loading and that will usually generate a lot of warnings from the compiler. Those warnings can be safely ignored. The files are only compiled the first time you load ACT-R. The compiled files are saved with the source files and on subsequent loadings there is no need to recompile everything. Thus, on all loadings after the first one, it should load faster and produce fewer warnings.

Once the loading is complete, you will see a listing of all the modules that were loaded for ACT-R along with their versions and brief descriptions followed by a line that looks like this:

######### Loading of ACT-R 6 is complete #########

At that point, ACT-R is ready to use. If there were any files in the user-loads directory then there will be at least two additional lines displayed. The first will be:

######### Loading user files #########

That will be followed by any information displayed while the files in that directory are compiled and loaded. After all of those files have been loaded this will then be displayed:

######### User files loaded #########

Logical Host

As part of loading the system a logical host of "ACT-R6" is defined which maps to the directory where the load-act-r-6.lisp file is located. That logical host is available for use by the user. It can be useful when working with the tutorial in a command-line only Lisp to load the tutorial models. Here is an example which will load the count model from unit1 (assuming that one has not moved the tutorial files):

```
> (load "ACT-R6:tutorial;unit1;count.lisp")
; Loading C:\Documents and Settings\Dan\Desktop\SVN\actr6\tutorial\unit1\count.lisp
T
```

Load order

For those considering adding extensions or just having files loaded automatically the files/directories are loaded in the following order:

- framework directory files in a predefined order
- core-modules directory files in a predefined order
- all .lisp files from the commands directory in no particular order
- the virtual device files
- any Lisp specific device files
- all .lisp files from the modules directory in no particular order
- all .lisp files from the tools directory in no particular order
    - the ACT-R Environment files are loaded as part of this step
- all .lisp files from the other-files directory in no particular order
- all .lisp files from the user-loads directory in order based on file name sorted using the Lisp string< function.

Recompiling

If one of the source files in the distribution changes (the date on the .lisp file is newer than the date on the compiled version of that file) then it will automatically be recompiled the next time it is loaded. However, there may be times when you need to force all of the ACT-R files to be recompiled. For instance, if you upgrade or change your Lisp system you will likely need to recompile everything. Also, if you get an update to your current set of ACT-R files it is often best to force a recompile the next time you load it because there may be some interdependencies that will require more than just the updated file to be recompiled.

To force ACT-R to recompile all of its files you should execute this call before loading the load-act-r-6.lisp file:

```
(push :actr-recompile *features*)
```

Packaging

By default, the ACT-R files are loaded into which ever package is current at the time they are loaded i.e. there are no package specifications. However, there are two features which can be set that will change the package into which ACT-R is loaded. Note that both of these options are still considered experimental and may not work properly in all systems – please contact Dan if you have any problems or questions.

Clean

The first option is to add the :clean-actr switch to the features list before loading:

```
(push :clean-actr *features*)
```

That will force the files to be loaded into the :cl-user package in most Lisps (the only exception is that when using ACL with the IDE it will force them into the :cg-user package because that is the typical default package there).

Packaged

The other option is to add the :packaged-actr switch to the features list before loading:

```
(push :packaged-actr *features*)
```

When the load file is then loaded it will create a new package called :act-r and force all of the files to be loaded into that package. Nothing is exported from that package by default.

Overall Software Design

The ACT-R software is composed of two major components. From the perspective of the user, these components operate together seamlessly to form ACT-R, but it is worth noting from the perspective of the theory of ACT-R that there are really two separate pieces to the system.

The first is a discrete event simulation system which controls the timing and coordination of operations within ACT-R. It was designed to provide all the support necessary to implement the current ACT-R theory, but is not itself a part of the theory. It defines the abstractions and tools which underlie the operations of the system, namely a meta-process, a module, a buffer, a chunk and a model (which will all be described in later sections). Some of those items are components of the theory of ACT-R, for example buffers and chunks, but their specific implementation in the software is not prescribed by the theory.

The other component is the set of modules that instantiate the theory of ACT-R. These modules contain the components that are used to model human cognition as described in the paper "Integrated Theory of the Mind" and the book "How Can the Human Mind Occur in the Physical Universe?". The actions and timing profiles generated by these modules when a model is run are the actual predictions of the theory. Anything else, for instance the actual time it takes the software to run the simulation, is not based on the theory. Most of the time, the distinction is unimportant to the user, but sometimes it is important to distinguish between what is a psychological claim of a model and what is just a consequence of the current software implementation.

Model files

Generally, when working with ACT-R one will generate text files that contain the description of a model along with any necessary control and support code which will be loaded into a Lisp that has the ACT-R system already loaded. This is not the only way to develop models in ACT-R, but is by far the most typical usage.

An ACT-R model file is a text file of Lisp source code. It can be generated in any text editor. Because it will be loaded into Lisp it must be syntactically correct Lisp code. Thus, it can be useful to use an editor that helps with that. The editors built into the GUI based Lisp systems (like MCL, LispWorks, or ACL with its IDE) are good choices if using such a Lisp, but if not, an editor like Emacs which has automatic Lisp indenting and parentheses matching will also help.

A typical model file will have the following structure:

(clear-all)
{Lisp functions for presenting an experiment, data collection or other support needs}
(define-model *model-name*
   (sgp *{parameter value}*)*
   {chunk-type definitions}
   {initial chunks are defined}
   {productions are specified}
   {any additional model set-up commands}
   {additional model parameter settings}
)

The ACT-R commands shown above and the model components referenced (chunk-types, chunks, and productions) will be described in later sections of this document, but for now here is a basic description of what the components of the model file do.

- **(clear-all)**
  The clear-all command completely resets ACT-R's state to a clean slate. This does not have to be the first thing in the file, but it should occur before defining any models.

- *{Lisp functions for presenting an experiment, data collection or other support needs}*
  The Lisp commands that define any experiment for the model or other code typically come before the ACT-R model description. The amount and nature of the code can vary significantly between models.

- **(define-model** *model-name*
  The define-model command is used to specify exactly what constitutes the components of the model and to give it a name for reference. Everything between the name specified for the model and the closing parenthesis of this command are considered the model's initial configuration. The commands are processed sequentially, thus the order of things does matter.

- ***(sgp*** *{parameter value}*)*

The sgp command is used to set parameters that control the general operation of the system. This is typically the first command in the model's definition so that all of the conditions are properly set before anything else occurs.

- *{chunk-type definitions}*
  Descriptions are given for the types of chunks that will be used in the model.

- *{initial chunks are defined}*
  The initial chunks for the model are created and typically placed into the model's declarative memory.

- *{productions are specified}*
  The productions that control how the model will act are written here.

- *{any additional model set-up commands}*
  Any other commands necessary to configure components of the model or modules are specified.

- *{additional model parameter settings}*
  Parameters for chunks and productions specified above are set.

- **)**
  The define-model call is ended with a closing parenthesis.

Meta-process

The main component of the simulation system is called a meta-process. It is essentially the clock and event coordinator for the system. It maintains a schedule of events that the other components have initiated and executes them at the desired time. It also maintains a list of events that are waiting for specific events to occur before they are added to the main event queue. It is not part of the ACT-R theory – it is purely a component of the software system.

It is possible to have more than one meta-process defined in a running ACT-R system. Doing so would allow one to have multiple asynchronous models. That is an advanced topic discussed in a later section of the manual. Typically there is only one meta-process (the default that exists when the system is loaded) and users will not need to create any others. For most users, the meta-process is essentially invisible – it runs the system behind the scene.

Regardless of how many meta-processes are defined, only one is accessible at any given time. This is referred to as the current meta-process. Only the current meta-process will be manipulated by the commands. If there is only one meta-process, then it will always be the current meta-process. If there is more than one meta-process defined, then it is up to the modeler to specify which is current before executing any commands (see the multiple models section for more details).

Commands

clear-all

Syntax:

clear-all -> **nil**

Arguments and Values:

none

Description:

clear-all restores ACT-R to its initial state. It removes all meta-processes except for the default meta-process and all attributes of the default meta-process are set to their initial values: there is no model defined, the time is set to 0.0, the event queue is cleared, waiting events are removed and the event hooks are cleared.

In addition, the current binding of the Lisp variable *load-truename* is recorded for use by the reload command.

Typically usage is to place clear-all at the top of a model file to ensure that when the model is defined it starts in a clean system and that the reload command can be used.

Examples:

```
> (clear-all)
NIL
```

reset

Syntax:

reset -> [meta-process-name | **nil**]

Arguments and Values:

meta-process-name ::= a symbol which is the name of the meta-process that was reset

Description:

The reset command is similar to clear-all except that it only affects the current meta-process and instead of removing all currently defined models they are restored to their initial conditions. Specifically, for the current meta-process the time is set to 0.0, the event queue is cleared, all waiting events are removed and then each of the currently defined models is reset. The details of what happens when a model is reset are described in the models section. The name of the meta-process which was reset is returned.

There are also two special situations which can result when there is a single empty model in the current meta-process (see the model section for the details of an empty model). If the empty model was loaded from a file, then a warning is displayed and that file is reloaded (using the reload command). If the empty model was not loaded from a file then the call to reset has no effect on the system and a warning is displayed to indicate that.

If there is no current meta-process, then a warning is displayed and **nil** is returned.

Examples:

```
> (reset)
DEFAULT

> (reset)
#|Warning: Resetting an empty model results in a reload |#
; Loading C:\model.cl
DEFAULT

> (reset)
#|Warning: CANNOT RESET an empty model that wasn't loaded. |#
#|Warning: RESET had no effect! |#
DEFAULT
```

```
E> (reset)
#|Warning: reset called with no current meta-process. |#
NIL
```

reload

Syntax:

reload {*compile?*} -> [load-return-value | **:none**]

Arguments and Values:

compile? ::= a generalized boolean indicating whether or not to compile the file
load-return-value ::= a generalized boolean returned from calling the load command

Description:

The reload command calls the Lisp load command to load the file recorded by the last call to the clear-all command. If the compile? parameter is specified with a true value and that file has a type of "lisp" it will be compiled before loading. The return value from reload is the value returned from the call to load which is a generalized boolean that indicates true for a successful load or false if there was an error.

If the compile? parameter is specified as true but the recorded file is not of type "lisp" then it is not compiled. A warning is printed and the file is just loaded.

If the recorded value from clear-all is **nil** then no file is loaded and the keyword **:none** is returned.

Additional information may be printed by the call to load depending on the Lisp implementation and current settings.

Reload is essentially a shortcut for reloading a model file that has been edited to incorporate those changes.

Examples:

```
> (reload)
; Loading C:\model.lisp
T

> (reload t)
;;; Compiling file C:\model.lisp
;;; Writing fasl file C:\model.fasl
;;; Fasl write complete
; Fast loading C:\model.fasl
T

> (reload t)
#|Warning: To use the compile option the pathname must have type lisp. |#
; Loading C:\model.txt
```

```
T

E> (reload)
#|Warning: No load file recorded |#
:NONE
```

mp-time

Syntax:

mp-time -> [current-time | **nil**]

Arguments and Values:

current-time ::= a number representing time in seconds

Description:

mp-time returns the current time of the current meta-process in seconds.

If there is no current meta-process, then a warning is displayed and **nil** is returned.

This is generally used for two purposes. First, it can be useful for debugging a model. It is also used for collecting response time data from a model.

Examples:

```
> (mp-time)
0.3

E> (mp-time)
#|Warning: mp-time called with no current meta-process. |#
NIL
```

mp-time-ms

Syntax:

mp-time-ms -> [current-time | **nil**]

Arguments and Values:

current-time ::= a number representing time in milliseconds

Description:

mp-time returns the current time of the current meta-process as an integer count of milliseconds.

If there is no current meta-process, then a warning is displayed and **nil** is returned.

This is generally used for two purposes. First, it can be useful for debugging a model. It is also used for collecting response time data from a model.

Examples:

```
> (mp-time-ms)
300

E> (mp-time-ms)
#|Warning: mp-time-ms called with no current meta-process. |#
NIL
```

Events

As indicated in the description of the meta-process, the simulation system for ACT-R is implemented using a sequence of events. Generally, each event consists of a time at which it should occur, an indication of which module made the request, the action that should occur and possibly some additional details of the action. Effectively, every action of the model occurs as an event in the system, and the model's trace when it runs is just a printing of those events.

More details of events will be discussed in the section that describes the mechanisms for creating them. Here it will just describe some commands which one can use to get information about existing events.

Commands

mp-show-queue

Syntax:

mp-show-queue -> [event-count | **nil**]

Arguments and Values:

event-count ::= a number indicating how many items are on the event queue

Description:

mp-show-queue prints all of the events that are on the event queue of the current meta-process to the Lisp stream ***standard-output**** in the order that they would be executed. It returns the number of events in the queue.

If there is no current meta-process then a warning is displayed and **nil** is returned.

This command can be useful for debugging, but is generally more important when working on creating modules and experiments than when debugging a model.

Examples:

```
> (mp-show-queue)
Events in the queue:
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   GOAL                  #<Function CLEAR-DELAYED-GOAL>
3

E> (mp-show-queue)
#|Warning: mp-show-queue called with no current meta-process. |#
NIL
```

mp-show-waiting

Syntax:

mp-show-waiting -> [event-count | **nil**]

Arguments and Values:

event-count ::= a number indicating how many items are in the waiting queue

Description:

mp-show-waiting prints all of the events that are on the waiting queue of the current meta-process to the Lisp stream ***standard-output**** along with a description of the condition necessary for each to be added to the main event queue. It returns the number of events that are in the waiting queue.

If there is no current meta-process a warning is displayed and **nil** is returned.

This command can be useful for debugging, but is generally more important when working on creating modules and experiments than when debugging a model.

Examples:

```
> (mp-show-waiting)
Events waiting to be scheduled:
       NIL   PROCEDURAL             CONFLICT-RESOLUTION Waiting for: (ANY NIL)
1

E> (mp-show-waiting)
#|Warning: mp-show-waiting called with no current meta-process. |#
NIL
```

mp-modules-events

Syntax:

mp-modules-events *module-name* -> [event-list | **nil**]

Arguments and Values:

module-name ::= a symbol which should be the name of a module
event-list ::= a list of events scheduled for the named module

Description:

mp-module-events returns a list of all of the events from both the regular and waiting queues of the current meta-process which have a module specified that matches the module-name provided.

If there is no current meta-process a warning is displayed and **nil** is returned.

Examples:

```
> (mp-modules-events 'procedural)
(#S(ACT-R-EVENT ...))

> (mp-modules-events 'not-a-module)
NIL

E> (mp-modules-events 'procedural)
#|Warning: mp-modules-events called with no current meta-process. |#
NIL
```

Module

Module is unfortunately an overloaded term in ACT-R because it has different connotations when talking about the software and the theory. At the software level a module is a basic component of the system. It can serve any number of purposes, for instance there is a printing module, a random number generator module, as well as a vision module, a declarative memory module and many others. Each module is essentially an independent component, and it is the modules which provide the functionality of the overall system. There are basically no restrictions built in to control what a software module can do and adding new modules is the primary way of extending or modifying the overall system.

From the theory perspective however a module is a reference to some cognitive faculty which can typically be ascribed to a particular region of the brain. Thus, something like the random number module in the software obviously would not be considered a module of the theory. Another issue is that the implementation of the cognitive modules as software modules is not always one-to-one. For example, the vision system of ACT-R, which is implemented in the software as one module, is more appropriately considered as two cognitive modules – one for location information and one for object information. In the other direction, the theory's procedural module is actually implemented as three modules in the software (one that controls production definition and matching, one to handle the utility computations and one to implement the production compilation mechanism).

Often the context in which one encounters "module" with respect to ACT-R makes it clear what is being discussed (the software or the theory) so it is not usually as confusing as it might seem. For clarity, from this point on in the manual, when it says module, the reference will always be to the actual software modules unless explicitly stated otherwise.

Each module will provide its own set of commands to the system and may also provide one or more buffers as an interface for other modules as well as a set of parameters that can be used to adjust its operation. The details of the modules of ACT-R and details on constructing and accessing modules, buffers and parameters are described in later sections.

Commands

mp-print-versions

Syntax:

mp-print-versions -> **nil**

Arguments and Values:

none

Description:

mp-print-versions prints the version number of the ACT-R framework and the name, version number, and documentation of each module which is currently defined. It always returns **nil**.

Examples:

```
> (mp-print-versions)
ACT-R Version Information:
Framework             : 1.1
VISION                : 2.4        A module to provide a model with a visual attention
AUDIO                 : 2.2        A module which gives the model an auditory system
GOAL                  : 1.0        The goal module creates new goals for the goal buffer
NAMING-MODULE         : 1.0        Provides safe and repeatable new name generation
PROCEDURAL            : 1.3        The procedural module handles production definition
PRINTING-MODULE       : 1.0        Coordinates output of the model.
BUFFER-PARAMS         : 1.0        Module to hold and control the buffer parameters
ENVIRONMENT           : 2.0        A module to handle the environment connection if opened
RANDOM-MODULE         : 1.0        Provide a source of pseudorandom numbers
SPEECH                : 2.2        A module to provide a model with the ability to speak
PRODUCTION-COMPILATION: 1.1        A module that compiles productions
CENTRAL-PARAMETERS    : 1.0        a module that maintains parameters
MOTOR                 : 2.3        Module to provide a model with virtual hands
IMAGINAL              : 1.1        a goal style buffer with a delay and an action buffer
DECLARATIVE           : 1.1        stores chunks from the buffers for retrieval
DEVICE                : 1.1        The device interface for a model
UTILITY               : 2.0        A module that computes production utilities
BUFFER-TRACE          : 1.0a1      a buffer based tracing mechanism.
NIL
```

Buffers

Buffers in ACT-R are the built in interface between modules. Each buffer is connected to a specific module and has a unique name by which it is referenced e.g. the goal buffer or the retrieval buffer which are associated with the goal and declarative modules respectively. A buffer is used to relay requests for actions to its module, to query its module about the module's state, and it can hold one chunk which is visible to all other modules. A module will respond immediately to a query through its buffer with a generalized-boolean. In response to a request, the module will usually generate one or more events to perform some action(s) and may place a chunk into the buffer to indicate the result of that action. Any module may access or modify the chunk in any buffer at any time, but typically a module will only manipulate its own buffer(s). A buffer will also respond directly to queries to determine whether or not it currently holds a chunk and for the status of how the chunk was placed into the buffer (whether it was the result of a specific request or if it was unrequested and spontaneously placed there by the module).

An important thing to note is that when a chunk is placed into a buffer the buffer makes a copy of that chunk which it then makes available. Any changes made to the chunk in the buffer only affect the copy that it holds – they do not impact the original from which it was copied.

One of the current research areas with ACT-R is in using the buffers to track the activity of their associated modules and then comparing that activity to data from fMRI studies to find correlations between regions of the brain and particular buffer/module activity in ACT-R models. Thus providing a mechanism for mapping cognitive modeling work onto actual brain regions and even being able to make predictions about where activation should show up in future fMRI research.

Typically, an ACT-R modeler interacts with the buffers through the production system. These commands provide general information about buffers which is most often needed for modeling work. A later section will describe the commands one can use for more low-level interaction with the buffers which would be necessary for creating a new module.

Commands

buffers

Syntax:

buffers -> (buffer-name*)

Arguments and Values:

buffer-name ::= a symbol which is the name of a currently existing buffer

Description:

The buffers command will return a list with the names of all the currently defined buffers in no particular order.

Examples:

```
> (buffers)
(VISUAL-LOCATION MANUAL RETRIEVAL IMAGINAL VISUAL AURAL PRODUCTION VOCAL AURAL-LOCATION
IMAGINAL-ACTION GOAL)
```

buffer-chunk

Syntax:

buffer-chunk *buffer-name** -> [(<buffer-name [chunk-name | **nil**]>*) | ([chunk-name | **:error**]*) | **nil**]
buffer-chunk-fct (*buffer-name**) -> [(<buffer-name [chunk-name | **nil**]>*) | ([chunk-name | **:error**]*) | **nil**]

Arguments and Values:

buffer-name ::= a symbol that names a buffer
chunk-name ::= a symbol that names a chunk

Description:

Generally, the buffer-chunk command prints out the names of buffers along with the chunks those buffers hold in the current model.

If no buffer names are specified, then it prints all the buffers and the chunk name of the chunk in that buffer (or **nil** if the buffer is empty) one per line to the model's command output stream and returns a list of cons cells where the car of the cons is the name of the buffer and the cdr is the name of the chunk it holds (or **nil**) in no particular order.

If specific buffers are provided, then for each of those buffers, in the order provided, it prints the buffer name followed by the name of the chunk in that buffer (or **nil** if the buffer is empty) and if there is a chunk in the buffer that chunk is also printed. In this case it returns a list of the names of the chunks in the buffers provided in the same order as they were specified in the call. If an invalid buffer name is provided the corresponding value in the return list will be the keyword **:error** and nothing will have been printed.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

```
> (buffer-chunk)
VISUAL-LOCATION: NIL
MANUAL: NIL
RETRIEVAL: E-0 [E]
IMAGINAL: NIL
VISUAL: NIL
```

```
AURAL: NIL
PRODUCTION: NIL
VOCAL: NIL
AURAL-LOCATION: NIL
IMAGINAL-ACTION: NIL
GOAL: NIL
…
 ((VISUAL-LOCATION) (MANUAL) (RETRIEVAL . E-0) (IMAGINAL) (VISUAL) (AURAL) (PRODUCTION)
(VOCAL) ...)

> (buffer-chunk-fct '(retrieval goal))
RETRIEVAL: E-0 [E]
E-0
  ISA COUNT-ORDER
   FIRST  4
   SECOND  5

GOAL: NIL
(E-0 NIL)

E> (buffer-chunk-fct '(bad-buffer-name))
(:ERROR)

E> (buffer-chunk retrieval bad-name goal)
RETRIEVAL: E-0 [E]
E-0
  ISA COUNT-ORDER
   FIRST  4
   SECOND  5

GOAL: NIL
(E-0 :ERROR NIL)

E> (buffer-chunk)
#|Warning: buffer-chunk called with no current model. |#
NIL
```

buffer-status

Syntax:

buffer-status *buffer-name** -> [([buffer-name | **:error**]*) | **nil**]
buffer-status-fct (*buffer-name**) -> [([buffer-name | **:error**]*) | **nil**]

Arguments and Values:

buffer-name ::= a symbol that names a buffer

Description:

The buffer-status command prints out the status information for the buffers and their modules from the current model to the current model's command output stream. For each buffer specified (or all buffers if none are specified) the buffer name is printed followed by the current state of the required status items (**t** or **nil**) for the buffer/module, one per line, followed by any module specific status the module prints (the module specific status is not constrained by the system and could be any type of output). It returns a list of the buffer names of the buffers for which the status was printed.

If specific buffers are provided, and an invalid buffer name is specified, the corresponding value in the return list will be the keyword **:error** and nothing will have been printed.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

```
> (buffer-status)
VISUAL-LOCATION:
  buffer empty          : T
  buffer full           : NIL
  buffer requested      : NIL
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
  attended new          : NIL
  attended nil          : NIL
  attended t            : NIL
MANUAL:
  buffer empty          : T
  buffer full           : NIL
  buffer requested      : NIL
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
  preparation free      : T
  preparation busy      : NIL
  processor free        : T
  processor busy        : NIL
  execution free        : T
  execution busy        : NIL
  last-command          : NONE
RETRIEVAL:
  buffer empty          : NIL
  buffer full           : T
  buffer requested      : T
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
  recently-retrieved nil: NIL
  recently-retrieved t  : T
…

 (VISUAL-LOCATION MANUAL RETRIEVAL IMAGINAL VISUAL AURAL PRODUCTION VOCAL ...)

> (buffer-status goal)
GOAL:
  buffer empty          : T
  buffer full           : NIL
  buffer requested      : NIL
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
(GOAL)

> (buffer-status-fct '(retrieval))
RETRIEVAL:
  buffer empty          : NIL
  buffer full           : T
```

```
  buffer requested      : T
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
  recently-retrieved nil: NIL
  recently-retrieved t  : T
(RETRIEVAL)

E> (buffer-status goal non-buffer)
GOAL:
  buffer empty          : T
  buffer full           : NIL
  buffer requested      : NIL
  buffer unrequested    : NIL
  state free            : T
  state busy            : NIL
  state error           : NIL
(GOAL :ERROR)

E> (buffer-status)
#|Warning: buffer-status called with no current model. |#
NIL
```

Models

An ACT-R model is one simulated cognitive agent. The software can have essentially any number of models loaded simultaneously (practically there is a limit that will depend on the hardware and Lisp software) and they can be run either individually or synchronized. However, the most common usage of ACT-R is to work with only one model at a time. Most of this manual assumes that one is working with only one model at a time. Information about dealing with more than one model simultaneously is covered in the multiple models section.

A model is referenced by a name specified when it is defined, and that name must be unique within the current meta-process. A model consists of the code specified in its definition, an instance of each module in the system (which is independent of any other model's copy of that module unless a specific module indicates otherwise), and its set of chunks (which are always independent of the chunks of any other model).

A model is explicitly created with the define-model command which specifies its initial conditions and causes the creation of a new instance of each module for that model to use. The reset command will return the model to that state. Specifically, when a model is reset the following sequence of actions occur:

- All chunk-types and chunks are deleted from the model
- All the model's buffers are marked as empty
- The default chunk-types and chunks are created
    - A chunk-type called chunk with no slots
    - Chunks named free, busy, error, empty, full, requested and unrequested all of type chunk
- The model's modules have their primary reset functions called (in no specific order)
- The parameters of all the modules are set to their specified default (in no specific order)
- The model's modules have their secondary reset functions called (in no specific order)
- The model's definition code is evaluated in the order given (left to right)
- The model's modules have their tertiary reset functions called (in no specific order)

As with meta-processes, it is possible to define more than one model at a time, and regardless of how many models are defined in a meta-process, only one is accessible at any given time. This is referred to as the current model (note that different meta-processes will each have their own current model). Only the current model in the current meta-process may be manipulated by the commands. If there is only one model in the current meta-process, then it will be the current model. If there is more than one model defined in the current meta-process, then it is up to the modeler to specify which is current before executing any commands (see the multiple models section for more details).

Commands

define-model

Syntax:

define-model *model-name {model-code*}* -> [model-name | **nil**]
define-model-fct *model-name* (*{model-code*}*) -> [model-name | **nil**]

Arguments and Values:

model-name ::= a symbol that will be the name of the model
model-code ::= a Lisp expression that will be evaluated when the model is created and when it is reset

Description:

The define-model command creates a new model with the given model-name in the current meta-process. Its initial conditions are specified by the model-code provided.

If there is not already a model by that name in the current meta-process and there are no errors in evaluation of the model-code forms then the new model is created and model-name is returned.

If there is not a current meta-process, model-name is already the name of a model in the current meta-process, or an error occurs during the evaluation of the model-code then a warning is printed and **nil** is returned.

Special case:

If no model-code is specified when the model is defined, then the new model is considered an "empty model". That has some implications when using the reset command, and generally empty models are not recommended.

Examples:

Only basic usage of define-model is shown here – see the tutorial for definition of actual cognitive models that perform meaningful tasks.

```
> (define-model-fct 'model-10 (list '(chunk-type start slot)))
MODEL-10

1> (define-model model-1 (chunk-type goal state))
MODEL-1

2E> (define-model-fct 'model-1 nil)
#|Warning: MODEL-1 is already the name of a model in the current meta-process.  Cannot be
redefined. |#
NIL

E> (define-model model-2)
#|Warning: define-model called with no current meta-process. |#
NIL

E> (define-model model-3 (pprint "start") (pprnt "end"))
```

```
"start"
#|Warning: Error encountered in model form:
(PPRNT "end")
Invoking the debugger. |#
#|Warning: You must exit the error state to continue. |#
Debug: attempt to call `PPRNT' which is an undefined function.
[condition type: UNDEFINED-FUNCTION]
#|Warning: Model MODEL-3 not defined. |#
NIL
```

delete-model

Syntax:

delete-model *{model-name}* -> [**t** | **nil**]
delete-model-fct *model-name* -> [**t** | **nil**]

Arguments and Values:

model-name ::= a symbol that should be the name of a model

Description:

The delete-model command removes the model with the specified model-name from the current meta-process. If model-name is not provided the current model is deleted. Deleting a model removes all events generated by that model from the event queues, deletes each of the model's instances of the modules, and removes the model from the set of models currently defined. If a model is successfully deleted then **t** is returned.

If there is not a current meta-process, model-name is not the name of a model in the current meta-process, or no model-name is given and there is no current model, then a warning is printed and **nil** is returned.

The delete-model command is typically only useful when working with multiple models.

Examples:

```
> (delete-model)
T

> (delete-model-fct 'model)
T

E> (delete-model)
#|Warning: delete-model called with no current meta-process.
No model deleted. |#
NIL

E> (delete-model)
#|Warning: No current model to delete. |#
NIL
```

```
E> (delete-model-fct 'model)
#|Warning: No model named MODEL in current meta-process. |#
NIL
```

Chunks & Chunk-types

Chunks are the elements of declarative knowledge in the ACT-R theory and are used to communicate information between modules through the buffers. A chunk is defined by its chunk-type, which specifies the slots that it has, and by the values that it has in those slots (which are typically other chunks). A chunk also has a name which is used to reference it, however, the name is not considered to be a part of the chunk itself.

In the ACT-R software each chunk also has a set of parameters associated with it that are independent of its chunk-type that contain specific information needed by the modules or the modeler. The chunk parameters are a construct of the software and not the ACT-R theory though they are used to implement the mechanisms of the theory. These general chunk parameters are not the same as the parameters that one accesses via the declarative memory module's sdm command. However, the declarative memory module does maintain the parameters accessed by sdm through the use of chunk parameters internally. Any module (or even the modeler in a specific model) may add chunk parameters for tracking whatever is needed with the chunks. See the section on extending chunks and chunk-types for more information on adding and manipulating chunk parameters.

Chunk-types define the structure which a chunk will have. When a chunk is created its chunk-type is specified and that cannot be changed. The chunk-type specifies what slots the chunk will have and what (if any) the initial value of those slots will be.

Chunk-types can be organized in a hierarchy. When creating a new chunk-type one can specify one other chunk-type to be the parent type for that chunk-type. The subtype will have all of the slots that its parent (or supertype) has and will also inherit any default values for those slots. It can also have any number of new slots (including zero) or specify different default values for the inherited slots. There is no limit to the depth of the inheritance – the supertype of a new chunk-type could itself be the subtype of another chunk-type. That new chunk-type would also be considered a subtype of its parent's supertype.

When a hierarchy of chunk-types is used in a model and a test is performed to determine if a chunk matches a specification the match should be successful for a chunk with the chunk-type given or any of its subtypes if all of the other constraints are also satisfied. That is true for all of the provided modules which perform chunk matching (the procedural, declarative and vision modules), but other modules could be implemented which handle their matching differently than the recommended practice. Thus, when using modules other than those provided by default with the system, you should check any accompanying documentation before using them with chunk-type hierarchies if they perform any chunk matching.

A new feature of ACT-R 6 is the ability to extend a chunk-type with new slots after the initial chunk-type declaration and even after chunks of that type have been created. This will be described in the extending chunks and chunk-types section and is also used by the dynamic pattern matching productions.

Generally, a modeler will only need to create new chunk-types and chunks and use the productions of the procedural module for matching, comparing and modifying chunks. For debugging though it may be necessary to check on some of the details of a chunk-type, particularly one which is created outside of the model (for instance in a module), and there are times when directly creating, manipulating, or inspecting chunks can be useful.

An important distinction between ACT-R 6 and previous versions of the software is that chunks are now independent of the declarative memory system of the model. Any module may use chunks as its internal representation. All modules must use them to communicate through buffers and those chunks do not need to belong to the set of chunks in the model's declarative memory. One thing to note however is that the chunks from the buffers will be collected by the declarative memory module and incorporated into the model's declarative memory automatically. See the declarative memory module for details of how that occurs. As noted in the buffer section, buffers hold a copy of the chunk placed into them, thus the other modules see a copy of the chunk that a module places into a buffer. The module that created it effectively still has the original which it can continue to use without affecting the chunk that is seen by the other modules.

Chunk-type Commands

chunk-type

Syntax:

chunk-type { [*type-name* | **(***type-name* **(:include** *parent-name***))**] {*doc-string*} [*slot-name* | (*slot-name default-value*)]*} -> [type-name | (type-name*) | **nil**]

chunk-type-fct [**nil** | ([*type-name* | **(***type-name* **(:include** *parent-name***))**] {*doc-string*} [*slot-name* | (*slot-name default-value*)]*)] -> [type-name |(type-name*) | **nil**]

Arguments and Values:

type-name ::= a symbol that is to be the name of the new chunk-type
parent-name ::= a symbol that names a chunk-type to be the supertype for this new chunk-type
doc-string ::= a string that is used as documentation for this chunk-type
slot-name ::= a symbol that names a slot which will be part of this chunk-type
default-value ::= any Lisp value which specifies the value that will initially be in the corresponding slot-name of a chunk created of this chunk-type

Description:

The chunk-type command creates a new chunk-type for the current model or displays all the currently defined chunk-types for the current model.

If no parameters are passed to the command (or **nil** to the function) then all of the existing chunk-types in the current model are printed to the command output stream and a list of their names is returned (in no particular order). The printing of a chunk-type shows the chunk-type name, and if it is a subtype of another chunk-type then the name is followed by "<-" and the name of its parent chunk-type and then the documentation string for the chunk-type, if it has one, is printed. Then the slot names of the chunk-type are printed one per line, and if a slot has a default value it is printed in parenthesis after the slot name.

If a valid chunk-type specification is provided then a new chunk-type is created for the current model and the name of that chunk-type is returned.

If there is no current model, the given type-name already names an existing chunk-type in the current model, or there is an error in the specification of the chunk-type then a warning is printed and **nil** is returned.

Examples:

```
> (chunk-type)

SOUND
   KIND
   CONTENT
   EVENT


AUDIO-COMMAND

MOVE-CURSOR <- MOTOR-COMMAND
   OBJECT
   LOC
   DEVICE

…


(SOUND AUDIO-COMMAND MOVE-CURSOR ...)


1> (chunk-type goal slot1 state)
GOAL

2> (chunk-type-fct '(other-type slot1 slot2))
OTHER-TYPE

3> (chunk-type (subgoal1 (:include goal)) new-slot)
SUBGOAL1

4> (chunk-type-fct '((sub-goal2 (:include goal))))
SUB-GOAL2

5> (chunk-type new-type (slot default-value) (other-slot 4))
NEW-TYPE
```

```
6> (chunk-type detailed-type "This documents the type detailed-type" slot)
DETAILED-TYPE

7E> (chunk-type sub-goal)
#|Warning: Chunk-type SUB-GOAL is already defined and redefinition is not allowed. |#
NIL

8> (chunk-type-fct nil)
…

GOAL
   SLOT1
   STATE

SUBGOAL1 <- GOAL
   SLOT1
   STATE
   NEW-SLOT

DETAILED-TYPE "This documents the type detailed-type"
   SLOT

SUB-GOAL <- GOAL
   SLOT1
   STATE

NEW-TYPE
   SLOT (DEFAULT-VALUE)
   OTHER-SLOT (4)

OTHER-TYPE
   SLOT1
   SLOT2
…

(… GOAL SUBGOAL1 DETAILED-TYPE SUB-GOAL NEW-TYPE OTHER-TYPE …)


E> (chunk-type goal slot1 state)
#|Warning: chunk-type called with no current model. |#
NIL

E> (chunk-type (new-type (:include bad-type)))
#|Warning: Unknown supertype BAD-TYPE specified for type NEW-TYPE. |#
NIL

E> (chunk-type (new-type :include bad-type))
#|Warning: Too many options specified for chunk-type NEW-TYPE. NO chunk-type created. |#
NIL
```

pprint-chunk-type

Syntax:

pprint-chunk-type *type-name* -> [type-name | **nil**]

pprint-chunk-type-fct *type-name* -> [type-name | **nil**]

Arguments and Values:

type-name ::= a symbol that is the name of a chunk-type

Description:

The pprint-chunk-type command is used to print a description of a chunk-type. The output is sent to the current model's command output stream.

If the parameter provided is the name of a chunk-type in the current model of the current meta-process then that chunk-type is printed in the same way chunk-types are displayed with the chunk-type command: the chunk-type name is printed and if it is a subtype of another chunk-type then the name is followed by "<-" and the name of its parent chunk-type, the documentation string for the chunk-type, if it has one, is printed, and then the slot names of the chunk-type are printed one per line with the slot's default value in parenthesis after the slot name if one was provided when the chunk-type was created.

If there is no current model, current meta-process, or the given type-name does not name an existing chunk-type in the current model then a warning is printed and **nil** is returned.

Examples:

```
1> (chunk-type test slot1 (slot2 2))
TEST

2> (chunk-type (subtest (:include test)) "a subtype of test" slot3)
SUBTEST

3> (pprint-chunk-type test)
TEST
   SLOT1
   SLOT2 (2)


TEST

4> (pprint-chunk-type-fct 'subtest)
SUBTEST <- TEST "a subtype of test"
   SLOT1
   SLOT2 (2)
   SLOT3


SUBTEST

E> (pprint-chunk-type not-a-chunk-type)
#|Warning: NOT-A-CHUNK-TYPE does not name a chunk-type in the current model. |#
NIL
```

chunk-type-p

Syntax:

chunk-type-p *chunk-type-name?* -> [**t** | **nil**]

chunk-type-p-fct *chunk-type-name?* -> [**t** | **nil**]

Arguments and Values:

chunk-type-name? ::= a symbol to be tested to determine if it names a chunk-type

Description:

The chunk-type-p command returns **t** if chunk-type-name? is a symbol that names a chunk-type in the current model and returns **nil** if it does not. If there is no current model then a warning is printed and **nil** is returned.

Examples:

```
> (chunk-type-p visual-object)
T

> (chunk-type-p-fct 'chunk)
T

> (chunk-type-p bad-name)
NIL

> (chunk-type-p-fct 'non-chunk-type)
NIL

E> (chunk-type-p chunk)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

chunk-type-slot-names

Syntax:

chunk-type-slot-names *chunk-type-name* -> [(slot-name*) | **nil**] exists
chunk-type-slot-names-fct *chunk-type-name* -> [(slot-name*) | **nil**] exists

Arguments and Values:

chunk-type-name ::= a value which should be a symbol that names a chunk-type
slot-name ::= a symbol that names a slot in chunk-type-name
exists ::= a generalized boolean indicating whether the chunk-type-name given is a valid chunk-type

Description:

The chunk-type-slot-names command returns two values. The first is a list of the names of the slots in the chunk-type chunk-type-name in the current model if chunk-type-name is a valid chunk-type. If chunk-type-name does not name a valid chunk-type in the current model then the first result will be **nil**. Note that the first result could also be **nil** if the named chunk-type does not have any slots.

The second value will be true if chunk-type-name was a valid name for a chunk-type in the current model and it will be **nil** if it was not a valid chunk-type name.

If there is no current model a warning is printed and both return values will be **nil**.

Examples:

```
> (chunk-type-slot-names sound)
(KIND CONTENT EVENT)
T

> (chunk-type-slot-names-fct 'move-cursor)
(OBJECT LOC DEVICE)
T

> (chunk-type-slot-names chunk)
NIL
T

E> (chunk-type-slot-names-fct 'bad-chunk-type-name)
NIL
NIL

E>(chunk-type-slot-names chunk)
#|Warning: get-chunk-type called with no current model. |#
NIL
NIL
```

chunk-type-documentation

Syntax:

chunk-type-documentation *chunk-type-name* -> [doc-string | **nil**]
chunk-type-documentation-fct *chunk-type-name* -> [doc-string | **nil**]

Arguments and Values:

chunk-type-name ::= a value which should be a symbol that names a chunk-type
doc-string ::= a string of the documentation provided when chunk-type-name was created

Description:

chunk-type-documentation returns the documentation string of the chunk-type chunk-type-name from the current model if it names a valid chunk-type and has a documentation string. Otherwise it returns **nil**. If there is no current model then a warning is printed and **nil** is returned.

Typically this command is not needed by a modeler because the chunk-type command will print out the chunk-type information, but it may be useful to someone creating a new module.

Examples:

These examples assume that the chunk-types shown in the chunk-type examples exist.

```
> (chunk-type-documentation detailed-type)
"This documents the type detailed-type"

> (chunk-type-documentation-fct 'visual-object)
NIL

> (chunk-type-documentation non-type)
NIL

E> (chunk-type-documentation visual-object)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

chunk-type-slot-default

Syntax:

chunk-type-slot-default *chunk-type-name slot-name* -> [default-slot-value | **nil**]
chunk-type-slot-default-fct *chunk-type-name slot-name* -> [default-slot-value | **nil**]

Arguments and Values:

chunk-type-name ::= a value which should be a symbol that names a chunk-type
slot-name ::= a value which should be a symbol that names a slot in chunk-type-name
default-slot-value ::= a value which will be the initial value for the slot slot-name of chunks created of type chunk-type-name

Description:

chunk-type-slot-default returns the default value for the slot slot-name in the chunk-type chunk-type-name from the current model if it names a valid chunk-type and has a slot named slot-name. Otherwise it returns **nil**. If there is no current model then a warning is printed and **nil** is returned.

Typically this command is not needed by a modeler because the chunk-type command will print out the chunk-type information, but it may be useful to someone creating a new module.

Examples:

These examples assume that the chunk-types shown in the chunk-type examples exist.

```
> (chunk-type-slot-default new-type other-slot)
4

> (chunk-type-slot-default-fct 'new-type 'slot)
DEFAULT-VALUE

> (chunk-type-slot-default visual-location screen-x)
NIL

> (chunk-type-slot-default-fct 'bad-name 'bad-slot)
NIL

E> (chunk-type-slot-default visual-location screen-x)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

chunk-type-subtype-p

Syntax:

chunk-type-subtype-p *subtype? supertype* -> result
chunk-type-subtype-p-fct *subtype? supertype* -> result

Arguments and Values:

subtype? ::= a value which should be a symbol that names a chunk-type to be tested
supertype ::= a value which should be a symbol that names a chunk-type
result ::= a generalized boolean (no guarantees on what value will be returned for true)

Description:

The chunk-type-subtype-p command determines if the chunk-type subtype? is a subtype of the chunk-type supertype in the current model. If it is, then a true value is returned. If subtype? is not a subtype of the chunk-type supertype or either subtype? or supertype does not name a valid chunk-type then **nil** is returned. If there is no current model then a warning is printed and **nil** is returned.

Note, a chunk-type will return true when checked as a subtype of itself.

Examples:

```
> (chunk-type-subtype-p move-cursor motor-command)
MOTOR-COMMAND

> (chunk-type-subtype-p-fct 'text 'visual-object)
VISUAL-OBJECT

> (chunk-type-subtype-p visual-location visual-location)
VISUAL-LOCATION

> (chunk-type-subtype-p text motor-command)
NIL

> (chunk-type-subtype-p-fct 'move-cursor 'visual-object)
NIL

> (chunk-type-subtype-p non-chunk-type chunk)
NIL

> (chunk-type-subtype-p move-cursor non-chunk-type)
NIL

E> (chunk-type-subtype-p move-cursor motor-command)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

chunk-type-subtypes

Syntax:

chunk-type-subtypes *chunk-type-name* -> [(subtype*) | **nil**]
chunk-type-subtypes-fct *chunk-type-name* -> [(subtype*) | **nil**]

Arguments and Values:

chunk-type-name ::= a value which should be a symbol that names a chunk-type
subtype ::= a symbol that names a chunk-type which is a subtype of chunk-type-name

Description:

chunk-type-subtypes returns a list of the names of the chunk-types which are subtypes of chunk-type-name if chunk-type-name names a valid chunk-type in the current model. The list of chunk-types returned will be in the order in which those subtypes were created with the most recent first and chunk-type-name always being the last element of the list. Otherwise, **nil** is returned. If there is no current model then a warning is printed and **nil** is returned.

Note that a chunk-type is always listed as one of its own subtypes.

Examples:

These examples assume that the chunk-types shown in the chunk-type examples exist.

```
> (chunk-type-subtypes visual-location)
(VISUAL-LOCATION)

> (chunk-type-subtypes-fct 'motor-command)
(PREPARE PUNCH PRESS-KEY POINT-HAND-AT-KEY PECK-RECOIL PECK MOVE-CURSOR HAND-TO-HOME HAND-
TO-MOUSE CLICK-MOUSE ...)

> (chunk-type-subtypes-fct 'sub-goal)
(SUB-GOAL)

> (chunk-type-subtypes goal)
(SUB-GOAL GOAL)

> (chunk-type-subtypes non-goal)
NIL

E> (chunk-type-subtypes-fct 'goal)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

chunk-type-supertypes

Syntax:

chunk-type-supertypes *chunk-type-name* -> [(supertype*) | **nil**]
chunk-type-supertypes-fct *chunk-type-name* -> [(supertype*) | **nil**]

Arguments and Values:

chunk-type-name ::= a value which should be a symbol that names a chunk-type
supertype ::= a symbol that names a chunk-type which is a supertype of chunk-type-name

Description:

chunk-type-supertypes returns a list of the names of the chunk-types which are supertypes of chunk-type-name if chunk-type-name names a valid chunk-type in the current model. The list of names will be in order such that the subtype appears before its supertype for all chunk-types in the list. Otherwise, **nil** is returned. If there is no current model then a warning is printed and **nil** is returned.

Note that a chunk-type is always listed as one of its own supertypes.

Examples:

These examples assume that the chunk-types shown in the chunk-type examples exist.

```
> (chunk-type-supertypes visual-location)
(VISUAL-LOCATION)

> (chunk-type-supertypes goal)
(GOAL)

> (chunk-type-supertypes-fct 'sub-goal)
(SUB-GOAL GOAL)

> (chunk-type-supertypes bad-name)
NIL

E> (chunk-type-supertypes goal)
#|Warning: get-chunk-type called with no current model. |#
NIL
```

Chunk Commands

define-chunks

Syntax:

define-chunks ({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***)*** -> [chunk-name-list | **nil**]
define-chunks-fct (({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***)*)** -> [chunk-name-list | **nil**]

Arguments and Values:

chunk-name ::= a symbol that will be the name of the chunk
doc-string ::= a string that will be the documentation for the chunk
chunk-type ::= a symbol that should name an existing chunk-type of the model
slot ::= a symbol that names a valid slot in chunk-type
value ::= any Lisp value which will be the contents of the correspondingly named slot for this chunk
chunk-name-list ::= a list of chunk-name symbols

Description:

The define-chunks command creates a new chunk in the current model for each valid chunk description list provided and returns a list of the names of the chunks that were created.

Within a chunk description list the chunk name is optional. If a chunk-name is provided, it must not name an existing chunk in the current model. If a chunk-name is not provided, a new name will be generated for the chunk, and that name is guaranteed to be unique.

The chunk-type must name a valid chunk type in the current model.

Each slot named must be a valid slot for the chunk-type provided. If a given slot is named more than once in the definition then the last value it is given (rightmost) will be the one set for the chunk. If a slot is not specified then it will be set to the default for the chunk-type.

If a value for a slot is a symbol then it is assumed to be the name of a chunk. If there is not already a chunk by that name, then one is created automatically of the chunk-type chunk.

However, within a call to define-chunks one can use the names of the chunks that are being defined in the other chunks without having them created as default chunks. Here is an example to clarify that:

```
(define-chunks (a isa some-chunk-type slot b)
               (b isa some-chunk-type slot a))
```

Because both a and b are being defined in the same call to define-chunks neither will need to be created automatically of chunk-type chunk.

If the syntax is incorrect or any of the components are invalid in a description list then a warning is displayed and no chunk is created for that chunk description, but any other valid chunks defined will still be created.

If there is no current model then a warning is displayed, no chunks are created and **nil** is returned.

Examples:

```
> (define-chunks (a isa chunk)
                 (b isa sound))
(A B)

> (define-chunks-fct '((c "this is chunk c" isa visual-location screen-x 10)
                       (isa visual-object screen-pos c)))
(C VISUAL-OBJECT0)

1> (define-chunks (d isa press-key key the-key))
#|Warning: Creating chunk THE-KEY of default type chunk |#
(D)

2E> (define-chunks-fct '((the-key isa chunk)))
#|Warning: Invalid chunk definition: (THE-KEY ISA CHUNK) names a chunk which already
exists. |#
NIL

E> (define-chunks (chunk-e isa chunk)
                  (chunk-f isa invalid-chunk-type)
                  (chunk-g isa visual-object))
#|Warning: Invalid chunk definition: (CHUNK-F ISA INVALID-CHUNK-TYPE) chunk-type specified
does not exist. |#
(CHUNK-E CHUNK-G)

E> (define-chunks (z isa chunk))
#|Warning: define-chunks called with no current model. |#
NIL
```

pprint-chunks & pprint-chunks-plus

Syntax:

pprint-chunks *chunk-name** -> [chunk-name-list | **nil**]
pprint-chunks-fct (*chunk-name****)** -> [chunk-name-list | **nil**]
pprint-chunks-plus *chunk-name** -> [chunk-name-list | **nil**]
pprint-chunks-plus-fct (*chunk-name****)** -> [chunk-name-list | **nil**]

Arguments and Values:

chunk-name ::= a symbol that should be the name of a chunk
chunk-name-list ::= ([chunk-name | **:error**]*)

Description:

The pprint-chunks family of commands are used to have the system print a description of each of the chunks specified, or all of the chunks in the model if no names are provided. The output is sent to the current model's command output stream.

For each chunk specified, on one line it will print the chunk's name followed by its "true name" if the chunk's true name differs from the chunk name itself (see merge-chunks and true-chunk-name below for more details on true name). If a documentation string was provided for the chunk that is printed on the next line. Then, **isa** followed by the chunk's chunk-type is printed on a line, and after that all of the slots and values for the chunk are printed on separate lines.

The pprint-chunks-plus command prints all of the chunk's parameters after the description of the chunk is printed as described above. The parameters are printed one per line with the name of the parameter and its current value. Note, that these chunk parameters are the ones that have been added to the chunks (typically by a module) and may not have any direct significance to the model or modeler. For example, the declarative memory parameters of chunks used by the declarative module to compute and record the activation of chunks should be viewed using the declarative module's sdp command because the values shown with pprint-chunks-plus are values used internally by the declarative module and may not adequately reflect the current value of activations as would be shown by calling the module's command for doing so (sdp).

These commands return a list with the names of all the chunks that were printed in the same order as they were specified. If an invalid chunk-name is given nothing is printed for that item and the value **:error** is returned in its place in the list.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (pprint-chunks)
GREEN
  ISA COLOR

SPEECH
  ISA CHUNK

C
"this is chunk c"
  ISA VISUAL-LOCATION
   SCREEN-X  10
   SCREEN-Y  NIL
   DISTANCE  NIL
   KIND  NIL
   COLOR  NIL
   VALUE  NIL
   SIZE  NIL
   NEAREST  NIL
   OBJECTS  NIL
   USERPROP1  NIL
   USERPROP2  NIL
```

```
   USERPROP3  NIL
   USERPROP4  NIL

…

(GREEN SPEECH C ...)

> (pprint-chunks-fct '(a chunk-e c))
A
  ISA CHUNK

CHUNK-E
  ISA CHUNK

C
"this is chunk c"
  ISA VISUAL-LOCATION
   SCREEN-X  10
   SCREEN-Y  NIL
   DISTANCE  NIL
   KIND  NIL
   COLOR  NIL
   VALUE  NIL
   SIZE  NIL
   NEAREST  NIL
   OBJECTS  NIL
   USERPROP1  NIL
   USERPROP2  NIL
   USERPROP3  NIL
   USERPROP4  NIL

(A CHUNK-E C)

> (pprint-chunks-plus a visual-object0)
A
  ISA CHUNK

  --chunk parameters--
   SJIS  NIL
   PERMANENT-NOISE  0.0
   SIMILARITIES  NIL
   REFERENCE-COUNT  0
   REFERENCE-LIST  NIL
   SOURCE-SPREAD  0
   BASE-LEVEL  0
   CREATION-TIME  0
   FAN-LIST  (A)
   FAN  1
   ACTIVATION  0


VISUAL-OBJECT0
  ISA VISUAL-OBJECT
   SCREEN-POS  C
   VALUE  NIL
   STATUS  NIL
   COLOR  NIL
   HEIGHT  NIL
   WIDTH  NIL

  --chunk parameters--
   SJIS  NIL
   PERMANENT-NOISE  0.0
   SIMILARITIES  NIL
   REFERENCE-COUNT  0
   REFERENCE-LIST  NIL
   SOURCE-SPREAD  0
```

```
   BASE-LEVEL  0
   CREATION-TIME  0
   FAN-LIST  (VISUAL-OBJECT0)
   FAN  1
   ACTIVATION  0


(A VISUAL-OBJECT0)

E> (pprint-chunks b bad-name chunk-e)
B
  ISA SOUND
   KIND  NIL
   CONTENT  NIL
   EVENT  NIL

CHUNK-E
  ISA CHUNK

(B :ERROR CHUNK-E)

E> (pprint-chunks (a b))
#|Warning: pprint-chunks called with no current model. |#
NIL
```

chunk-p

Syntax:

chunk-p *chunk-name?* -> [**t** | **nil**]
chunk-p-fct *chunk-name?* -> [**t** | **nil**]

Arguments and Values:

chunk-name? ::= a symbol which is being tested to determine if it names a chunk

Description:

The chunk-p command returns **t** if chunk-name? is a symbol that names a chunk in the current model and returns **nil** if it does not. If there is no current model then a warning is printed and **nil** is returned.

Examples:

These examples assume that chunks named a and b have been created.

```
> (chunk-p a)
T

> (chunk-p not-chunk)
NIL

> (chunk-p-fct 'b)
T

E> (chunk-p-fct 'a)
#|Warning: get-chunk called with no current model. |#
NIL
```

chunk-chunk-type

Syntax:

chunk-chunk-type *chunk-name* -> [chunk-type-name | **nil**]
chunk-chunk-type-fct *chunk-name* -> [chunk-type-name | **nil**]

Arguments and Values:

chunk-name ::= a value which should be a symbol that names a chunk
chunk-type-name ::= a symbol which is the name of a chunk-type in the model

Description:

chunk-chunk-type returns the name of the chunk-type of the chunk chunk-name from the current model if it names a valid chunk. If chunk-name is not the name of a chunk in the current model or there is no current model then a warning is printed and **nil** is returned.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (chunk-chunk-type a)
CHUNK

> (chunk-chunk-type-fct 'c)
VISUAL-LOCATION

E> (chunk-chunk-type not-a-chunk)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (chunk-chunk-type a)
#|Warning: get-chunk called with no current model. |#
NIL
```

chunk-documentation

Syntax:

chunk-documentation *chunk-name* -> [doc-string | **nil**]
chunk-documentation-fct *chunk-name* -> [doc-string | **nil**]

Arguments and Values:

chunk-name ::= a value which should be a symbol that names a chunk
doc-string ::= a string of the documentation provided when chunk-name was created

Description:

chunk-documentation returns the documentation string of the chunk chunk-name from the current model if it names a valid chunk and has a documentation string. If it does not have a documentation string it returns **nil**. If chunk-name is not the name of a chunk in the current model or there is no current model then a warning is printed and **nil** is returned.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (chunk-documentation c)
"this is chunk c"

> (chunk-documentation a)
NIL

> (chunk-documentation-fct 'c)
"this is chunk c"

E> (chunk-documentation-fct 'not-a-chunk)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (chunk-documentation c)
#|Warning: get-chunk called with no current model. |#
NIL
```

chunk-slot-value

Syntax:

chunk-slot-value *chunk-name slot-name* -> [slot-value [**t** | **nil**] | **nil**]
chunk-slot-value-fct *chunk-name slot-name* -> [slot-value [**t** | **nil**] | **nil**]

Arguments and Values:

chunk-name ::= a symbol which should be the name of a chunk
slot-name ::= a symbol that should be the name of a slot in the chunk chunk-name
slot-value ::= the Lisp value from slot-name in chunk chunk-name

Description:

chunk-slot-value returns two values if chunk-name is the valid name of a chunk in the current model and slot-name is the name of a slot in the chunk-type of chunk-name. The first value is the value in the slot-name slot of the chunk chunk-name in the current model. The second value will be **t** if slot-value is not **nil**. If the slot is empty (has a value of **nil**) then the second value will be **nil** if the slot is empty because that is its default value and it will be **t** if slot-value is **nil** because it has been explicitly cleared. Effectively, the second value indicates whether the slot has ever been set to a value or if it has been empty from its creation.

If either parameter is invalid or there is no current model then a warning is printed and **nil** is the only value returned.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (chunk-slot-value c screen-x)
10
T

> (chunk-slot-value-fct 'c 'screen-y)
NIL
NIL

E> (chunk-slot-value-fct 'a 'not-a-slot-name)
#|Warning: chunk A does not have a slot called NOT-A-SLOT-NAME. |#
NIL

E> (chunk-slot-value not-a-chunk slot)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (chunk-slot-value c screen-x)
#|Warning: get-chunk called with no current model. |#
NIL
```

set-chunk-slot-value

Syntax:

set-chunk-slot-value *chunk-name slot-name slot-value* -> [slot-value | **nil**]
set-chunk-slot-value-fct *chunk-name slot-name slot-value* -> [slot-value | **nil**]

Arguments and Values:

chunk-name ::= a symbol which should be the name of a chunk
slot-name ::= a symbol that should be the name of a slot in the chunk chunk-name
slot-value ::= a Lisp value for slot-name in chunk chunk-name

Description:

set-chunk-slot-value is used to set the value of the slot slot-name in the chunk chunk-name in the current model to the value slot-value. If successful, slot-value is returned.

If slot-value is a symbol and not the name of a current chunk in the current model then it is created as a new chunk of chunk-type chunk and a warning is displayed.

If either chunk-name or slot-name is invalid or there is no current model then a warning is printed and **nil** is returned.

This command is not often used by modelers because the model's chunks are typically created and changed by the productions of the model as it runs. However, sometimes it is necessary to manipulate chunks outside of the model's control, and it can be important to those creating new modules for maintaining their internal chunks.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (set-chunk-slot-value c distance 35)
35

> (set-chunk-slot-value-fct 'b 'content "sound")
"sound"

> (set-chunk-slot-value b content new-slot-value)
#|Warning: Creating chunk NEW-SLOT-VALUE of default type chunk |#
NEW-SLOT-VALUE

E> (set-chunk-slot-value not-chunk slot value)
#|Warning: NOT-CHUNK does not name a chunk in the current model. |#
NIL

E> (set-chunk-slot-value-fct 'c 'bad-slot 100)
#|Warning: chunk C does not have a slot called BAD-SLOT. |#
NIL

E> (set-chunk-slot-value b content "value")
#|Warning: get-chunk called with no current model. |#
NIL
```

mod-chunk

Syntax:

mod-chunk *chunk-name* {*slot-name slot-value* }* -> [chunk-name | **nil**]
mod-chunk-fct *chunk-name* **(**{*slot-name slot-value* }***)** -> [chunk-name | **nil**]

Arguments and Values:

chunk-name ::= a symbol which should be the name of a chunk
slot-name ::= a symbol that should be the name of a slot in the chunk chunk-name
slot-value ::= a Lisp value for the corresponding slot-name in chunk chunk-name

Description:

mod-chunk is used to set the value of multiple slots in the chunk chunk-name of the current model. It is essentially a short hand for multiple calls to set-chunk-slot-value.

If chunk-name is the name of a chunk in the current model and there are an even number of items specified thereafter, then those items are considered pair-wise to be the name of a slot in that chunk and a new value for that slot. All of those slots in the chunk are set to the new values specified and chunk-name is returned.

Each slot name may only be specified once in the set of slot-names.

If any slot-value is a symbol and not the name of a chunk in the current model then it is created as a new chunk of chunk-type chunk and a warning is displayed.

If chunk-name does not name a chunk in the current model, there is no current model, there are an odd number of items provided after the chunk-name, or any of the slot names are invalid or duplicated then a warning is displayed, no changes are made, and **nil** is returned.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (mod-chunk c screen-x 20 screen-y 30)
C

> (mod-chunk-fct 'b '(content "sound" kind new-value))
#|Warning: Creating chunk NEW-VALUE of default type chunk |#
B

E> (mod-chunk-fct 'b '(event))
#|Warning: Odd length modifications list in call to mod-chunk. |#
NIL

E> (mod-chunk c non-slot 10)
#|Warning: Invalid slot name in modifications list. |#
NIL

E> (mod-chunk-fct 'non-chunk '(slot value))
#|Warning: NON-CHUNK does not name a chunk in the current model. |#
NIL

E> (mod-chunk c distance 30)
#|Warning: get-chunk called with no current model. |#
NIL
```

copy-chunk

Syntax:

copy-chunk *chunk-name* -> [new-name | **nil**]
copy-chunk-fct *chunk-name* -> [new-name | **nil**]

Arguments and Values:

chunk-name ::= a symbol which should be the name of a chunk
new-name ::= a symbol which will be a unique name for a new chunk

Description:

copy-chunk creates a copy of the chunk chunk-name in the current model and returns the name of the newly created chunk. The copy has the same chunk-type as chunk-name and the same values for all of its slots. The values of the parameters defined for the new chunk will have the default value unless the parameter was specified with a copy-function, in which case, the value will be the one returned by that function.

If chunk-name does not name a chunk in the current model or there is no current model then a warning is displayed and **nil** is returned.

Examples:

These examples assume that there are chunks named a and b in the current model.

```
> (copy-chunk b)
B-0

> (copy-chunk-fct 'a)
A-1

E> (copy-chunk not-a-chunk)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (copy-chunk b)
#|Warning: get-chunk called with no current model. |#
NIL
```

chunk-copied-from

Syntax:

chunk-copied-from *chunk-name* -> [original-name | **nil]**
chunk-copied-from-fct *chunk-name* -> [original-name | **nil]**

Arguments and Values:

chunk-name ::= a symbol which should be the name of a chunk
original-name ::= a symbol which is the name of a chunk

Description:

The chunk-copied-from command is used to return the name of the chunk from which the chunk chunk-name was created using the copy-chunk command. If chunk-name is the name of a chunk in the current model, it was created with copy-chunk, it has not been modified since its creation as a copy and the original chunk has not been modified such that it now differs from the copy (the original could have been modified but if it is still a match using equal-chunk it is still considered the same) then the name of the chunk from which chunk-name was copied is returned. If it was not created using copy-chunk, it has since been modified, or the original chunk has been modified in such a way that the two now differ then **nil** is returned.

If chunk-name does not name a chunk in the current model or there is no current model then a warning is displayed and **nil** is returned.

This command is rarely used by modelers because the model's chunks are typically created and changed by the productions of the model as it runs. However, sometimes it is necessary to manipulate chunks outside of the model's control. It can be important to those creating new modules where it can be used to determine if a chunk passed in as part of a request is a copy of a chunk which

the module had placed into a buffer i.e. the request is using a copy of a chunk for which the module has created the original.

Examples:

These examples assume that the copy-chunk examples have been executed and that a chunk named c exists.

```
> (chunk-copied-from b-0)
B

> (chunk-copied-from-fct 'a-1)
A

> (chunk-copied-from c)
NIL

E> (chunk-copied-from not-a-chunk)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (chunk-copied-from b-0)
#|Warning: get-chunk called with no current model. |#
NIL
```

chunks

Syntax:

chunks -> [**(**chunk-name***)** | **nil**]

Arguments and Values:

chunk-name ::= the name of a chunk in the current model

Description:

The chunks command returns a list of the names of all the chunks defined in the current model in no particular order.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

```
> (chunks)
(GREEN CYAN SPEECH C DARK-CYAN RED-COLOR B-0 OVAL ...)

E> (chunks)
#|Warning: chunks called with no current model. |#
NIL
```

delete-chunk

Syntax:

delete-chunk *chunk-name* -> [chunk-name | **nil**]
delete-chunk-fct *chunk-name* -> [chunk-name | **nil**]

Arguments and Values:

chunk-name ::= a symbol that should be the name of a chunk

Description:

delete-chunk removes the chunk named chunk-name from the set of chunks in the current model. If chunk-name is the name of a chunk in the current model then after that chunk is deleted chunk-name is returned.

If chunk-name does not name a chunk in the current model or there is no current model then a warning is printed and **nil** is returned.

Note: there is no additional clean-up done in conjunction with deleting the chunk. Thus, if it is used as a slot value in another chunk or currently residing in a buffer undefined consequences could arise. delete-chunk should be used rarely and only when it is certain that the chunk being deleted is not referenced elsewhere.

Examples:

These examples assume that chunks named b-0 and a-1 exist.

```
> (delete-chunk b-0)
B-0

1> (delete-chunk-fct 'a-1)
A-1

2E> (delete-chunk a-1)
#|Warning: A-1 does not name a chunk in the current model. |#
NIL

E> (delete-chunk b)
#|Warning: get-chunk called with no current model. |#
NIL
```

purge-chunk

Syntax:

purge-chunk *chunk-name* -> [**t** | **nil**]
purge-chunk-fct *chunk-name* -> [**t** | **nil**]

Arguments and Values:

chunk-name ::= a symbol that should be the name of a chunk

Description:

Purge-chunk removes the chunk named chunk-name from the set of chunks in the current model using delete-chunk and releases the name of that chunk using the release-name command as described under the naming module. If chunk-name is the name of a chunk in the current model and its name was released then **t** is returned.

If chunk-name does not name a chunk in the current model or there is no current model then a warning is printed and **nil** is returned.

If the chunk is deleted, but the name is not released **nil** is returned without a warning being printed.

As with delete-chunk, there is no additional clean-up done in conjunction with purging the chunk. Thus, if it is used as a slot value in another chunk or currently residing in a buffer undefined consequences could arise.

Because purge-chunk also attempts to unintern the name of the chunk it should only be used for chunks for which the name was automatically generated by the system or explicitly generated with new-name. This is not going to be a command used by most modelers. However, in situations where (computer) memory usage is important in long running models or models which generate a lot of temporary chunks explicitly freeing some of that space may be necessary.

Examples:

```
1> (define-chunks (c1 isa chunk)
                  (isa chunk))
(C1 CHUNK0)

2> (purge-chunk chunk0)
T

3> (purge-chunk-fct 'c1)
NIL

E> (purge-chunk bad-name)
#|Warning: BAD-NAME does not name a chunk in the current model. |#
NIL

E> (purge-chunk-fct 'free)
#|Warning: get-chunk called with no current model. |#
#|Warning: get-chunk called with no current model. |#
NIL
```

merge-chunks

Syntax:

merge-chunks *chunk-name-1 chunk-name-2* -> [chunk-name-1 | **nil**]
merge-chunks-fct *chunk-name-1 chunk-name-2* -> [chunk-name-1 | **nil**]

Arguments and Values:

chunk-name-1 ::= a symbol that should be the name of a chunk
chunk-name-2 ::= a symbol that should be the name of a chunk

Description:

If the chunks named by chunk-name-1 and chunk-name-2 are of the same chunk-type and have all of the same values for their slots, then both chunks are replaced by a single chunk. See equal-chunks below for a more thorough definition of what it means for two chunks to have the same values for their slots – the named chunks must return **t** if passed to equal-chunks in order to be merged. Effectively, the two chunks are merged into one chunk. The "true name" of the merged chunk will be chunk-name-1, but references to either name will still be valid.

If the chunks are merged, then any additional chunk parameters that have been added to the chunks will remain those that existed for chunk-name-1 unless there is a merge-function defined for the parameter.

If either chunk is later deleted, both of the chunks will become unavailable i.e. deleting any one of a set of merged chunks deletes all of those merged chunks.

If the chunks have already been merged previously, then no actions are taken and chunk-name-1 is returned.

If the chunks are successfully merged, then chunk-name-1 is returned.

If the chunks do not match on chunk-type or any slot value then no merging occurs and **nil** is returned.

If either name does not name a chunk in the current model or there is no current model then a warning is displayed and **nil** is returned.

The merge-chunks command is primarily for use by the declarative memory module, and it is not expected to be used elsewhere but is available if one finds such a need. As with delete-chunk, it should be used carefully to avoid circumstances were chunks to which other modules already have references are merged which could result in unexpected consequences.

Examples:

These examples assume that the chunks created in the examples for define-chunks exist.

```
> (merge-chunks a a-1)
A

> (merge-chunks-fct 'a 'chunk-e)
A

> (merge-chunks a b)
NIL

E> (merge-chunks not-a-chunk a)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (merge-chunks b b-0)
#|Warning: get-chunk called with no current model. |#
#|Warning: get-chunk called with no current model. |#
NIL
```

create-chunk-alias

Syntax:

create-chunk-alias *chunk-name alias* -> [alias | **nil**]
create-chunk-alias-fct *chunk-name alias* -> [alias | **nil**]

Arguments and Values:

chunk-name ::= a symbol that should be the name of a chunk
alias ::= a symbol that should not be the name of a chunk

Description:

If the chunk specified by chunk-name exists in the current model and the symbol provided as alias is not the name of a chunk in the current model then alias will be created as a reference to the chunk chunk-name. This works essentially the same as if a chunk named alias had been merged with the chunk chunk-name.

If the alias is successfully created, then alias is returned.

If chunk-name does not name a chunk in the current model, alias is not a symbol, alias is already the name of a chunk in the model, or there is no current model then a warning is displayed and **nil** is returned.

Examples:

```
1> (chunk-type test slot)
TEST

2> (define-chunks (a isa test slot a)
                  (b isa test slot b)
                  (c isa test slot c))
(A B C)
```

```
3> (create-chunk-alias a new-a)
NEW-A

4> (pprint-chunks new-a)
NEW-A (A)
  ISA TEST
   SLOT  A

(NEW-A)

5> (create-chunk-alias-fct 'b 'my-b)
MY-B

6E> (create-chunk-alias c my-b)
#|Warning: MY-B is already the name of a chunk in the current model and cannot be used as
an alias. |#
NIL

E> (create-chunk-alias-fct 'not-a-chunk 'new-d)
#|Warning: NOT-A-CHUNK is not the name of a chunk in the current model. |#
NIL

E> (create-chunk-alias x new-x)
#|Warning: create-chunk-alias called with no current model. |#
NIL
```

true-chunk-name

Syntax:

true-chunk-name *chunk-name* -> [true-name | chunk-name]
true-chunk-name-fct *chunk-name* -> [true-name | chunk-name]

Arguments and Values:

chunk-name ::= a Lisp value
true-name ::= a symbol that is the name of a chunk in the current model

Description:

true-chunk-name is used to find the "true name" of a chunk. The true name of a chunk which has not been merged with another chunk is its own name. The true name of a chunk that has been merged with another chunk is the true name of the chunk that was returned from a merging of that chunk with another.

If chunk-name is the name of a chunk in the current model then its true name is returned. If chunk-name is any other value, then chunk-name is returned.

If there is no current model then a warning is printed and chunk-name is returned.

Examples:

```
1> (define-chunks (x1 isa chunk)
```

```
                 (x2 isa chunk)
                 (x3 isa chunk))
(X1 X2 X3)

2> (true-chunk-name x1)
X1

3> (true-chunk-name-fct 'x2)
X2

4> (merge-chunks x2 x1)
X2

5> (true-chunk-name x1)
X2

6> (true-chunk-name x2)
X2

7> (merge-chunks x3 x2)
X3

8> (true-chunk-name-fct 'x1)
X3

9> (true-chunk-name-fct 'x2)
X3

10> (pprint-chunks x1 x2 x3)
X1 (X3)
  ISA CHUNK

X2 (X3)
  ISA CHUNK

X3
  ISA CHUNK

(X1 X2 X3)

> (true-chunk-name "not-a-chunk")
"not-a-chunk"

> (true-chunk-name-fct 'not-a-chunk)
NOT-A-CHUNK

E> (true-chunk-name a)
#|Warning: get-chunk called with no current model. |#
A
```

eq-chunks

Syntax:

eq-chunks *chunk-name-1 chunk-name-2* -> equal-result
eq-chunks-fct *chunk-name-1 chunk-name-2* -> equal-result

Arguments and Values:

chunk-name-1 ::= a symbol that should be the name of a chunk
chunk-name-2 ::= a symbol that should be the name of a chunk

equal-result ::= a generalized boolean indicating whether the chunks are the same

Description:

Eq-chunks is used to determine if the chunks named by chunk-name-1 and chunk-name-2 are the exact same chunk in the current model. They will be the same chunk if chunk-name-1 and chunk-name-2 are the same symbol or if the two named chunks have been merged. If they are the same chunk, then a true value is returned. Otherwise, **nil** will be returned.

If either name does not name a chunk or there is no current model, then a warning is printed and **nil** is returned.

Examples:

```
1> (define-chunks (c1 isa chunk)
                  (c2 isa chunk)
                  (c3 isa visual-location screen-x 10)
                  (c4 isa visual-location screen-x 10)
                  (c5 isa visual-location screen-x 20))
(C1 C2 C3 C4 C5)

2> (eq-chunks c1 c1)
T

3> (eq-chunks c1 c2)
NIL

4> (merge-chunks c1 c2)
C1

5> (eq-chunks-fct 'c1 'c2)
T

> (eq-chunks-fct 'c3 'c4)
NIL

> (eq-chunks c3 c5)
NIL

E> (eq-chunks not-a-chunk x1)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (eq-chunks-fct 'x1 'x2)
#|Warning: get-chunk called with no current model. |#
#|Warning: get-chunk called with no current model. |#
NIL
```

equal-chunks

equal-chunks *chunk-name-1 chunk-name-2* -> equal-result
equal-chunks-fct *chunk-name-1 chunk-name-2* -> equal-result

Arguments and Values:

chunk-name-1 ::= a symbol that should be the name of a chunk
chunk-name-2 ::= a symbol that should be the name of a chunk
equal-result ::= a generalized boolean indicating whether the chunks are equal

Description:

The equal-chunks command can be used to determine if the chunks named by chunk-name-1 and chunk-name-2 are equivalent chunks in the current model. They will be equivalent if they are eq-chunks (as described above) or if they have the same chunk-type and for all of the slots in that chunk-type the values of those slots in the two chunks are the same as determined by the chunk-slot-equal function. If the two chunks are equivalent, then a true value is returned. Otherwise, **nil** will be returned.

If either name does not name a chunk or there is no current model, then a warning is printed and **nil** is returned.

Examples:

```
1> (define-chunks (c1 isa chunk)
                  (c2 isa chunk)
                  (c3 isa visual-location screen-x 10)
                  (c4 isa visual-location screen-x 10)
                  (c5 isa visual-location screen-x 20))
(C1 C2 C3 C4 C5)

2> (equal-chunks c1 c2)
T

3> (equal-chunks c2 c3)
NIL

4> (equal-chunks-fct 'c3 'c4)
T

5> (equal-chunks-fct 'c4 'c5)
NIL

E> (equal-chunks not-a-chunk a)
#|Warning: NOT-A-CHUNK does not name a chunk in the current model. |#
NIL

E> (equal-chunks c1 c2)
#|Warning: get-chunk called with no current model. |#
#|Warning: get-chunk called with no current model. |#
NIL
```

chunk-slot-equal

chunk-slot-equal *val-1 val-2* -> equal-result

Arguments and Values:

val-1 ::= any value

val-2 ::= any value
equal-result ::= a generalized boolean indicating whether the chunks are equal

Description:

The chunk-slot-equal command is used to determine if two values are considered equivalent as the contents of slots in chunks. The values will be equivalent if one of the following is true:

- the values are eq
- both values are symbols which name chunks in the current model and those chunks return true from eq-chunks
- both values are strings and those strings return true from string-equal
- if the values are not both chunk names or not both strings and they return true from equalp

If the two values are equivalent, then a true value is returned. Otherwise, **nil** will be returned.

Examples:

```
> (chunk-slot-equal 1 1)
T
> (chunk-slot-equal 1 1.5)
NIL
> (chunk-slot-equal "String1" "strING1")
T
> (chunk-slot-equal 'not-a-chunk 'not-a-chunk)
T
> (chunk-slot-equal 'not-a-chunk :not-a-chunk)
NIL

1> (define-chunks (c1 isa chunk)
                  (c2 isa chunk))
(C1 C2)
2> (chunk-slot-equal 'c1 'c2)
NIL
3> (merge-chunks c1 c2)
C1
4> (chunk-slot-equal 'c1 'c2)
T
```

normalize-chunk-names

normalize-chunk-names { *unintern* } -> **nil**

Arguments and Values:

unintern ::= a generalized boolean indicating whether to delete the merged chunks and release the names

Description:

The normalize-chunk-names command will iterate through all chunks in the current model and replace all chunk references in slots with the true name of that chunk. That may be useful for

debugging purposes and the naming module has a parameter (:ncnar) which can trigger this call automatically.

In addition, if the unintern parameter is true then all chunks which have been merged with other chunks (those for which their name is not the chunk's true name) will be deleted from the model and the chunk name will be released using release-name.

The command will always return **nil**. If there is no current model, then a warning will be printed indicating that.

Notes: This command may take a long time to run if the model has a large number of chunks. Also, the unintern option is generally not recommended because it may cause problems for modules which have stored internal references to those temporary names. However, in some extreme circumstances (a very long continuous run or a model which does a lot of buffer manipulations over a long run) a model can generate so many chunk name symbols than it can become unable to continue running (the Lisp heap or the physical memory of the machine is exhausted) thus calling normalize-chunk-names periodically with the unintern option would be necessary to continue running. If you are encountering such situations, please let me know about it because there may be other options or changes that could be made to the underlying system.

Examples:

To show the command in use, there must be a chunk which has been merged with another and also used in a slot value.

```
1> (chunk-type goal previous next)
GOAL
2> (define-chunks (g1 isa goal previous nil next g2)
                  (g2 isa goal previous g1 next nil))
(G1 G2)
3> (copy-chunk g1)
G1-0
4> (set-chunk-slot-value g2 next g1-0)
G1-0
5> (merge-chunks g1 g1-0)
G1
6> (pprint-chunks)
…

G2
  ISA GOAL
   PREVIOUS  G1
   NEXT  G1-0

G1-0 (G1)
  ISA GOAL
   PREVIOUS  NIL
   NEXT  G2

G1
  ISA GOAL
   PREVIOUS  NIL
   NEXT  G2
```

```
(… G2 G1-0 G1)
```

Now, here are the results of calling normalize-chunk-names after that both with and without the unintern parameter:

```
7> (normalize-chunk-names t)
NIL
8> (pprint-chunks)

…

G2
  ISA GOAL
   PREVIOUS  G1
   NEXT  G1

G1
  ISA GOAL
   PREVIOUS  NIL
   NEXT  G2

(… G2 G1)


7> (normalize-chunk-names)
NIL
8> (pprint-chunks)
…

G2
  ISA GOAL
   PREVIOUS  G1
   NEXT  G1

G1-0 (G1)
  ISA GOAL
   PREVIOUS  NIL
   NEXT  G2

G1
  ISA GOAL
   PREVIOUS  NIL
   NEXT  G2

(… G2 G1-0 G1)


E> (normalize-chunk-names)
#|Warning: No current model in which to normalize chunk names. |#
NIL
```

Special Chunk Functions

There are three additional functions which can be used, but should be done so with extreme care: fast-chunk-slot-value-fct, fast-set-chunk-slot-value-fct, and fast-mod-chunk-fct. They are each equivalent to the corresponding function without the “fast-” prefix. However, the “fast” versions do not do any of the validity checks on the slot-names in order to save time. Thus, if they are passed invalid slot-names they may still set such values and thus make the chunk invalid with respect to its chunk-type (this is not the same as the provided mechanism for extending a chunk described in the

dynamic pattern matching section of the procedural module). These commands should only be used when the values have been verified before making the call via some other means and when the time required for the duplicate testing is unacceptable.

General Parameters

General parameters are the primary means of configuring the operation of ACT-R both from a usability standpoint and at the level of controlling the performance of a model. They can be used to control how much output is shown when a model runs or to adjust how long it takes a model to retrieve a chunk from its declarative memory as well as many other things. Each module in the system can make available any number of general parameters that are relevant to its operation. The specific parameters of each module will be described in that module's section. In this section, the common aspects of those parameters will be described along with the command that is used to set or show them.

The general parameters are each referenced by a name which is a Lisp keyword e.g. :v or :trace-detail, and can be set to some value which is meaningful to the module that owns the parameter. Each one has a default value specified by the owning module and often there are limits as to what values can be given to a particular parameter. Attempting to set an invalid value will result in a warning and no change in the parameter. In most cases the parameters are independent between models i.e. two concurrent models could have different values for the same general parameter. However, there can be exceptions to that. For example, a module that allows models to connect to some external simulation might provide parameters to specify where to connect to that simulation, but may require that all models connect to the same simulation. None of the provided modules operate that way, but it is worth noting that modules could be added which have parameters that are linked between models.

One final thing to note about general parameters is that it is possible for modules other than the parameter's owning module to monitor the parameter setting and possibly modify the parameter. The details of doing that are covered in the module creation sections. Because of that one should be aware that it is possible for parameters to start with values other than their specified default after a model is reset or to be set to a value different than one the user requests if a monitoring module changes it. An example of the first situation (a starting value other than the default) exists in the main ACT-R system with the :do-not-harvest parameter. The procedural module owns that parameter and specifies a default value of **nil**, but the goal module will change that parameter at reset time to include the goal buffer. It is also the case that if one starts the ACT-R Environment then several of the tracing and hook parameters will be set automatically to values which allow the Environment to operate. There are no modules in the provided set which modify the values a user specifies, but an example where such a situation could be used might be a module which provides support for modeling alertness or sleepiness. It could automatically adjust the parameters that a user specifies for controlling other modules to take into account the current alertness setting. Of course it does not have to work that way, but it is a possibility which modelers and module writers should know about.

Commands

sgp

Syntax:

sgp {[*param-name** | *param-value-pair**]} -> [**nil** | ([param-value | **:bad-parameter-name** | **:invalid-value**]*)]
sgp-fct ({[*param-name** | *param-value-pair**]}**)** -> [**nil** | ([param-value | **:bad-parameter-name** | **:invalid-value**]*)]

Arguments and Values:

param-name ::= a keyword which names a parameter
param-value-pair ::= *param-name new-param-value*
new-param-value ::= a Lisp value to which the preceding param-name is to be set
param-value ::= the current value of a param-name

Description:

sgp is used to set or get the value of the parameters from the modules of the current model.

If no parameters are provided, all of the current model's parameters are printed to the model's command output stream. They are organized alphabetically by module name and by parameter name within a module and **nil** is returned. For each parameter, its name and current value is printed followed by the default value and any documentation provided by the module that owns the parameter.

If all of the parameters passed to sgp are keywords, then it is a request for the current values of those general parameters named in the current model. Those parameters are printed and a list of their values in the order requested is returned. If any of the names are not of valid parameters then a warning is displayed and the keyword :bad-parameter-name is returned for that position in the list. Note: because the test to determine that a call to sgp is a request for parameter values is that all the values passed to sgp are keywords, a module should never have a parameter accept a keyword as a possible value because it will not be possible to set such a parameter value on its own.

If there are any non-keyword parameters in the call to sgp and the total number of elements is even, then they are assumed to be pairs of a parameter name and a parameter value. Each of those parameter values will be passed to the corresponding parameter's owning module and all monitoring modules. The return value will be the current settings of those parameters in the order given (the values may or may not be the same as the values passed in to set them depending on the module) unless a parameter value was not of the appropriate type as required by the module. In that case, a warning is printed and the value returned in that position will be the keyword :invalid-value.

If there are non-keywords passed to sgp and the number of items is odd, or if there is no current model at the time of the call, then a warning is displayed and **nil** is returned.

Examples:

```
> (sgp)
--------------------------------
:AUDIO module
--------------------------------
:DIGIT-DETECT-DELAY 0.3   default: 0.3   : Lag between onset and detectability for digits
:DIGIT-DURATION     0.6   default: 0.6   : Default duration for digit sounds.
:DIGIT-RECODE-DELAY 0.5   default: 0.5   : Recoding delay for digit sound content.
:HEAR-NEWEST-ONLY   NIL   default: NIL   : Whether to stuff only the newest unattended
audio-event from the audicon into the aural-location buffer.
:SOUND-DECAY-TIME   3.0   default: 3.0   : The amount of time after a sound has finished
it takes for the sound to be deleted from the audicon
:TONE-DETECT-DELAY  0.05  default: 0.05  : Lag between sound onset and detectability for
tones
:TONE-RECODE-DELAY  0.285 default: 0.285 : Recoding delay for tone sound content.
--------------------------------
BOLD module
--------------------------------
...


> (sgp :v :lf)
:V T (default T) : Verbose controls model output
:LF 1.0 (default 1.0) : Latency Factor
(T 1.0)

> (sgp-fct '(:v nil :lf 4.5))
(NIL 4.5)

E> (sgp-fct '(:v t :lf nil))
#|Warning: Parameter :LF cannot take value NIL because it must be a positive number. |#
(T :INVALID-VALUE)

E> (sgp :not-a-parameter 10)
#|Warning: Parameter :NOT-A-PARAMETER is not the name of an available parameter |#
(:BAD-PARAMETER-NAME)

E> (sgp :esc t :v)
#|Warning: Odd number of parameters and values passed to sgp. |#
NIL

E> (sgp)
#|Warning: sgp called with no current model. |#
NIL
```

get-parameter-default-value

Syntax:

get-parameter-default-value *param-name* -> [param-default | **:bad-parameter-name**]

Arguments and Values:

param-name ::= a keyword which should name a parameter
param-default ::= the default value specified for param-name when it was defined

Description:

The get-parameter-default-value command is used to get the default value that a parameter was given when it was defined. If param-name is the name of a general parameter then the default value specified for that parameter is returned. If param-name does not name a general parameter then a warning is printed and **:bad-parameter-name** is returned.

Examples:

```
> (get-parameter-default-value :v)
T

E> (get-parameter-default-value :not-a-param)
#|Warning: Invalid parameter name :NOT-A-PARAM in call to get-parameter-default-value. |#
:BAD-PARAMETER-NAME
```

with-parameters

Syntax:

with-parameters *parameter-list form** -> [result | **nil**]
with-parameters-fct *parameter-list form** -> [result | **nil**]

Arguments and Values:

parameter-list ::= ({*param-name value*}*)
param-name ::= a keyword which should name a parameter
value ::= a Lisp value to which the preceding parameter should temporarily be set
form ::= a valid Lisp expression to evaluate
result ::= the value returned from the last form evaluated

Description:

The with-parameters commands are used to temporarily set some parameters in the current model of the current meta-process and then execute some commands. If all of the param-name values provided name valid parameters then each will be set to the corresponding value given before executing the forms. After those forms have been evaluated each of those parameters will be set back to the value it had previously and the result of the last form evaluated will be returned. The forms are evaluated in an unwind-protect so that the restoring of the parameters occurs even if the forms result in an error.

If any of the param-name values do not name a valid parameter or there is no current model or current meta-process then a warning will be printed, the forms will not be evaluated, and **nil** is returned.

The difference between with-parameters and with-parameters-fct is not quite the same as it is for other commands. In this case both are macros, but with-parameters-fct evaluates the items on the parameter-list and with-parameters does not. Thus the parameter-list for with-parameters will look

similar to what one would provide to sgp whereas the parameter-list for with-parameters-fct may contain expressions and variables which need to be evaluated.

Examples:

This example sequence assumes that the count model from unit 1 of the tutorial is loaded.

```
1> (reset)
DEFAULT
2> (run .05)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   PROCEDURAL            PRODUCTION-SELECTED START
     0.000   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL            PRODUCTION-FIRED START
     0.050   PROCEDURAL            MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL            MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.050   DECLARATIVE           START-RETRIEVAL
     0.050   PROCEDURAL            CONFLICT-RESOLUTION
     0.050   ------                Stopped because time limit reached
0.05
13
NIL
3> (with-parameters (:v nil)
     (run .05))
0.05
8
NIL
4> (with-parameters-fct (:trace-detail 'low)
     (run .05))
     0.150   PROCEDURAL            PRODUCTION-FIRED INCREMENT
2
     0.150   ------                Stopped because time limit reached
0.05
6
NIL
5> (run .05)
     0.200   DECLARATIVE           RETRIEVED-CHUNK D
     0.200   DECLARATIVE           SET-BUFFER-CHUNK RETRIEVAL D
     0.200   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   PROCEDURAL            PRODUCTION-SELECTED INCREMENT
     0.200   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.200   PROCEDURAL            BUFFER-READ-ACTION RETRIEVAL
     0.200   ------                Stopped because time limit reached
0.05
7
NIL

E> (with-parameters (:not-valid 10)
     (run .05))
#|Warning: :NOT-VALID is not the name of a parameter. with-parameters body ignored. |#
NIL

E> (with-parameters-fct (:v)
     (run .05))
#|Warning: Odd length parameters list in call to with-parameters. The body is ignored. |#
NIL

E> (with-parameters (:v t)
     (run 1))
#|Warning: with-parameters called with no current model. |#
NIL
```

Printing and output

Many of the commands in ACT-R result in output being printed. There is a printing module which can be used to control where and when certain things are printed, and that is described in detail in a separate section. For now the general aspects of the output will be described as well as the commands that are used to generate the output.

There are three basic types of output that ACT-R generates: model output, command output, and warnings. They are generated by different output functions described below and it is up to module writers to use the appropriate ones for any output which they create so as to conform to what is expected.

Model Output

Model output is essentially all the things that are printed by a running model. The trace of the model is considered model output as are various internal module specific traces and notices. The default is to send the model output to the Lisp stream *standard-output*, but there is a parameter available which allows one to send the output elsewhere or disable it.

Command Output

Command output is what gets printed when one calls one of the ACT-R commands, for example the parameter listing when one calls sgp. By default this is also sent to the *standard-output* stream, and it is controlled by a separate parameter from model output. Thus, one could have model output going one place and command output going elsewhere if desired. Often, one does not need or want the printed output from an ACT-R command because only the returned value is important. In those situations, there is a command that can be used to temporarily disable command output.

Warnings

Warnings from ACT-R are always enclosed inside of a Lisp comment block (between the characters #| and |#) and start with "Warning:". The reason they are inside a comment block is so they do not create a problem if someone is using Lisp to read an output file generated by a model trace which might contain warnings. It also distinguishes them from any other warnings that may occur within the Lisp. There are two general classes of warnings, each created with a different command. The first is referred to as model warnings. These are things like "undefined chunk FOO being created of default type chunk." They inform the modeler of something that was assumed or may be unusual within a model. They are generally just hints or suggestions and can often be ignored. In fact, there is a parameter switch to actually suppress such warnings if desired (though if the model is not working as one would expect turning the model warnings back on and reading them carefully is probably a good first thing to look at). The other type is just referred to as a warning, and is generated when a command receives invalid parameters or a more serious issue has occurred e.g. the "… called with no current model" warning. These are usually more important issues and cannot be turned off with a

simple switch. Warnings are sent to the Lisp stream *error-output* and model warnings are sent to the stream *error-output* as well as to the current model's model output stream if it differs from *error-output*.

Below are the commands that are used by the system for outputting information and which are available for use if one wants their model or experiments using ACT-R to print in the ways described above. Those adding new modules to the system should use the appropriate commands for any output that their module generates.

Commands

model-output

Syntax:

model-output *control-string* {*args**} -> **nil**

Arguments and Values:

control-string ::= a Lisp format control (a format string or function as returned by the formatter macro)
args ::= arguments as required by the control-string provided

Description:

model-output is used to print output to the current model's model output stream, which defaults to *standard-output* and is controlled by the printing module. It passes the provided control-string and args to format for output followed by a new line if model output is enabled for the current model. It does not test the control-string or args for correctness, so any problems will likely trigger an error or warning from the format function.

If there is no current model a warning is printed.

It always returns **nil**.

Examples:

```
> (model-output "This is ~A the ACT-R ~d model-output command" "output from" 6)
This is output from the ACT-R 6 model-output command
NIL

E> (model-output "This is ~A the ACT-R ~d model-output command" "output from" 6)
#|Warning: get-module called with no current model. |#
NIL
```

meta-p-output

Syntax:

meta-p-output *control-string* {*args**} -> **nil**

Arguments and Values:

control-string ::= a Lisp format control (a format string or function as returned by the formatter macro)
args ::= arguments as required by the control-string provided

Description:

meta-p-output is used to print output to all of the models in the current meta-process. It uses each model's model output stream as if model-output were used, but only prints once to a given stream in the event that more than one model is using the same stream for model output. It does not test the control-string or args for correctness, so any problems will likely trigger an error or warning from the format function.

If there is no current meta-process a warning is printed.

It always returns **nil**.

meta-p-output is currently used for actually printing the trace because there can be multiple models running concurrently. It is not likely that users or module writers will have need for meta-p-output because it is above the level of a model or module, but it is described because its results are seen when using simultaneous multiple models.

One thing to note about meta-p-output is that it will evaluate the args separately for each stream to which the output is written. If there are no output streams (all models have :v set to nil for example) then the args are not evaluated. Thus, if there are any actions with side effects in the args the results could differ when the number of streams to which output is written changes.

Examples:

```
> (meta-p-output "This is from ~s" "meta-p-output")
This is from "meta-p-output"
NIL

E> (meta-p-output "This is from ~s" "meta-p-output")
#|Warning: No current meta-process in call to meta-p-output |#
NIL
```

command-output

Syntax:

command-output *control-string* {*args**} -> **nil**

Arguments and Values:

control-string ::= a Lisp format control (a format string or function as returned by the formatter macro)
args ::= arguments as required by the control-string provided

Description:

command-output is used to print output to the current model's command output stream, which defaults to *standard-output* and is controlled by the printing module. It passes the provided control-string and args to format for output followed by a new line if command output is enabled for the current model. It does not test the control-string or args for correctness, so any problems will likely trigger an error or warning from the format function.

If there is no current model a warning is printed.

It always returns **nil**.

Command-output is generally for use by things that print in response to being called outside of a model run, like the display of parameters from sgp or the chunk printing from pprint-chunks and can be turned off by the modeler using a parameter or the no-output command.

Examples:

```
> (command-output "A command-output ~s" 'example)
A command-output EXAMPLE
NIL

> (command-output "A command-output ~s" 'example)
#|Warning: get-module called with no current model. |#
NIL
```

no-output

Syntax:

no-output {*forms**} -> [result | **nil**]

Arguments and Values:

forms ::= a Lisp form to evaluate
result ::= the return value from the last form evaluated

Description:

no-output is used to disable the command output stream of the current model while evaluating the forms provided. It returns the value returned by the last form evaluated.

If there is no current model a warning is printed and **nil** is returned.

no-output can be useful if one wants to get the results from some other ACT-R command without having to see any of its output and without needing to explicitly disable and then possibly re-enable the command output parameter.

Examples:

```
> (no-output (pprint-chunks ))
(EXTERNAL LIGHT-GRAY INTERNAL DIGIT CURRENT FULL FREE BLACK ...)

> (no-output (sgp-fct '(:v :lf)))
(T 1.0)

E> (no-output (sgp-fct '(:v :lf)))
#|Warning: get-module called with no current model. |#
NIL
```

capture-model-output

Syntax:

capture-model-output {*forms**} -> [output-string | **nil**]

Arguments and Values:

forms ::= a Lisp form to evaluate
result ::= a string containing all the model output generated by the forms

Description:

Capture-model-output is used to save a model's output to a string and return it. It sets both the :v and :cmdt parameters to a string-output stream before evaluating the forms provided. After evaluating the forms those parameters are returned to the values they had when the command started. It returns the string generated by the string-output stream.

If there is no current model a warning is printed and **nil** is returned.

Examples:

```
> (capture-model-output (pprint-chunks free busy))
"FREE
  ISA CHUNK

BUSY
  ISA CHUNK

"

> (capture-model-output (model-output "Model...") (command-output "Command..."))
"Model...
Command...
"
```

```
E> (capture-model-output (pprint-chunks))
#|Warning: get-module called with no current model. |#
NIL
```

print-warning

Syntax:

print-warning *control-string* {*args**} -> [result | **nil**]

Arguments and Values:

control-string ::= a Lisp format control (a format string or function as returned by the formatter macro)
args ::= arguments as required by the control-string provided
result ::= a string containing the output

Description:

print-warning is used to print a warning message to *error-output*. It passes the provided control-string and args to format for output after printing "#| Warning:" and followed by "|#" and a new line. It does not test the control-string or args for correctness, so any problems will likely trigger an error or warning from the format function.

If *error-output* is **nil** then the output string from the call to format is returned, otherwise it returns **nil**.

print-warning is generally for use in printing notices of problems or errors that occurred within a module or command.

Examples:

```
> (print-warning "This is a warning from ACT-R ~a" "!!")
#|Warning: This is a warning from ACT-R !! |#
NIL
```

model-warning

Syntax:

model-warning *control-string* {*args**} -> **nil**

Arguments and Values:

control-string ::= a Lisp format control (a format string or function as returned by the formatter macro)
args ::= arguments as required by the control-string provided

Description:

model-warning is used to print a warning to the current model's model output stream and to *standard-error* if it is a different stream. It passes the provided control-string and args to format for output after printing "#| Warning:" and followed by "|#" and a new line if model output is enabled for the current model and model-warnings are not disabled. It does not test the control-string or args for correctness, so any problems will likely trigger an error or warning from the format function.

If there is no current model a warning is printed. If there is more than one model currently defined then the warning will also include the name of the model in which the warning was generated.

It always returns **nil**.

Model-warning is generally for use when the model causes a problem within a module or a less serious situation has occurred which the modeler might want to be informed about but may often be safely ignore.

Examples:

```
> (model-warning "This may not be what you wanted: ~s" 'bad-value)
#|Warning: This may not be what you wanted: BAD-VALUE |#
NIL

> (with-model bar (model-warning "There is more than one model defined."))
#|Warning (in model BAR): There is more than one model defined. |#
NIL

E> (model-warning "This may not be what you wanted: ~s" 'bad-value)
#|Warning: get-module called with no current model. |#
NIL
```

suppress-warnings

Syntax:

suppress-warnings {*form**} -> result

Arguments and Values:

form ::= a Lisp form to evaluate
result ::= the return value from the last form evaluated

Description:

Suppress-warnings is used to turn off all ACT-R warnings which would normally be shown while evaluating the forms provided. It returns the value returned by the last form evaluated.

Note: suppress-warnings may also stop the output of Lisp warnings and errors because it binds ***error-output*** to a null stream during the evaluation of the forms. Because of that, suppress-warnings is only recommended for use in situations where one is certain that the code is correct and the warnings can be ignored.

Examples:

```
1> (progn (add-dm (a isa visual-object value b)) (sgp :lf .5))
#|Warning: Creating chunk B of default type chunk |#
#|Warning: Changing declarative parameters with chunks in dm not supported. |#
#|Warning: Results may not be what one expects. |#
(0.5)

2> (reset)
DEFAULT

3> (suppress-warnings (add-dm (a isa visual-object value b)) (sgp :lf .5))
(0.5)
```

Running the system

Running the system means executing the events that are on the queue of the current meta-process. Those events may lead to other events being scheduled and that will continue until the condition specified for the command used to run the system is met. There are several commands for running the system which specify various stopping conditions as well as allowing users to specify arbitrary end conditions.

The system can run in either a simulated time frame where the events are processed as fast as possible or in "real time" where the execution of the events is synchronized with the passing of time from some other source. Generally, real time is associated with the actual passage of time and the model is constrained to that, but it is possible to synchronize it with other external time sources and that is covered in another section. For now, we will focus mostly on simulated time running.

When running in simulated time the time stamps on the events control the advancement of the clock in the meta-process. When a meta-process is created or whenever it is reset the current time is set to 0.0. The event with the lowest time stamp is always the next one executed and if that time is greater than the current time the clock is updated. This allows the system to run much faster than real time for most models. The important thing to remember is that the timing of the events is produced by the modules which instantiate the ACT-R theory and thus the predictions do not depend on how the model is run or the source of the clock.

An important thing to note is that it is a meta-process which is run. All of the models that are included in that meta-process will be running simultaneously. The same commands are used to run the system regardless of how many models or meta-processes are defined.

Commands

run

Syntax:

run *run-time* {**:real-time** *real-time?*} -> [**nil** | time-passed event-count break?]

Arguments and Values:

run-time ::= a number greater than 0 indicating the number of seconds to run
real-time? ::= a generalized boolean to indicate whether to run in real time (default is **nil**)
time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run will run the current meta-process until there are either no events remaining to execute, run-time seconds have passed, or a break event is executed. If the real-time? keyword parameter is provided with a non-**nil** value then the model will be run in real time.

If run-time is not a number greater than 0, or there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model during this run. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

This is the primary function used for running the system and the one you are most likely to encounter when looking at model files.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
> (run 10)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     …
     0.300   PROCEDURAL           CLEAR-BUFFER GOAL
     0.300   PROCEDURAL           CONFLICT-RESOLUTION
     0.300   ------               Stopped because no events left to process
0.3
46
NIL

> (run .1 :real-time t)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL           PRODUCTION-FIRED START
     0.050   PROCEDURAL           MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL           MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL           CLEAR-BUFFER RETRIEVAL
     0.050   DECLARATIVE          START-RETRIEVAL
     0.050   PROCEDURAL           CONFLICT-RESOLUTION
     0.100   DECLARATIVE          RETRIEVED-CHUNK C
     0.100   DECLARATIVE          SET-BUFFER-CHUNK RETRIEVAL C
     0.100   PROCEDURAL           CONFLICT-RESOLUTION
     0.100   PROCEDURAL           PRODUCTION-SELECTED INCREMENT
     0.100   PROCEDURAL           BUFFER-READ-ACTION GOAL
     0.100   PROCEDURAL           BUFFER-READ-ACTION RETRIEVAL
     0.100   ------               Stopped because time limit reached
0.1
19
```

```
NIL

> (run 10)
     0.000   GOAL                    SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
     0.000   PROCEDURAL              PRODUCTION-SELECTED START
     0.000   PROCEDURAL              BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL              PRODUCTION-FIRED START
     0.050   PROCEDURAL              MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL              MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL              CLEAR-BUFFER RETRIEVAL
     0.050   DECLARATIVE             START-RETRIEVAL
     0.050   PROCEDURAL              CONFLICT-RESOLUTION
     0.075   ------                  BREAK-EVENT
0.075
13
T

E> (run 0)
#|Warning: run-time must be a number greater than zero. |#
NIL

E> (run 'foo)
#|Warning: run-time must be a number greater than zero. |#
NIL

E> (run 10)
#|Warning: run called with no current meta-process. |#
NIL
```

run-full-time

Syntax:

run-full-time *run-time* {**:real-time** *real-time?*} -> [**nil** | time-passed event-count break?]

Arguments and Values:

run-time ::= a number greater than 0 indicating the number of seconds to run
real-time? ::= a generalized boolean to indicate whether to run in real time (default is **nil**)
time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run-full-time will run the current meta-process until either run-time seconds have passed or a break event is executed. This differs from the run command because unless there is a break event run-full-time will always run for the full run-time specified. If the real-time? keyword parameter is provided with a non-**nil** value then the model will be run in real time.

If run-time is not a number greater than 0, or there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run-full-time will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

This is also a commonly used function for running models and it is useful when fixed time sequences are desired.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
> (run-full-time 1.0)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
  …
     0.300   PROCEDURAL           CONFLICT-RESOLUTION
     1.000   ------               Stopped because time limit reached
1.0
47
NIL

> (run-full-time 2.0)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL           PRODUCTION-FIRED START
…
     0.300   PROCEDURAL           CLEAR-BUFFER GOAL
     0.300   PROCEDURAL           CONFLICT-RESOLUTION
     0.550   ------               BREAK-EVENT
0.55
47
T

E> (run-full-time -1)
#|Warning: run-time must be a number greater than zero. |#
NIL

E> (run-full-time "2.0")
#|Warning: run-time must be a number greater than zero. |#
NIL

E> (run-full-time 1.0)
#|Warning: run-full-time called with no current meta-process. |#
NIL
```

run-until-time

Syntax:

run-until-time *end-time* {**:real-time** *real-time?*} -> [**nil** | time-passed event-count break?]

Arguments and Values:

end-time ::= a number greater than 0 indicating the explicit time at which the run should stop
real-time? ::= a generalized boolean to indicate whether to run in real time (default is **nil**)
time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run-until-time will run the current meta-process until either the specified end-time is reached (including if the current time is greater than the specified time) or a break event is executed. This differs from the run and run-full-time commands because an explicit time is specified instead of a duration time. If the real-time? keyword parameter is provided with a non-**nil** value then the model will be run in real time.

If end-time is not a number greater than 0, or there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run-until-time will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
1> (run-until-time .125)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL           PRODUCTION-FIRED START
     0.050   PROCEDURAL           MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL           MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL           CLEAR-BUFFER RETRIEVAL
     0.050   DECLARATIVE          START-RETRIEVAL
     0.050   PROCEDURAL           CONFLICT-RESOLUTION
     0.100   DECLARATIVE          RETRIEVED-CHUNK C
     0.100   DECLARATIVE          SET-BUFFER-CHUNK RETRIEVAL C
```

```
     0.100   PROCEDURAL            CONFLICT-RESOLUTION
     0.100   PROCEDURAL            PRODUCTION-SELECTED INCREMENT
     0.100   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.100   PROCEDURAL            BUFFER-READ-ACTION RETRIEVAL
     0.125   ------                Stopped because time limit reached
0.125
20
NIL

2> (run-until-time .100)
     0.125   ------                Stopped because end time already passed
0
0
NIL

3> (run-until-time 10.0)
     0.150   PROCEDURAL            PRODUCTION-FIRED INCREMENT
2
     0.150   PROCEDURAL            MOD-BUFFER-CHUNK GOAL
     0.150   PROCEDURAL            MODULE-REQUEST RETRIEVAL
     0.150   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.150   DECLARATIVE           START-RETRIEVAL
  …
     0.300   PROCEDURAL            CONFLICT-RESOLUTION
    10.000   ------                Stopped because time limit reached
9.875
28
NIL

> (run-until-time .5)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   PROCEDURAL            PRODUCTION-SELECTED START
     0.000   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL            PRODUCTION-FIRED START
     0.050   PROCEDURAL            MOD-BUFFER-CHUNK GOAL
  …
     0.150   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   ------                BREAK-EVENT
0.2
26
T

E> (run-until-time -10)
#|Warning: end-time must be a number greater than zero. |#
NIL

E> (run-until-time 1)
#|Warning: run-until-time called with no current meta-process. |#
NIL
```

run-until-condition

Syntax:

run-until-condition *condition* {**:real-time** *real-time?*} -> [**nil** | time-passed event-count break?]

Arguments and Values:

condition ::= a function or the name of a function that takes no parameters
real-time? ::= a generalized boolean to indicate whether to run in real time (default is **nil**)

time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run-until-condition will run the current meta-process until either the provided condition function returns non-**nil**, there are no events left to process, or a break event is executed. The condition function will be called before every event is executed and as soon as it returns non-**nil** the run is terminated. If the real-time? keyword parameter is provided with a non-**nil** value then the model will be run in real time.

If condition is not a function or the name of a function, or there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run-until-condition will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
> (run-until-condition (lambda () nil))
     0.000   GOAL                    SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
     0.000   PROCEDURAL              PRODUCTION-SELECTED START
…
     0.300   PROCEDURAL              CLEAR-BUFFER GOAL
     0.300   PROCEDURAL              CONFLICT-RESOLUTION
     0.300   ------                  Stopped because no events to process
0.3
46
NIL

> (run-until-condition (lambda () nil))
     0.000   GOAL                    SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
     0.000   PROCEDURAL              PRODUCTION-SELECTED START
     0.000   PROCEDURAL              BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL              PRODUCTION-FIRED START
  …
     0.250   PROCEDURAL              PRODUCTION-SELECTED STOP
     0.250   PROCEDURAL              BUFFER-READ-ACTION GOAL
     0.275   ------                  BREAK-EVENT
```

```
0.275
42
T

1> (defvar *count* 0)
*COUNT*

2> (defun stop-at-10 ()
       (> (incf *count*) 10))
STOP-AT-10

3> (run-until-condition 'stop-at-10)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   PROCEDURAL            PRODUCTION-SELECTED START
     0.000   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL            PRODUCTION-FIRED START
     0.050   PROCEDURAL            MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL            MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.050   ------                Stopped because condition is true
0.05
10
NIL

E> (run-until-condition "not-a-function")
#|Warning: condition must be a function. |#
NIL

E> (run-until-condition (lambda () nil))
#|Warning: run-until-condition called with no current meta-process. |#
NIL
```

run-n-events

Syntax:

run-n-events *num-events* {**:real-time** *real-time?*} -> [**nil** | time-passed event-count break?]

Arguments and Values:

num-events ::= a number greater than 0 indicating the number of events to run
real-time? ::= a generalized boolean to indicate whether to run in real time (default is **nil**)
time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run-n-events will run the current meta-process until either num-events events have been processed, there are no events remaining, or a break event is executed. If the real-time? keyword parameter is provided with a non-**nil** value then the model will be run in real time.

If num-events is not a number greater than 0, or there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run-n-events will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
> (run-n-events 10)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
     0.050   PROCEDURAL           PRODUCTION-FIRED START
     0.050   PROCEDURAL           MOD-BUFFER-CHUNK GOAL
     0.050   PROCEDURAL           MODULE-REQUEST RETRIEVAL
     0.050   PROCEDURAL           CLEAR-BUFFER RETRIEVAL
     0.050   ------               Stopped because event limit reached
0.05
10
NIL

> (run-n-events 100)
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
  …
     0.300   PROCEDURAL           CLEAR-BUFFER GOAL
     0.300   PROCEDURAL           CONFLICT-RESOLUTION
     0.300   ------               Stopped because no events to process
0.3
46
NIL

E> (run-n-events 'a)
#|Warning: event-count must be a number greater than zero. |#
NIL

E> (run-n-events 10)
#|Warning: run-n-events called with no current meta-process. |#
NIL
```

run-step

Syntax:

run-step -> [**nil** | time-passed event-count break?]

Arguments and Values:

time-passed ::= a number indicating the number of seconds in model time which passed during the run
event-count ::= a number indicating how many events were executed during this run
break? ::= [**t** | **nil**] indicating whether the run terminated due to a break event

Description:

run-step will run the current meta-process one event at a time. For each event a summary of the event is printed to *standard-output* and the user is prompted to respond as to whether that event should be executed, deleted, or the run terminated. The user can also show various debugging information before deciding what to do with the current event. The response is read from *standard-input* and should be one of the characters "e" for execute, "d" for delete, "a" for abort or "q" for quit ("a" and "q" have the same effect) for determining how to handle the event or "s" for showing the current event queue, "w" to show the events on the waiting queue, or "b" to show the current buffer contents for the debugging information. It will continue to run the model until the user requests it to stop, there are no events remaining, or a break event is executed. Using run-step cannot run the model in real time.

If there is no current meta-process then a warning is printed and **nil** is returned.

If there is a meta-process to run, then when one of the end conditions has been met, run-step will output a line in the trace to indicate which condition terminated the run and it will return three values.

The first value is the number of seconds that passed for the model. The second is a count of the number of events that were executed (which could be greater than the number of lines shown in the trace because some events may have no output), and the last indicates whether or not the trial was terminated by a break event. If it was, then the third value will be **t** otherwise it will be **nil**.

run-step can be a useful function for debugging a model because it allows one to walk through the events one at a time and stop to inspect the state of the system before or after any one.

Examples:

For this example the count model from unit 1 of the ACT-R tutorial is the only model that is loaded.

```
> CG-USER(76): (run-step)
Next Event:  0.000   GOAL         SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
[A]bort (or [q]uit)
[D]elete
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
e

     0.000   GOAL                   SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
Next Event:  0.000   PROCEDURAL             CONFLICT-RESOLUTION
[A]bort (or [q]uit)
[D]elete
```

```
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
s
Events in the queue:
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   GOAL                  #<Function CLEAR-DELAYED-GOAL>
Next Event:  0.000   PROCEDURAL            CONFLICT-RESOLUTION
[A]bort (or [q]uit)
[D]elete
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
w
Events waiting to be scheduled:
Next Event:  0.000   PROCEDURAL            CONFLICT-RESOLUTION
[A]bort (or [q]uit)
[D]elete
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
b

RETRIEVAL: empty
IMAGINAL: empty
MANUAL: empty
GOAL:
FIRST-GOAL-0
  ISA COUNT-FROM
   START  2
   END  4
   COUNT  NIL

IMAGINAL-ACTION: empty
VOCAL: empty
AURAL: empty
PRODUCTION: empty
VISUAL-LOCATION: empty
AURAL-LOCATION: empty
VISUAL: empty
Next Event:  0.000   PROCEDURAL            CONFLICT-RESOLUTION
[A]bort (or [q]uit)
[D]elete
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
e

     0.000   PROCEDURAL            CONFLICT-RESOLUTION
Next Event:  0.000   PROCEDURAL            PRODUCTION-SELECTED START
[A]bort (or [q]uit)
[D]elete
[S]how event queue
[W]aiting events
[B]uffer contents
[E]xecute
e

     0.000   PROCEDURAL            PRODUCTION-SELECTED START
Next Event:  0.000   PROCEDURAL            START
[A]bort (or [q]uit)
[D]elete
[S]how event queue
```

```
[W]aiting events
[B]uffer contents
[E]xecute
q

     0.000   ------                 Stepping stopped
0.0
3
NIL

E> (run-step)
#|Warning: run-step called with no current meta-process. |#
NIL
```

Scheduling Events

The event system that drives ACT-R models is also available to the modeler for use in writing experiments or "driver code" for the models. In fact, because ACT-R relies on the events to trigger actions such as conflict-resolution, this is the preferred mechanism for creating experiments or making other run-time changes. It is also essential when adding new modules to schedule events to affect any changes which the module has on buffers as well as when changing its internal state or affecting outside actions.

When writing experiments for a model, one useful approach is to have the model's actions trigger the events that make changes in such a way that one only needs to call one of the ACT-R "run" functions to execute both the model and the task. That has the benefit of not introducing any discrepancies into the model timing relative to the task and also allows for the task to be run using the provided stepping tools or continued after a break in the model. That is not always practical for a simple model/task and often one may want to use a run, stop, change, run again style. When using the run-stop style, it is still important to schedule any direct effects that one makes to buffers or chunks so that the model properly notes the changes.

In general, most of the module commands will schedule some event as a response, but many of the general commands which perform similar actions may not. For example, mod-chunk (being a general command) does not generate an event, but mod-focus (a command specific to the goal module) does.

Details of events

Each event has several attributes associated with it that are specified when the event is created with one of the scheduling functions provided. Most of the time the user will not need to work with the events directly, but there are some situations where access to the details of an event may be useful (for instance the event hooks allow one to add functions which see each event before or after it is executed). Here are the attributes which an event has

time - The simulation time at which the event will occur. All times are rounded to the millisecond when the event is created.

priority - When multiple events are scheduled to occur at the same time they are ordered by their priorities. The priority is either a number or one of the keywords **:max** or **:min**. An event with a priority of **:max** will occur before any event at the same time which has a priority other than **:max**. An event with a priority of **:min** will occur after any event at the same time which has a priority other than **:min**. An event with a numeric priority will be executed before any other events at the same time which have a lower numeric priority i.e. numeric priorities are ordered from highest to lowest with no bounds on the numbers given.

Events which have both the same time and same priority do not have any guarantee as to ordering.

action - The function that will be called when this event is executed.

parameters - The list of values which will be passed to the action function when the event is executed.

model - The name of the model in which the event was generated.

module - The name of the module which generated the event or the keyword **:none** if no module was specified when the event was created.

destination - If this action is to be sent *to* a specific module, then that module's name can be given as the destination and the instance of that module will be passed as the first parameter to the action. Using this is can be simpler and more informative than just making the instance of the module the first element in the parameters list.

details - The details can be a string which will be output in the trace for the event. If details are specified that is all that is printed after the time, model and module. If the details are not specified then the action and parameters are printed in the trace.

output - The output controls under which trace-detail levels the event will be displayed. It can have a value of **t**, **high, medium**, **low**, or **nil**. A value of **t** or **high** means it will be displayed only for the high trace detail setting and **nil** means not to show it at all. **Medium** means that it should be shown under both medium and high trace details and a value of **low** means it will be shown for any trace detail setting. The output value effectively specifies the lowest detail setting for which the output will be displayed.

The specific implementation of an event is not part of the API for ACT-R (one should not assume anything about the structure or object that is returned as an event). To get at the detailed information a set of accessors are provided. Because all of the accessors operate the same way they are all presented in one description. Note that the accessors are not intended to be used to change a value of an event only to read the value that it has - even though the specific implementation may allow one to use them with setf to change a value that is not a recommended practice and could result in unexpected consequences within the model.

Event Accessors

Syntax:

evt-time *event* -> time
evt-priority *event* -> priority
evt-action *event* -> action
evt-params *event* -> parameters
evt-model *event* -> model
evt-module *event* -> module
evt-destination *event* -> destination

evt-details *event* -> details
evt-output *event* -> output

Arguments and Values:

event ::= an ACT-R event
time, priority, action, parameters, model, module, destination, details, output ::= the corresponding attribute of event

Description:

Each of the event accessors returns the corresponding attribute from the event specified. There is no error checking to make sure that event is a valid ACT-R event. If it is not a valid event, then a Lisp error is likely to occur with the current implementation of events.

Examples:

```
> (let ((event (schedule-event 30 'model-output :params '("some text"))))
               (format t "~S~%" (evt-time event))
               (format t "~S~%" (evt-action event))
               (format t "~S~%" (evt-module event))
               (format t "~S~%" (evt-params event)))
30.0
MODEL-OUTPUT
:NONE
("some text")
NIL

E> (evt-time 'not-an-event)
Error: Non-structure argument NOT-AN-EVENT passed to ref of structure
       slot 1
[condition type: SIMPLE-ERROR]
```

General Event Commands

format-event

Syntax:

format-event *event* -> [event-string | **nil**]

Arguments and Values:

event ::= an ACT-R event
event-string ::= a string that contains the text that would be printed for this event during a trace

Description:

format-event can be used to get a string with the representation of what the provided event will look like in the trace when it is executed. If event is not a valid ACT-R event then **nil** is returned.

This would likely be used with some sort of stepping tool or data logger which was tied into the event hooks to be able to record or display the event independently of the trace.

Examples:

```
> (let ((event (schedule-event 30 'model-output :params '("some text"))))
               (format-event event))

"    30.000   NONE                   MODEL-OUTPUT some text "

E> (format-event 'not-an-event)
NIL
```

event-displayed-p

Syntax:

event-displayed-p *event* -> [**t** | **nil**]

Arguments and Values:

event ::= an ACT-R event

Description:

event-displayed-p can be used to determine whether or not an event would be printed given the current setting of the trace detail parameter and any potential trace filter settings of the model in which the event was generated. If event would be printed with the current settings of that model's parameters, then **t** is returned and if not then **nil** is returned. If event is not an ACT-R event then **nil** is returned.

This command might be useful when working with the event hooks or for developing an interactive stepper or tracing tool.

Examples:

```
> (let ((event (schedule-event 30 'model-output :params '("some text") :output 'medium)))
    (no-output (sgp :trace-detail high))
    (format t "trace-detail high output medium: ~S~%" (event-displayed-p event))
    (no-output (sgp :trace-detail medium))
    (format t "trace-detail medium output medium: ~S~%" (event-displayed-p event))
    (no-output (sgp :trace-detail low))
    (format t "trace-detail low output medium: ~S~%" (event-displayed-p event)))

trace-detail high output medium: T
trace-detail medium output medium: T
trace-detail low output medium: NIL
NIL

E> (event-displayed-p 'not-an-event)
NIL
```

Scheduling Commands

Events can be generated using a variety of scheduling functions described here, as well as automatically by certain module commands. There are three different types of events that can be generated: normal (or model events), maintenance events, and break events. Model events are things that are generated by the "cognitive" modules or outside actions which the model may need to detect (in particular, the conflict resolution mechanism of the procedural module is sensitive only to model events). Maintenance events are generated by the non-theory parts of the system or things which are not of importance to the model (for instance an event which signals the time at what a particular run is going to stop). Practically, the only difference between model and maintenance events is in whether events that are waiting to be scheduled consider any event or only model events (they are generated with the same functions). The break events are a special type of maintenance event in that whenever a break event is executed the current run is terminated. Break events are generated with a separate set of functions because they do not perform any actions.

When an event's action is executed the current model will be set to the model which generated the event (if there is one). When working with a single model that does not make a difference, but in the context of multiple models it means that the action function does not need to use with-model or make any explicit checks to ensure that it is working in the proper context.

schedule-event

Syntax:

schedule-event *time action* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

time ::= a number representing an absolute time for the event in seconds or milliseconds
action ::= a function name or function which specifies the action to be evaluated
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:module** *module-value* |
:destination *destination-value* |
:priority *priority-value* |
:params *params-value* |
:time-in-ms *time-units* |
:maintenance *maintenance-value* |
:details *details-value* |
:output *output-value*]
module-value ::= a symbol which names the module which is scheduling the event (default **:none**)
destination-value ::= a symbol which names a module (default **nil**)
priority-value ::= [**:max** | **:min** | a number] (default 0)
params-value ::= a list of values to pass to the action (default **nil**)
time-units ::= a generalized boolean indicating whether the time value is seconds or milliseconds (default is **nil**)
maintenance-value ::= generalized boolean indicating whether this is a maintenance event (default **nil**)

details-value ::= a string to output in the trace or **nil** (default **nil**)
output-value ::= [**t** | **high** | **medium** | **low** | **nil**] (default **t**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-event creates a new event using the supplied parameters for its corresponding attributes and the current model will be used for its model. It will then be added to the event queue of the current meta-process to occur at the specific time provided and the event will be returned.

If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled.

If any of the parameters are invalid or there is no current model or current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

Examples:

```
>(schedule-event 10 'goal-focus-fct :priority :min :params '(new-goal-chunk) :output nil)
#S(ACT-R-EVENT ...)

> (schedule-event 45 (lambda (module) (do-something module)) :maintenance t :destination
:some-module :details "Do Something")
#S(ACT-R-MAINTENANCE-EVENT ...)

> (mp-show-queue)
Events in the queue:
    10.000   NONE                  GOAL-FOCUS NEW-GOAL-CHUNK
    45.000   NONE                  Do Something

E> (schedule-event 'bad-time (lambda ()))
#|Warning: Time must be non-negative number. |#
NIL

E> (schedule-event 0 'bad-function-name)
#|Warning: Can't schedule BAD-FUNCTION-NAME not a function or function name. |#
NIL

E> (schedule-event 10 'goal-focus :priority :min :params '(new-goal-chunk) :output nil)
#|Warning: Can't schedule GOAL-FOCUS because it is a macro and not a function. |#
NIL

E> (schedule-event 0 (lambda ()) :priority 'value)
#|Warning: Priority must be a number or :min or :max. |#
NIL

E> (schedule-event 0 (lambda (x)) :params 10)
#|Warning: params must be a list. |#
NIL

E> (schedule-event 0 'pprint)
#|Warning: schedule-event called with no current model. |#
NIL
```

schedule-event-relative

Syntax:

schedule-event-relative *delta-time action* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

delta-time ::= a number representing how many seconds or milliseconds to delay before executing the event
action ::= a function name or function which specifies the action to be evaluated
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:module** *module-value* |
:destination *destination-value* |
:priority *priority-value* |
:params *params-value* |
:time-in-ms *time-units* |
:maintenance *maintenance-value* |
:details *details-value* |
:output *output-value*]
module-value ::= a symbol which names the module which is scheduling the event (default **:none**)
destination-value ::= a symbol which names a module (default **nil**)
priority-value ::= [**:max** | **:min** | a number] (default 0)
params-value ::= a list of values to pass to the action (default **nil**)
time-units ::= a generalized boolean indicating whether the time value is seconds or milliseconds (default is **nil**)
maintenance-value ::= generalized boolean indicating whether this is a maintenance event (default **nil**)
details-value ::= a string to output in the trace or **nil** (default **nil**)
output-value ::= [**t** | **high** | **medium** | **low** | **nil**] (default **t**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-event-relative creates a new event using the supplied parameters for its corresponding attributes and the current model will be used for its model. It will then be added to the event queue of the current meta-process to occur delta-time seconds (or milliseconds if :time-in-ms is specified as true) from the current time and the event will be returned.

If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled.

If any of the parameters are invalid or there is no current model or current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

Examples:

see schedule-event for related examples

schedule-event-after-module

Syntax:

schedule-event-after-module *after-module action* {*event-descriptors*} -> [actr-event | **nil**] [**t** | **nil** | **:abort**]

Arguments and Values:

after-module ::= a symbol which names a module
action ::= a function name or function which specifies the action to be evaluated
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:module** *module-value* |
:destination *destination-value* |
:params *params-value* |
:maintenance *maintenance-value* |
:details *details-value* |
:output *output-value* |
:delay *delay-value* |
:include-maintenance *include-maintenance-value* |
:dynamic *dynamic-value*]
module-value ::= a symbol which names the module which is scheduling the event (default **:none**)
destination-value ::= a symbol which names a module (default **nil**)
params-value ::= a list of values to pass to the action (default **nil**)
maintenance-value ::= generalized boolean indicating whether this is a maintenance event (default **nil**)
details-value ::= a string to output in the trace or **nil** (default **nil**)
output-value ::= [**t** | **high** | **medium** | **low** | **nil**] (default **t**)
delay-value ::= [**t** | **nil** | **:abort**] (default **t**)
include-maintenance-value ::= a generalized boolean indicating whether to consider maintenance events when determining whether to schedule this event (default **nil**)
dynamic-value ::= generalized boolean indicating whether to allow rescheduling under real time mode (default **nil**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-event-after-module creates a new event using the supplied parameters for its corresponding attributes and the current model for its model.

If there is an event currently in the event queue with the module name of after-module and the same model as the current model and either include-maintenance-value is **t** or the event is not a maintenance event, then this new event is placed into the event queue at the time of the next such matching event (lowest time) with a priority of **:min**. If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled.

If there is no event in the event queue that matches on model, module and of the appropriate type, then the value of delay-value determines what happens to the new event.

If delay-value is **t** then the new event is placed into the set of waiting events to be scheduled after an event which matches the conditions necessary to schedule this new event.

If delay-value is **nil** then the new event is added to the event queue for immediate execution. Its time will be set to the current time and its priority will be **:max**.

If delay-value is **:abort** then the new event is discarded without being scheduled or placed onto the waiting queue.

The setting of dynamic-value does not matter under normal circumstances, but may be useful if a custom clock is provided for real time operations. See the Configuring Real Time Operations section for details of how it works.

schedule-event-after-module returns two values. If there is no current model or current meta-process or any of the parameters are invalid, then no event is scheduled and both values are **nil**.

If an event is scheduled then the first value will be the event and the second value will be **t** if the event is in the waiting queue or **nil** if it is in the event queue.

If the event is aborted, the first value will be **nil** and the second value will be **:abort**.

Examples:

```
1> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
1

2> (schedule-event-after-module 'procedural (lambda ()) :details "has a matching event")
#S(ACT-R-EVENT …)
NIL

3> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   NONE                   has a matching event
2

4> (schedule-event-after-module :vision (lambda ()) :details "no event so wait" :delay t)
#S(ACT-R-EVENT …)
T

5> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   NONE                   has a matching event
2

6> (mp-show-waiting)
```

```
Events waiting to be scheduled:
       NIL   NONE                  no event so wait Waiting for: (MODULE VISION NIL)
1

7> (schedule-event-after-module :motor (lambda ()) :details "no event so go now" :delay
nil)
#S(ACT-R-EVENT …)
NIL
> (mp-show-queue)
Events in the queue:
     0.000   NONE                  no event so go now
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   NONE                  has a matching event
3

8> (schedule-event-after-module :audio (lambda ()) :details "aborted" :delay :abort)
NIL
:ABORT

E> (schedule-event-after-module 'bad-module-name (lambda ()))
#|Warning: after-module must name a module. |#
NIL
NIL
```

schedule-event-after-change

Syntax:

schedule-event-after-change *action* {*event-descriptors*} -> [actr-event | **nil**] [**t** | **nil** | **:abort**]

Arguments and Values:

action ::= a function name or function which specifies the action to be evaluated
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:module** *module-value* |
:destination *destination-value* |
:params *params-value* |
:maintenance *maintenance-value* |
:details *details-value* |
:output *output-value*|
:delay *delay-value* |
:include-maintenance *include-maintenance-value* |
:dynamic *dynamic-value*]
module-value ::= a symbol which names the module which is scheduling the event (default **:none**)
destination-value ::= a symbol which names a module (default **nil**)
priority-value ::= [**:max** | **:min** | a number] (default 0)
params-value ::= a list of values to pass to the action (default **nil**)
maintenance-value ::= generalized boolean indicating whether this is a maintenance event (default **nil**)
details-value ::= a string to output in the trace or **nil** (default **nil**)
output-value ::= [**t** | **high** | **medium** | **low** | **nil**] (default **t**)
delay-value ::= [**t** | **nil** | **:abort**] (default **t**)
include-maintenance-value ::= a generalized boolean indicating whether to consider maintenance events when determining when to schedule this event (default **nil**)
dynamic-value ::= generalized boolean indicating whether to allow rescheduling under real time mode

(default **nil**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-event-after-change creates a new event using the supplied parameters for its corresponding attributes and the current model for its model.

If there is any event currently in the event queue with the same model as the current model and either include-maintenance-value is **t** or the event is not a maintenance event, then this new event is placed into the event queue at the time of the next such matching event (lowest time) with a priority of **:min**. If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled.

If there is no event in the event queue that matches on model and is of the appropriate type, then the value of delay-value determines what happens to the new event.

If delay-value is **t** then the new event is placed into the set of waiting events to be scheduled after an event which matches the conditions necessary to schedule this new event.

If delay-value is **nil** then the new event is added to the event queue for immediate execution. Its time will be set to the current time and its priority will be **:max**.

If delay-value is **:abort** then the new event is discarded without being scheduled or placed onto the waiting queue.

The setting of dynamic-value does not matter under normal circumstances, but may be useful if a custom clock is provided for real time operations. See the Configuring Real Time Operations section for details of how it works.

schedule-event-after-change returns two values. If there is no current model or current meta-process or any of the parameters are invalid, then no event is scheduled and both values are **nil**. If an event is scheduled then the first value will be the event and the second value will be **t** if the event is in the waiting queue or **nil** if it is in the event queue. If the event is aborted, the first value will be **nil** and the second value will be **:abort**.

Examples:

see schedule-even-after-module for related examples

schedule-periodic-event

Syntax:

schedule-periodic-event *period action* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

period ::= a number indicating how many seconds or milliseconds after which this action should be evaluated again
action ::= a function name or function which specifies the action to be evaluated
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:module** *module-value* |
:destination *destination-value* |
:priority *priority-value* |
:params *params-value* |
:time-in-ms *time-units* |
:maintenance *maintenance-value* |
:details *details-value* |
:output *output-value*|
:initial-delay initial-delay-value]
module-value ::= a symbol which names the module which is scheduling the event (default **:none**)
destination-value ::= a symbol which names a module (default **nil**)
priority-value ::= [**:max** | **:min** | a number] (default 0)
params-value ::= a list of values to pass to the action (default **nil**)
time-units ::= a generalized boolean indicating whether the time value is seconds or milliseconds (default is **nil**)
maintenance-value ::= generalized boolean indicating whether this is a maintenance event (default **nil**)
details-value ::= a string to output in the trace or **nil** (default **nil**)
output-value ::= [**t** | **high** | **medium** | **low** | **nil**] (default **t**)
initial-delay-value ::= a number indicating how many seconds or milliseconds before the first such event (default 0)
actr-event ::= the actual event used by the meta-process

Description:

schedule-periodic-event creates a new event with a time that is equal to the current time plus initial-delay and using the other supplied parameters for its corresponding attributes and the current model for its model which is then added to the event queue of the current meta-process. After that event occurs a new event will automatically be scheduled to occur period seconds (or milliseconds if :time-in-ms is specified as true) after that time with the same parameters as the initial one. That rescheduling will continue every period seconds (or milliseconds) until the event this function returned is deleted.

If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled, and every time that it is rescheduled there will be a check of the waiting events.

If any of the parameters are invalid or there is no current model or current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

The scheduled event is returned when successfully created and scheduled.

Note that there are actually two events generated for each occurrence of the event described. The first is a maintenance event with the priority provided. It schedules the actual event described with the parameters specified with a priority of **:max** (so that it should be the next event to execute) and also schedules the next periodic event at the appropriate delay.

Examples:

```
1> (schedule-periodic-event 1 (lambda ()
                                (model-output "Periodic event"))
                              :initial-delay .5)
#S(ACT-R-PERIODIC-EVENT :TIME 0.5 …)

2> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.500   NONE                   Periodic-Action Unnamed function 1
2

3> (run 3)
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
Periodic event
     0.500   PROCEDURAL             CONFLICT-RESOLUTION
Periodic event
     1.500   PROCEDURAL             CONFLICT-RESOLUTION
Periodic event
     2.500   PROCEDURAL             CONFLICT-RESOLUTION
     3.000   ------                 Stopped because time limit reached
3
10
NIL

E> (schedule-periodic-event 'a (lambda ()))
#|Warning: period must be greater than 0. |#
NIL
```

schedule-break

Syntax:

schedule-break *time* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

time ::= a number representing an absolute time for the event in seconds
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:details** *details-value* | **:priority** *priority-value*]
details-value ::= a string to output in the trace or **nil** (defaults to **nil**)
priority-value ::= [**:max** | **:min** | a number] (defaults to **:max**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-break creates a new break event at the specified time with the priority-value and details-value provided. The model of the event will be **nil** (a break event does not need to exist within a specific model), the module is set to :none, and the output for that event is set to low. A break event does not have an action and is only used to stop the scheduler. That new event is then added to the event queue of the current meta-process.

If any of the parameters are invalid or there is no current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

The scheduled event is returned when successfully created and scheduled.

Examples:

```
1> (schedule-break 12.5 :details "Stop the system now")
#S(ACT-R-BREAK-EVENT …)

2> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
    12.500   ------                BREAK-EVENT Stop the system now
2

E> (schedule-break 'bad-time)
#|Warning: Time must be non-negative number. |#
NIL

E> (schedule-break 10 :priority 'bad-priority)
#|Warning: Priority must be a number or :min or :max. |#
NIL

E> (schedule-break 10)
#|Warning: schedule-break called with no current meta-process. |#
NIL
```

schedule-break-relative

Syntax:

schedule-break-relative *delta-time* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

delta-time ::= a number representing how many seconds to delay before executing the event
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:details** *details-value* | **:priority** *priority-value*]
details-value ::= a string to output in the trace or **nil** (defaults to **nil**)
priority-value ::= [**:max** | **:min** | a number] (defaults to **:max**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-break-relative creates a new break event delta-time seconds from the current time with the priority-value and details-value provided. The model of the event will be **nil** (a break event does not need to exist within a specific model), the module is set to :none, and the output for that event is set to low. A break event does not have an action and is only used to stop the scheduler. That new event is then added to the event queue of the current meta-process.

If any of the parameters are invalid or there is no current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

The scheduled event is returned when successfully created and scheduled.

Examples:

see schedule-break for related examples

schedule-break-after-module

Syntax:

schedule-break-after-module *after-module* {*event-descriptors*} -> [actr-event | **nil**]

Arguments and Values:

after-module ::= a symbol which names a module
event-descriptors ::= 0 or 1 instance of each possible event-key-value-pair
event-key-value-pair ::= [**:details** *details-value* | **:delay** *delay-value* | **:dynamic** *dynamic-value*]
details-value ::= a string to output in the trace or **nil** (defaults to **nil**)
delay-value ::= [**t** | **nil** | **:abort**] (defaults to **t**)
dynamic-value ::= generalized boolean indicating whether to allow rescheduling under real time mode (defaults to **nil**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-break-after-module creates a new event using the supplied parameters for its corresponding attributes which will be scheduled to occur after the next event of the specified module.

If there is an event currently in the event queue with the module name of after-module for any model then this new break event is placed into the event queue at the time of the next such matching event (lowest time) with a priority of **:min**. If there are any events waiting to be scheduled they are checked to see if this new event allows them to be scheduled.

If there is no event in the event queue that matches on module, then the value of delay-value determines what happens to the new break event.

If delay-value is **t** then the new break event is placed into the set of waiting events to be scheduled after an event which matches the conditions necessary to schedule this new event.

If delay-value is **nil** then the new break event is added to the event queue for immediate execution. Its time will be set to the current time and its priority will be **:max**.

If delay-value is **:abort** then the new break event is discarded without being scheduled or placed onto the waiting queue.

The setting of dynamic-value does not matter under normal circumstances, but may be useful if a custom clock is provided for real time operations. See the Configuring Real Time Operations section for details of how it works.

schedule-break-after-module returns two values. If there is no current meta-process or any of the parameters are invalid, then no event is scheduled and both values are **nil**. If an event is scheduled then the first value will be the event and the second value will be **t** if the event is in the waiting queue or **nil** if it is in the event queue. If the event is aborted, the first value will be **nil** and the second value will be **:abort**.

Examples:

```
1> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
1

2> (schedule-break-after-module 'procedural :details "after procedural")
#S(ACT-R-BREAK-EVENT …)
NIL

3> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   ------                 BREAK-EVENT after procedural
2

4> (schedule-break-after-module :vision :details "waiting for vision")
#S(ACT-R-BREAK-EVENT …)
T

5> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   ------                 BREAK-EVENT after procedural
2
6> (mp-show-waiting)
Events waiting to be scheduled:
       NIL   ------        BREAK-EVENT waiting for vision Waiting for: (MODULE VISION T)
1

7> (schedule-break-after-module :vision :details "not waiting for vision" :delay nil)
#S(ACT-R-BREAK-EVENT …)
NIL

8> (mp-show-queue)
Events in the queue:
```

```
     0.000   ------                 BREAK-EVENT not waiting for vision
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   ------                 BREAK-EVENT after procedural
3

9> (mp-show-waiting)
Events waiting to be scheduled:
       NIL   ------        BREAK-EVENT waiting for vision Waiting for: (MODULE VISION T)
1
10> (schedule-break-after-module :vision :delay :abort :details "aborted")
NIL
:ABORT

11> (mp-show-queue)
Events in the queue:
     0.000   ------                 BREAK-EVENT not waiting for vision
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   ------                 BREAK-EVENT after procedural
3

12> (mp-show-waiting )
Events waiting to be scheduled:
       NIL   ------        BREAK-EVENT waiting for vision Waiting for: (MODULE VISION T)
1

13> (schedule-event 3 (lambda ()) :module :vision)
#S(ACT-R-EVENT …)

14> (mp-show-queue)
Events in the queue:
     0.000   ------                 BREAK-EVENT not waiting for vision
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.000   ------                 BREAK-EVENT after procedural
     3.000   VISION                 RUN
     3.000   ------                 BREAK-EVENT waiting for vision
5

15> (mp-show-waiting)
Events waiting to be scheduled:
0
```

schedule-break-after-all

Syntax:

schedule-break-after-all {**:details** *details-value*} -> [actr-event | **nil**]

Arguments and Values:

details-value ::= a string to output in the trace or **nil** (defaults to **nil**)
actr-event ::= the actual event used by the meta-process

Description:

schedule-break-after-all creates a new break event with the provided details. The time for this new event is the greatest time of any event currently in the event queue of the current meta-process and its priority is :min. It will be inserted into the event queue such that it will occur after all of the events currently scheduled.

If there is no current meta-process then a warning is printed, no event is scheduled, and **nil** is returned.

The scheduled event is returned when successfully created and scheduled.

Examples:

```
1> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
    12.000   NONE                   a future action
2

2> (schedule-break-after-all :details "at the end")
#S(ACT-R-BREAK-EVENT …)

3> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
    12.000   NONE                   a future action
    12.000   ------                 BREAK-EVENT at the end
3

E> (schedule-break-after-all)
#|Warning: schedule-break called with no current meta-process. |#
NIL
```

delete-event

Syntax:

delete-event *actr-event* -> [**t** | **nil**]

Arguments and Values:

actr-event ::= an actual ACT-R event as returned by one of the scheduling functions

Description:

If actr-event is an event which is currently in either the main event queue or the waiting queue of the current meta-process then delete-event removes that event from the queue that it is in and returns **t**.

If there is no current meta-process or the item is not in either event queue no action is taken and **nil** is returned.

Examples:

```
1> (schedule-break 10)
#S(ACT-R-BREAK-EVENT …)

2> (defvar *event* *)
*EVENT*
```

```
3> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
    10.000   ------                 BREAK-EVENT
2

4> (delete-event *event*)
T

5> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
1

6> (delete-event *event*)
NIL

E> (delete-event 'not-an-event)
#|Warning: NOT-AN-EVENT is not a valid event. |#
NIL
```

Event Hooks

In addition to being able to schedule events it is possible to add functions which can monitor the events as they are executed. One can add what is called an event hook function which will be passed each event either before or after it is executed. The event hook can be used for recording information about what has happened in the model (for instance if one wanted to add an alternate tracing mechanism) or for checking for particular events to occur for data collection or other purposes. The hook function should not modify the event that is passed to it, and as noted above, the API does not provide any mechanism for doing so. When created, the hook functions are added to the current meta-process and persist across a reset. They are only removed if they are explicitly deleted with the delete-event-hook command described below, the meta-process in which they were created is itself deleted, or with a call to clear-all.

Event Hook Commands

add-pre-event-hook

Syntax:

add-pre-event-hook *hook-fn* {*warn-for-duplicate*} -> [hook-id | **nil**]

Arguments and Values:

hook-fn ::= a function or the name of a function which takes one parameter
hook-id ::= a number which is the reference for the hook function that was added
warn-for-duplicate ::= a generalized boolean which indicates whether or not to show a warning if the same function is attempted to be put on the event hook again

Description:

If hook-fn is a function or the name of a function which is not already in the set of pre-event hooks for the current meta-process then it will be added to that set. That function will be called before each event is evaluated and it will be passed that event as its only parameter. The hook function will remain in the pre-event hook set for that meta-process until it is either explicitly removed or until a clear-all occurs.

If the hook function is added to the set, then a unique hook-id is returned which can be used to explicitly remove that function from the set of pre-event hook functions.

If hook-fn is invalid or there is no current meta-process then a warning is printed and **nil** is returned. If hook-fn is already in the set of pre-event hook functions then **nil** is also returned and a warning is printed unless warn-for-duplicate is provided as **nil.**

Examples:

This example assumes that the count model from unit 1 of the tutorial is loaded.

```
1> (defun show-event (event)
     (format t "Hook sees event with module: ~S~%" (evt-module event)))
SHOW-EVENT

2> (add-pre-event-hook 'show-event)
0

3> (run .05)
Hook sees event with module: GOAL
     0.000   GOAL                 SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
Hook sees event with module: PROCEDURAL
     0.000   PROCEDURAL           CONFLICT-RESOLUTION
Hook sees event with module: PROCEDURAL
     0.000   PROCEDURAL           PRODUCTION-SELECTED START
Hook sees event with module: PROCEDURAL
Hook sees event with module: PROCEDURAL
     0.000   PROCEDURAL           BUFFER-READ-ACTION GOAL
Hook sees event with module: GOAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL           PRODUCTION-FIRED START
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL           MOD-BUFFER-CHUNK GOAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL           MODULE-REQUEST RETRIEVAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL           CLEAR-BUFFER RETRIEVAL
Hook sees event with module: DECLARATIVE
     0.050   DECLARATIVE          START-RETRIEVAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL           CONFLICT-RESOLUTION
Hook sees event with module: NIL
     0.050   ------               Stopped because time limit reached
0.05
12
NIL

4E> (add-pre-event-hook 'show-event)
#|Warning: SHOW-EVENT is already on the pre-event-hook list not added again |#
NIL
```

```
5> (add-pre-event-hook 'show-event nil)
NIL

E> (add-pre-event-hook 'show-event)
#|Warning: add-pre-event-hook called with no current meta-process |#
NIL

E> (add-pre-event-hook 'bad-function-name)
#|Warning: parameter BAD-FUNCTION-NAME to add-pre-event-hook is not a function |#
NIL
```

add-post-event-hook

Syntax:

add-post-event-hook *hook-fn* {*warn-for-duplicate*} -> [hook-id | **nil**]

Arguments and Values:

hook-fn ::= a function or the name of a function which takes one parameter
hook-id ::= a number which is the reference for the hook function that was added
warn-for-duplicate ::= a generalized boolean which indicates whether or not to show a warning if the same function is attempted to be put on the event hook again

Description:

If hook-fn is a function or the name of a function which is not already in the set of post-event hooks for the current meta-process then it will be added to that set. That function will be called after each event is evaluated and it will be passed that event as its only parameter. The hook function will remain in the post-event hook set for that meta-process until it is either explicitly removed or until a clear-all occurs.

If the hook function is added to the set, then a unique hook-id is returned which can be used to explicitly remove that function from the set of post-event hook functions.

If hook-fn is invalid or there is no current meta-process then a warning is printed and **nil** is returned. If hook-fn is already in the set of post-event hook functions then **nil** is also returned and a warning is printed unless warn-for-duplicate is provided as **nil.**

Examples:

This example assumes that the count model from unit 1 of the tutorial is loaded.

```
1> (defun show-event (event)
     (format t "Hook sees event with module: ~S~%" (evt-module event)))
SHOW-EVENT

2> (add-post-event-hook 'show-event)
1

3> (run .05)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
```

```
Hook sees event with module: GOAL
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
Hook sees event with module: PROCEDURAL
     0.000   PROCEDURAL             PRODUCTION-SELECTED START
Hook sees event with module: PROCEDURAL
Hook sees event with module: PROCEDURAL
     0.000   PROCEDURAL             BUFFER-READ-ACTION GOAL
Hook sees event with module: PROCEDURAL
Hook sees event with module: GOAL
     0.050   PROCEDURAL             PRODUCTION-FIRED START
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL             MOD-BUFFER-CHUNK GOAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL             MODULE-REQUEST RETRIEVAL
Hook sees event with module: PROCEDURAL
     0.050   PROCEDURAL             CLEAR-BUFFER RETRIEVAL
Hook sees event with module: PROCEDURAL
     0.050   DECLARATIVE            START-RETRIEVAL
Hook sees event with module: DECLARATIVE
     0.050   PROCEDURAL             CONFLICT-RESOLUTION
Hook sees event with module: PROCEDURAL
Hook sees event with module: NIL
     0.050   ------                 Stopped because time limit reached
0.05
12
NIL

4E> (add-post-event-hook 'show-event)
#|Warning: SHOW-EVENT is already on the post-event-hook list not added again |#
NIL

5> (add-post-event-hook 'show-event nil)
NIL

E> (add-post-event-hook 'not-a-function)
#|Warning: parameter NOT-A-FUNCTION to add-post-event-hook is not a function |#
NIL

E> (add-post-event-hook 'show-event)
#|Warning: add-post-event-hook called with no current meta-process |#
NIL
```

delete-event-hook

Syntax:

delete-event-hook *hook-id* -> [hook-fn | **nil**]

Arguments and Values:

hook-id ::= a hook function id returned by one of the add event hook functions
hook-fn ::= the function or function name that was removed from the event hook

Description:

If the event hook function associated with hook-id is still a member of the set of event hooks in the current meta-process then it is removed from the set of hook functions and the function or function name that was used to create the event hook is returned.

If hook-id does not correspond to the id of an event hook or the event has already been removed from the set of event hooks then **nil** is returned. If there is no current meta-process, then a warning is printed and **nil** is returned.

Examples:

This example assumes that the event hook shown in the example for add-pre-event-hook exists

```
1> (delete-event-hook 0)
SHOW-EVENT

2> (delete-event-hook 0)
NIL

E> (delete-event-hook 'hook)
NIL

E> (delete-event-hook 0)
#|Warning: delete-event-hook called with no current meta-process |#
NIL
```

About the Included Modules

The modules that are included with ACT-R fall into three general categories. The first is system or control modules which are not based on the theory and only serve to provide functionality to the software. The second category is the modules which instantiate the cognitive components of the theory, and the third is the set of modules which provide the perceptual and motor actions which allow the models to interact with an environment. The latter two both serve to instantiate the current theory and the only reason for distinguishing between the two is that the perceptual and motor modules have an additional interface for interacting with the world whereas the purely cognitive modules do not.

The following sections will describe the details of the modules that are included with the current system. For each module the operation of the module will be described, any parameters that the module has will be shown, if the module has any buffers their uses will be covered, and any commands which the module provides will be documented.

The basic system modules will be described first. Then the cognitive modules will be described, and after some description of their interface to the world the perceptual and motor modules will be described.

Printing module

The printing module controls what the system prints and where it goes. This module provides several parameters to configure the output. The commands available for outputting information are described in the Printing and Output section above. Because it is a system module it has no buffer or impact on modeling results.

Parameters

:cbct

The copy buffer chunk trace parameter. This parameter controls whether or not an event will be shown in the trace indicating that a buffer has made a copy of a chunk. It can take a value of **t** or **nil**.

The default is **nil**.

If it is set to **t** then an event like this will be shown in the trace each time a buffer makes a copy of a chunk:

```
0.135   BUFFER      Buffer VISUAL copied chunk TEXT0 to TEXT0-0
```

It indicates which buffer made the copy along with the name of the original chunk and the name of the copy. Those events will be shown with the high and medium trace detail settings.

:cmdt

The command trace parameter controls where the command output (as described in the Printing and Output section) is displayed.

The possible values for :cmdt are:

- **nil –** this turns off all command output for this model
- **t –** send command output to the ***standard-output*** stream
- a stream – command output is sent to that stream
- a pathname – the specified file is opened and output is appended to it
- a string – if the string denotes a valid pathname, then it is used as a pathname above

The default value is **t.**

If a file is used, it will be opened when the parameter is set and closed when either the parameter is changed or the model is deleted. Note that for file output the actual output to the file may be buffered in the Lisp before being written. Thus, that output file should not be opened or read until the model is done with its output. Resetting or deleting the model will signal that it is done as will setting the :cmdt parameter to some other value.

:model-warnings

The model-warnings parameter controls whether or not model warnings (as described in the Printing and Output section) are displayed. It can be set to **t** or **nil**.

The default value is **t**.

If it is set to **t**, then the model warnings are shown and if it is set to **nil** then they are not.

:show-all-slots

The show all slots parameter is used to determine how to print chunks for which the chunk-type has been extended. It can take a value of **t** or **nil**.

The default is **nil**.

If it is set to **nil**, then only the original slots of the chunk-type and the extended slots for which a value have been provided are displayed when the chunk is printed. If it is set to **t** then all of the slots for the chunk-type are displayed for the chunk even if it does not have a value for an extended slot. It will show as having a value of **nil** for an "unfilled" extended slot, but that is not quite correct because there is a difference between having a value of **nil** to indicate a slot is empty and not having a value at all for the extended slot (because the chunk is not to be changed once it enters declarative memory).

Generally, this parameter should be left at the default of **nil** to avoid confusion about what is happening because that reflects how the mechanisms are intended, but there may be debugging situations where one wants to see all of the available slots for a chunk.

:trace-detail

The trace detail parameter controls which events are shown in the model's trace. It can be set to one of the values: **high**, **medium**, or **low**. The default value is **medium**.

If it is set to **high**, then all events which have a non-**nil** output setting are displayed. If it is set to **medium** then only those events with a **medium** or **low** output setting are shown, and if it is set to **low**, then only those events with a **low** output setting are shown.

:trace-filter

The trace filter parameter allows one more detailed control over which events are displayed in the trace. It can be set to a function, function name, or **nil**.

The default is **nil**.

If it is set to a function, then that function should take one parameter. For each event that occurs that function will be called with the event as its parameter. If the function returns **nil** then that event will not be displayed in the trace. Otherwise, the trace-detail level will be used to determine whether or not to display the event.

There is one filter function available with the system called production-firing-only. If that is set as the value of :trace-filter it will restrict the printed trace to only the production-fired events.

:v

The verbose parameter. The :v parameter controls where the model output (as described in the Printing and Output section) is displayed. The trace of the model is included in model output.

The possible values for :v are:

- **nil –** this turns off all model output for this model
- **t –** send model output to the ***standard-output*** stream
- a stream – model output is sent to that stream
- a pathname – the specified file is opened and output is appended to it
- a string – if the string denotes a valid pathname, then it is used as a pathname above

The default value is t.

If a file is used, it will be opened when the parameter is set and closed when either the parameter is changed or the model is deleted. Note that for file output the actual output to the file may be buffered in the Lisp before being written. Thus, that output file should not be opened or read until the model is done with its output. Resetting or deleting the model will signal that it is done as will setting the :v parameter to some other value.

Naming Module

The naming module provides the system with all of the symbols that it generates for the names of things. It guarantees that the system does not duplicate names within a model and that the name returned does not already name a chunk (chunks are the predominant item for which names are created by the system). It also allows for the uninterning of those symbols that were generated when the model is reset or deleted if they are not also in use in other models. This is preferable to the use of gentemp or gensym because those do not have a means of automatically cleaning up the symbol once it is no longer needed.

The names are generated by appending an increasing counter to the end of the provided name prefix (each prefix has its own counter). An additional benefit of the naming module is that the counters are reset to 0 when the model is reset. Thus, a deterministic model will always result in the same sequence of names being created when it is run after being reset, which can be very useful for debugging a model. Because the random module allows one to set the seed for the pseudo-random numbers the model generates, one can temporarily make a stochastic model deterministic for debugging.

Parameters

:ncnar

The normalize chunk names after run parameter. The :ncnar parameter controls whether the model will call normalize-chunk-names after every call to one of the model running functions. If it is set to **t** then normalize-chunk-names will be called (without specifying the unintern parameter). If it is set to the value **delete** then normalize-chunk-names will be called with the unintern parameter true. If it is set to **nil** then normalize-chunk-names will not be called.

Having normalize-chunk-names called can be useful for debugging, but if the model generates a lot of chunks it may take a significant amount of time to complete. Thus for models that generate a lot of chunks, or for which there are several calls to model running functions this parameter should be set to **nil** to improve performance.

The value of **delete** is provided as an option for extreme cases where the model is exhausting the computer memory and unable to run. Setting it to **delete** is not recommended for general use because some modules may have internal references to the chunk names which will be made invalid when the uninterning option is used. Extra caution should therefore be used when specifying a value of **delete** for :ncnar.

The default value is **t**.

:dcnn

The dynamic chunk name normalizing parameter. The :dcnn parameter works in conjunction with the :ncnar parameter to normalize chunk names. If :ncnar is set to **t** or **delete** then :dcnn controls whether the model will normalize the chunk names while the model runs in addition to normalizing at the end of the run. If :dcnn is set to **t** then the chunk names stored in slots of chunks will be automatically updated whenever chunks are merged such that all chunks hold only the true chunk names of chunks in their slots. It essentially spreads the normalizing out during the run instead of performing it all at the end, but it will not delete any chunks until the end of the run if :ncnar is set to do so. This may be more efficient for some models and may also make debugging easier when a model breaks or while stepping through a run. If :ncnar is set to **nil** then the setting of the :dcnn parameter has no effect on the system.

The default value is **t**.

:dcsc-hook

The dynamic chunk slot change hook parameter. The :dcsc-hook parameter provides a way for modules or other code to be notified if a chunk is dynamically changed as a result of chunk normalizing. This parameter can be set with a function which takes one parameter and any number of such functions may be set. The reported value of this parameter is a list of all functions which have been set. Whenever a chunk is modified by normalizing, after the normalizing has changed a slot value, each of the functions set for this parameter will be called with the name of the chunk that had a slot modified through normalizing. The hook functions will be called every time a chunk changes due to normalizing regardless of how the normalizing occurred.

If the parameter is set to **nil** then all functions are removed from the conflict-set-hook.

The default value is **nil**.

:short-copy-names

The :short-copy-name parameter controls how chunk names are created when a chunk is copied. The most common place for this to occur is when a chunk is placed into a buffer and it gets copied automatically. If the parameter is set to **nil** then the copy will have a hyphen and a number appended to it. The number is typically 0, but if that would conflict with another name it will be incremented until it is "safe" (see the new-name command below). If this parameter is set to **t** then instead of adding a new hyphen and number when copying a chunk which is itself a copy only the number will be incremented as needed.

Assuming there are no conflicts, with this parameter set to **nil** if a chunk named "chunk" is copied it will be named chunk-0 and if chunk-0 is copied that new chunk will be named chunk-0-0. If this parameter is set to **t** then copying chunk will still result in chunk-0, but copying chunk-0 will result in

the name chunk-1. In either case, if a chunk named chunk-0 is created explicitly by the model (it is not a copy of a chunk named chunk) then a copy of that chunk will be named chunk-0-0.

This parameter only really matters if copies of chunks are being made from copies – either directly or through the actions of modules like declarative or vision which may reuse copies of chunks. Its setting should not affect how the model operates with the standard modules because they do not rely on specific chunk names.

The default value is **nil**.

Commands

new-name

Syntax:

new-name {*prefix*} -> [name-symbol | **nil**]
new-name-fct {*prefix*} -> [name-symbol | **nil**]

Arguments and Values:

prefix ::= if provided should be a string or symbol (defaults to "CHUNK" if not given)
name-symbol ::= a symbol created by appending a number onto the prefix

Description:

new-name is used to generate unique name symbols (which have been interned) within a model, similar to the Lisp function gentemp. Unlike gentemp, it does not guarantee that the symbol does not already exist. What it does guarantee is that it is was not previously returned by new-name within the current run of the model and that it is not currently used to name a chunk in the current model.

When the module is deleted or reset it clears its name space and uninterns any symbols it has generated which are no longer "necessary". By necessary, it means that no instance of the naming module has generated such a name, nor was that symbol interned prior to new-name generating it for the first time.

If there is no current model then a warning is printed and **nil** is returned.

Anywhere a model would use gentemp, new-name should probably be used instead to guarantee the automatic cleanup upon reset or model deletion. Note that it is typically not necessary to generate a name for a new chunk because omitting a name in the call to define-chunks results in the chunk getting a name generated by new-name automatically.

Examples:

```
> (new-name)
```

```
CHUNK0

> (new-name temp)
TEMP0

1> (new-name-fct 'fact)
FACT0

2> (new-name-fct "FACT")
FACT1

1> (new-name "temp")
TEMP1

2> (define-chunks (temp2 isa chunk))
(TEMP2)

3> (new-name "temp")
TEMP3

E> (new-name)
#|Warning: get-module called with no current model. |#
#|Warning: No naming module available cannot create new name. |#
NIL
```

release-name

Syntax:

release-name *name* -> [**t** | **nil**]
release-name-fct *name* -> [**t** | **nil**]

Arguments and Values:

name ::= should be a symbol which was generated by new-name

Description:

release-name can be used to possibly unintern symbols which have been generated by new-name. This is the same process which occurs on a reset or deletion of the naming module for symbols generated by new-name, but in some circumstances one may want to perform such a cleanup without resetting. Thus, if the symbol given in name was generated by the new-name command and no instance of the naming module other than the one in the current model has generated such a name and that symbol was not interned prior to new-name generating it for the first time then it is uninterned.

If the symbol is uninterned, then **t** is returned otherwise **nil** is returned.

If there is no current model then a warning is printed and **nil** is returned.

Generally, this command is not necessary because a reset or clear-all will automatically clear out the symbols. However, if one is generating an extremely large number of temporary names with new-

name it can lead to issues with the size of the symbol table in Lisp and explicitly removing names prior to a reset may be useful.

Examples:

```
1> (find-symbol "CHUNK0")
NIL
NIL

2> (new-name )
CHUNK0

3> 'chunk1
CHUNK1

4> (find-symbol "CHUNK1")
CHUNK1
:INTERNAL
5> (new-name)
CHUNK1

6> (release-name-fct 'chunk0)
T

7> (release-name chunk1)
NIL

8> (release-name-fct 'chunk0)
NIL

E> (release-name chunk0)
#|Warning: get-module called with no current model. |#
#|Warning: No naming module available cannot release name CHUNK0. |#
NIL
```

new-symbol

Syntax:

new-symbol {*prefix*} -> [new-symbol | **nil**]
new-symbol-fct {*prefix*} -> [new-symbol | **nil**]

Arguments and Values:

prefix ::= if provided should be a string or symbol (defaults to "CHUNK" if not given)
new-symbol ::= a newly interned symbol created by appending a number onto the prefix

Description:

new-symbol is used to generate and intern a unique symbol, similar to the Lisp function gentemp and the new-name command. Like gentemp, it guarantees that the symbol does not already exist. Unlike the command new-name, it does not guarantee that the numbering is reset with the model.

When the module is deleted or reset all new-symbols created are uninterned.

If there is no current model then a warning is printed and **nil** is returned.

new-symbol should only be used when one needs a completely new symbol and the name of that symbol is not meaningful to the model (for instance something that might show up in the trace should use new-name).

Examples:

```
> (new-symbol )
CHUNK-0

1> (new-symbol "temp")
TEMP-0

2> (new-symbol-fct 'temp)
TEMP-1

3> (let (temp-2 temp-3))
NIL

4> (new-symbol temp)
TEMP-4

E> (new-symbol)
#|Warning: get-module called with no current model. |#
#|Warning: No naming module available cannot create new symbol. |#
NIL
```

Random module

The random module provides a consistent pseudorandom number generator for the system. It is not dependent on the Lisp random function or the Lisp *random-state* global variable. This makes it consistent across all instances of ACT-R regardless of the Lisp application or OS being used. This is very useful for teaching because it guarantees the output of the tutorial material will be the same for all users. It also makes models and modules easier to debug and verify because the random state can be set with an ACT-R parameter for testing. It also serves to protect the model from any potential weaknesses in the random function of a particular Lisp.

The particular pseudorandom number generator chosen is the Mersenne Twister (as implemented by the mt19937ar.c code) because it is designed for Monte-Carlo simulations. Details can be found at:

http://www.math.sci.hiroshima-u.ac.jp/~m-mat/MT/emt.html

That algorithm is used by CMUCL and Allegro Common Lisp for the Lisp random function already. However, because their internal representations of state differ it is still necessary to use the specific random module implementation for consistency of ACT-R across systems.

Parameters

:randomize-time

This parameter can be set to **t**, **nil**, or an integer. It is used by the randomize-time command to determine the range in which a specified time will be randomized. The randomize-time command is used mainly by the perceptual and motor modules to add noise to the action times (see the randomize-time command below for more details).

The default value is **nil** which means not to randomize the times. A value of **t** is the same as setting the value to 3.

:seed

This is the current seed for the pseudorandom number generator. It must be a list of two numbers. The first is used to initialize the array used by the Mersenne Twister algorithm and the second is an offset from that starting point where the model should start (or where it currently is if the value is read after the model has been run). Thus, if one is specifying a seed explicitly, the second number should probably be kept "small" because that many pseudorandom numbers will be generated when the parameter is set to get to the offset point.

There is no default value for the seed parameter. When the module is created in a model it generates a new seed based on the current result of get-internal-real-time. Resetting the model does not return

the seed to that point – the random module will continue generating new pseudorandom numbers from the point where it last left off.

Commands

act-r-random

Syntax:

act-r-random *limit* -> [value | **nil**]

Arguments and Values:

limit ::= a positive number (either an integer or floating point)
value ::= a pseudorandom number which is non-negative and less than limit

Description:

act-r-random will operate like random as defined in the ANSI Lisp specification, except without the optional parameter for a random-state. It uses the seed value from the current model to generate the next random number. Thus unless models explicitly set the same seed value each model will have a different sequence of pseudorandom numbers returned by act-r-random.

It returns a pseudorandom number that is a non-negative number less than limit and of the same type as limit. An approximately uniform choice distribution is used. If limit is an integer, then each of the possible results occurs with (approximate) probability 1/limit.

If an invalid value is passed to act-r-random then a warning is printed and **nil** is returned.

If there is no current model a warning will be printed and a pseudorandom number generated from a special instance of the random module will be returned.

Examples:

```
1> (sgp :seed)
:SEED (94875970549 0) (default NO-DEFAULT) : Current seed of the random number generator
((94875970549 0))

2> (act-r-random 100)
46

3> (act-r-random 34.5)
11.947622

4> (act-r-random 1000)
679

5> (act-r-random 0.5)
0.31684825

6> (sgp :seed (94875970549 1))
```

```
((94875970549 1))

7> (act-r-random 34.5)
11.947622

8> (act-r-random 1000)
679

9> (act-r-random 0.5)
0.31684825

E> (act-r-random 'a)
#|Warning: Act-r-random called with an invalid value A |#
NIL

E> (act-r-random 2)
#|Warning: get-module called with no current model. |#
0
```

act-r-noise

Syntax:

act-r-noise *s* -> [value | **nil**]

Arguments and Values:

s ::= a non-negative number
value ::= a pseudorandom number generated as described below

Description:

act-r-noise generates a value from a logistic distribution (approximation of a normal distribution) with a mean of 0 and an s value as given. It does this using the act-r-random function. The s value is related to the variance of the distribution, σ^2, by this equation:

$$\sigma^2 = \frac{\pi^2}{3} s^2$$

If s is invalid a warning is printed and **nil** is returned.

If there is no current model a warning will be printed and a pseudorandom number generated from a special instance of the random module will be returned (as indicated by act-r-random).

Examples:

```
> (act-r-noise 0)
0.0

> (act-r-noise .5)
0.15807568
```

```
> (act-r-noise .5)
1.4271247

E> (act-r-noise 'a)
#|Warning: Act-r-noise called with an invalid s A |#
NIL

E> (act-r-noise .5)
#|Warning: get-module called with no current model. |#
-1.131652
```

randomize-time

Syntax:

randomize-time *time* -> [time | rand-time]

Arguments and Values:

time ::= should be a number
rand-time ::= a randomized time value based as described below

Description:

randomize-time is used to return a number randomly chosen from a uniform distribution around the provided time. It depends on the setting of the :randomize-time parameter in the current model. If the parameter is set to **nil** then no randomization is done by the randomize-time command and time is returned.

If the :randomize-time parameter is a number or **t** (which means use the default number 3) then a number randomly chosen from the uniform distribution in the range of:

$$\left[time * \frac{n-1}{n}, time * \frac{n+1}{n} \right)$$

where n is the value of :randomize-time, will be returned.

If time is not a number or there is no current model, then a warning is printed and time is returned.

Examples:

```
1> (sgp :randomize-time nil)
(NIL)

2> (randomize-time 10)
10

1> (sgp :randomize-time t)
(T)

2> (randomize-time 50)
65.277435
```

```
3> (randomize-time 50.0)
58.443718

1> (sgp :randomize-time 100)
(100)

2> (randomize-time 100)
100.1965

3> (randomize-time 100)
99.349

E> (randomize-time 'a)
#|Warning: Invalid value passed to randomize-time: A |#
A

E> (randomize-time 10)
#|Warning: get-module called with no current model. |#
10
```

Buffer trace module

The buffer trace module records the actions which occur through the buffers while a model runs and can report that information in a text display (an alternative to the standard trace) or return a list of Lisp structures which encode the actions that took place.

The module has no buffer of its own. It has five parameters that control the tracing and a command for retrieving the trace information.

Here is an example of the buffer trace using the demo2 model from the tutorial:

```
> (do-experiment)
          |    PRODUCTION    |       GOAL       | VISUAL-LOCATION |      VISUAL      |      MANUAL      |
    0.000 |  +FIND-UNATTEN+  | .     GOAL       | .     LOC0      |                  |                  |
    0.025 |  **************  | .                | .               |                  |                  |
    0.050 |  +ATTEND-LETTE+  | .    =======     | .     LOC1      |                  |                  |
    0.075 |  **************  | .                | .               |                  |                  |
    0.100 |  **************  | .    =======     | .    -------    |  +MOVE-ATTENTI+  |                  |
    0.125 |                  | .                |                 |  **************  |                  |
    0.150 |                  | .                |                 |  **************  |                  |
    0.175 |                  | .                |                 |  **************  |                  |
    0.185 |  +ENCODE-LETTE+  | .                |                 | .     TEXT1      |                  |
    0.210 |  **************  | .                |                 | .                |                  |
    0.235 |  +   RESPOND  +  | .    =======     |                 | .    -------     |                  |
    0.260 |  **************  | .                |                 |                  |                  |
    0.285 |  **************  | .    =======     |                 |                  |  +  PRESS-KEY +  |
    0.310 |                  | .                |                 |                  |  **************  |
    0.335 |                  | .                |                 |                  |  **************  |
    0.360 |                  | .                |                 |                  |  **************  |
    0.385 |                  | .                |                 |                  |  **************  |
    0.410 |                  | .                |                 |                  |  **************  |
    0.435 |                  | .                |                 |                  |  **************  |
    0.460 |                  | .                |                 |                  |  **************  |
    0.485 |                  | .                |                 |                  |  **************  |
    0.510 |                  | .                |                 |                  |  **************  |
    0.535 |                  | .                |                 |                  |  **************  |
    0.560 |                  | .                |                 |                  |  **************  |
    0.585 |                  | .                |                 |                  |  **************  |
    0.610 |                  | .                |                 |                  |  **************  |
    0.635 |                  | .                |                 |                  |  **************  |
    0.660 |                  | .                |                 |                  |  **************  |
    0.685 |                  | .                |                 |  **************  |  **************  |
    0.710 |                  | .                |                 |  **************  |  **************  |
    0.735 |                  | .                |                 |  **************  |  **************  |
    0.760 |                  | .                |                 |  **************  |  **************  |
    0.770 |                  | .                |                 |E                 |  **************  |
    0.795 |                  | .                |                 |E                 |  **************  |
    0.820 |                  | .                |                 |E                 |  **************  |
    0.835 |                  | .                |                 |E                 |                  |
    0.860 |                  | .                |                 |E                 |                  |
    0.885 |                  | .                |                 |E                 |                  |
    0.910 |                  | .                |                 |E                 |                  |
    0.935 |                  | .                |                 |E                 |                  |
    0.960 |                  | .                |                 |E                 |                  |
    0.985 |                  | .                |                 |E                 |                  |
    0.985   ------                Stopped because no events left to process
"v"
```

These are the parameters that were set to achieve that:

```
(sgp :buffer-trace t :buffer-trace-step .025 :traced-buffers (production goal visual-
location visual manual))
```

The details of the parameters are described below.

The following information is recorded at each event of the model and then aggregated over all events at a given time on a buffer by buffer basis:

- Whether the buffer's module is busy
- Whether the buffer's module is in an error state
- Whether the buffer is full
- If the buffer is cleared
- If the chunk in the buffer is modified
- If a request is sent to the module
- If a new chunk is set in the buffer

For the first 5, if the stated condition is true during any event at the current time the buffer record will indicate it as t. For requests, only the last request at the given time is recorded and the information that is recorded is the chunk-type of the request or the details string of the event if it has one. If a chunk is set into the buffer, then the name of that chunk is recorded, and as with requests, only the last setting at a specific time is recorded.

The buffer trace attempts to show all of that information in a textual format. At each time step of the model i.e. each time that would be shown in the regular trace, and at extra time steps if needed to meet the :trace-step setting, there will be one line of trace printed. At the start of the line will be the time of the summary and for each buffer traced there will be a column of information in the trace (the columns are separated by the vertical bar character '|'). In a column for a buffer, the first character will be "E" if the module is in an error state or a space otherwise. The second character will be a "." if there is currently a chunk in the buffer or a space if it is empty. The rest of the column will show one of the following things in their order of priority (truncated to maintain the column width):

- If there is a new chunk set in the buffer the name of that chunk
- If there is a request the request is shown between two "+" characters
- If the buffer is modified it will show a series of "=" characters
- If the buffer is cleared it will show a series of "-" characters
- If the module is busy it will show a series of "*" characters
- otherwise it will be filled with spaces.

The graphic tracing tools of the ACT-R Environment rely on the buffer trace module to generate the data it uses as does the BOLD computation module.

Parameters

:buffer-trace

If the :buffer-trace parameter is set to **t**, then the normal event trace is disabled and the buffer trace is printed instead. The default value for this parameter is **nil**.

:buffer-trace-hook

This parameter allows the modeler to have access to the buffer trace summaries "on the fly". It defaults to **nil**, but if it is set to a function which takes one parameter then that function will be called with every buffer-record structure (as described in the get-current-buffer-trace command below) at the time they are available. They are made available when the clock changes, if :buffer-trace-step is set to a time and that amount of time has passed since the last update, or when the run terminates.

:buffer-trace-step

If :buffer-trace-step is set to a number it specifies the maximum amount of time that is allowed to elapse before creating a new buffer summary. Note however that there may be smaller time steps that correspond to model actions. The default value is **nil** which means to only create the records when there are events i.e. there is no minimum or maximum time guaranteed between the buffer summaries.

:save-buffer-trace

This parameter controls whether the buffer trace information is recorded for later recovery by the get-current-buffer-trace command (described below). It defaults to **nil**, which means do not record the information. If it is set to **t**, then the buffer trace module will record the summary data so that it can be retrieved for later use. This parameter does not alter the printed trace i.e. if :buffer-trace is **nil** and :save-buffer-trace is **t** then the standard event trace will be printed even though the buffer trace data is being collected by the module.

:traced-buffers

This can be set to a list of buffers which are to be traced. It has a default value of **t**, which means to trace all buffers. Only those buffers specified on this list will have their data recorded. The order of the buffers in this list is the order they will be printed in the output. If it is set to **t** all buffers will be displayed in alphabetical order.

Commands

get-current-buffer-trace

Syntax:

get-current-buffer-trace {*clear*} -> (buffer-record*)

Arguments and Values:

buffer-record ::= a structure which is defined like this:

```
(defstruct buffer-record ms-time buffers)
```

In the buffer-record structure the ms-time slot is a number indicating the model time at which the summary was recorded in milliseconds and the buffers slot is a list of buffer-summary structures.

buffer-summary ::= a structure which is defined like this:

```
(defstruct buffer-summary name cleared busy busy->free error
           error->clear full modified request chunk-name notes)
```

In the buffer-summary structure the name slot holds the name of the buffer for which this is a record. The cleared, busy, busy->free, error, error->clear, full, and modified slots are flags which will be either **t** or **nil** to indicate if the named condition was true during that time. The request slot will hold either the chunk-type of the request or the document string of the event (if it had one) for the last request made at the recorded time or **nil** if there was no request made through the buffer at that time. The chunk-name slot will hold the name of the last chunk which was placed into the buffer at the specified time, or **nil** if there was no chunk placed into the buffer at that time. The notes slot will contain the last note added to the buffer using the add-buffer-trace-notes command, or **nil** if no notes have been added to the buffer.

Description:

The get-current-buffer-trace command takes no parameters. It returns a list of the buffer-record structures which have been collected since the save-buffer-trace parameter was set to **t** in the current model. If the :save-buffer-trace parameter was not set it will return **nil**. If there is no current model then the command will print a warning and return **nil**.

This command, along with the :buffer-trace-hook parameter, are provided as a mechanism for modelers to collect buffer/module activity without needing to engineer special purpose hooks or make any module modifications for such purpose. This data is what is used by the graphic tracing tools in the ACT-R Environment as well by the code which produces BOLD predictions from model runs.

Examples:

This example uses the demo2 model as was shown in the buffer trace above with the :save-buffer-trace parameter also set to **t**.

```
> (pprint (get-current-buffer-trace))

(#S(BUFFER-RECORD :TIME-STAMP 0.0
                  :BUFFERS (#S(BUFFER-SUMMARY :NAME PRODUCTION
                                              :CLEARED NIL
                                              :BUSY T
                                              :BUSY->FREE NIL
                                              :ERROR NIL
                                              :ERROR->CLEAR NIL
                                              :FULL NIL
```

```
                                        :MODIFIED NIL
                                        :REQUEST "FIND-UNATTENDED-LETTER"
                                        :CHUNK-NAME NIL
                                        :NOTES NIL)
                              #S(BUFFER-SUMMARY :NAME GOAL
                                        :CLEARED NIL
                                        :BUSY NIL
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL T
                                        :MODIFIED NIL
                                        :REQUEST NIL
                                        :CHUNK-NAME "GOAL"
                                        :NOTES NIL)
                              #S(BUFFER-SUMMARY :NAME VISUAL-LOCATION
                                        :CLEARED NIL
                                        :BUSY NIL
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL T
                                        :MODIFIED NIL
                                        :REQUEST NIL
                                        :CHUNK-NAME "LOC0"
                                        :NOTES NIL)
                              #S(BUFFER-SUMMARY :NAME VISUAL
                                        :CLEARED NIL
                                        :BUSY NIL
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL NIL
                                        :MODIFIED NIL
                                        :REQUEST NIL
                                        :CHUNK-NAME NIL
                                        :NOTES NIL)
                              #S(BUFFER-SUMMARY :NAME MANUAL
                                        :CLEARED NIL
                                        :BUSY NIL
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL NIL
                                        :MODIFIED NIL
                                        :REQUEST NIL
                                        :CHUNK-NAME NIL
                                        :NOTES NIL)))
#S(BUFFER-RECORD :TIME-STAMP 0.025
                 :BUFFERS (#S(BUFFER-SUMMARY :NAME PRODUCTION
                                        :CLEARED NIL
                                        :BUSY T
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL NIL
                                        :MODIFIED NIL
                                        :REQUEST NIL
                                        :CHUNK-NAME NIL
                                        :NOTES NIL)
                              #S(BUFFER-SUMMARY :NAME GOAL
                                        :CLEARED NIL
                                        :BUSY NIL
                                        :BUSY->FREE NIL
                                        :ERROR NIL
                                        :ERROR->CLEAR NIL
                                        :FULL T
```

```
                                    :MODIFIED NIL
                                    :REQUEST NIL
                                    :CHUNK-NAME NIL
                                    :NOTES NIL)
                            #S(BUFFER-SUMMARY :NAME VISUAL-LOCATION
                                    :CLEARED NIL
                                    :BUSY NIL
                                    :BUSY->FREE NIL
                                    :ERROR NIL
                                    :ERROR->CLEAR NIL
                                    :FULL T
                                    :MODIFIED NIL
                                    :REQUEST NIL
                                    :CHUNK-NAME NIL
                                    :NOTES NIL)
                            #S(BUFFER-SUMMARY :NAME VISUAL
                                    :CLEARED NIL
                                    :BUSY NIL
                                    :BUSY->FREE NIL
                                    :ERROR NIL
                                    :ERROR->CLEAR NIL
                                    :FULL NIL
                                    :MODIFIED NIL
                                    :REQUEST NIL
                                    :CHUNK-NAME NIL
                                    :NOTES NIL)
                            #S(BUFFER-SUMMARY :NAME MANUAL
                                    :CLEARED NIL
                                    :BUSY NIL
                                    :BUSY->FREE NIL
                                    :ERROR NIL
                                    :ERROR->CLEAR NIL
                                    :FULL NIL
                                    :MODIFIED NIL
                                    :REQUEST NIL
                                    :CHUNK-NAME NIL
                                    :NOTES NIL)))
```

…

```
E> (get-current-buffer-trace)
#|Warning: get-module called with no current model. |#
NIL
```

add-buffer-trace-notes

Syntax:

add-buffer-trace-notes *buffer notes* -> [notes | **nil**]

Arguments and Values:

buffer ::= a symbol which should be the name of a buffer
notes ::= any data which one wants to have stored in the buffer trace

Description:

The add-buffer-trace-notes command takes two parameters. The first is a symbol which should name a buffer and the second is some data to store in the buffer trace of the current model in the current meta-process at the current time. If buffer is the name of a buffer in the current model then notes will be recorded in the buffer-summary for the named buffer at the current time and notes will be returned. If there is no current model or buffer does not name a valid buffer then the command will print a warning and return **nil**.

Any notes which are added will also be displayed in the graphic tracing tools of the environment when one places the mouse over an event and notes have been added to that buffer during that event's duration.

Examples:

```
> (add-buffer-trace-notes 'goal "save this string")
"save this string"

E> (add-buffer-trace-notes 'not-a-buffer 10)
#|Warning: NOT-A-BUFFER does not name a buffer in the current model no notes added. |#
NIL

E> (add-buffer-trace-notes 'goal "no model")
#|Warning: No current model so cannot add notes. |#
NIL
```

Central Parameters Module

This module maintains three parameters of the system and provides no other model relevant components. These parameters are used by more than one of the cognitive modules to control how they operate. Thus, they need to exist outside of any one of them in particular, and may also be referred to by new modules as well.

This module does provide a way for other modules to register that they are using its :esc parameter and note which of their parameters rely on :esc being set to **t**. It will signal a warning if :esc is **nil** at the start of a model run if those registered parameters have been changed.

This section will only provide the basic details of the parameters. See the specific modules' sections for the exact details of how these parameters modify their operations.

This module has no buffer.

Parameters

:er

This is the Enable Randomness parameter. It specifies how deterministically modules should operate. It can be set to **t** which means act non-deterministically or **nil** which means act deterministically. The default value is **nil**. For the provided modules this specifies what methods should be used to break "ties" during conflict resolution and memory retrievals. Generally, this has more impact when :esc is **nil** because if the subsymbolic parameters are enables there are not often ties for those operations.

:esc

This is the Enable Subsymbolic Computations parameter. It specifies whether modules should work in a purely symbolic fashion or whether they should use their full subsymbolic processing. The default value is **nil** which means that modules should be purely symbolic. If it is set to **t**, then modules should use whatever subsymbolic computations they provide (for example utility for production selection in the procedural module and activation for chunk selection from the declarative module).

:ol

This is the Optimized Learning parameter. It specifies whether modules should use their full computational forms of subsymbolic quantities or use some simplified approximation. Currently, it is only used by the declarative system to control the base-level learning equation, but other modules could also check it as a guide. It can be set to **t**, which means use the optimized (or simplified) form

of the computation, **nil**, which means use the full computation, or a positive number, which can be used as a parameter specifying how much optimization to apply. The default value is **t**.

Commands

register-subsymbolic-parameters

Syntax:

register-subsymbolic-parameters { *param**} -> **nil**

Arguments and Values:

param ::= a keyword which should name a valid parameter

Description:

The register-subsymbolic-parameters command is used to indicate when a module's parameters depend on the :esc parameter being set to **t**. When a model first starts running (time 0) if :esc is set to **nil** and any of the parameters which have been registered in this way have a value other than their default value a warning will be printed like this:

```
#|Warning: Subsymbolic parameters have been set but :esc is currently nil. |#
```

This command only needs to be called once for a given parameter. It does not need to go into the creation or reset functions of a module, and should be called directly after the module definition.

It always returns **nil**.

Examples:

```
> (register-subsymbolic-parameters :ul :alpha)
NIL
```

The Procedural System

The procedural system implements the procedural cognitive module of the theory. The procedural system is implemented as three separate modules in the code. Those three modules are the procedural module, the utility module and the production-compilation module. The procedural module handles the productions' specification and matching at the symbolic level and the conflict resolution among productions which relies on the utility module. The utility module handles the computation of the subsymbolic quantity Utility for the productions and maintains the parameters and history information necessary to do so. Finally, the production-compilation module is responsible for the learning of new productions by the model when it is enabled. Each of those modules is described in detail below.

Procedural Module

The procedural module implements the procedural memory system. It provides the commands for specifying productions, a pattern matcher that works in conjunction with the utility module to choose which production to fire, and tools for inspecting and debugging the productions of a model. This module holds a central role in the system because the productions coordinate the interaction between all of the other modules of the theory.

Productions specify a set of conditions to match against the current contents of the buffers and the states of the modules along with a set of actions to take when the conditions are met. Those actions will then modify the contents of the buffers and make requests of the modules. See the ACT-R tutorial for more details on specifying and using productions.

Conflict Resolution

Only one production can be selected and fired at any time. The process by which the next production to fire is chosen is called conflict resolution. When conflict resolution occurs all productions have their conditions checked to determine which ones match the current state. The conditions specify a conjunction of tests which must all be true for the production to match (see the p command below and tutorial unit 1 for more information on how the matches occur). Among those that match, the one that has the highest utility value will be chosen (see the utility module for details on the utility calculations). If there is a tie for the highest utility value then the setting of the :er parameter (in the central parameters module) determines how that tie is broken. If :er is **t** then the tie is broken randomly. If :er is **nil** then a deterministic process is used such that the same production will be chosen for that model each time the same tie condition occurs. However, that process is not specified as part of the procedural module's definition because it is not intended to be a process which one relies on for production ordering or model control.

The procedural module will automatically schedule conflict-resolution events. The first one is scheduled at time 0 and a new one is scheduled after each production fires. If no production is selected during a conflict-resolution event then a new conflict-resolution event is scheduled to occur after the next change occurs. A change in this context is any other non-maintenance event. The module also schedules production-selected and production-fired events as a result of conflict resolution. Those events will indicate the specific production which was selected and fired and will look like this in the trace:

```
0.000   PROCEDURAL            CONFLICT-RESOLUTION
0.000   PROCEDURAL            PRODUCTION-SELECTED START
0.050   PROCEDURAL            PRODUCTION-FIRED START
```

There is also a procedural module request event scheduled after the production-selected event. That event will not be shown in the trace and serves to indicate that the procedural module has started an action for purposes of the buffer trace module (the event itself performs no actions). Several other events are scheduled as a result of the production selection and production firing processes. Those will be described under the production creation commands (p and p*) below.

The production-fired event is scheduled based on the production's specified action time. That defaults to 50ms, but is controlled by parameters (see the utility module). In addition, if one sets the :vpft parameter to **t** then that time has noise added to it using the randomize-time command (see the random module).

Parameters

:conflict-set-hook

This parameter allows one to specify functions which can intervene in the production selection process. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). During conflict-resolution, after all productions have been matched and have had their utilities calculated, a list of the productions which matched in order of utility (highest first – thus the car of the list is the production which will normally be selected) will be passed to each of the functions on the conflict-set-hook list. The return value of the hook function is used as follows:

- If it is the name of a production in the conflict set then that production will be the one selected regardless of the normal conflict resolution mechanism.
- If it is a string, no production will be selected and a warning will be output to the trace indicating that conflict resolution was canceled and the string returned will be provided as a reason in that warning. The next conflict resolution event will be scheduled to occur after the default action time (see the :dat parameter in the utility module).
- If it is **nil** then the normal conflict resolution mechanism is used.
- If it is anything else, a warning will be output and the default mechanism will be used.

If multiple hook functions are set and more than one returns a non-nil value a warning will be displayed and the result of one of those non-nil values will be used. Which one gets used is picked by an unspecified mechanism. No assumptions should be made as to which will be applied and it may vary from run to run. In general one should not have more than one conflict-set-hook function returning non-nil.

If the parameter is set to **nil** then all functions are removed from the conflict-set-hook.

:crt

The Conflict Resolution Trace parameter can be used to include the details of the conflict resolution process in the trace. If it is set to **t** then after each conflict-resolution event, for each production, it will print out either that the production matches the current state or that it fails to match along with the first condition which failed to match (the information shown by the whynot command).

:cst

The Conflict Set Trace parameter can be used to include the details of the productions in the conflict set during conflict resolution in the model's trace. If it is set to **t** then after each conflict-resolution event the current instantiation of each production that matches is printed in the trace. The instantiation of a production is the production text with the variables replaced by the specific values they have based on the current buffer contents.

:cycle-hook

This parameter allows one to specify functions to be called automatically when productions fire. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). During the production-fired event each of the functions on the cycle-hook list will be called with the name of the production that is firing as the parameter. The return values of those functions are ignored. If the parameter is set to **nil** then all functions are removed from the cycle-hook. A function should only be set once. If a specific function is specified more than once as a value for the cycle-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:do-not-harvest

This parameter controls the strict harvesting mechanism of the productions. By default all buffers are subjected to the strict harvesting practice, but buffers can be exempted from that by specifying them with the :do-not-harvest parameter. The parameter is set one buffer at a time:

```
(sgp :do-not-harvest goal :do-not-harvest visual)
```

but it returns a list of all buffers which have been set as the current value. If it is set to **nil** then all buffers will be subjected to strict harvesting. A particular buffer should only be set once and if it is specified again a warning will be displayed and **nil** will be returned as the current value.

:lhst

The Left Hand Side Trace parameter controls whether the matching conditions from the selected production are shown in the trace. If this parameter is set to **t** (which is the default) and the :trace-detail parameter is set to high then the matching conditions are displayed. If this parameter is set to **nil** or the :trace-detail is medium or low, then such events are not shown.

:ppm

The Procedural Partial Matching parameter controls whether productions are allowed to be selected and fired even if they are not a perfect match to the buffers' current contents. If this parameter is set to a number then production matching is allowed to occur for buffer tests which are not a perfect match to the chunk in the buffer. The default value is **nil** which means productions will only match when the buffer tests are exact matches.

If the procedural partial matching is enabled, then slots tested for equality (slots without a modifier and those with an explicit = modifier) in buffer tests of productions may be considered a match even if the value is not chunk-equal to the current value in the slot of the chunk in the buffer. The partial match will occur if there is a similarity value between the value specified for the slot in the production and the value currently in that slot of the buffer and that similarity is greater than the maximum similarity difference as returned from the declarative module's similarity command.

A production which is not a perfect match will have its utility value decremented for purposes of determining which production to fire, but the production's utility parameters and the learning of utility are not affected by that decrementing. The default decrement will be that for each slot which is not a perfect match the matching utility of the production will be adjusted by adding the similarity difference (a negative value) between the specification and the current buffer chunk's slot value multiplied by the value of the :ppm parameter. Thus, when the procedural partial matching is enabled the utility used to determine whether production i should be selected among those that match would be:

$$U'_i(t) = U_i(t) + \varepsilon + \sum_j ppm * similarity(s_j, v_j)$$

Ui(t) is the production's current true utility value
ε is the noise which may be added to the utility
j is the set of slots for which production i had a partial match
s_j is the specification for the slot j in production i
v_j is the value in the slot j of the chunk in the buffer

Alternatively, one can use the :ppm-hook parameter to specify a function for computing a custom penalty for mismatched production tests. In that case the expression used in the summation above is specified by the user.

:ppm-hook

The Procedural Partial Matching Hook parameter allows one to specify a function that will compute the utility offset added to a production which does not match the current state exactly when the procedural partial matching is enabled. The default value for the parameter is **nil** which results in the offset being computed as described for the :ppm parameter. However, if the parameter is set to a function then that function will be passed a production name and a list of mismatch lists, one for each mismatch which occurred while testing the named production. A mismatch list will be a 5 element list consisting of: a buffer name, a slot name, the specified slot value, the actual value in the slot of the chunk in the buffer, and the reported similarity between those two items. If the hook function returns a number that will be added to the production's utility, any other return value will result in the default calculation being added.

:rhst

The Right Hand Side Trace parameter controls whether the actions from the fired production are shown in the trace. If this parameter is set to **t** (which is the default) and the :trace-detail parameter is set to high then the production's actions are displayed. If this parameter is set to **nil** or the :trace-detail is medium or low, then such events are not shown. Note that this only controls the direct actions made by the procedural module. Whether any events generated by other modules as a result of those actions are displayed is controlled by those modules.

:use-tree

The use tree parameter controls whether a decision tree is created to use during production matching. If the parameter is **nil** (the default value) then each production is tested individually to determine if it matches (basically the way ACT-R has always worked). If :use-tree is set to **t**, then when the model is loaded a decision tree is created based on the constant tests used in the productions and that tree is consulted first in production matching to potentially reduce the set of productions that need to be tested further. This should result in a faster model run time, but does have an initial tree creation cost and requires additional memory to store the tree. That additional time and space used are typically insignificant relative to what it takes to run a model, but in some situations may become a factor.

This new feature is still undergoing testing and refinement. So, if you use it and find any significant problems please let me know.

:vpft

The Variable Production Firing Time parameter controls whether the time of a production's firing is constant or variable. If the parameter is **nil** (the default value) then each production takes its specified action time exactly each time it fires. If :vpft is **t**, then the randomize-time command is

used to randomize the production's action time. Note that randomize-time depends on the setting of the :randomize-time parameter and if it is **nil** then there will be no randomization.

Production buffer

The procedural module has a buffer called production. It exists for the purpose of allowing the module to have its state tracked. It never has any chunks placed into it and practically speaking it does not accept any requests. There is no reason to use the production buffer other than for tracking the state of the procedural module (for instance via the buffer-trace module).

Activation spread parameter: :production-activation
Default value: 0.0

Queries

The production buffer only responds to the default queries.

'State busy' will be **t** when a production is firing (the time between the production-selected and production-fired events). It will be **nil** at all other times.

'State free' will be **nil** when a production is firing and **t** at all other times.

'State error' will always be **nil**.

Requests

Isa *any-valid-chunk-type*
{*slot value*}*

The module will accept any chunk-type as a request without a warning or error, but the request is completely ignored – no actions are performed regardless of the chunk-type or slots specified.

Commands

p/define-p

Syntax:

p production-definition -> [p-name | **nil**]
p-fct (production-definition) -> [p-name | **nil**]
define-p production-definition -> [p-name | **nil**]
define-p-fct (production-definition) -> [p-name | **nil**]

Arguments and Values:

production-definition ::= p-name {doc-string} condition* **==>** action*
p-name ::= a symbol that serves as the name of the production for reference
doc-string ::= a string which can be used to document the production
condition ::= [buffer-test | query | eval | binding | multiple-value-binding]
action ::= [buffer-modification | request | buffer-clearing | modification-request | buffer-overwrite | eval | binding | multiple-value-binding | output | **!stop!**]
buffer-test ::= **=**buffer-name**> isa** chunk-type slot-test*
buffer-name ::= a symbol which is the name of a buffer
chunk-type ::= a symbol which is the name of a chunk-type in the model
slot-test ::= {slot-modifier} slot-name slot-value
slot-modifier ::= [**= | - | < | > | <= | >=**]
slot-name ::= a symbol which names a slot in the specified chunk-type
slot-value ::= a variable or any Lisp value
query ::= **?**buffer-name**>** query-test*
query-test ::= {**-**} queried-item query-value
queried-item ::= a symbol which names a valid query for the specified buffer
query-value ::= a bound-variable or any Lisp value
buffer-modification ::= =buffer-name> slot-value-pair*
slot-value-pair ::= slot-name bound-slot-value
bound-slot-value ::= a bound variable or any Lisp value
request ::= +buffer-name> [direct-value | **isa** chunk-type request-spec*]
request-spec ::= {slot-modifier} [slot-name | request-parameter] slot-value
request-parameter ::= a Lisp keyword naming a request parameter provided by the buffer specified
direct-value ::= a variable or Lisp symbol
buffer-clearing ::= -buffer-name>
modification-request ::= +buffer-name> slot-value-pair*
buffer-overwrite ::= =buffer-name> direct-value

variable ::= a symbol which starts with the character **=**
eval ::= [**!eval!** | **!safe-eval!**] form
binding ::= [**!bind!** | **!safe-bind!**] variable form
multiple-value-binding ::= **!mv-bind! (**variable^{+}**)** form
output ::= **!output!** [output-value | **(** format-string format-args***)** | **(**output-value***)**]
output-value ::= any Lisp value or a bound-variable
format-string ::= a Lisp string which may contain format specific parameter processing character
format-args ::= any Lisp values, including bound-variables, which will be processed by the preceding format-string
bound-variable ::= a variable which is used in the buffer-test conditions of the production (including a variable which names the buffer that is tested in a buffer-test or dynamic-buffer-test) or is bound with an explicit binding in the production
form ::= a valid Lisp form

Here is an example production that assumes the goal, declarative, imaginal, and visual modules as described elsewhere in this document are available, that this chunk-type has been defined:

```
(chunk-type goal-type slot1 value test buffer state step)
```

and that there are functions defined called check-value, get-a-state, and record-results.

This production is purely for demonstration – it does not represent any particular usage from a real model.

```
(p example-production "a production showing all syntactic elements"
  =goal>
    isa goal-type
      state start
      test =test
      < value 4
      value =value
      - slot1 =test
      slot1 =last-loc
      buffer =check
  ?visual>
      state =check
      buffer empty
  =visual-location>
    isa visual-location
      >= screen-x =value
      <= screen-x 100
      >  screen-y =value
      <  screen-y =max-value
      value =current-value
  =imaginal>
    isa visual-object

  !eval! (check-value =value)
  !bind! =max-value (+ =value 100)
  !mv-bind! (=quotient =remainder) (floor =max-value)
==>
  !safe-bind! =new-state (get-a-state)
  =goal>
      state =new-state
      value =quotient
      step continue
  +retrieval>
    isa visual-location
      :recently-retrieved nil
      < screen-x =max-value
      - value =current-value
      color blue
  +visual-location> =last-loc
  +imaginal>
      status done
  =visual> =imaginal
  !output! (Moving to state =new-state with max-value of =max-value)
  !safe-eval! (record-results =check 75 =quotient =remainder)
  !stop!
)
```

Description:

The p family of commands is used to create the productions for a model. p and p* are the primary commands for creating standard and dynamic pattern matching productions respectively. The "define-" commands are provided as a convenience for those using the MCL editor and operate like the corresponding command without the "define-".

A production must be given a name and can be given an optional documentation string. Then it contains a set of conditions to be tested and a set of actions to be executed when the production is fired. If the specification of the production is syntactically correct, then that production is entered into the procedural memory of the current model, as maintained by the procedural module, and the production's name is returned.

If the name given for a production is already used by a production in the procedural memory of the current model then a warning is printed, the old production is removed, and it is replaced with the newly defined production.

If there is an error in parsing the production then one or more warnings will be output indicating what was wrong, no new production is entered into the procedural memory, and **nil** is returned.

Within a production there are many possible components and each will be described in detail below.

Variables

Productions contain variables to allow for more general matching and actions. The variables are symbols which start with an "=" character e.g. =slot, =answer, =goal. The variables are only relevant within the context of a single production and serve two purposes. The first is to compare two or more values, and the other is to copy a value from a condition into an action or specific query. A single variable may be used for both purposes within a production i.e. it could compare two slots to determine that they are the same and then copy that value into a request action. One thing to note about variables in a production is that they cannot be used to directly compare that two slots are empty (have the value **nil**) thus any positive test which involves a variable will automatically fail if the slot being tested is empty.

Constants

Any symbols used in the production for values which are not variables are assumed to be the names of chunks. If there is not a chunk with such a name at the time the production is created then a new chunk, of chunk-type chunk, will automatically be created with that name.

Modifiers

When testing slot values in conditions and checking queries in a production there are several modifiers which can be used: =, - , <, >, <=, and >=. The = modifier is used to check that the value in the buffer chunk's slot and the value given in the production are equal (see chunk slot equality below). If no modifier is provided, then the = modifier is assumed (one generally never sees the = modifier in a production). The – modifier means to negate the test. In a buffer test that means that the buffer chunk's slot does not equal the value specified in the production and for a query it means that the match should succeed if the specified query returns false. The inequality tests (<, >, <=, and =>) can only be used when the values are numbers (the test fails if either of the elements being tested is

not a number). If the values are numbers then the test is true if the inequality holds between the value in the specified slot of the chunk in the buffer and the value specified in the production in that order i.e. if the test were < slot1 10 then the condition matches if the value in the slot1 chunk of the buffer is less than 10.

Conditions

The conditions of the production are also referred to as the production's Left Hand Side (LHS). They are a conjunction of tests which must all be true for the production to be selected. The order in which the conditions are specified does not matter – there are no ordering constraints and the order in which the tests are performed will not necessarily be the same as they are specified in the production. Here is the general description of the conditions that can be tested in a production. When a production is selected during conflict resolution it will generate an event to indicate each buffer match and buffer query condition that it contains. They are only shown in the trace if :trace-detail is high and :lhst is t.

buffer-test

The buffer-test is the primary condition used in productions. It is comparing the chunk currently in a specific buffer to a pattern provided in the production. The slot comparison is done using the same mechanisms described for the equal-chunks command (note however if the :ppm parameter is set then imperfect matches may be allowed as described under :ppm). In a production which is selected, this is referred to as harvesting the chunk in the buffer. Here is an example of a buffer-test:

```
=goal>
   isa goal-chunk
   slot1  =value
   state   start
 - slot2  =value
```

Every buffer test starts with a variable that names the buffer followed by the '>' character. Thus, this is testing the chunk in the model's goal buffer. Then, the buffer-test requires checking the chunk-type of the chunk with the **isa** *chunk-type*. In this case it is checking if it is of the type goal-chunk which will also match if the chunk is of a sub-type of the chunk-type goal-chunk. Then the slots of that chunk may be tested. In this case it is testing that the state slot contains the chunk named start, that the slot1 slot holds some value (it is not empty because as noted above variables will not match to an empty slot), and that the slot2 slot does not have the same value as the slot1 slot.

In the trace a buffer-test will show up as a buffer-read-action event like this:

```
     0.000   PROCEDURAL             BUFFER-READ-ACTION GOAL
```

indicating which buffer was tested by the production.

query

A query is one or more tests of a buffer or module. There are several default queries which may be made of any buffer/module and a module may provide many more queries to which it will respond. Each query will be respond as either true or false. The production will only match if the result of each query is true, or if the result is false and the negative test modifier, '-', is used. The queries that can be specified for every buffer/module are:

```
buffer empty
buffer full
buffer requested
buffer unrequested
state free
state busy
state error
error t
error nil
```

The first four are tests of the buffer itself and the module is not contacted to determine the status. The rest, and any others which a module provides, are tests which are relayed to the module to get its response. For the first four, the semantics of the queries are the same for all buffers and are as follows:

- buffer full: is true only if there is currently any chunk in the buffer
- buffer empty: is true only if there is not a chunk currently in the buffer
- buffer requested: is true only if there currently is a chunk in the buffer and the module has indicated that it was put there as a result of a request to the module (note: that the default call to set-buffer-chunk is to indicate that it is requested so commands which put chunks into buffers other than as a request must indicate they are not requested for this to be meaningful)
- buffer unrequested: is true only if there currently is a chunk in the buffer and it has been marked as not having been put there as a result of a request to the module

The other queries are dependent on the how the module responds to them and thus one needs to check the particular module description to determine how they are used. Generally, they have the following semantics, but some modules may not follow this convention:

- state free: is true if the module is ready for new requests
- state busy: is true if the module is currently handling a request
- state error: is true if the last request resulted in some sort of error
- error t: this is the same as a test of state error (that is the query which will be sent to the module). This is provided as a shorthand notation to possibly make the production easier to read

- error nil: this is the same as a query for "– state error" thus checking that the module is not currently reporting that "state error" is true and again is a shorthand notation in the production syntax

Here is an example query to the goal buffer:

```
?goal>
  state free
  buffer full
 - state error
```

A query starts with a symbol composed of a '?', the name of the buffer being queried, and the symbol '>'. This query is testing that the goal module is currently reporting as state free, there is currently a chunk in the goal buffer, and that the goal module is not currently reporting an error.

In the trace each buffer queried by the selected production will show up as a query-buffer-action:

```
     0.450   PROCEDURAL             QUERY-BUFFER-ACTION GOAL
```

eval

The !eval! condition is provided to allow the modeler to add any arbitrary conditions to the LHS of a production or to perform some side effects (like data collection or model tracking information). In the testing of the production's conditions the form provided to evaluate will be called during conflict resolution. If the result of the evaluation is **nil**, then the production cannot be selected, but any other return value will allow the production to continue with the pattern matching of the LHS. Using !eval! is something that should be considered carefully when modeling. Generally, they should be used for abstracting away components of the model or task which are unnecessary for the current modeling or for performing non-model related operations because the actions performed by a !eval! are not necessarily based on the principles of the ACT-R theory.

Here is an example of a call to !eval!:

```
!eval! (special-test =var1 =var2 start)
```

This would pass three parameters to the function called special-test. Those parameters will be the current bindings for the =var1 and =var2 variables in the production and the symbol start. If that function returns a non-**nil** value then this production can continue in conflict resolution, but if it returns **nil** then it will be removed from the current conflict set.

There are actually two forms of the eval condition !eval! and !safe-eval!. Both do the same thing, and the difference is only meaningful for the production compilation mechanism which is described in a different section.

binding

The !bind! condition is very similar to the !eval! condition. However, with !bind! the return value of the evaluation is saved in a variable of the production which can then be used just as any other variable i.e. to test chunk slots or be copied into the actions of the production. As with !eval! the value must be non-**nil** for the production to continue in the conflict set. Here is an example of a !bind!:

```
!bind! =test-value (convert-value =var)
```

This will pass the current binding of the =var variable to the function convert-value and then bind the result to the =test-value variable in the production.

Just like !eval!, there is also a second binding condition !safe-bind! which operates exactly like the !bind! condition for conflict resolution purposes, but has a difference with respect to how production compilation occurs.

It is also possible to bind multiple return values in a single test with the !mv-bind! condition. This works the same as !bind! except a list of variables is specified and each is bound to the corresponding return value from the evaluation. If there are fewer return values than variables to be bound the production will not match, and if any of the variables specified results in a binding to **nil** then the production will also not match. Here is an example of !mv-bind!:

```
!mv-bind! (=value1 =value2) (split-values =var)
```

Actions

When a production fires it executes all of its actions, which are also referred to as its Right Hand Side (RHS). Those actions are executed in a specific order regardless of how they are specified within the production definition. Other than the eval, output, and bind actions, all of the actions are handled as individual events at the time of the production's firing. The ordering of those events is fixed by using the priority in the scheduling of the events. Those events will be shown in the trace if :trace-detail is high and :rhst is t. The ordering of the actions, along with their specific priorities, is as follows:

1. All eval, output and bind calls occur during the production-fired event and the other events are then created with the priorities specified

2. All mod-buffer actions [priority 100]
3. All buffer overwrite actions [priority 90]
4. All module requests and module modification requests [priority 50]
5. All buffer clearings [priority 10]
6. A !stop! action generates a break event [priority :min]

In general the production actions fall into three categories: cognitive actions performed directly by the production (any that begin with an = or -), actions that are passed off to another module to handle (those that begin with a +), and debugging/modeler extension actions (those that begin with an !). The different actions possible are described in the following sections.

buffer modification

A buffer modification action is used to directly change the slot values of a chunk in a buffer. This is done directly by the production and works the same for every buffer (the buffer's module is not contacted about the change). It is essentially the same as using the mod-chunk command on the chunk in the buffer. Here is an example of a buffer modification:

```
=goal>
   state next-step
   slot1 =value
```

The buffer modification must first name the buffer to be modified by using a symbol composed of the '=' character, the name of the buffer and the '>' character. That is followed by pairs of slot names and new values. Thus, this example will change the state slot of the chunk in the goal buffer to now contain the chunk next-step and the slot1 slot will now hold whatever the variable =value is bound to in the production.

In order to perform a buffer modification action that buffer must have also been tested with a buffer-test in the conditions of the production.

The buffer modification actions will show up in the trace as mod-buffer-chunk events indicating the buffer that is modified:

```
     0.050   PROCEDURAL             MOD-BUFFER-CHUNK GOAL
```

buffer-clearing

A buffer clearing action is used to remove a chunk from a buffer. As with buffer modification actions, this is done directly by the production without consulting the buffer's module. Note however, that a module may be monitoring for buffer clearing events independently of the procedural module. Once the action completes the buffer will be empty. Here is an example that would clear the goal buffer:

```
-goal>
```

The action shows up in the trace as a clear-buffer event indicating which buffer was cleared:

```
     0.150   PROCEDURAL             CLEAR-BUFFER GOAL
```

A buffer can be cleared regardless of whether or not it was tested on the production's LHS. Note that often one does not need to explicitly clear a buffer because there are two situations which result in buffers being cleared implicitly (see "Implicit Production Actions" below).

buffer overwrite

A buffer overwrite action is used to copy a specific chunk into a particular buffer. As with the buffer modification and buffer clearing actions, this is performed directly by the production without notifying the buffer's module. This action does not clear the buffer first. Thus, the chunk which was in the buffer is essentially lost when this action occurs (the declarative module will not store that chunk in the model's declarative memory). Here is an example of a buffer overwrite action:

```
=goal> =value
```

This will replace the chunk in the goal buffer with the chunk that is bound to the =value variable. It will show up in the trace as an overwrite-buffer-chunk event indicating the buffer and the chunk being copied into it:

```
     0.600   PROCEDURAL             OVERWRITE-BUFFER-CHUNK GOAL CHUNK-10
```

If =value is not bound to a valid chunk name in this production's instantiation, then a warning will be printed at run time and no change will be made to the buffer:

```
#|Warning: overwrite-buffer-chunk called with an invalid chunk name BAD-NAME |#
```

request

A request is a how the production asks another module to perform some action. Syntactically, a request can be specified for any buffer. However, semantically, what a request actually does is specific to the module and some modules may not even accept requests through their buffers or may have a more restrictive syntax than the general syntax available in the production (for instance only specifying a slot once in the request). Thus, to know what can be requested, how it needs to be specified, and how that will then be processed one needs to know the details of the modules. A

syntactically correct production could make semantically invalid requests which would typically generate warnings at run time.

In the production, there are two ways to specify the request. It can be done by specifying the details of the request (similar to how buffer tests are constructed) or by directly specifying a chunk. The direct specification with a chunk is essentially the same as specifying all the slots and values of that chunk in the request (example provided below). As far as the module which receives the request is concerned, there is no difference between the different specifications in the production i.e. the module has no way to distinguish a direct chunk request from one which was specified by explicit slot value specifications.

Here is an example of specifying the details of a request:

```
+retrieval>
  isa some-type
   slot1 =value
   - slot1 10
   slot2  start
   <= count =count
   :recently-retrieved nil
```

Assuming that the model has a chunk-type named some-type which has slots called slot1, slot2, and count that request would be sent off to the retrieval buffer's module for handling. What it does depends on the module. Note that in addition to the slots which are valid for the chunk-type specified a buffer may have additional items which can be specified (in this case :recently-retrieved). Those are referred to as request parameters and always start with a ':'. They are specific to the buffer and as with all other aspects of the request, one should consult the module to determine what request parameters are available and what purpose they serve.

Here is an example of a direct chunk request:

```
+retrieval> =value
```

If =value is bound to a chunk name in the instantiation of the production being fired, then that chunk is essentially expanded to its slot value pairs to make the request. Thus, if =value were bound to the chunk A and the chunk A were defined like this:

```
(chunk-type test-type state slot1 slot2)
(define-chunks (a isa test-type state start slot2 10))
```

Then that would be equivalent to specifying this in the production:

```
+retrieval>
  isa test-type
   state start
   slot1 nil
   slot2 10
```

If a variable used in a direct chunk request is not bound to the name of a chunk in the production's instantiation, then a warning is printed and no request is made (note that the implicit clearing described below is still performed even if such a warning is encountered). The warning will look like this in the trace:

```
#|Warning: schedule-module-request called with an invalid chunk-spec NIL |#
```

A valid request action will show up in the trace as a module-request event specifying the buffer to which the request was sent:

```
     0.800   PROCEDURAL             MODULE-REQUEST GOAL
```

Typically, that will be followed by events from the module to which the request was made performing the requested action.

There is one additional note on request actions which may be useful for those implementing new modules. If a module has a warning function, then whenever a production is selected that has requests to that module the procedural module will call that module's warning function at the end of the conflict-resolution event. See the module creation section for more details.

modification request

A modification request is similar to the request action. It is a way for the production to ask a module to do something which looks like a buffer modification. As with the buffer modification action, the buffer to which this request is made must have been used in a buffer test on the production's LHS. As with a request, what the module does in response to a modification request is purely up to the module and most of the modules provided do not even accept such requests. Here is an example of a modification-request:

```
+imaginal>
   slot1 =value
   slot2 start
```

This would send those slot and value pairs off to the imaginal buffer's module to process. A modification request will show up in the trace as a module-mod-request event specifying the buffer to which the request is made:

```
     1.000   PROCEDURAL             MODULE-MOD-REQUEST IMAGINAL
```

If a module does not accept modification requests then a warning like this will be displayed when the production is fired:

```
#|Warning: Module XXXXX does not support buffer modification requests. |#
```

eval

The eval action works just like the eval condition except that the return value does not matter.

binding

The binding action works just like the binding condition except that a returned value of **nil** can be bound to the variable or variables in the action.

output

The !output! action allows one to embed additional text in the model's trace. The output will be shown when the :v parameter is non-**nil** under any of the :trace-detail setting.

There are three ways to use the output action. It can be used to just print a single value like this:

```
!output! =value
!output! started
```

In that case the item specified will be output followed by a newline in the trace. If the item is a variable then it is the binding of the variable which is output.

It can also output several items if they are placed into a list:

```
!output! (the value is =value)
```

In that case all of the items will be printed on one line followed by a newline. Again, variables will be replaced with their current bindings before outputting.

Finally, it can use the Lisp format control mechanisms to output the text. If the first item given in a list to an !output! action is a string then that string is assumed to be a format specification. It is used to generate the output text using the remaining arguments in the same way that the Lisp format command would:

```
!output! ("The count is ~6,3f.~%The value is ~a~%" =count =value)
```

stop

The stop action is used to force the model to stop after firing that production. A stop action is created with this:

```
!stop!
```

A break event will be generated by the stop action that will cause the current run to terminate.

Implicit production Actions

In addition to the events specified in the production there are two situations where a buffer clearing action will be implicitly executed when the production fires. They are referred to as strict harvesting and implicit clearing.

strict harvesting

Strict harvesting means that when a production tests a buffer on its LHS (harvests the chunk) it will automatically clear that buffer as well unless one of two things are done. If a modification is performed on that buffer (either a procedural modification with an = or a module modification request with a +) then the buffer will not be cleared. Also, if the buffer has been specified as one which should not be strict harvested using the :do-not-harvest parameter then it will never be subject to the strict harvesting policy.

request clearing

For each buffer which has a module request on the RHS of a production there is an implicit buffer clearing action performed on that buffer. There is no mechanism provided for suppressing this clearing action.

Examples:

For examples of productions in actual models see the tutorial example models.

Here are examples showing the types of warnings generated by productions for implicit chunk creation, some syntax errors, and lack of a current model. This does not cover all possible syntax errors or warnings. Only those examples which result in no production being defined are indicated as errors.

For these examples the following chunk-type is assumed to have been defined:

```
(chunk-type goal-type slot slot2 state)

1> (p test
    "Automatically creating a chunk which is referenced"
    =goal>
     isa goal-type
      state start
```

```
    ==>
   )
#|Warning: Creating chunk START of default type chunk |#
TEST

2> (p test
    "Redefining the production test"
    =goal>
     isa goal-type
      state start
    ==>
   )
#|Warning: Production TEST already exists and it is being redefined. |#
TEST

E> (p test
    "No current model"
    =goal>
     isa goal-type
      state start
    ==>
   )
#|Warning: get-module called with no current model. |#
#|Warning: No procedural modulue found cannot create production. |#
NIL

E> (p test2
    "Invalid slot name in condition"
    =goal>
     isa goal-type
      bad-slot start
    ==>
   )
#|Warning: Invalid slot-name BAD-SLOT in call to define-chunk-spec. |#
#|Warning: Invalid syntax in =GOAL> condition. |#
#|Warning: No production defined for (TEST2 "Invalid slot name in condition" =GOAL> ISA
GOAL-TYPE BAD-SLOT START ==>). |#
NIL

E> (p test2
    "Invalid buffer name in condition"
    =buffer>
     isa goal-type
      state start
    ==>
   )
#|Warning: First item on LHS is not a valid command |#
#|Warning: No production defined for (TEST2 "Invalid buffer name in condition" =BUFFER>
ISA GOAL-TYPE STATE START ==>). |#
NIL

E> (p test2
    "Invalid buffer in query after a valid buffer test"
     =goal>
       isa goal-type
     ?buffer>
       buffer empty
     ==>
   )
#|Warning: Invalid slot-name ?BUFFER> in call to define-chunk-spec. |#
#|Warning: Invalid syntax in =GOAL> condition. |#
#|Warning: No production defined for (TEST2 "Invalid buffer in query after a valid buffer
test" =GOAL> ISA GOAL-TYPE ?BUFFER> BUFFER EMPTY ==>). |#
NIL

E> (p test2
    "Buffer not tested on LHS for modification action"
```

```
    ==>
     =goal>
       state start
    )
#|Warning: Cannot modify buffer GOAL if not matched on LHS. |#
#|Warning: No production defined for (TEST2 "Buffer not tested on LHS for modification
action" ==> =GOAL> STATE START). |#
NIL

E> (p test2
    "Invalid buffer modification slot"
     =goal>
      isa goal-type
    ==>
     =goal>
      bad-slot start
)
#|Warning: Invalid buffer modification (=GOAL> BAD-SLOT START). |#
#|Warning: No production defined for (TEST2 "Invalid buffer modification slot" =GOAL> ISA
GOAL-TYPE ==> =GOAL> BAD-SLOT START). |#
NIL
```

p*/define-p*

Syntax:

p* dynamic-production-definition -> [p-name | **nil**]
p*-fct (dynamic-production-definition) -> [p-name | **nil**]
define-p* dynamic-production-definition -> [p-name | **nil**]
define-p*-fct (dynamic-production-definition) -> [p-name | **nil**]

Arguments and Values:

dynamic-production-definition ::= p-name {doc-string} dynamic-condition* **==>** dynamic-action*
p-name ::= a symbol that serves as the name of the production for reference
doc-string ::= a string which can be used to document the production
condition ::= [buffer-test | query | eval | binding | multiple-value-binding]
action ::= [buffer-modification | request | buffer-clearing | modification-request | buffer-overwrite | eval | binding | multiple-value-binding | output | **!stop!**]
dynamic-condition ::= [dynamic-buffer-test | condition]
dynamic-action ::= [dynamic-buffer-modification | dynamic-request | dynamic-modification-request | action]
buffer-test ::= **=**buffer-name**> isa** chunk-type slot-test*
buffer-name ::= a symbol which is the name of a buffer
chunk-type ::= a symbol which is the name of a chunk-type in the model
slot-test ::= {slot-modifier} slot-name slot-value
slot-modifier ::= [**=** | **-** | **<** | **>** | **<=** | **>=**]
slot-name ::= a symbol which names a slot in the specified chunk-type
slot-value ::= a variable or any Lisp value
dynamic-buffer-test ::= **=**buffer-name**> isa** chunk-type dynamic-slot-test*
dynamic-slot-test ::= {slot-modifier} [slot-name | variable] slot-value
query ::= **?**buffer-name**>** query-test*
query-test ::= {**-**} queried-item query-value
queried-item ::= a symbol which names a valid query for the specified buffer
query-value ::= a bound-variable or any Lisp value

buffer-modification ::= **=**buffer-name**>** slot-value-pair*
slot-value-pair ::= slot-name bound-slot-value
bound-slot-value ::= a bound-variable or any Lisp value
request ::= **+**buffer-name**>** [direct-value | **isa** chunk-type request-spec*]
request-spec ::= {slot-modifier} [slot-name | request-parameter] slot-value
request-parameter ::= a Lisp keyword naming a request parameter provided by the buffer specified
direct-value ::= a variable or Lisp symbol
buffer-clearing ::= **-**buffer-name**>**
modification-request ::= **+**buffer-name**>** slot-value-pair*
buffer-overwrite ::= **=**buffer-name**>** direct-value
dynamic-buffer-modification ::= **=**buffer-name**>** dynamic-slot-value-pair*
dynamic-slot-value-pair ::= [slot-name | bound-variable] bound-slot-value
dynamic-request ::= **+**buffer-name**>** [direct-value | **isa** chunk-type dynamic-request-spec*]
dynamic-request-spec ::= {slot-modifier} [slot-name | request-parameter | bound-variable] slot-value
dynamic-modification-request ::= **+**buffer-name**>** dynamic-slot-value-pair*
variable ::= a symbol which starts with the character =
eval ::= [**!eval!** | **!safe-eval!**] form
binding ::= [**!bind!** | **!safe-bind!**] variable form
multiple-value-binding ::= **!mv-bind! (**variable^{+}**)** form
output ::= **!output!** [output-value | (format-string format-args*) | (output-value*)]
output-value ::= any Lisp value or a bound-variable
format-string ::= a Lisp string which may contain format specific parameter processing character
format-args ::= any Lisp values, including a bound-variable, which will be processed by the preceding format-string
bound-variable ::= a variable which is used in a buffer-test condition of the production (including a variable which names the buffer that is tested in a buffer-test or dynamic-buffer-test) or is bound with an explicit binding in the production
form ::= a valid Lisp form

Description:

The p* command operates just like the p command but there are two additional things which are allowed in p* that make it more flexible (referred to as dynamic pattern matching).

The general operation is described under the p command above and only the new functionality will be described here.

The first extension is that in the buffer tests, buffer modifications, requests and modification requests a variable may be used in the slot-name position. Here is an example production showing that:

```
(p* dynamic-production
  =goal>
   isa goal-type
    slot =slot1
    modify =slot2
=retrieval>
   isa fact
    =slot1 =value
==>
  =goal>
   =slot2 =value
```

```
 +retrieval>
   isa fact
   =slot2 =value
)
```

There are however two restrictions on how that can be used. First, there is no search performed in the matching. Thus all variable slot names must be "grounded" by having a binding as either a slot value in an explicitly named slot or with an explicit bind. This means the dynamic pattern matching cannot be used to "find a slot which has a specific value" like this:

```
(p* invalid
    =visual-location>
      isa visual-location
      =slot  150
==>
   …
)
```

Also, there is only one level of indirection allowed in the use of variablized slot names. Thus it is not possible to do something like this:

```
(p* invalid
   =visual-location>
    isa visual-location
     screen-x =val
     =val =val2
     =val2 300
==>
…
)
```

However, one can go one level deep across multiple buffers:

```
(p* valid
  =goal>
   isa visual-location
    screen-x =slot1
    =slot2 =value
  =imaginal>
   isa visual-location
    screen-y =slot2
    =slot1 =value
==>
…)
```

The second extension p* enables is an adjustment to how the buffer modification action operates when variablized slots are used. Here is an example for reference:

```
(p modify-buffer
  =goal>
   isa goal-type
    slot =slot
==>
  =goal>
    =slot new-value
)
```

If the binding of =slot is the name of a slot in the chunk-type goal-type then this action is exactly as it is described for the p command. However, if the binding of =slot does not name a valid slot in the goal-type chunk-type then this action will extend the chunk-type to now have a slot of that name and then modify the value of that slot as would normally be done with the action. That will show up in the trace with an extending-chunk-type event which shows the chunk-type and the slot which is being added:

```
     0.300   PROCEDURAL             EXTENDING-CHUNK-TYPE GOAL-TYPE NEW-SLOT
```

Effectively, this allows one to create the chunk-types dynamically with slots that are meaningful at the time of the run (instead of needing to name all slots in advance). See the section on extending chunk-types for more details on what it means to extend the chunk-type.

Examples:

As with the p command only examples of incorrect p* productions will be shown to demonstrate some of the warnings given. Not all possible syntax errors are presented.

For these examples the following chunk-type is assumed to have been defined:

```
(chunk-type goal-type slot slot2 state)

E> (p* test2
    "Ungrounded variablized slot"
    =goal>
     isa goal-type
      =slot start
    ==>
   )
#|Warning: No production defined for (TEST2 "Ungrounded variablized slot" =GOAL> ISA GOAL-
TYPE =SLOT START ==>) because =SLOT is not bound on the LHS. |#
NIL
E> (p* test2
    "Multilevel indirection"
    =goal>
     isa goal-type
      slot2 =slot
      =slot =slot2
      =slot2 start
    ==>
   )
#|Warning: No production defined for (TEST2 "Multilevel indirection" =GOAL> ISA GOAL-TYPE
SLOT2 =SLOT =SLOT =SLOT2 =SLOT2 START ==>) because slot-name variable =SLOT2 is not bound
in a constant named slot i.e. there is more than one level of indirection. |#
NIL

E> (p* test2
    "Variable used in a query slot"
    !bind! =query (generate-query)
    ?goal>
      =query free
     ==>
    )
#|Warning: Invalid buffer query (?GOAL> =QUERY FREE). |#
#|Warning: No production defined for (TEST2 "Variable used in a query slot" !BIND! =QUERY
(GENERATE-QUERY) ?GOAL> =QUERY FREE ==>). |#
```

```
NIL
```

all-productions

Syntax:

all-productions -> (production-name*)

Arguments and Values:

production-name ::= a symbol which names a production in the current model

Description:

The all-productions command takes no parameters. It returns a list of the names of all the productions defined in the current model. If there is no current model it prints a warning and returns **nil** (an empty list).

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
> (all-productions)
(START INCREMENT STOP)

E> (all-productions)
#|Warning: get-module called with no current model. |#
NIL
```

pp

Syntax:

pp *production-name** -> (production-name*)
pp-fct (*production-name**) -> (production-name*)

Arguments and Values:

production-name ::= a symbol which names a production in the current model

Description:

The pp command is used to print the production text of a production. It takes any number of production names and for each one prints out the text of the named production in the current model. If no names are provided it prints out all of the productions in the current model (which can be useful when production compilation is enabled to see what productions the model has learned). It returns a list of the names of the productions that were printed.

If there is no current model a warning is printed and **nil** is returned. If an invalid production name is given a warning is printed.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
> (pp)
(P START
   =GOAL>
        ISA COUNT-FROM
        START =NUM1
        COUNT NIL
 ==>
   =GOAL>
        COUNT =NUM1
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
)
(P INCREMENT
   =GOAL>
        ISA COUNT-FROM
        COUNT =NUM1
    -   END =NUM1
   =RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
        SECOND =NUM2
 ==>
   =GOAL>
        COUNT =NUM2
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM2
   !OUTPUT! (=NUM1)
)
(P STOP
   =GOAL>
        ISA COUNT-FROM
        COUNT =NUM
        END =NUM
 ==>
   -GOAL>
   !OUTPUT! (=NUM)
)
(START INCREMENT STOP)

> (pp start)
(P START
   =GOAL>
        ISA COUNT-FROM
        START =NUM1
        COUNT NIL
 ==>
   =GOAL>
        COUNT =NUM1
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
)
(START)

> (pp-fct '(increment))
```

```
(P INCREMENT
   =GOAL>
        ISA COUNT-FROM
        COUNT =NUM1
     -  END =NUM1
   =RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
        SECOND =NUM2
 ==>
   =GOAL>
        COUNT =NUM2
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM2
   !OUTPUT! (=NUM1)
)
(INCREMENT)

E> (pp bad-name start)
#|Warning: No production named BAD-NAME is defined |#
(P START
   =GOAL>
        ISA COUNT-FROM
        START =NUM1
        COUNT NIL
 ==>
   =GOAL>
        COUNT =NUM1
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
)
(START)

> (pp)
#|Warning: get-module called with no current model. |#
#|Warning: No procedural module found |#
NIL
```

pbreak/punbreak

Syntax:

pbreak *production-name** -> (break-production*)
pbreak-fct (*production-name**) -> (break-production*)
punbreak *production-name** -> (break-production*)
punbreak-fct (*production-name**) -> (break-production*)

Arguments and Values:

production-name ::= a symbol that names a production in the current model
break-production ::= a symbol that names a production which is currently set to break the run in the current model

Description:

The pbreak command can be used to force a break event to occur when particular productions are selected during conflict resolution. Each production which is specified in a call to pbreak will force a break event if it is selected. Before the break, the current instantiation of the production will be output to the trace.

The punbreak command is used to remove the productions from the break condition. Each production passed to punbreak will no longer force a break event upon its selection. If no productions are specified for punbreak then all productions have their break status cleared.

Both commands return a list of all productions which currently have a break status set in the current model.

If there is no current model or a production name is invalid a warning is printed.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
1> (pbreak)
NIL

2> (pbreak start)
(START)

3> (run 10)
     0.000   GOAL                    SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
     0.000   PROCEDURAL              PRODUCTION-SELECTED START
     (P START
   =GOAL>
       ISA COUNT-FROM
       START 2
       COUNT NIL
 ==>
   =GOAL>
       COUNT 2
   +RETRIEVAL>
       ISA COUNT-ORDER
       FIRST 2
)
0.000   ------                  BREAK-EVENT PRODUCTION START

4> (pbreak-fct '(start increment))
(INCREMENT START)

5> (punbreak start)
(INCREMENT)

6> (pbreak start stop)
(STOP INCREMENT START)

7> (punbreak-fct '(increment stop))
(START)

8E> (pbreak bad-name)
#|Warning: BAD-NAME is not the name of a production |#
(START)
```

```
9E> (punbreak-fct '(not-a-production))
#|Warning: NOT-A-PRODUCTION is not the name of a production |#
(START)

10> (punbreak)
NIL

11> (pbreak)
NIL

E> (pbreak)
#|Warning: There is no current model - pbreak cannot be used. |#
NIL

E> (punbreak start)
#|Warning: There is no current model - punbreak cannot be used. |#
NIL
```

pdisable/penable

Syntax:

pdisable *production-name** -> (disabled-production*)
pdisable-fct (*production-name**) -> (disabled-production*)
penable *production-name** -> (disabled-production*)
penable-fct (*production-name**) -> (disabled-production*)

Arguments and Values:

production-name ::= a symbol that names a production in the current model
disabled-production ::= a symbol that names a production which is currently disabled in the current model

Description:

The pdisable command can be used to disable particular productions. A production which is disabled will not participate in conflict resolution. Each production which is specified in a call to pdisable will be disabled.

The penable command is used to enable productions which have been disabled. Each production passed to penable will no longer be disabled. If no productions are specified for penable then all productions will be enabled.

Both commands return a list of all productions which currently have been disabled in the current model.

If there is no current model or a production name is invalid a warning is printed.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
1> (pdisable)
```

```
NIL

2> (pdisable start stop)
(STOP START)

3> (penable-fct '(start))
(STOP)

4> (pdisable-fct '(start increment))
(STOP INCREMENT START)

5> (penable)
NIL

E> (penable)
#|Warning: There is no current model - penable cannot be used. |#
NIL

E> (pdisable bad-name)
#|Warning: BAD-NAME is not the name of a production |#
NIL

E> (penable-fct '(not-a-production))
#|Warning: NOT-A-PRODUCTION is not the name of a production |#
NIL
```

whynot

Syntax:

whynot *production-name** -> (matching-production*)
whynot-fct (*production-name**) -> (matching-production*)

Arguments and Values:

production-name ::= a symbol that names a production in the current model
matching-production ::= a symbol that names a production which matches at the current time in the current model

Description:

The whynot command is a very useful model debugging tool. For each of the named productions passed to it (or all productions if no names are provided) it will print out whether the production matches the current state or not. If it does match, then the instantiation of the production is printed and if it does not match then the production text is printed and the first condition that is unsatisfied at the current time is provided.

If the :ppm parameter is enabled to allow for imperfect matching then the instantiation of a production which is a partial match will indicate the current slot value, the imperfectly matching buffer slot value and the similarity between those values.

It returns a list of all the productions which do match the current state in the current model (regardless of whether they were passed into whynot for display).

If there is no current model then a warning is printed and **nil** is returned. If an invalid production-name is provided a warning will be displayed.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
1> (reset)
DEFAULT

2> (whynot)

Production START does NOT match.
(P START
   =GOAL>
        ISA COUNT-FROM
        START =NUM1
        COUNT NIL
 ==>
   =GOAL>
        COUNT =NUM1
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
)
It fails because:
The GOAL buffer is empty.

Production INCREMENT does NOT match.
(P INCREMENT
   =GOAL>
        ISA COUNT-FROM
        COUNT =NUM1
    -   END =NUM1
   =RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM1
        SECOND =NUM2
 ==>
   =GOAL>
        COUNT =NUM2
   +RETRIEVAL>
        ISA COUNT-ORDER
        FIRST =NUM2
   !OUTPUT! (=NUM1)
)
It fails because:
The GOAL buffer is empty.

Production STOP does NOT match.
(P STOP
   =GOAL>
        ISA COUNT-FROM
        COUNT =NUM
        END =NUM
 ==>
   -GOAL>
   !OUTPUT! (=NUM)
)
It fails because:
The GOAL buffer is empty.
NIL

3> (run-n-events 2)
```

```
     0.000   GOAL                    SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000   ------                  Stopped because event limit reached
0.0
1
NIL

4> (whynot-fct '(increment))

Production INCREMENT does NOT match.
(P INCREMENT
   =GOAL>
       ISA COUNT-FROM
       COUNT =NUM1
    -  END =NUM1
   =RETRIEVAL>
       ISA COUNT-ORDER
       FIRST =NUM1
       SECOND =NUM2
 ==>
   =GOAL>
       COUNT =NUM2
   +RETRIEVAL>
       ISA COUNT-ORDER
       FIRST =NUM2
   !OUTPUT! (=NUM1)
)
It fails because:
The COUNT slot of the chunk in the GOAL buffer is empty.
(START)

5> (whynot start)

Production START matches:
(P START
   =GOAL>
       ISA COUNT-FROM
       START 2
       COUNT NIL
 ==>
   =GOAL>
       COUNT 2
   +RETRIEVAL>
       ISA COUNT-ORDER
       FIRST 2
)
(START)
```

This example uses a simple model definition to show a production which is a partial match with :ppm enabled:

```
1> (define-model test
     (sgp :esc t :ppm 1)
     (chunk-type test slot)
     (define-chunks (buffer-value isa chunk) (production-test isa chunk))
     (set-similarities (buffer-value production-test -.5))
     (set-buffer-chunk 'goal (car (define-chunks (isa test slot buffer-value))))

     (p test
        =goal>
           isa test
           slot production-test
      ==>))
TEST

2> (whynot)
```

```
Production TEST partially matches the current state:
(P TEST
   =GOAL>
       ISA TEST
       SLOT [PRODUCTION-TEST, BUFFER-VALUE, -0.5]
 ==>
)


E> (whynot)
#|Warning: Whynot called with no current model. |#
NIL
E> (whynot bad-name)

BAD-NAME does not name a production.
(START)
```

production-firing-only

Syntax:

production-firing-only *event* -> production-firing-event?

Arguments and Values:

event ::= an ACT-R event
production-firing-event? ::= a generalized boolean that is true if event has an action of production-fired and is false otherwise

Description:

This is not a command which would be called by the modeler directly. It is provided as a possible value for the :trace-filter parameter to restrict the trace to only the production-fired events.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
1> (reset)
DEFAULT

2> (sgp :trace-filter production-firing-only)
(PRODUCTION-FIRING-ONLY)

3> (run 10)
     0.050   PROCEDURAL             PRODUCTION-FIRED START
     0.150   PROCEDURAL             PRODUCTION-FIRED INCREMENT
2
     0.250   PROCEDURAL             PRODUCTION-FIRED INCREMENT
3
     0.300   PROCEDURAL             PRODUCTION-FIRED STOP
4
     0.300   ------                 Stopped because no events left to process
0.3
46
NIL
```

un-delay-conflict-resolution

Syntax:

un-delay-conflict-resolution -> **nil**

Arguments and Values:

Description:

The un-delay-conflict-resolution command takes no parameters and will cause a new conflict-resolution event to be scheduled in the current model if the procedural module is currently waiting for some change in the system to schedule the next conflict-resolution. If there is no current model then this command has no effect and a warning is output. Generally, this is not a command for use by a modeler but may be necessary for those creating new modules.

Right now, it is only used by the procedural system modules (procedural, utility, and production-compilation) to ensure that conflict resolution gets rescheduled if necessary when parameters are changed or new productions are created. However, in rare circumstances other modules could put the system in such situations and thus may need to use this command (though typically the other module should just be able to schedule an event which would allow conflict resolution to occur normally).

Examples:

```
> (un-delay-conflict-resolution)
NIL

> (un-delay-conflict-resolution)
#|Warning: get-module called with no current model. |#
NIL
```

clear-productions

Syntax:

clear-productions -> **nil**

Arguments and Values:

Description:

The clear-productions command will delete all of the productions from the current model. It is not recommended, but there may be times where one finds doing so necessary. It will also print out a warning indicating that it is not recommended. If there is no current model then a warning is printed.

It always returns **nil**.

Examples:

```
> (clear-productions)
#|Warning: Clearing the productions is not recommended |#
NIL

E> (clear-productions)
#|Warning: get-module called with no current model. |#
#|Warning: No procedural module was found. |#
NIL
```

Utility module

The utility module provides the support for the productions' subsymbolic utility value which is used in conflict resolution. This is a numeric quantity associated with each production that can be learned while the model runs or specified in advance for each production. The description here is for the current default version of the mechanism and not the older version which is still available under the extras of the system.

Only an overview of how utility works is provided here. The details of the utility calculation are described in the additional documentation file new-utility.doc and tutorial units 6 and 7. The variable noise mechanism discussed in the new-utility document is not implemented at this time.

Each production has a utility value associated with it, which we will call U. Of the productions in the conflict set (those which match the current state) the one with the highest current U will be the one selected. When the utility learning is enabled, the U value is based on the rewards that a production receives and will change as the model runs. The learning of utilities is controlled by the following equation for a production *i* at time n:

$$U_i(n) = U_i(n-1) + \alpha\left[R_i(n) - U_i(n-1)\right]$$

α is the learning rate set by a parameter.
Ri(n) is the effective reward value given to production i at time n.
Ui(0) is set by a parameter.

The learning occurs when a reward is triggered, and all productions that have fired since the last reward are updated. The effective reward of a production *i* is the reward value received at time n minus the time since the selection of production *i* (unless overridden by use of the :reward-hook parameter).

When :esc is enabled the utility values may also have a noise component added to them (regardless of whether the learning mechanism is enabled). Each time a production's utility is calculated it may also have a noise value added to it. That noise is generated using the act-r-random command and the s of the distribution is controlled with the :egs parameter.

Parameters

:alpha

This is the α parameter in the utility learning equation. The default value is .2.

:dat

The :dat (default action time) parameter specifies the default time that it takes to fire a production in seconds. That is the amount of time that passes between the production's selection and fired events. The default value is .05 (50ms) and generally that value is not changed.

:egs

This is the expected gain s parameter. It specifies the s parameter for the noise added to the utility values. It defaults to 0 which means there is no noise in utilities.

:iu

The initial utility value for a user defined production. This is the U(0) value for a production if utility learning is enabled and the default utility if learning is not enabled. The default value is 0.

:nu

This is the starting utility for a newly learned production (those created by the production compilation mechanism described in the next module). This is the U(0) value for such a production if utility learning is enabled and the default utility if learning is not enabled. The default value is 0.

:reward-hook

The reward-hook parameter allows the modeler to override the default calculation for effective reward, $R_i(n)$. It can be set to a function which must take three parameters. If the :reward-hook parameter is not **nil** (which is the default value) then each time a reward is propagated back to a production the reward-hook function will be called. It will be passed the name of the production as the first parameter, the reward value being propagated as the second, and the time since the production was selected (in seconds) as the third. If that function returns a number then that number is used as the $R_i(n)$ value in updating the production's utility instead of the normal calculation (which is the reward minus the time since the production's selection). If any other value is returned, then the standard calculation for $R_i(n)$ is used. Only one reward-hook function may be specified at a time and if the parameter is changed from one function to another a warning will be output.

:reward-notify-hook

This parameter allows one to specify functions which will be called whenever there is a reward provided to the model. This parameter can be set to a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). Whenever trigger-reward is called the functions set with this parameter will be called during the propagate-reward event that gets generated as a result of that trigger-reward. Each of the functions that has been set for this parameter will be called with one parameter which is the

reward value passed to trigger-reward. The return value from a function called through this hook is ignored. If the parameter is set to **nil** then all functions are removed from the reward-notify-hook list. A function should only be set once. If a function is specified more than once as a value for the reward-notify-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:ul

This is the utility learning flag. If it is set to **t** then the utility learning equation used above will be used to learn the utilities as the model runs. If it is set to **nil** then the explicitly set utility values for the productions are used (though the noise will still be added if :egs is non-zero). The default value is **nil**.

:ult

This is the utility learning trace flag. If it is set to **t** then when a reward is received and utilities are updated the corresponding changes will be output in the model trace. If it is set to **nil** then there will be no additional trace output from utility updating. The default value is **nil**.

:ut

This is the utility threshold. If it is set to a number then that is the minimum utility value that a production must have to compete in conflict resolution. Productions with a lower utility value than that will not be selected. The default value is **nil** which means that there is no threshold value and all productions will be considered.

:utility-hook

The utility-hook parameter allows the modeler to override or bypass the default utility calculation. It can be set to a function which must take one parameter. If the :utility-hook parameter is not **nil** (which is the default value) then each time a production's utility is to be calculated, first this hook function is called with the name of the production as the parameter. If that function returns a number then that number is used as the production's utility instead of using the normal mechanisms. Only one utility-hook function may be specified at a time and if the parameter is changed from one function to another a warning will be output.

:utility-offsets

This parameter allows one to specify functions which can extend the utility equation with new terms. This parameter can be set to a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). Whenever a production's utility is computed each of the functions that has been set for this parameter will be called with one parameter which is the name of the production. If a function called returns a

number then that value will be added to the utility of the production. If a function returns any other value then no change is made to the utility of the production. If the parameter is set to **nil** then all functions are removed from the utility-offsets list. A function should only be set once. If a function is specified more than once as a value for the utility-offsets a warning will be displayed and a value of **nil** will be returned as the current value.

Commands

trigger-reward

Syntax:

trigger-reward reward -> [**t** | **nil**]

Arguments and Values:

reward ::= [reward-value | **nil**]
reward-value ::= a number which indicates the amount of reward to apply.

Description:

The trigger-reward command allows the modeler to present rewards to the current model for the purposes of utility learning. If the reward specified is a number then that value is used in computing the updated utility for all of the productions that have fired since the last reward. If the reward is **nil** then no utilities are updated but this still indicates when the last reward was given. This function can be called at any time to introduce a reward to the model – it does not need to be called synchronously with a production's firing. If there is a current model and the reward value is valid, then a propagate-reward event will be generated in the trace to perform the new computations and **t** will be returned. The event will show the value of the reward being used like this:

```
    0.000   UTILITY                PROPAGATE-REWARD 10
```

If utility learning is not enabled, then that will be followed by a warning indicating that no change has occurred:

```
#|Warning: Trigger-reward can only be used if utility learning is enabled. |#
```

If there is no current model or the parameter provided is invalid then a warning is printed, no utilities are changed, and **nil** is returned.

Examples:

```
> (trigger-reward 10)
T
```

```
> (trigger-reward nil)
T

E> (trigger-reward "value")
#|Warning: Trigger-reward must be called with a number or nil. |#
NIL

E> (trigger-reward 10)
#|Warning: No current model.  Trigger-reward has no effect. |#
NIL
```

spp

Syntax:

spp [{[*production-name* | (*production-name**)}{[*param-name**| *param-value-pair**]} |
(*production-name* [*param-name**| *param-value-pair**])*] -> (param-values*)
spp-fct ([{[*production-name* | (*production-name**)}{[*param-name**| *param-value-pair**]} |
(*production-name* [*param-name**| *param-value-pair**])*])-> (param-values*)

Arguments and Values:

production-name ::= a symbol which is the name of a production in the current model
param-name ::= a keyword which names a production parameter
param-value-pair ::= param-name new-param-value
new-param-value ::= a Lisp value to which the preceding param-name is to be set
param-values ::= [(param-value*) | (production-name*)| **:error**]
param-value ::= the current value of a requested production parameter or **:error**

Description:

Spp is used to set or get the value of the parameters of the productions in the current model. It is very similar to the sgp command which is used to set and get the module parameter.

Each production has five parameters associated with it. Two of those are read only, but the other three can be adjusted by the modeler. Those parameters are:

at

The action time of the production, how long between the production's selection and when it fires. This can be set explicitly and defaults to the :dat value at the time the production was created.

name

The name parameter returns the name of the production. This cannot be changed. Requesting this parameter is useful for annotating the results that are returned as seen in the examples.

u

The u parameter returns the current U(n) value for the production. This can be set directly when the utility learning mechanism is not enabled. It defaults to the value of the :iu parameter at the time the production is created.

utility

The last computed utility value of the production during conflict resolution (including any noise which was added). This cannot be changed by the modeler. If the production has not yet been a member of the conflict set, then the value will be **nil**.

reward

This is a reward value to apply when this production fires. The default is **nil** which means the production does not provide a reward. If it is set to a number then after this production fires a trigger-reward call will be made using that reward value. If it is set to **t** then after the production fires a trigger-reward call will be made with a value of **nil** (a null reward which clears the history without adjusting any utilities).

When spp prints the parameters for a production it prints the production's name followed by the parameters which are currently appropriate based on the settings of :esc and :ul. If :esc is **nil**, then the :u and :at parameters are printed. If :esc is **t** and :ul is **nil** :utility, :u and :at are printed, and if :esc is **t** and :ul is **t**, then :utility, :u, :at , and :reward are printed.

If no parameters are provided to spp, then all of the current model's productions' parameters are printed and a list of all the production names is returned.

If a production or list of productions is specified as the first parameter to spp then the following parameters are set or retrieved from only those productions. If no production names are provided then the settings are applied to or retrieved from all productions that exist at the time of the call to spp.

If production names are specified but no specific parameters are specified then the parameters for those productions are printed and the list of those production names is returned.

If any of the production names provided are invalid a warning will be printed and the corresponding element of the return list will be **:error**.

If all of the parameters passed to spp (after any production names) are keywords, then it is a request for the current values of the parameters named. Those parameters are printed for the productions specified and a list containing a list for each production specified is returned. Each sub-list contains the values of the parameters requested in the order requested and the sub-lists are in the order of the

productions which were requested. If an invalid parameter is requested, then a warning is printed and the value returned in that position will be the keyword **:error**.

If there are any non-keyword parameters in the call to spp and the number of parameters (not counting the production names) is even, then they are assumed to be pairs of a parameter name and a parameter value. For all of the specified productions (or all productions if none are specified) those parameters will be set to the provided values. The return value will be a list containing a list for each production specified. Each sub-list contains the values of the parameters set in the order they were set and the sub-lists are in the order of the productions which were specified. If a particular parameter value was not of the appropriate type, then a warning is printed and the value returned in that position will be the keyword **:error**.

It is also possible to pass lists of production-name and parameter settings to spp. Essentially, each list provided must be formatted as something that could be passed to spp on its own and they will each be processed as appropriate.

If there is no current model at the time of the call, then a warning is displayed and **nil** is returned.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
1> (sgp :esc nil :ul nil)
 (NIL NIL)

2> (spp)
Parameters for production START:
 :u   0.000
 :at  0.050
Parameters for production INCREMENT:
 :u   0.000
 :at  0.050
Parameters for production STOP:
 :u   0.000
 :at  0.050
(START INCREMENT STOP)

3> (sgp :esc t)
 (T)

4> (spp)
Parameters for production START:
 :utility    NIL
 :u   0.000
 :at  0.050
Parameters for production INCREMENT:
 :utility    NIL
 :u   0.000
 :at  0.050
Parameters for production STOP:
 :utility    NIL
 :u   0.000
```

```
 :at  0.050
(START INCREMENT STOP)

5> (sgp :ul t)
 (T)

6> (spp)
Parameters for production START:
 :utility    NIL
 :u   0.000
 :at  0.050
 :reward    NIL
Parameters for production INCREMENT:
 :utility    NIL
 :u   0.000
 :at  0.050
 :reward    NIL
Parameters for production STOP:
 :utility    NIL
 :u   0.000
 :at  0.050
 :reward    NIL
(START INCREMENT STOP)

7> (spp start)
Parameters for production START:
 :utility    NIL
 :u   0.000
 :at  0.050
 :reward    NIL
(START)

> (spp-fct '((increment stop) :name :u))
Parameters for production INCREMENT:
 :NAME INCREMENT
 :U  0.000
Parameters for production STOP:
 :NAME   STOP
 :U  0.000
((INCREMENT 0) (STOP 0))

1> (spp :at 10)
((10) (10) (10))

2> (spp-fct nil)
Parameters for production START:
 :utility    NIL
 :u   0.000
 :at 10.000
 :reward    NIL
Parameters for production INCREMENT:
 :utility    NIL
 :u   0.000
 :at 10.000
 :reward    NIL
Parameters for production STOP:
 :utility    NIL
 :u   0.000
 :at 10.000
 :reward    NIL
(START INCREMENT STOP)

1> (reset)
DEFAULT

2> (sgp :esc t :egs 3)
 (T 3)
```

```
3> (run 10)
…
0.3
46
NIL

4> (spp-fct '(:name :utility :u))
Parameters for production START:
 :NAME  START
 :UTILITY -1.806
 :U  0.000
Parameters for production INCREMENT:
 :NAME INCREMENT
 :UTILITY -1.594
 :U  0.000
Parameters for production STOP:
 :NAME   STOP
 :UTILITY -3.252
 :U  0.000
((START -1.80585 0) (INCREMENT -1.5941277 0) (STOP -3.2521996 0))

5> (spp (start) (stop :name :utility) (increment :at 10))
Parameters for production START:
 :utility -1.806
 :u   0.000
 :at  0.050
Parameters for production STOP:
 :NAME   STOP
 :UTILITY -3.252
(START (STOP -3.2521996) (10))

E> (spp (start end))
Parameters for production START:
 :utility    NIL
 :u   0.000
 :at 10.000
 :reward    NIL
#|Warning: Spp cannot adjust parameters because production END does not exist |#
(START :ERROR)

E> (spp start :u :ve)
Parameters for production START:
 :U  0.000
#|Warning: NO PARAMETER VE DEFINED FOR PRODUCTIONS. |#
 :VE  ERROR
((0 :ERROR))

E> (spp)
#|Warning: get-module called with no current model. |#
NIL
```

Production Compilation Module

The production compilation module implements the process of learning new productions. More details of the production compilation process can be found in the additional document compilation.doc and tutorial unit 7. Only the basic mechanisms of the module will be described here.

Production compilation works by combining two productions that fire in sequence into one new production. When enabled, it will attempt to create a new production for each pair of productions that fire. To determine if two productions can be combined into one production all of the buffers that are referenced in those productions (in any condition or action) are checked to see if they have a compatible usage between the two productions. If any buffer does not have a compatible usage between the two productions then the productions cannot be combined.

Compatible usage is determined by the "compilation type" of the buffer. The compilation type also controls how the usage of that buffer in the productions gets combined into the new production. The provided module specifies five different compilation types, and each of the buffers in the system is considered to be of one of those types. The five types are goal, imaginal, retrieval, perceptual, and motor. The details of what constitutes valid usage for those compilation types are described in the excel spreadsheet compilation.xls and the mechanism used to create the new production based on the compilation type is described in the compilation.doc file. It is possible to change the compilation type of a buffer using the specify-compilation-buffer-type command described below and it is also possible to add new compilation types to the system (see the section on adding new compilation types for details). For the buffers provided in the default system this is the assignment of buffer to compilation type:

Buffer Name	Compilation Type
goal	Goal
imaginal	Imaginal
retrieval	Retrieval
aural	Perceptual
aural-location	Perceptual
visual	Perceptual
visual-location	Perceptual
temporal	Perceptual
imaginal-action	Motor
production	Motor
manual	Motor
vocal	Motor

Any buffer added with a new module will be of the motor compilation type by default, but may be changed with the specify-compilation-buffer-type command.

If all of the buffers have a compatible usage between two successive productions which fire then the following situations are checked. If any of these are true the productions cannot be combined:

- is the time between the productions greater than the threshold time?
- does either production have a !eval! condition or action?
- does either production have a !bind! or !safe-bind! condition?
- does either production have a !bind! action?
- does either production use !mv-bind! in either the conditions or actions?
- does either production test the same buffer more than once in its conditions?
- does either production have a buffer overwrite action?
- does either production use a direct chunk request?
- does either production use slot modifiers other than = in its conditions?
- does the first production make multiple requests using the same buffer?
- does the first production have a RHS !stop! action?

If none of those situations are true, then the two productions are combined into one new production.

If either of the productions which is being combined was defined using the p* command then the newly created production will also be defined using the p* command if after the combining of the conditions and actions there is still dynamic pattern matching required (variablized slot names).

After creating the new production, it is compared against the other productions in the procedural memory of the model. If the new production is not semantically equivalent to an existing production then the new production is also added to the procedural memory of the model. The parameters for the new production are set as follows:

- The utility is the value of the :nu parameter.
- The at parameter is set to the max of the at parameters from its two parent productions.
- If both of the parent productions have a numeric reward the new production gets the max of those two as its reward. If only one of the parents has a numeric reward the new production gets that value as its reward. If neither parent has a numeric reward, but at least one has a value of **t** for the reward then the new production will get a value of **t**. If both parents have a **nil** reward value the new production also gets a **nil** reward value.

If the newly formed production is semantically equivalent to an existing production then what happens depends on whether the production to which it is equivalent was also created by production compilation or whether it was one of the explicitly specified productions of the model and also whether utility learning is enabled.

If the production is equivalent to one of the explicitly specified productions or utility learning is not enabled, then nothing happens and the newly created production is ignored.

If the production is equivalent to one which was previously created by production compilation and utility learning is enabled then that production receives an update to its utility. The reward which it receives is the current u value of the first of the two productions which fired to create it.

Parameters

:epl

The :epl (enable production learning) parameter controls whether the production compilation process is enabled or disabled. If :epl is set to **t** then the process is enabled and if it is set to **nil** then it is disabled. The default value is **nil**.

:pct

The :pct (production compilation trace) parameter controls whether information about the production compilation process is output to the trace. If it is set to **t** then after each production fires a notice about the production compilation process will be displayed. If a new production was created then that production will be printed along with its parameter values. If a new production was not created then information indicating why not will be displayed. If the parameter is set to **nil** then no output will be given for production compilation. The default value is **nil**.

:tt

The :tt (threshold time) parameter specifies the maximum amount of time in seconds that is allowed to pass between the firing of two productions and still allow them to be combined through production compilation. The default value is 2 seconds.

Commands

show-compilation-buffer-types

Syntax:

show-compilation-buffer-types -> **nil**

Description:

The show-compilation-buffer-types command can be used to print out the current assignments of all the buffers' compilation types in the current model. If there is no current model a warning is printed.

Examples:

```
> (show-compilation-buffer-types)
  Buffer                 Type
VISUAL                 PERCEPTUAL
TEMPORAL               PERCEPTUAL
AURAL-LOCATION         PERCEPTUAL
VISUAL-LOCATION        PERCEPTUAL
PRODUCTION             MOTOR
AURAL                  PERCEPTUAL
VOCAL                  MOTOR
IMAGINAL-ACTION        MOTOR
MANUAL                 MOTOR
GOAL                   GOAL
IMAGINAL               IMAGINAL
RETRIEVAL              RETRIEVALNIL

E> (show-compilation-buffer-types)
#|Warning: get-module called with no current model. |#
#|Warning: No production compilation module found |#
NIL
```

compilation-buffer-type

Syntax:

compilation-buffer-type *buffer-name* -> [buffer-type | **nil**]
compilation-buffer-type-fct *buffer-name* -> [buffer-type | **nil**]

Arguments and Values:

buffer-name ::= should be a symbol which names a buffer
buffer-type ::= the compilation type of buffer-name in the current model

Description:

compilation-buffer-type will return the compilation type for a buffer in the current model. If there is no current model or the buffer name is invalid then **nil** is returned.

Examples:

```
> (compilation-buffer-type-fct 'manual)
MOTOR

> (compilation-buffer-type goal)
GOAL

> (compilation-buffer-type not-a-buffer)
NIL

E> (compilation-buffer-type goal)
#|Warning: get-module called with no current model. |#
#|Warning: No production compilation module found |#
NIL
```

specify-compilation-buffer-type

Syntax:

specify-compilation-buffer-type *buffer-name buffer-type* -> [**t** | **nil**]
specify-compilation-buffer-type-fct *buffer-name buffer-type* -> [**t** | **nil**]

Arguments and Values:

buffer-name ::= should be a symbol which names a buffer
buffer-type ::= a symbol which names a valid compilation type

Description:

Specify-compilation-buffer-type allows one to change the compilation type for the buffers of the current model. If buffer-name and buffer-type are both valid, then that buffer will now be treated as a buffer-type buffer for compilation purposes, and **t** will be returned. If either parameter is invalid or there is no current model, then a warning is printed and **nil** is returned.

Note that this setting is only valid until the model is reset because the production compilation module will return all buffers to their default types when it is reset. For that reason, if one wants to make a new module's buffers default to a type other than motor automatically (without needing to specify this call in each model definition) this setting must be placed into the secondary reset function for that module to ensure that the setting is not overwritten by the resetting of the production compilation module (it uses the primary reset function to set the default values).

Examples:

```
1> (specify-compilation-buffer-type goal motor)
T

2> (specify-compilation-buffer-type-fct 'visual-location 'retrieval)
T

3> (show-compilation-buffer-types)
  Buffer                 Type
VISUAL                 PERCEPTUAL
TEMPORAL               PERCEPTUAL
AURAL-LOCATION         PERCEPTUAL
VISUAL-LOCATION        RETRIEVAL
PRODUCTION             MOTOR
AURAL                  PERCEPTUAL
VOCAL                  MOTOR
IMAGINAL-ACTION        MOTOR
MANUAL                 MOTOR
GOAL                   GOAL
IMAGINAL               IMAGINAL
RETRIEVAL              RETRIEVAL
NIL

E> (specify-compilation-buffer-type visual bad-type)
#|Warning: Invalid compilation buffer type BAD-TYPE. |#
```

```
NIL

E> (specify-compilation-buffer-type-fct 'bad-buffer 'motor)
#|Warning: No buffer named BAD-BUFFER found. |#
NIL

E> (specify-compilation-buffer-type goal perceptual)
#|Warning: get-module called with no current model. |#
#|Warning: No production compilation module found |#
NIL
```

Goal Module

The goal module provides the system with a goal buffer which is typically used to maintain the current task state of a model and to hold relevant information for the current task. The goal buffer also serves as a source of activation for retrievals by default. The only action which the goal module provides to a model is the creation of new chunks.

Goal buffer

The goal module sets the goal buffer to **not** be strict harvested.

Activation spread parameter: :ga
Default value: 1.0

Queries

The goal buffer only responds to the default queries.

'State busy' will always be **nil**.

'State free' will always be **t**.

'State error' will always be **nil**.

Requests

Isa *any-valid-chunk-type*
{*slot value*}*

Each slot in the request should be specified at most once and no modifiers are allowed.

The request is used to create a new chunk which is placed into the goal buffer immediately. It will result in two events which look like this in the trace:

```
0.050   GOAL                    CREATE-NEW-BUFFER-CHUNK GOAL ISA CHUNK
0.050   GOAL                    SET-BUFFER-CHUNK GOAL CHUNK0
```

There is also a third event generated which will not show up in the trace. It is a maintenance event with the action clean-up-goal-chunk which performs some system clean up and will occur after the set-buffer-chunk event.

Modification Requests

{*slot value*}*

The goal buffer accepts modification requests for any valid slot of the chunk in the buffer and those specified buffer modifications are passed to mod-buffer-chunk for the goal buffer at the time of the request. It is assumed that the chunk will still be there at that time.

The event below will show up in the trace as a result of such an action being made by a production (always at the same time as the procedural request):

```
0.050   GOAL                    MOD-BUFFER-CHUNK GOAL
```

Such a request is equivalent to doing a direct modification of the chunk in the buffer using a buffer modification action in the production. The only difference is that by using a modification request to perform the change to the chunk an event is attributed to the goal module in the trace which may be important for purposes of predicting the BOLD response or useful for tracing purposes.

Commands

goal-focus

Syntax:

goal-focus {*chunk-name*} -> [goal-chunk | **nil**]
goal-focus-fct {*chunk-name*} -> [goal-chunk | **nil**]

Arguments and Values:

chunk-name ::= should be a symbol which names a chunk
goal-chunk ::= a symbol which names the chunk in the goal buffer or the chunk which will be in the goal buffer

Description:

If chunk-name is provided, then goal-focus will schedule an event to put that chunk into the goal buffer of the current model at the current time with a priority of :max. This will result in the unrequested query being true for the buffer because this chunk was not placed into the buffer as a result of a module request. There will also be a maintenance event scheduled with an action of clear-delayed-goal following the set-buffer-chunk event which updates some internal information for the goal module but which will not show up in the trace. If an event is created to place this chunk into

the buffer then chunk-name is returned. If chunk-name is not a valid chunk or there is no current model, then a warning is printed and **nil** is returned.

If chunk-name is not provided, then the chunk currently in the goal buffer is printed if there is one and that chunk's name is returned. If the buffer is empty, then a message stating that is printed and **nil** is returned. If there is a pending change to the chunk in the goal buffer (an event generated by goal-focus has been scheduled but not executed), then a notice of that is printed along with any chunk which may be in the buffer currently and the name of the chunk which will be in the buffer is returned.

This command typically occurs in a model to provide the initial state in the goal buffer. If declarative learning of past goals is something that the model will be doing, then one should consider using define-chunks to create that initial goal instead of add-dm so that it is not in declarative memory prior to the start of the task.

Examples:

```
> (goal-focus)
Goal buffer is empty
NIL

1> (goal-focus black)
BLACK

2> (goal-focus)
Will be a copy of BLACK when the model runs
BLACK
  ISA COLOR

BLACK

3> (run-n-events 1)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL BLACK REQUESTED NIL
     0.000   ------                Stopped because event limit reached
0.0
1
NIL

4> (goal-focus)
BLACK-0
  ISA COLOR

BLACK-0

5> (goal-focus-fct 'free)
FREE

6> (goal-focus-fct )
Will be a copy of FREE when the model runs
Currently holds:
BLACK-0
  ISA COLOR

FREE

7> (run-n-events 1)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FREE REQUESTED NIL
     0.000   ------                Stopped because event limit reached
```

```
0.0
1
NIL

8> (goal-focus)
FREE-0
  ISA CHUNK

FREE-0

E> (goal-focus notchunk)
#|Warning: NOTCHUNK is not the name of a chunk in the current model - goal-focus failed |#
NIL

E> (goal-focus black)
#|Warning: get-module called with no current model. |#
#|Warning: get-chunk called with no current model. |#
#|Warning: BLACK is not the name of a chunk in the current model - goal-focus failed |#
NIL
```

mod-focus

Syntax:

mod-focus {*slot-name slot-value* }* -> [chunk-name | **nil**]
mod-focus-fct ({*slot-name slot-value* }***)** -> [chunk-name | **nil**]

Arguments and Values:

slot-name ::= a symbol that should be the name of a slot of the chunk in the goal buffer
slot-value ::= a Lisp value to set for the value of the corresponding slot-name
chunk-name ::= a symbol which will be the name of the chunk in the goal buffer

Description:

Mod-focus is used to modify the chunk currently in the goal buffer. The slot-name and slot-value pairs provided are passed to mod-chunk along with the name of the chunk which is in the goal buffer of the current model. In addition, an event is scheduled with the action goal-modification and priority :max so that the model can detect that the buffer has been changed outside of its actions.

If there is a chunk in the buffer and the modifications are valid for that chunk, then that chunk's name is returned. If there is no current model, no chunk in the goal buffer, or the modifications are invalid a warning is printed and **nil** is returned.

Examples:

```
1> (goal-focus)
G-0
  ISA TASK
   COLOR  NIL
   STATE  START
```

```
G-0

2> (mod-focus color green)
G-0

3> (goal-focus)
G-0
  ISA TASK
   COLOR  GREEN
   STATE  START

G-0

4> (run 1)
     0.000   GOAL                    GOAL-MODIFICATION
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
     0.000   ------                  Stopped because no events left to process
0.0
2
NIL

5> (mod-focus-fct '(state finished))
G-0

6> (goal-focus)
G-0
  ISA TASK
   COLOR  GREEN
   STATE  FINISHED

G-0

E> (mod-focus slot)
#|Warning: Odd length modifications list in call to mod-chunk. |#
NIL

E> (mod-focus slot value)
#|Warning: No chunk in the goal buffer to modify |#
NIL

E> (mod-focus bad-slot green)
#|Warning: Invalid slot name in modifications list. |#
NIL

E> (mod-focus slot value)
#|Warning: buffer-read called with no current model. |#
#|Warning: No chunk in the goal buffer to modify |#
NIL
```

Imaginal Module

The imaginal module provides the system with an imaginal buffer which is typically used to maintain context relevant to the current task and a buffer called imaginal-action which can be used to call user functions for manipulating the contents of the imaginal buffer. The imaginal buffer operates like the goal buffer in creating new chunks. However, unlike the goal buffer, requests to create chunks using the imaginal module take time (which can be specified by a parameter). It also allows one to make modification requests, which function like a RHS = modification, but also take time to complete.

Parameters

:imaginal-delay

The imaginal-delay parameter controls how long it takes a request or modification request to the imaginal buffer to complete. It can be set to a non-negative time (in seconds) and defaults to .2.

:vidt

The variable imaginal delay time parameter controls whether the actions of the imaginal buffer take exactly the amount of time specified by :imaginal-delay or if they are randomized with the randomize-time command. If it is set to **t**, then randomize-time is used to variablize the delay time, and if it is set to **nil**, which is the default, then the delay times are fixed at the :imaginal-delay time.

Imaginal buffer

The imaginal buffer is typically used to create and hold task relevant information. It operates similar to the goal buffer except that there is a time cost associated with creating and manipulating the chunks.

Activation spread parameter: :imaginal-activation
Default value: 0.0

Queries

The imaginal buffer only responds to the default queries. Both buffers of the module will respond in the same way regardless of which is queried because they report the module's state information.

'State busy' will be **t** after a new request or modification request is received (through either buffer). If the request came through the imaginal buffer the state will return to **nil** once the request is

completed. If the request came through the imaginal-action buffer then the busy state will remain **t** until the set-imaginal-free command is used to clear the busy state back to **nil**.

'State free' will be **t** when the 'state busy' flag is **nil** i.e. when the module is not currently handling a request and it will be **nil** when the module is handling a request.

'State error' will be **nil** unless set by the user with the set-imaginal-error command which will cause it to be **t**. If set with the command, it will stay **t** until the next request is made to either of the module's buffers.

Requests

Isa *any-valid-chunk-type*
{*slot value*}*

Each slot should be specified at most once and no modifiers are allowed.

The request is used to create a new chunk which is placed into the imaginal buffer after :imaginal-delay seconds. That will result in two events showing up in the trace:

```
0.750   IMAGINAL              CREATE-NEW-BUFFER-CHUNK IMAGINAL ISA VISUAL-OBJECT
0.750   IMAGINAL              SET-BUFFER-CHUNK IMAGINAL VISUAL-OBJECT1
```

There are three other maintenance events generated which will occur at the same time as the two actions shown but will not show up in the trace. The first occurs before the create-new-buffer-chunk event and will have an action of goal-style-request. The second has an action of clean-up-goal-chunk which performs some system cleanup as happens for the goal module and will occur after the set-buffer-chunk event. The final event, which occurs after the clean-up-goal-chunk event, has the action set-imaginal-free and serves to set the module back to the state free after it has created the new chunk.

The module can only handle one request at a time. If a request is made while the module is busy processing a previous request it will print a warning and ignore the newer request.

```
#|Warning: Imaginal request made to the IMAGINAL buffer while the imaginal module was
busy. New request ignored. |#
```

Modification requests

{*slot value*}*

The imaginal buffer accepts modification requests for any valid slot of the chunk in the buffer and those specified buffer modifications are passed to mod-buffer-chunk for the imaginal buffer after :imaginal-delay seconds have passed. It is assumed that the chunk will still be there at that time.

This event will show up in the trace as a result of such an action:

```
1.000   IMAGINAL              MOD-BUFFER-CHUNK IMAGINAL
```

There will also be a maintenance event generated which will not output to the trace. It will have the action of set-imaginal-free and occur after the mod-buffer-chunk event. It serves to set the module back to the free state after the buffer-modification is complete.

Imaginal-action buffer

The imaginal-action buffer is available for users to extend the capabilities of the imaginal module. It does not perform any actions on its own nor does the module place any chunks into the buffer. It essentially provides a hook for the modeler to perform actions on the imaginal buffer which are attributed to the imaginal module for purposes of the graphic trace or predicting BOLD responses.

Activation spread parameter: :imaginal-action-activation
Default value: 0.0

Queries

The imaginal-action buffer only responds to the default queries. Both buffers of the module will respond in the same way regardless of which is queried because they report the module's state information.

'State busy' will be **t** after a new request or modification request is received (through either buffer). If the request came through the imaginal buffer the state will return to **nil** once the request is completed. If the request came through the imaginal-action buffer then the busy state will remain **t** until the set-imaginal-free command is used to clear the busy state back to **nil**.

'State free' will be **t** when the 'state busy' flag is **nil** i.e. when the module is not currently handling a request and it will be **nil** when the module is handling a request.

'State error' will be **nil** unless set by the user with the set-imaginal-error command which will cause it to be **t**. If set with the command, it will stay **t** until the next request is made to either of the module's buffers.

Requests

Isa generic-action
action *function-name*

This request to the imaginal-action buffer requires the action slot be specified and its value must name a function. When the request is received by the module the state busy query for the module will be set to **t**, the state error query will be set to **nil**, and the function specified by function-name will be called with no parameters. No chunks will be placed into the buffer by default and the function which is called must return the module to the state free using the set-imaginal-free command either directly or by scheduling an event to do so at a later time. The function may also call the set-imaginal-error command to set the state error to **t** for the module if that is needed.

This action essentially allows users to manipulate the chunk which is in the imaginal buffer via arbitrary functions and have the action attributed to the imaginal module i.e. it is essentially the same as a call to !eval! in a production except that the request is marked as going to the imaginal module and the module is in the state busy during that time. This allows modelers to add commands which they feel should be attributed to the imaginal module (things like rotations, translations or other manipulations of the representation) without having to change the code for the module. Eventually, such actions could become direct requests one could make to the module, but because there is no consensus as to how things should be represented or manipulated at this time it is left open for the modeler to use as needed.

No events are explicitly generated by this request, but the function which is called should generate events for any changes it makes to the buffer and to schedule the call to set-imaginal-free.

Isa simple-action
action *function-name*

This request to the imaginal-action buffer requires the action slot be specified and its value must name a function. When the request is received by the module the state busy query for the module will be set to **t**, the state error query will be set to **nil**, the imaginal buffer will be cleared, and the function specified by function-name will be called with no parameters. The named function must return either the name of a chunk or **nil**. If it returns the name of a chunk then after the current imaginal-delay time passes that chunk will be copied into the imaginal buffer and the module will be returned to the free state. If the function returns **nil** then after the imaginal-delay time passes the module will be set to the free state and it will be marked as also being in the error state. This request provides an easy way to have code create arbitrary chunks for the imaginal buffer without having to schedule any events or manage the internal imaginal state flags directly.

A valid request of this type will generate two events. One will be an event with the action of set-imaginal-free. The other depends on whether the action function returned a chunk of **nil**. If it returns

a chunk then an event with the action set-buffer-chunk will be generated, but if **nil** was returned an event with the action set-imaginal-error will be created.

Commands

set-imaginal-free

Syntax:

set-imaginal-free -> [**t** | **nil**]

Description:

Set-imaginal-free is used to clear the busy state of the imaginal module in the current model. It should only be used by functions that are called as a result of a generic-action request to the imaginal-action buffer.

If there is a current model then it returns **t**. If there is no current model then it returns **nil** and no change is made.

Examples:

```
> (set-imaginal-free)
T

E> (set-imaginal-free)
#|Warning: get-module called with no current model. |#
#|Warning: Call to set-imaginal-free failed |#
NIL
```

set-imaginal-error

Syntax:

set-imaginal-error -> [**t** | **nil**]

Description:

Set-imaginal-error is used to set the error state of the imaginal module in the current model. It should only be used by functions that are called as a result of a generic-action request to the imaginal-action buffer. It causes queries of either of the imaginal module's buffers for 'state error' to return **t**. That error state will remain until another request is made to either of the module's buffers.

If there is a current model then it returns **t**. If there is no current model then it prints a warning, returns **nil**, and no change is made.

Examples:

```
> (set-imaginal-error)
T

E> (set-imaginal-error)
#|Warning: get-module called with no current model. |#
#|Warning: Call to set-imaginal-error failed |#
NIL
```

Declarative module

The declarative module provides the model with a declarative memory which stores the chunks that are generated by the model and it provides a mechanism for retrieving those chunks. The retrieval of chunks from the declarative memory depends on many factors that affect the accuracy and speed with which a chunk can be retrieved which is based on research of human memory performance.

The model's declarative memory (DM) consists of all the chunks which are explicitly added to it by the modeler as well as all of the chunks which are cleared from the buffers. Whenever a chunk is cleared from a buffer the declarative module merges that chunk into the model's DM. The merging process compares the chunk being added to the chunks already in DM. If the chunk being added is equivalent to a chunk which is already in DM, then the new chunk is merged with the existing chunk (see the merge-chunks command for details) and that chunk is strengthened by giving it another reference at the time of the merging. If the chunk being added is not equivalent to any chunk in DM then that chunk is added to DM.

Retrieval of chunks from DM is done through requests to the module. A request specifies a description of a chunk which is desired (see the request details below). If there are chunks in DM which match the specification request, then one of those chunks is placed into the retrieval buffer as a response. If no such chunk is found then it signals that a failure to retrieve occurred by signaling the state error and leaving the buffer empty.

The time it takes to complete the request and how a single chunk is chosen among possibly many which match the request are controlled by several parameters. First, the setting of the :esc parameter determines very coarsely what process is used.

If the :esc parameter is **nil** then only the symbolic matching is considered. The chunks are always retrieved immediately and if there is more than one chunk which matches the request the setting of :er determines how a chunk is chosen. If :er is **t** then the choice is made randomly. If :er is **nil** then a deterministic process is used such that the same chunk will be chosen for that model each time the same set of possible chunks could be retrieved. However, that process is not specified as part of the declarative module's definition because it is not intended to be a process which one relies on for chunk preferences.

If the :esc parameter is **t** then the selection of which chunk is retrieved and how long it takes is controlled by a quantity called activation. Each chunk in DM has an activation value associated with it and among the chunks which match the request the one with the highest activation value, above a parameterized threshold, is the one that will be retrieved. If no matching chunk has an activation above the threshold then a failure to retrieve occurs. The activation of that chunk also determines how long the request takes to complete. If multiple matching chunks have the same highest

activation, then the :er parameter determines how one of those chunks is chosen in the same way it happens when :esc is **nil**.

Activation

How the activation of a chunk is computed is based on the setting of several parameters which determine which mechanisms are to be used and those will be discussed in the specific sections which follow. Here is the general equation for the activation (A) of a chunk i:

$$A_i = B_i + S_i + P_i + \varepsilon_i$$

B_i: This is the base-level activation and reflects the recency and frequency of use of the chunk.
S_i: This is the spreading activation value computed for the chunk which reflects the effect that the contents of the buffers have on the retrieval process.
P_i: This is the partial matching value computed for the chunk which reflects the degree to which the chunk matches the specification requested.
ε_i: A noise value with both a transient and permanent component.

Each of those components will be described in more detail below. Note that for each of those components it is possible for the modeler to replace the mechanism as described with their own mechanism using the hook functions available in the declarative module.

Base-level

The base-level component, B_i, is computed differently based on the setting of the :bll and :ol parameters.

If :bll is **nil** then the setting of :ol does not matter and the base-level is a constant value determined by the :blc parameter or specific user settings for the chunk.

$$B_i = \beta_i$$

β_i: A constant offset which is determined by the :blc parameter or the chunk's :base-level parameter if specified.

If :bll is set to a number, then the setting of :ol determines how the base-level is computed.

If :ol is **nil** then this equation is used:

$$B_i = \ln(\sum_{j=1}^{n} t_j^{-d}) + \beta_i$$

***n*:** The number of presentations for chunk *i*.
***t*$_j$**: The time since the *jth* presentation. A presentation is either the chunk's initial entry into DM or when another chunk is merged with a chunk which is in DM (these are also called the chunk's references).
d: The decay parameter which is set using the :bll (base-level learning) parameter.
βi: A constant offset determined by the :blc parameter

If :ol is **t** then this approximation to that equation is used which does not require recording the complete history of the chunk:

$$B_i = \ln(n/(1-d)) - d * \ln(L) + \beta_i$$

***n*:** The number of presentations of chunk *i*.
***L*:** The lifetime of chunk *i* (the time since its creation).
***d*:** The decay parameter (the value of :bll)
βi: A constant offset determined by the :blc parameter

If :ol is set to a number, then a hybrid of those is used such that the specified number of true references are used and the approximation is used for any remaining references (if there are not more total references than the parameter setting for :ol (n <= k) then the full equation is used and the extra term in this equation is not computed):

$$B_i = \ln(\sum_{j=1}^{k} t_j^{-d} + \frac{(n-k)*(t_n^{1-d} - t_k^{1-d})}{(1-d)*(t_n - t_k)}) + \beta_i$$

k: is the value of the :ol parameter.
***t*$_j$**: The time since the *jth* presentation (for this equation t_1 is the time since the most recent presentation and t_n the time since the first presentation)
***n*:** The total number of presentations of chunk *i*.
***d*:** The decay parameter (the value of :bll)
βi: A constant offset determined by the :blc parameter

Spreading Activation

Whether spreading activation is used is determined by the setting of the :mas parameter. If it is **nil**, which is the default value, then the value of S_i is 0 in the activation equation. If :mas is set to a number, then this equation determines the spreading activation component of chunk *i*'s activation:

$$S_i = \sum_k \sum_j W_{kj} S_{ji}$$

The elements *k* being summed over are all of the buffers in the model.

The elements *j* being summed over are the chunks which are in the slots of the chunk in buffer *k* (these are referred to as the sources of activation).

W_{kj}**:** This is the amount of activation from source *j* in buffer *k*. It is the source activation of buffer *k* divided by the number of sources *j* in that buffer.

S_{ji}**:** This is the strength of association from source *j* to chunk *i*.

strength of association

The strength of association, S_{ji}, between two chunks is computed using the following equations by default, but can be set explicitly by the modeler using the add-sji command or thorough the sji-hook parameter.

If chunks *j* and *i* are not the same chunk and *j* is not in a slot of chunk *i*:

$$S_{ji} = 0$$

If chunks *j* and *i* are the same chunk or chunk *j* is in a slot of chunk *i*:

$$S_{ji} = S - \ln(fan_{ji})$$

S: The maximum associative strength set with the :mas parameter.

fan_{ji}**:** a measure of how many chunks are associated with chunk j.

The fan is typically thought of as the number of chunks in which *j* is the value of a slot plus one for chunk *j* being associated with itself. However, because *j* may appear in more than one slot of the chunk *i*, this is the general calculation which is used to compute the fan:

$$fan_{ji} = \frac{1 + slots_j}{slotsof_{ji}}$$

***slots*$_j$:** the number of slots in which *j* is the value across all chunks in DM.
***slotsof*$_{ji}$:** the number of slots in chunk *i* which have *j* as the value (plus 1 when chunk *i* is chunk *j*).

The S_{ji} value can become negative as the fan_{ji} value grows, but that is generally an undesirable situation. By default the declarative module will print a warning if S_{ji} becomes negative due to that calculation and use 0.0 instead of the negative value, but that can be changed using the **:nsji** parameter.

Partial Matching

When the partial matching process is enabled it is possible for a chunk that is not a perfect match to the retrieval specification to be the one that is retrieved. To enable the partial matching one needs to set the :mp parameter to a number instead of its default of **nil**. When enabled, the similarity of the values requested to those in the slots of the chunks of the appropriate chunk-type in DM are computed to determine the activation value. If partial matching is disabled then P_i is 0, but if it is enabled it is computed with this equation:

$$P_i = \sum_k PM_{ki}$$

The elements *k* being summed over are the slot values of the retrieval specification for slots with an = or – modifier only.

***P*:** This is a match scale parameter (set with :mp) that reflects the amount of weighting given to the similarity.
***M*$_{ki}$:** The similarity between the value *k* in the retrieval specification and the value in the corresponding slot of chunk *i*.

similarities

The possible range of default similarity values is configurable using the maximum similarity parameter (:ms) and the maximum difference parameter (:md). The default range is from 0 to -1 with 0 being the most similar and -1 being the largest difference. In general, the similarity can be thought of more as a difference penalty because the concept is not to boost the similar items, but to penalize

the different ones. Since it gets added to the activation value, the values should be negative for items that are not the same and using positive similarities is not recommended (though not prohibited).

By default, a chunk has a maximum similarity to itself and a maximum difference to all other chunks. Any other similarities must be set explicitly by the modeler either using the set-similarities command or the sim-hook parameter. For non-chunk slot values in the retrieval request, the similarity is the maximum similarity if the values are equal using the chunk-slot-equal function and the maximum difference if they are not. The only way to set non-default similarity values for items which are not chunks is through the sim-hook capability. Similarities set explicitly with the declarative commands or through the sim-hook function are not constrained by the :ms and :md parameters.

One final note on the computation of the M_{ki} values. If the retrieval specification is requesting the value using the negation modifier, then the M_{ki} value for that slot test *k* is not the specific similarity value between the items involved. If the similarity between those the items is equal to the maximum similarity then M_{ki} is set to the maximum difference. Otherwise, M_{ki} is set to 0 for that slot. Essentially, if they are the same (or perfectly similar items), then the chunk is given the maximum penalty since the request specified that it not have that value and if they are different (any similarity other than a perfect match) then no penalty is applied.

Noise

The noise calculation has two components. There is a transient component which is computed each time a retrieval request is made and there is a permanent component which is associated specifically with the chunk which is generated once when the chunk is entered into DM. The total noise added to the activation is the sum of the two components. Often, the transient component is sufficient for modeling and the permanent noise is left disabled.

Each one is generated using the act-r-noise command. Thus they are generated from a logistic distribution with a mean of 0 and an s as specified by the corresponding parameter of the declarative module. The parameter for the transient noise s value is :ans and the parameter for the permanent noise s value is :pas. The default value for each parameter is **nil**. For the transient noise that means to not generate any transient noise and for the permanent noise it means to leave the chunk's permanent noise set to 0. The permanent noise is always added to the activation of the chunk and can be set by the modeler using the sdp command for creating specific offset values when needed.

Retrieval time

The time that it takes the declarative module to respond to a request for a chunk, *i*, is determined by the activation that the chunk has using this equation when the subsymbolic computations are enabled:

$$RT = Fe^{-(f*A_i)}$$

RT: The time to retrieve the chunk in seconds.
A_i: The activation of the chunk *i* which is being retrieved.
F: The latency factor parameter.
f : The latency exponent parameter.

If there is no chunk found in response to a request or the chunk with the highest activation is below the retrieval threshold then the time required to indicate a failure to retrieve any chunk is determined by this equation when subsymbolic computations are enabled:

$$RT = Fe^{-(f*\tau)}$$

RT: The time until the failure is noted in seconds.
τ : The retrieval threshold parameter (:rt)
F: The latency factor parameter (:lf)
f : The latency exponent parameter (:le)

Declarative finsts

The declarative module maintains a record of the chunks which have been retrieved and provides a mechanism which allows one to explicitly retrieve or not retrieve one which is so marked. This is done through the use of a set of finsts (fingers of instantiation) which mark those chunks. The finsts are limited in the number that are available and how long they persist. The number and duration are both controlled by parameters. If more finsts are required than are available, then the oldest one (the one marking the chunk retrieved at the earliest time) is removed and used to mark the most recently retrieved chunk. Details on how to use the finsts in a request are covered in the section detailing the use of the retrieval buffer.

Parameters

The declarative module has a lot of parameters which can be set and they fall into four general categories. The first category contains the parameters which are used in the activation equations as described above. The next category contains the parameters which control basic functionality of the module. The third category is parameters which allow the user to adjust the chunk activation equation: each of the four primary components may be replaced by the user, the default computations for strengths of association and similarities can be replaced, and additional terms may

be added to the equation. The final set of parameters allow the user to install functions to monitor the operations of the module.

Note on parameters for the declarative module. It is recommended that one not change parameters for the declarative module once chunks have been entered into DM (this also includes the :ol and :esc parameters which are used by the declarative module). The reason for this is that the module does not attempt to reconcile differences in interpretations which may result due to such changes i.e. chunks which have had their internal parameters set under one set of parameters may no longer be valid under different settings. A warning will be printed if one does change such parameters after there are chunks in DM. That warning does not mean that things will necessarily break (there are situations where the warning can be safely ignored), but one should be cautious when changing things in that manner.

:act

The activation trace parameter controls whether or not the declarative module should print the details of the activation computation when it is computed (during a retrieval request or otherwise). If it is set to **t** then all of the components of the equation are output to the model's trace when a chunk's activation is computed, and if it is set to **nil** then no extra trace is generated. The default value is **nil**.

There are also two lesser output levels available for the activation trace if one specifies a setting of **medium** or **low** for the parameter value. The medium output level does not print the information about chunks which did not match the retrieval request and the low level only prints the final activation values computed for the chunks.

:activation-offsets

This parameter allows one to specify functions which can extend the activation equation with new terms. This parameter can be set to a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). Whenever a chunk's activation is computed each of the functions that has been set for this parameter will be called with one parameter which is the name of the chunk. If a function called returns a number then that value will be added to the activation of the chunk and if the activation trace is enabled a line will be shown indicating the name of the function and the offset added. If a function returns any other value then no change is made to the activation of the chunk. If the parameter is set to **nil** then all functions are removed from the activation-offsets list. A function should only be set once. If a function is specified more than once as a value for the activation-offsets a warning will be displayed and a value of **nil** will be returned as the current value.

:ans

The activation noise s parameter specifies the s value used to generate the instantaneous noise added to the activation equation if it is set to a positive number. If it is set to **nil**, which is the default, then no instantaneous noise is added to the activations.

:bl-hook

This parameter allows one to override the base-level calculation. If it is set to a function then that function will be passed one parameter which is the name of the chunk for which a base-level is needed. If the function returns a number then that will be the B_i value used in the activation equation.

:blc

The base-level constant parameter specifies the default value for the βi component of the base-level equations. If base-level learning is disabled (:bll is nil) and the :base-level parameter for the chunk is set (see sdp below) then that overrides the :blc setting. The default value is 0.0.

:bll

The base-level learning parameter controls whether base-level learning is enabled, and if so what the value of the decay parameter, d, is set to. It can be set to any positive number or the value **nil**. The value **nil** means do not use base-level learning and is the default value, any number means that base-level is enabled.

:chunk-add-hook

This parameter allows one to specify functions to be called automatically when chunks are added to the current model's DM. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). Whenever a chunk is added into DM each of the functions that has been set will be called with one parameter which is the name of the chunk that was added into DM. This call is made after the chunk has been added to DM and its declarative parameters updated appropriately. The return values of those functions are ignored. If the parameter is set to **nil** then all functions are removed from the chunk-add-hook. A function should only be set once. If a specific function is specified more than once as a value for the chunk-add-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:chunk-merge-hook

This parameter allows one to specify functions to be called automatically when chunks are merged into to the current model's DM. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). Whenever a chunk is merged into DM each of the functions that has been set will be called with one parameter which is the name of the chunk that was merged into DM.

This call is made after the chunk has been merged into DM and its declarative parameters updated appropriately. The return values of those functions are ignored. If the parameter is set to **nil** then all functions are removed from the chunk-merge-hook. A function should only be set once. If a specific function is specified more than once as a value for the chunk-add-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:declarative-num-finsts

This parameter controls how many finsts are available to the declarative module. It can be set to any positive number and the default is 4.

:declarative-finst-span

This parameter controls how long a finst can mark a chunk as having been retrieved. After a finst has been on a chunk for this amount of time the finst is removed and the chunk is no longer marked as recently retrieved. It can be set to any positive number and defaults to 3.0.

:fast-merge

This parameter controls whether a fast lookup algorithm can be used to determine if a chunk needs to be merged with any chunks in DM. If it is set to **t,** which is the default, then that lookup algorithm is used. If it is set to **nil**, then for each chunk that is to be merged a complete scan of all chunks of that type in DM must be performed to determine if it should be merged. Generally, one will leave this parameter at **t**, but if one is modifying the chunks that are already in DM explicitly then the lookup algorithm may fail to merge chunks which should be merged and you will need to set this to **nil**. Modifying chunks which are already in DM is not a recommended practice and it cannot happen with the default production actions or buffer manipulations – you would have to call mod-chunk directly to do so.

:le

The latency exponent value, f, in the equation for retrieval times. It can be set to any non-negative value and defaults to 1.0.

:lf

The latency factor value, F, in the equation for retrieval times. It can be set to any non-negative value and defaults to 1.0.

:mas

The maximum associative strength parameter controls whether the spreading activation calculation is used, and if so, what the S value in the Sji calculations will be. It can be set to any number or the

value **nil.** The value **nil** means do not use spreading activation and is the default value, any number means that spreading activation is enabled.

:md

The maximum difference. This is the default similarity value between a chunk and any chunk other than itself. It can be set to any number and defaults to -1.0.

:mp

The mismatch penalty parameter controls whether the partial matching system is enabled, and if so, what the value of the penalty parameter, P, in the activation equation is set to. It can be set to any number or the value **nil**. The value **nil** means do not use partial matching, and is the default. When partial matching is not enabled only chunks which match the retrieval request exactly will be retrieved. If it is set to a number then partial matching is enabled.

:ms

The maximum similarity. This is the default similarity value between a chunk and itself. It can be set to any number and defaults to 0.0.

:nsji

Whether or not to allow negative Sji values from the S-log(fan) calculation, Can be set to **t** which means that they are allowed, or **nil** which means that negative values will be treated as 0 activation spread and a warning will be displayed. A value of **nil** does not prevent the user from setting explicit negative values if desired. The default is **nil**.

:noise-hook

This parameter allows one to override the noise calculation. If it is set to a function then that function will be passed one parameter which is the name of the chunk for which a noise value is needed. If the function returns a number then that will be the noise value used in the activation equation.

:partial-matching-hook

This parameter allows one to override the partial matching calculation. If it is set to a function then that function will be passed two parameters. The first will be the name of the chunk for which a partial matching value is needed and the second will be the chunk-spec of the request. If the function returns a number then that will be the P_i value used in the activation equation.

:pas

The permanent activation noise s parameter specifies the s value used to generate the permanent noise added to the activation equation of a chunk if it is set to a positive number. The permanent noise is only generated once when the chunk is added to DM. If it is set to **nil**, which is the default, then no permanent noise is generated for the chunks, but they may still have such a value set explicitly using the sdp command described below.

:retrieved-chunk-hook

This parameter allows one to specify functions to be called automatically when chunks are retrieved or a failure to retrieve occurs. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). When there is a retrieved-chunk event these functions will be called with the name of the chunk which has been retrieved, and when there is a retrieval-failure event these functions will be called with **nil** as the parameter. The return values of those functions are ignored. If the parameter is set to **nil** then all functions are removed from the retrieved-chunk-hook. A function should only be set once. If a specific function is specified more than once as a value for the retrieved-chunk-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:retrieval-request-hook

This parameter allows one to specify functions to be called automatically when a retrieval request is made. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). When there is a start-retrieval event these functions will be called with the chunk-spec of the request as the parameter. The return values of those functions are ignored. If the parameter is set to **nil** then all functions are removed from the retrieval-request-hook. A function should only be set once. If a specific function is specified more than once as a value for the retrieval-request-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:retrieval-set-hook

This parameter allows one to specify functions to be called during the retrieval process. This parameter can be set with a function which takes one parameter and any number of such functions may be set (the reported value of this parameter is a list of all functions which have been set). After the set of chunks which match have been determined and their activations are calculated this function will be called with the list of the chunk names that match the request. The first chunk on the list is the one that will be retrieved (if its activation is above the threshold). This function can be used to override the choice of which chunk to retrieve. If this function returns a cons of a chunk name and a number, then that chunk will be the one placed in the retrieval buffer after that many seconds pass. If the function returns a number, then the declarative module will signal a retrieval failure after that many seconds pass. If the function returns anything else then the normal retrieval process will occur.

If more than one function on the list for this parameter return a value, then none of those values will be used and the default mechanisms will be applied. If the parameter is set to **nil** then all functions are removed from the retrieval-set-hook. A function should only be set once. If a specific function is specified more than once as a value for the retrieval-set-hook a warning will be displayed and a value of **nil** will be returned as the current value.

:rt

The retrieval threshold. This is the minimum activation a chunk must have to be able to be retrieved, τ, in the retrieval failure time equation. It can be set to any number and defaults to 0.0.

:sact

The save activation trace parameter controls whether or not the declarative module should save the details of the activation computation when it is computed during a retrieval request. If it is set to a non-nil value then all of the components of the activation calculations are saved and a trace like the one displayed when using the :act parameter can be printed out after a run using the print-activation-trace and print-chunk-activation-trace commands. The default value is **nil**.

The parameter can be set to values like :act i.e. **t**, **medium**, **low**, or **nil**. The output of the print-activation-trace and print-chunk-activation-trace commands will use the specific setting of this parameter to display the requested amount of detail in the traces shown.

:sim-hook

This parameter allows one to override the similarity calculation. If it is set to a function then that function will be passed two parameters. The first will be the slot contents of the request specification, the *k* from the partial matching equation, and the second will be the considered chunk's value for that slot. If the function returns a number that will be the M_{ki} value used for that term in the partial matching equation. If the function returns **nil** or a non-numeric value the default M_{ki} value will be used.

:sji-hook

This parameter allows one to override the strength of association calculation. If it is set to a function then that function will be passed two parameters. The first will be the chunk j from a slot in a buffer chunk and the second will be the considered chunk i. If the function returns a number that will be the S_{ji} value used in the equation of S_i for the chunk i. If the function returns **nil** or a non-numeric value the default S_{ji} value will be used.

:spreading-hook

This parameter allows one to override the spreading activation calculation. If it is set to a function then that function will be passed one parameter which is the name of the chunk for which a spreading activation value is needed. If the function returns a number then that will be the S_i value used in the activation equation. If the function returns **nil** or a non-numeric value the default spreading activation calculation will be used.

:w-hook

This parameter allows one to override the default values for W_{kj} in the strength of association calculation. If it is set to a function then that function will be passed two parameters. The first will be the name of the buffer, the k, and the second will be the name of a slot for which the source of activation, the j, is being spread. If the function returns a number that will be the W_{kj} value used in the equation of S_i at that time. If the function returns **nil** or a non-numeric value the default W_{kj} value will be used.

Retrieval buffer

The retrieval buffer is used to retrieve chunks from the model's declarative memory using the mechanisms described above.

Activation spread parameter: :retrieval-activation
Default value: 0.0

Queries

In addition to the default queries the retrieval buffer can be queried with recently-retrieved which can be checked for the values of **t** or **nil**.

'State busy' will be **t** while a retrieval request is being processed – the time between the start-retrieval event and either the retrieved-chunk or retrieval-failure event. It will be **nil** at all other times.

'State free' will be **nil** while a retrieval request is being processed – the time between the start-retrieval event and either the retrieved-chunk or retrieval-failure event. It will be **t** at all other times.

'State error' will be **t** if no chunk matching the most recent request was found – when there is a retrieval-failure event and **nil** otherwise. Once it becomes **t** it will not change back to **nil** until the next retrieval request is made.

'Recently-retrieved t' will be **t** if there is a chunk in the retrieval buffer and there is a chunk in DM from which that chunk was copied which is currently marked with a declarative finst. Otherwise this query will be **nil**.

'Recently-retrieved nil' will be **t** if there is a chunk in the retrieval buffer and there is a chunk in DM from which that chunk was copied which is currently not marked with a declarative finst. Otherwise this query will be **nil**.

Requests

Isa *any-valid-chunk-type*
{*{modifier} slot value*}*
{:recently-retrieved [**t** | **nil** | **reset**]}
{:mp-value [**nil** | *temp-value*]}

A request to the retrieval buffer is a description of a chunk which the declarative module will try to find in DM and place into the retrieval buffer, and there are two request parameters which can be used to modify how that request is handled. The :recently-retrieved request parameter can be used to test the declarative finsts associated with the chunks in addition to the chunks' contents. If :recently-retrieved is specified as **t** then the request will only match to chunks which have a finst set on them at the time of the request. If :recently-retrieved is specified as **nil** then the request will only match to chunks which do not have a finst set on them at the time of the request, and if :recently-retrieved is specified as **reset** then all of the declarative finsts are removed before the request is processed. The :mp-value request parameter allows one to temporarily change the setting of the declarative module's :mp parameter while this request is processed. That can only be used if the :mp parameter has been enabled (set to a number) for the model, and the value provided can be anything that is valid for :mp (a number or **nil**).

If a chunk which matches the request is found it will be placed into the retrieval buffer. If no chunk is found, or no chunk which matches has an activation which is above the retrieval threshold when the :esc parameter is **t**, then the buffer is left empty and an error is signaled.

The declarative module will only process one request at a time. If a new request comes in prior to the completion of a previous request the older request is terminated immediately – no chunk will be placed into the buffer or error signaled as a result of that request. A warning will be output to the trace indicating the early termination of the previous request and the module will remain busy while processing the new request.

A successful request to the declarative module will show events like this:

```
 0.050   DECLARATIVE            START-RETRIEVAL
 …
 0.100   DECLARATIVE            RETRIEVED-CHUNK C
 0.100   DECLARATIVE            SET-BUFFER-CHUNK RETRIEVAL C
```

A failed request will show events like this:

```
10.250   DECLARATIVE            START-RETRIEVAL
 …
10.300   DECLARATIVE            RETRIEVAL-FAILURE
```

If a request is terminated prematurely by a new request this is the warning that will show in the trace:

```
    10.350   DECLARATIVE            START-RETRIEVAL
    …
#|Warning: A retrieval event has been aborted by a new request |#
```

Commands

add-dm

Syntax:

add-dm ({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***)*** -> [chunk-name-list | **nil**]
add-dm-fct (({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***)*) ->** [chunk-name-list | **nil**]

Arguments and Values:

chunk-name ::= a symbol that will be the name of the chunk
doc-string ::= a string that will be the documentation for the chunk
chunk-type ::= a symbol that should name an existing chunk-type of the model
slot ::= a symbol that names a valid slot in chunk-type
value ::= any Lisp value which will be the contents of the preceding named slot for this chunk
chunk-name-list ::= a list of chunk-name symbols

Description:

The add-dm command functions exactly like the define-chunks command to create new chunks for the model (see define-chunks for more details). In addition, add-dm places those chunks into the current model's declarative memory. It returns a list of the names of the chunks that were created.

If the syntax is incorrect or any of the components are invalid a list describing a chunk then a warning is displayed and no chunk is created for that chunk description, but any other valid chunks defined will still be created.

If there is no current model then a warning is displayed, no chunks are created and **nil** is returned.

Add-dm is used to provide the model with a set of initial memories. It should not be used for creation of general chunks. In particular, it should not be used by other modules to create the chunks to place into their buffers because those chunks will be added to DM automatically when the buffer is cleared and should not be placed there prior to that.

Examples:

```
1> (chunk-type number value)
NUMBER

2> (add-dm (isa number value 1)
```

```
           (two isa number value 2))
(NUMBER0 TWO)

3> (add-dm-fct (list '(three isa number value 3)
                     '(isa number value three)))
(THREE NUMBER1)

E> (add-dm (bad-chunk isa invalid-chunk-type))
#|Warning: Invalid chunk definition: (BAD-CHUNK ISA INVALID-CHUNK-TYPE) chunk-type
specified does not exist. |#
NIL

E> (add-dm (four isa number value 4))
#|Warning: get-module called with no current model. |#
#|Warning: Could not create chunks because no declarative module was found |#
NIL
```

dm

Syntax:

dm *chunk-name** -> (chunk-name*)
dm-fct (*chunk-name**) -> (chunk-name*)

Arguments and Values:

chunk-name ::= should be a symbol which names a chunk

Description:

The dm command is used to print out chunks which are in the declarative memory of the current model. For each chunk name provided that chunk will be printed to the current model's command output stream. If no chunk names are provided then all of the chunks in DM will be printed. A list of the names of the chunks which are printed will be returned.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

This example assumes the count model from unit 1 of the tutorial has been loaded.

```
> (dm)
FIRST-GOAL
  ISA COUNT-FROM
   START  2
   END  4
   COUNT  NIL

F
  ISA COUNT-ORDER
   FIRST  5
   SECOND  6

E
```

```
  ISA COUNT-ORDER
   FIRST  4
   SECOND  5

D
  ISA COUNT-ORDER
   FIRST  3
   SECOND  4

C
  ISA COUNT-ORDER
   FIRST  2
   SECOND  3

B
  ISA COUNT-ORDER
   FIRST  1
   SECOND  2

(FIRST-GOAL F E D C B)

> (dm b d)
B
  ISA COUNT-ORDER
   FIRST  1
   SECOND  2

D
  ISA COUNT-ORDER
   FIRST  3
   SECOND  4

(B D)

> (dm-fct '(first-goal c))
FIRST-GOAL
  ISA COUNT-FROM
   START  2
   END  4
   COUNT  NIL

C
  ISA COUNT-ORDER
   FIRST  2
   SECOND  3

(FIRST-GOAL C)

E> (dm bad-name)
NIL

E> (dm)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

sdm

Syntax:

sdm [**isa** *chunk-type slot-test** | *slot-value**] -> (chunk-name*)
sdm-fct ([**isa** *chunk-type slot-test** | *slot-value**]) -> (chunk-name*)

Arguments and Values:

chunk-type ::= a symbol which names a chunk-type
slot-test ::= {slot-modifier} slot-value
slot-modifier ::= [**=** | **-** | **<** | **>** | **<=** | **>=**]
slot-value ::= slot value
slot ::= a symbol which names a slot
value ::= any Lisp value
chunk-name ::= a symbol which names a chunk

Description:

The sdm command is used to search the declarative memory of the current model and print out chunks which match the search specification. If no parameters are provided then all chunks in DM are printed. If parameters are provided then all chunks which match the specification provided are printed. If the chunk-type is specified then the slots given must be valid for that chunk-type and slot modifiers may be used. If no chunk-type is provided then only slots and values may be provided, but any chunk which has a slot by that name can match. A list of the names of the chunks which are printed is returned.

If there is an error in the specification or there is no current model a warning is printed and **nil** is returned.

Examples:

```
1> (chunk-type type1 slot1 slot2)
TYPE1

2> (chunk-type number name value)
NUMBER

3> (chunk-type type2 name slot1)
TYPE2

4> (add-dm (one isa chunk)
           (a isa type1 slot1 1 slot2 a)
           (b isa type1 slot1 2 slot2 a)
           (c isa number name one value 1)
           (d isa type2 name one slot1 3))
(ONE A B C D)

5> (sdm isa type1)
A
  ISA TYPE1
   SLOT1  1
   SLOT2  A

B
  ISA TYPE1
   SLOT1  2
   SLOT2  A

(A B)

6> (sdm name one)
D
```

```
  ISA TYPE2
   NAME  ONE
   SLOT1  3

C
  ISA NUMBER
   NAME  ONE
   VALUE  1

(D C)

7> (sdm-fct '(isa type1 < slot1 2))
A
  ISA TYPE1
   SLOT1  1
   SLOT2  A

(A)

8> (sdm-fct '(slot2 a))
A
  ISA TYPE1
   SLOT1  1
   SLOT2  A

B
  ISA TYPE1
   SLOT1  2
   SLOT2  A

(A B)

9E> (sdm-fct '(isa type2 value))
#|Warning: Invalid slot-name VALUE in call to define-chunk-spec. |#
#|Warning: chunk-spec-chunk-type called with a non-chunk-spec |#
#|Warning: NIL is not a valid chunk-spec in call to find-matching-chunks. |#
NIL

E> (sdm isa bad-chunk-type)
#|Warning: Invalid chunk-type BAD-CHUNK-TYPE passed to sdm |#
NIL

E> (sdm < slot1 1)
#|Warning: Specification list to sdm without an isa is not an even length |#
NIL

E> (sdm)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

print-dm-finsts

Syntax:

print-dm-finsts -> (<chunk-name time-stamp>*)

Arguments and Values:

chunk-name ::= a symbol which names a chunk in DM
time-stamp ::= a number indicating the time the finst was applied to the chunk chunk-name

Description:

Print-dm-finsts can be used to see which chunks in the current model have declarative finst markers. It takes no parameters and will print out a table of the chunks with finsts on them showing the time at which the finst was set in seconds. It returns a list of cons cells where each cell has the name of a chunk with a finst on it as the car and the creation time of its finst as the cdr.

If there is no current model then a warning is printed and **nil** is returned.

Examples:

This example assumes that the count model from tutorial unit 1 has been loaded.

```
1> (print-dm-finsts)

Chunk name     Time Stamp
-------------------------
NIL


2> (run 10)
...

3> (print-dm-finsts)

Chunk name     Time Stamp
-------------------------
E                  0.300
D                  0.200
C                  0.100
((E . 0.3) (D . 0.2) (C . 0.1))

E> (print-dm-finsts)
#|Warning: get-module called with no current model. |#
NIL
```

sdp

Syntax:

sdp [{[*chunk-name* | (*chunk-name**)}{[*param-name**| *param-value-pair**]} |
(*chunk-name* [*param-name**| *param-value-pair**])*] -> (param-values*)
sdp-fct ([{[*chunk-name* | (*chunk-name**)}{[*param-name**| *param-value-pair**]} |
(*chunk-name* [*param-name**| *param-value-pair**])*])-> (param-values*)

Arguments and Values:

chunk-name ::= a symbol which is the name of a chunk in the declarative memory of the current model
param-name ::= a keyword which names a declarative parameter
param-value-pair ::= param-name new-param-value

new-param-value ::= a Lisp value to which the preceding param-name is to be set
param-values ::= [(param-value*) | (chunk-name*)| **:error**]
param-value ::= the current value of a requested declarative parameter or **:error**.

Description:

Sdp is used to set or get the declarative parameters of the chunks in the current model. It is very similar to the sgp command which is used to set and get the module parameters.

Each chunk has several declarative parameters associated with it, and most of those are relate to the computation of the activation equation. The declarative parameters are only relevant when the :esc parameter is enabled, and even then, some of the parameters are only available when specific options of the declarative module are also enabled.

The declarative parameters available through sdp are listed below. An important thing to note is that while these declarative parameters are maintained using general chunk parameters not all of the general chunk parameters are available through sdp. Only the chunk parameters which are relevant to the declarative module are accessible through the sdp command, and the mapping of declarative parameters onto chunk parameters may not be one-to-one. Thus, these parameters should only be accessed through the sdp command and should not be read or changed through the general chunk parameter accessors since their internal representations are not part of the declarative module's API.

- name := the name of the chunk. Cannot be changed.
- activation := the chunk's current activation value. Cannot be changed through sdp.
- permanent-noise := the permanent noise is a value which is added to the activation of the chunk each time it is computed. It defaults to 0.0. If :pas is set to a number, then when a chunk is initially added to DM a random noise value generated using the :pas value as the s parameter to act-r-noise will be generated and set as the chunk's permanent noise. It can be set by the modeler to any number, which will override the default and automatically generated values.
- base-level := the chunk's current base-level value. Cannot be changed directly through sdp when base-level learning is enabled because in that case it is controlled by the chunk's creation-time, reference-count, and/or reference-list. If base-level learning is disabled then it can be set to a number which will be the β_i value for the chunk.
- creation-time := the time (in seconds) when the chunk was first added to DM. Used by the base-level equations to determine the t_j values and the chunk's life time. Can be set to any time (including negative values) which is less than or equal to the current time. This is only applicable when :bll is set to a non-**nil** value.
- reference-count := the number of references which the chunk has received. Can be set to any positive value. It is applicable when :bll is non-**nil** and :ol is either **t** or a number. It is the n value used in the optimized base-level equations. If the reference-count is set by the user then the reference-list for the chunk will be adjusted to contain an appropriate number of references as follows. If the reference-list is as long as the reference-count specified or :ol is **t**

then the reference-list will be unchanged. If the reference-list is currently longer than the specified reference-count it will be truncated to that many of the most recent entries. If the reference-list is shorter than the specified reference-count but has as many items as the current setting of :ol it will be unchanged. Otherwise, the reference-list will be set to an evenly distributed set of references as would be done by the set-base-level command.

- reference-list := the list of times at which the chunk's references have occurred (most recent first). Can be set to a list of times. It is applicable when :bll is non-**nil** and :ol is either **nil** or a number. If :ol is **nil**, then the list will contain all of the reference times of the chunk. If :ol is set to a number then it will only hold that many references (the most recent). If more references are provided than are needed, the list is truncated to the necessary length. When the reference-list is set by the user the reference-count may be adjusted automatically. If :ol is **nil**, then the reference-count will be updated to the length of the reference-list (even though the reference-count is not actually used when :ol is **nil**). If :ol is a number and the reference-count is less than the length of the (possibly truncated) reference-list it will be set to the length of the reference-list. Otherwise, the reference-count will be unchanged.
- references := This parameter is deprecated and should not be used, but is still available for compatibility with older models. This parameter will not be shown for a chunk and modelers should use reference-count and reference-list instead to get/set the relevant values.
- source := the chunk's current activation spread from the current buffer contents. Cannot be changed directly through sdp. Only applicable when the :mas parameter is set to a number.
- sjis := this reports the S_{ji} value for chunks j to the chunk i (where i is the chunk for which the value is being reported). The reported value is a list of cons cells where the car of a cons is the name of a chunk j and the cdr is the S_{ji} between that chunk j and the chunk i. Only chunks j which have a connection with i are reported – all other S_{ji} values to chunk i will be 0.0 (unless a provided :sji-hook overrides that). This parameter is only relevant when the :mas parameter is set to a number. It is possible to set this parameter using a list of cons cells (or two element lists). Each value specified is effectively added to the set of S_{ji} values for the chunk as if the add-sji command was called (possibly replacing a value which was previously set or overriding a default value). The add-sji command is the recommended way to set S_{ji} values instead of using this parameter through sdp.
- similarities := this reports the similarities (the M_{ki} values) between other chunks k and this chunk, i. The reported value is a list of cons cells where the car of the cell is the name of the chunk k and the cdr is the similarity value M_{ki}. Only chunks k for which a similarity value has been set and the similarity of the chunk with itself are reported. All other M_{ki} values will be the maximum difference (the :md parameter setting). This parameter is only relevant when the :mp parameter is set to a number. It is possible to set this parameter using a list of cons cells (or two element lists). Each value specified is effectively added to the similarity values for the chunk (possibly replacing a value which was previously set or overriding a default value). The set-similarities command is the recommended means of setting similarities, but if one wants asymmetric similarities between chunks they must be set explicitly with sdp per chunk (set-similarities always sets the values symmetrically).

- last-retrieval-activation := the activation that the chunk had the last time that it was attempted to be retrieved. This value is computed during the start-retrieval event and will be updated for all chunks which match the retrieval request. Cannot be changed through sdp.
- last-retrieval-time := the time at which the last attempt to retrieve this chunk occurred i.e. the time at which the last-retrieval-activation value was set. Cannot be changed through sdp.

Note: because parameter settings are applied in the order provided and there are dependences between the creation-time, reference-count, and reference-list the order in which they are given may affect the resulting values. The ordering to achieve what is typically wanted would be to set creation-time, then reference-count, and then reference-list. That ensures that the creation-time has been updated before any automatic references are generated and that the specified reference-list is not overwritten by one automatically created by the reference-count. It is not required that they be provided in that order however, and one may use other orderings to achieve different resultant values as desired.

If no parameters are provided to sdp, then all of the current model's chunks' parameters are printed and a list of all the chunk names is returned.

If a chunk or list of chunks is specified as the first parameter to sdp then the following parameters are set or retrieved from only those chunks. If no chunk names are provided then the settings are applied to or retrieved from all chunks in DM at the time of the call to sdp.

If chunk names are specified but no specific parameters are specified then the parameters for those chunks are printed and the list of those chunk names is returned.

When sdp prints the parameters for a chunk its name is printed followed by the parameters which are currently appropriate based on the declarative module's parameter settings to the command output stream.

If any of the chunk names provided are invalid a warning will be printed and the corresponding element of the return list will be **:error**.

If all of the parameters passed to sdp (after any chunk names) are keywords, then it is a request for the current values of the parameters named. Those parameters are printed for the chunks specified and a list containing a list for each chunk specified is returned. Each sub-list contains the values of the parameters requested in the order requested and the sub-lists are in the order of the chunks which were requested. If an invalid parameter is requested, then a warning is printed and the value returned in that position will be the keyword **:error**.

If there are any non-keyword parameters in the call to sdp and the number of parameters (not counting the chunk names) is even, then they are assumed to be pairs of a parameter name and a parameter value. For all of the specified chunks (or all chunks in DM if none are specified) those

parameters will be set to the provided values. The return value will be a list containing a list for each chunk specified. Each sub-list contains the values of the parameters set in the order they were set and the sub-lists are in the order of the chunks which were specified. If a particular parameter value was not of the appropriate type, then a warning is printed and the value returned in that position will be the keyword **:error**.

It is also possible to pass lists of a chunk name and parameter settings to sdp. Essentially, each list provided could be formatted as something that could be passed to sdp and they will each be processed as appropriate.

If there is no current model at the time of the call, then a warning is displayed and **nil** is returned.

There is one small issue worth noting about using sdp. If the :activation or :base-level value is returned (either because it is explicitly specified or because no parameters were specified and thus it gets returned automatically) that will cause the chunk's activation to be recomputed at the current time if it is not currently at the time of the chunk's last retrieval attempt (the value of the :last-retrieval-time parameter). That activation computation will include the activation noise if there is any. There are two consequences of that. First, multiple calls to sdp will likely return different :activation values for a given chunk, even if those calls occur at the same model time. The other consequence is that if there is noise in the activations then if sdp has to recomputed the chunk activations it will affect the random sequence which will likely change how a model with a set :seed parameter runs from that point on relative to how it would had sdp not been called.

Examples:

The examples assume that this model has been defined:

```
(define-model test
  (sgp :esc t :bll .5 :mas 2 :mp 1)
  (chunk-type test slot1 slot2)
  (add-dm (a isa test)
          (b isa test slot1 a slot2 c)
          (c isa test slot1 a slot2 c)
          (d isa test slot2 b)))

> (sdp)
Declarative parameters for chunk D:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((D . 2.0) (B . 1.3068528))
 :Similarities ((D . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk C:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
```

```
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((A . 0.9013877) (C . 1.5945349))
 :Similarities ((C . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk B:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((B . 1.3068528) (A . 0.9013877) (C . 0.9013877))
 :Similarities ((B . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk A:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((A . 0.9013877))
 :Similarities ((A . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(D C B A)

1> (sdp a :permanent-noise)
Declarative parameters for chunk A:
 :PERMANENT-NOISE  0.000
((0.0))

2> (sdp a :permanent-noise .3)
((0.3))

3> (sdp a)
Declarative parameters for chunk A:
 :Activation  2.491
 :Permanent-Noise  0.300
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((A . 0.9013877))
 :Similarities ((A . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(A)

4> (sdp (a b) :name :activation)
Declarative parameters for chunk A:
 :NAME      A
 :ACTIVATION  2.491
Declarative parameters for chunk B:
 :NAME      B
 :ACTIVATION  2.191
((A 2.4910133) (B 2.1910133))

5> (sdp-fct '(c))
Declarative parameters for chunk C:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
```

```
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((A . 0.9013877) (C . 1.5945349))
 :Similarities ((C . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(C)

6> (sdp-fct '((d b) :sjis))
Declarative parameters for chunk D:
 :SJIS ((D . 2.0) (B . 1.3068528))
Declarative parameters for chunk B:
 :SJIS ((B . 1.3068528) (A . 0.9013877) (C . 0.9013877))
((((D . 2.0) (B . 1.3068528))) (((B . 1.3068528) (A . 0.9013877) (C . 0.9013877))))

7> (sdp (a :base-level) (b :creation-time -1.0))
Declarative parameters for chunk A:
 :BASE-LEVEL  2.191
((2.1910133) (-1.0))

8> (sdp b)
Declarative parameters for chunk B:
 :Activation  0.693
 :Permanent-Noise  0.000
 :Base-Level  0.693
 :Creation-Time -1.000
 :Reference-Count  1.000
 :Source-Spread  0.000
 :Sjis ((B . 1.3068528) (A . 0.9013877) (C . 0.9013877))
 :Similarities ((B . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(B)

9> (sdp-fct '(:reference-count 3.0))
((3.0) (3.0) (3.0) (3.0))

10> (sdp-fct '((a b)))
Declarative parameters for chunk A:
 :Activation  3.590
 :Permanent-Noise  0.300
 :Base-Level  3.290
 :Creation-Time  0.000
 :Reference-Count  3.000
 :Source-Spread  0.000
 :Sjis ((A . 0.9013877))
 :Similarities ((A . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk B:
 :Activation  1.792
 :Permanent-Noise  0.000
 :Base-Level  1.792
 :Creation-Time -1.000
 :Reference-Count  3.000
 :Source-Spread  0.000
 :Sjis ((B . 1.3068528) (A . 0.9013877) (C . 0.9013877))
 :Similarities ((B . 0.0))
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(A B)

E> (sdp bad-chunk)
#|Warning: BAD-CHUNK does not name a chunk in DM. |#
(:ERROR)

E> (sdp a :bad-parameter)
```

```
Declarative parameters for chunk A:
#|Warning: BAD-PARAMETER is not a declarative parameter for chunks. |#
((:ERROR))

E> (sdp a :name value)
#|Warning: CHUNK NAME CANNOT BE SET. |#
((:ERROR))

E> (sdp a)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

sji/add-sji

Syntax:

sji *chunk-name-j chunk-name-i* -> [sji | **nil**]
sji-fct *chunk-name-j chunk-name-i* -> [sji | **nil**]
add-sji (*chunk-name-j chunk-name-i sji*)* -> ([sji | **:error**]*)
add-sji-fct ((*chunk-name-j chunk-name-i sji*)*) -> ([sji | **:error**]*)

Arguments and Values:

chunk-name-j ::= should be a symbol which names a chunk
chunk-name-i ::= should be a symbol which names a chunk
sji ::= a number which is the associative strength from chunk-name-j to chunk-name-i i.e. the Sji value in the spreading activation equation

Description:

The sji command is used to get the S_{ji} value between two chunks in the current model. It takes two parameters which are the names of the chunk j and the chunk i respectively, and it returns the S_{ji} value between them. The S_{ji} value will be either the value determined by the equation provided above, the explicit value which has been set using the add-sji command, or the result returned by the sji-hook if it is specified. The sji-hook function overrides an explicit setting and the default calculation, and an explicitly set value will override the default calculation. If either of the chunk names is invalid then a warning is printed and an S_{ji} of 0.0 is returned. If there is no current model then a warning is printed and **nil** is returned.

The add-sji command is used to specify explicit S_{ji} values between chunks. It can be used to set any number of S_{ji} values at a time. Each parameter to add-sji (or element of the list passed to add-sji-fct) should be a list of three items. Those items are the chunk j, the chunk i, and the S_{ji} value between them respectively. It applies the S_{ji} values in order left to right. Thus, if any pair of items is specified more than once it will be the right most setting for the pair that will be their S_{ji}. It returns a list of the S_{ji} values set in the order they were specified. If any of the lists are not three elements long, have bad chunk names, or an invalid S_{ji} value then that item is ignored for purposes of setting an S_{ji}, a warning is printed, and the corresponding element of the return list will be **:error**.

Examples:

The example assumes this initial model is defined.

```
(define-model sji-demo
   (sgp :esc t :mas 2)
   (chunk-type item slot)
   (add-dm (a isa item slot nil)
           (b isa item slot a)
           (c isa item slot d)
           (d isa item slot c)
           (e isa item slot c)
           (f isa item slot f)
           (g isa item slot f)))

> (sji a b)
1.3068528

> (sji b a)
0.0

> (sji c d)
0.9013877

> (sji d c)
1.3068528

> (sji-fct 'a 'a)
1.3068528

> (sji-fct 'f 'f)
1.5945349

E> (sji-fct 'bad-name 'a)
#|Warning: BAD-NAME does not name a chunk in the current model. |#
0.0

E> (sji-fct 'b 'c)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL

1> (add-sji (a b 2.5) (b a 10))
(2.5 10)

2> (sji a b)
2.5

3> (sji b a)
10

1> (add-sji-fct '((f f 1) (d c 0)))
(1 0)

2> (sji f f)
1

3> (sji d c)
0

1> (add-sji (c d 1.0) (c d 2.0))
(1.0 2.0)

2> (sji c d)
2.0
```

```
E> (add-sji a b 1.0)
#|Warning: Bad Sji setting in A|#
#|Warning: Bad Sji setting in B |#
#|Warning: Bad Sji setting in 1.0 |#
(:ERROR :ERROR :ERROR)

E> (add-sji (a bad-name 1.0))
#|Warning: Bad Sji setting in (A BAD-NAME 1.0) |#
(:ERROR)

E> (add-sji-fct '(a b 2))
#|Warning: Bad Sji setting in A |#
#|Warning: Bad Sji setting in B |#
#|Warning: Bad Sji setting in 2 |#
(:ERROR :ERROR :ERROR)

E> (add-sji (a b 2))
#|Warning: get-chunk called with no current model. |#
#|Warning: Bad Sji setting in (A B 2) |#
(:ERROR)
```

similarity/set-similarities

Syntax:

similarity *item1 item2* -> [sim | **nil**]
similarity-fct *item1 item2*-> [sim | **nil**]
set-similarities (*chunk-name-k chunk-name-i sim*)* -> ([sim | **:error**]*)
set-similarities-fct ((*chunk-name-k chunk-name-i sim*)*) -> ([sim | **:error**]*)

Arguments and Values:

item1 ::= any value
item2 ::= any value
chunk-name-k ::= should be a symbol which names a chunk
chunk-name-i ::= should be a symbol which names a chunk
sim ::= a number which is the similarity between the specified items

Description:

The similarity command is used to get the similarity value between two items in the current model (they do not have to be chunks). It takes two parameters which are the items, and it returns the similarity value between them (the M_{ki} from the partial matching equation). The computation of the similarity value is described above and it will be determined either by the default calculation, explicit user settings, or the hook function. The sim-hook function overrides an explicit setting and the default calculation, and an explicitly set value will override the default calculation. If there is no current model then a warning is printed and **nil** is returned.

The set-similarities command is used to specify explicit similarity values between chunks (to use values other than the defaults between non-chunk items one must use the hook function). It can be used to set any number of similarity values at a time. Each parameter to set-similarities (or element

of the list passed to set-similarities-fct) should be a list of three items. Those items are the chunk k, the chunk i, and the similarity value between them respectively. It applies the similarity values in order left to right. Thus, if any pair of items is specified more than once it will be the right most setting for the pair that will be their similarity. Note that similarities are set reciprocally with this command, and thus setting the similarity for k i also sets the similarity for i k. It returns a list of the similarity values set in the order they were specified. If any of the lists are not three elements long, have bad chunk names, or an invalid similarity value then that item is ignored for purposes of setting a similarity, a warning is printed, and the corresponding element of the return list will be **:error**. If there is no current model then a warning will be printed and all elements in the list will be **:error**.

Examples:

This example assumes that this initial model is defined.

```
(define-model sim-demo
   (sgp :esc t :mp 1)
   (add-dm (a isa chunk)
           (b isa chunk)
           (c isa chunk)))

> (sgp :ms :md)
:MS 0.0 (default 0.0) : Maximum Similarity
:MD -1.0 (default -1.0) : Maximum Difference
(0.0 -1.0)

> (similarity a b)
-1.0

> (similarity a a)
0.0

> (similarity-fct 'a 'c)
-1.0

> (similarity-fct "String" "string")
0.0

> (similarity "String" string)
-1.0

> (similarity-fct 3.4 3.4)
0.0

E> (similarity a b)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL

1> (set-similarities (a b -.5) (b c -2))
(-0.5 -2)

2> (similarity a b)
-0.5

2> (similarity b a)
-0.5

3> (similarity b c)
-2
```

```
1> (set-similarities-fct '((a a .5) (a c -1) (a c -2)))
(0.5 -1 -2)

2> (similarity a c)
-2

3> (similarity a a)
0.5

E> (set-similarities a b .5)
#|Warning: Bad similarity setting in A |#
#|Warning: Bad similarity setting in B |#
#|Warning: Bad similarity setting in 0.5 |#
(:ERROR :ERROR :ERROR)

E> (set-similarities (d e .5))
#|Warning: Bad similarity setting in (D E 0.5) |#
(:ERROR)

E> (set-similarities (a b 1.0) (a d 1.0) (b c 1.0))
#|Warning: Bad similarity setting in (A D 1.0) |#
(1.0 :ERROR 1.0)

E> (set-similarities (a b 1))
#|Warning: get-chunk called with no current model. |#
#|Warning: Bad similarity setting in (A B 1) |#
(:ERROR)
```

get-base-level/set-base-levels/set-all-base-levels

Syntax:

get-base-level {*chunk-name**} -> ([base-level | **:error**]*)
get-base-level-fct (*chunk-name**) -> ([base-level | **:error**]*)
set-base-levels (*chunk-name level {creation-time}*)* -> ([base-level | **:error**]*)
set-base-levels-fct ((*chunk-name level {creation-time}*)*) -> ([base-level | **:error**]*)
set-all-base-levels *level {creation-time}* -> [**t** | **nil**]

Arguments and Values:

chunk-name ::= should be a symbol which names a chunk
base-level ::= a number representing the base-level activation of a chunk
level ::= a number which is the setting for the base-level of chunk-name (interpretation depends on the :bll parameter setting)
creation-time ::= a number which represents the time at which chunk-name was added to DM

Description:

Get-base-level will return a list of the current base-level activations in the current model for the chunks provided in the same order as they are given. This will result in the base-level being recomputed for those chunks. If a chunk-name given does not name a chunk which is in the DM of the current model then the corresponding base-level value will be **:error**. If there is no current model then a warning is printed and **nil** is returned.

Set-base-levels is used to set the base-level activation for chunks in the DM of the current model. For each chunk specified, its base-level is set as described below and if a new creation time is specified that is also set for the chunk. The list of current base-level activations is returned for the chunks specified in the same order as they were given. If a chunk-name is invalid, the level is not a number, or the creation time is specified and is not a number then a warning is printed, no change is made to the chunk's parameters and the corresponding base-level returned will be **:error**.

The setting of the chunk's base-level depends on the settings of the :bll and :ol parameters. If :bll is **nil** then the level provided is used directly as the chunk's base-level. If :bll is non-**nil** then the setting of the :ol parameter determines how the level is used. If :ol is **t** then the level is the number of references for the chunk (n in the optimized learning equation). If :ol is **nil** then the level specifies how many references the chunk has and a history of the chunk is generated which evenly spaces those references between the current time and the chunk's creation time (which will be the new value if provided). If :ol is a number, then the level specifies the number of references for the chunk (the n in the hybrid optimized equation) and a history list is generated which evenly spaces either the value of :ol or level (whichever is lesser) references between the current time and the chunk's creation-time.

The set-all-base-levels command works like the set-base-levels command except that it applies the level and creation-time (if provided) to all chunks in DM of the current model at the time it is called. If it was successful it returns **t**. If there was a problem then a warning is printed and **nil** is returned.

Examples:

```
1> (define-model test-base-levels
       (sgp :esc t :bll nil)
       (add-dm (a isa chunk)
               (b isa chunk)
               (c isa chunk)))
TEST-BASE-LEVELS

2> (get-base-level a b)
(0.0 0.0)

3> (set-all-base-levels 1.5)
T

4> (set-base-levels (c -1))
(-1)

5> (get-base-level a b c)
(1.5 1.5 -1)


1> (define-model test-base-levels-2
      (sgp :esc t :bll .5 :ol t)
      (add-dm (a isa chunk)
              (b isa chunk)
              (c isa chunk)))
TEST-BASE-LEVELS-2
```

```
2> (get-base-level-fct '(a b c))
(2.1910133 2.1910133 2.1910133)

3> (set-all-base-levels 4 -1)
T

4> (sdp)
Declarative parameters for chunk C:
 :Activation  2.079
 :Permanent-Noise  0.000
 :Base-Level  2.079
 :Creation-Time -1.000
 :Reference-Count  4.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk B:
 :Activation  2.079
 :Permanent-Noise  0.000
 :Base-Level  2.079
 :Creation-Time -1.000
 :Reference-Count  4.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk A:
 :Activation  2.079
 :Permanent-Noise  0.000
 :Base-Level  2.079
 :Creation-Time -1.000
 :Reference-Count  4.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(C B A)

5> (set-base-levels-fct '((a 2 -10)))
(0.2350018)

6> (get-base-level-fct '(a b c))
(0.2350018 2.0794415 2.0794415)

E> (get-base-level bad-name)
(:ERROR)

E> (set-all-base-levels :not-a-number)
#|Warning: Invalid level :NOT-A-NUMBER |#
NIL

E> (set-all-base-levels 1.5 :not-a-number)
#|Warning: Invalid creation-time :NOT-A-NUMBER |#
NIL

E> (set-base-levels (a))
#|Warning: Invalid level in setting (A) |#
(:ERROR)

E> (set-base-levels (a 1.5) (:not-a-chunk 1.5))
#|Warning: :NOT-A-CHUNK does not name a chunk in DM. |#
(1.5 :ERROR)

E> (get-base-level a)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL

E> (set-base-levels (b 3))
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

```
E> (set-all-base-levels 10)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

clear-dm

Syntax:

clear-dm -> [**t** | **nil**]

Arguments and Values:

Description:

The clear-dm command can be used to remove all chunks from the declarative memory of the current model. It is not recommended for general use, but one may encounter situations where it would be needed. The command returns **t** if the current model's DM was cleared and **nil** if there was no current model or some other problem was encountered. It will always print a warning that states either that all chunks were cleared or that a problem occurred.

Examples:

```
> (clear-dm)
#|Warning: All the chunks cleared from DM. |#
T

E> (clear-dm)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative memory module found |#
NIL
```

reset-declarative-finsts

Syntax:

reset-declarative-finsts -> **nil**

Arguments and Values:

Description:

The reset-declarative-finsts command can be used to remove all of the finst markers from the declarative module of the current model. It takes no parameters and always returns **nil**. If there is no current model, then it will print a warning.

This command is not recommended for typical modeling use because the ":recently-retrieved reset" request parameter setting can be used in the procedural requests to accomplish the same thing in a more model driven manner. However, sometimes it may be necessary or more convenient to do that through the Lisp code driving the model.

Examples:

```
> (reset-declarative-finsts)
NIL

E> (reset-declarative-finsts)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative module found - cannot reset the finsts. |#
NIL
```

merge-dm

Syntax:

merge-dm ({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***)*** -> [chunk-name-list | **nil**]
merge-dm-fct (({[*chunk-name* | *chunk-name doc-string*]} **isa** *chunk-type* {*slot value*}***))*** -> [chunk-name-list | **nil**]

Arguments and Values:

chunk-name ::= a symbol that will be the name of the chunk
doc-string ::= a string that will be the documentation for the chunk
chunk-type ::= a symbol that should name an existing chunk-type of the model
slot ::= a symbol that names a valid slot in chunk-type
value ::= any Lisp value which will be the contents of the preceding named slot for this chunk
chunk-name-list ::= a list of chunk-name symbols

Description:

The merge-dm command functions exactly like the add-dm command to create new chunks for the model. However, unlike add-dm merge-dm will merge those chunks into the current model's declarative memory in the same way they would be merged if they had been cleared from a buffer. Thus, if any of the chunks created by merge-dm are equal to a chunk in declarative memory that existing declarative memory chunk is strengthened with a new reference at the current time and those two chunks are merged. If a chunk created by merge-dm is not equal to an existing chunk in the current model's declarative memory then that new chunk is added to declarative memory as if it had been created using add-dm.

If there are dependencies among the chunks created with merge-dm then those chunks will be merged into declarative memory in an order that allows for proper merging of all chunks if such an order exists. If there are dependencies and no safe order exists a warning will be displayed to indicate that and the chunks will be merged into declarative memory in the order that they are provided. Merge-

dm returns a list of the names of the chunks that were created in the order in which they were merged into declarative memory (first chunk returned was the first merged).

If the syntax is incorrect or any of the components are an invalid list describing a chunk then a warning is displayed and no chunk is created for that chunk description, but all valid chunks defined will still be created.

If there is no current model then a warning is displayed, no chunks are created and **nil** is returned.

Examples:

These examples assume that the base-level learning is enabled so that there is a strengthening of activations when additional references to a chunk occur.

```
1> (chunk-type node slot1 slot2)
NODE

2> (add-dm (a isa node slot1 b slot2 c)
           (b isa node slot1 10)
           (c isa node slot2 20))
(A B C)

3> (dm)
C
  ISA NODE
   SLOT1  NIL
   SLOT2  20

B
  ISA NODE
   SLOT1  10
   SLOT2  NIL

A
  ISA NODE
   SLOT1  B
   SLOT2  C

(C B A)

4> (sdp)
Declarative parameters for chunk C:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk B:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk A:
 :Activation  2.191
 :Permanent-Noise  0.000
```

```
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(C B A)

5> (merge-dm (d isa node slot1 e slot2 f)
             (e isa node slot1 10)
             (f isa node slot2 20)
             (x isa node slot1 30))
(E F D X)

6> (dm)
X
  ISA NODE
   SLOT1  30
   SLOT2  NIL

C
  ISA NODE
   SLOT1  NIL
   SLOT2  20

B
  ISA NODE
   SLOT1  10
   SLOT2  NIL

A
  ISA NODE
   SLOT1  B
   SLOT2  C

(X C B A)

7> (sdp)
Declarative parameters for chunk X:
 :Activation  2.191
 :Permanent-Noise  0.000
 :Base-Level  2.191
 :Creation-Time  0.000
 :Reference-Count  1.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk C:
 :Activation  2.884
 :Permanent-Noise  0.000
 :Base-Level  2.884
 :Creation-Time  0.000
 :Reference-Count  2.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk B:
 :Activation  2.884
 :Permanent-Noise  0.000
 :Base-Level  2.884
 :Creation-Time  0.000
 :Reference-Count  2.000
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
Declarative parameters for chunk A:
 :Activation  2.884
 :Permanent-Noise  0.000
 :Base-Level  2.884
 :Creation-Time  0.000
 :Reference-Count  2.000
```

```
 :Last-Retrieval-Activation    NIL
 :Last-Retrieval-Time    NIL
(X C B A)

8> (merge-dm-fct '((y isa node)))
(Y)

9> (merge-dm (g isa node slot1 h)
             (h isa node slot2 g))
#|Warning: Chunks in call to merge-dm have circular references. |#
#|Warning:   Because of that there is no safe order for merging and they will be merged in
the order provided. |#
(G H)

E> (merge-dm (isa not-a-chunk-type))
#|Warning: Invalid chunk definition: (ISA NOT-A-CHUNK-TYPE) chunk-type specified does not
exist. |#
NIL

E> (merge-dm (i isa node))
#|Warning: get-module called with no current model. |#
#|Warning: Could not create chunks because no declarative module was found |#
NIL
```

print-activation-trace

Syntax:

print-activation-trace *time* -> **nil**

Arguments and Values:

time ::= a number which is the time in seconds of a start-retrieval event

Description:

The print-activation-trace command works in conjunction with the :sact parameter to allow one to print the activation trace information for retrieval requests that occurred during a model run after the model has stopped. If the :sact parameter is non-**nil**, then this command will print out the activation trace for the time provided from the current model in the current meta-process as it would have appeared in the model trace if the :act parameter had been set, except that this trace information will be printed to the command output instead of the model output. If the :sact parameter is **nil**, the time provided does not correspond to the time of a start-retrieval event, or there is no current model or meta-process then a warning will be printed instead of an activation trace.

Examples:

These examples assume that the fan model from unit 5 of the ACT-R tutorial has been loaded and modified to set the :sact parameter to t.

```
1> (fan-sentence-model "hippie" "park" t 'person)
     0.000   VISION  SET-BUFFER-CHUNK VISUAL-LOCATION VISUAL-LOCATION0-0 REQUESTED NIL
...
     1.444   PROCEDURAL            CONFLICT-RESOLUTION
```

```
     1.444   ------                 Stopped because no events left to process
(1.354 T)

2> (print-activation-trace 0.485)
Chunk PARK matches
Computing activation for chunk PARK
Computing base-level
User provided chunk base-level: 10.0
Total base-level: 10.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE)
    Spreading activation  0.0 from source HIPPIE level  1.0 times Sji 0.0
Total spreading activation: 0.0
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk PARK has an activation of: 10.0
Chunk PARK with activation 10.0 is the best
NIL

3> (print-activation-trace 0.585)
Chunk P3 matches
Chunk P2 matches
Chunk P1 matches
Computing activation for chunk P3
Computing base-level
Starting with blc: 0.0
Total base-level: 0.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE PARK)
    Spreading activation  0.10685283 from source HIPPIE level  0.5 times Sji 0.21370566
    Spreading activation  0.0 from source PARK level  0.5 times Sji 0.0
Total spreading activation: 0.10685283
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk P3 has an activation of: 0.10685283
Computing activation for chunk P2
Computing base-level
Starting with blc: 0.0
Total base-level: 0.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE PARK)
    Spreading activation  0.10685283 from source HIPPIE level  0.5 times Sji 0.21370566
    Spreading activation  0.0 from source PARK level  0.5 times Sji 0.0
Total spreading activation: 0.10685283
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk P2 has an activation of: 0.10685283
Computing activation for chunk P1
Computing base-level
Starting with blc: 0.0
Total base-level: 0.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE PARK)
    Spreading activation  0.10685283 from source HIPPIE level  0.5 times Sji 0.21370566
    Spreading activation  0.10685283 from source PARK level  0.5 times Sji 0.21370566
Total spreading activation: 0.21370566
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk P1 has an activation of: 0.21370566
Chunk P1 with activation 0.21370566 is the best
NIL

4> (print-activation-trace 0.050)
```

```
#|Warning: No activation trace information available for time 0.05 |#
NIL

E> (PRINT-ACTIVATION-TRACE 0.0)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative module available for reporting activation trace. |#
NIL
```

print-chunk-activation-trace

Syntax:

print-chunk-activation-trace *chunk-name time* -> [**nil |** total base-level spreading similarity noise]
print-chunk-activation-trace-fct *chunk-name time* -> [**nil |** total base-level spreading similarity noise]

Arguments and Values:

chunk-name ::= a symbol which should name a chunk in the model's declarative memory
time ::= a number which is the time in seconds of a start-retrieval event
total ::= a number which is the total activation the chunk had for the retrieval
base-level ::= a number which is the total value of the base-level component of the chunk's activation
spreading ::= a number which is the total spreading activation component of the chunk's activation or **nil** if spreading activation is not enabled
similarity ::= a number which is the total partial matching component of the chunk's activation or **nil** if partial matching is not enabled
noise ::= a number which is the total amount of noise added to the chunk's activation

Description:

The print-chunk-activation-trace command works in conjunction with the :sact parameter to allow one to print the activation trace information for the retrieval requests that occurred during a model run after the model has stopped. If the :sact parameter is non-**nil**, then this command will print out the activation trace for the specified chunk at the time provided from the current model in the current meta-process similar to how it would have appeared in the model trace if the :act parameter had been set, except that this trace information will be printed to the command output instead of the model output. If the :sact parameter is **nil**, the time provided does not correspond to the time of a start-retrieval event, or there is no current model or meta-process then a warning will be printed instead of an activation trace. If the provided chunk-name doesn't name a chunk or wasn't an element in declarative memory then the output will indicate it doesn't have any activation information to display.

If there was chunk activation information displayed then this command will return five values. The first value will be the total activation for the chunk. The remaining four values are the primary components of that activation value: base-level activation, spreading activation, partial matching penalty, and noise. The spreading activation and partial matching penalty values will be **nil** if the corresponding mechanism is not enabled for the model. If there is no chunk activation information displayed then the return value of the command is **nil**.

Examples:

These examples assume that the fan model from unit 5 of the ACT-R tutorial has been loaded and modified to set the :sact parameter to t.

```
1> (fan-sentence-model "hippie" "park" T 'person)
     0.000   VISION   SET-BUFFER-CHUNK VISUAL-LOCATION VISUAL-LOCATION0-0 REQUESTED NIL
...
     1.444   ------                 Stopped because no events left to process
(1.354 T)

2> (print-chunk-activation-trace park .485)
Computing activation for chunk PARK
Computing base-level
User provided chunk base-level: 10.0
Total base-level: 10.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE)
    Spreading activation  0.0 from source HIPPIE level  1.0 times Sji 0.0
Total spreading activation: 0.0
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk PARK has an activation of: 10.0
10.0
10
0.0
NIL
0.0

3> (print-chunk-activation-trace-fct 'p1 0.585)
Computing activation for chunk P1
Computing base-level
Starting with blc: 0.0
Total base-level: 0.0
Computing activation spreading from buffers
  Spreading 1.0 from buffer IMAGINAL chunk COMPREHEND-SENTENCE0-0
    sources of activation are: (HIPPIE PARK)
    Spreading activation  0.10685283 from source HIPPIE level  0.5 times Sji 0.21370566
    Spreading activation  0.10685283 from source PARK level  0.5 times Sji 0.21370566
Total spreading activation: 0.21370566
Adding transient noise 0.0
Adding permanent noise 0.0
Chunk P1 has an activation of: 0.21370566
0.21370566
0.0
0.21370566
NIL
0.0

4> (print-chunk-activation-trace-fct 'p5 0.585)
Chunk P5 did not match the request.
NIL

5> (print-chunk-activation-trace park 0.585)
Chunk PARK was not considered.
NIL

6> (print-chunk-activation-trace not-a-chunk 0.585)
Chunk NOT-A-CHUNK was not considered.
NIL

7E> (print-chunk-activation-trace park 0.0)
#|Warning: No activation trace information available for time 0.0 |#
NIL
```

```
E> (print-chunk-activation-trace chunk 0.0)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative module available for reporting activation trace. |#
NIL
```

saved-activation-history

Syntax:

saved-activation-history -> (activation-history*)

Arguments and Values:

activation-history ::= (time chunk-name*)
time ::= a number which is the time of a retrieval request for which a history has been saved
chunk-name ::= a symbol which names a chunk for which activation information was stored at time

Description:

The saved-activation-history command returns a list which indicates what retrieval information has been saved as a result of the :sact parameter being enabled for the current model in the current meta-process. If the :sact parameter is enabled then this command will return a list of lists where each sub-list consists of a time and the chunks which were attempted to be retrieved at that time for which the activation information was recorded. There will be a separate sub-list for each time for which activation details are recorded and those lists will be in order based on the times (lowest time first). If the :sact parameter is not enable or there is no current model or meta-process then a warning will be printed and the return value will be **nil**.

Examples:

This first example assume that the fan model from unit 5 of the ACT-R tutorial has been loaded and modified to set the :sact parameter to t.

```
1> (fan-sentence-model "hippie" "park" T 'person)
     0.000   VISION   SET-BUFFER-CHUNK VISUAL-LOCATION VISUAL-LOCATION0-0 REQUESTED NIL
...
     1.444   ------                 Stopped because no events left to process
(1.354 T)

2> (saved-activation-history)
((0.235 HIPPIE) (0.485 PARK) (0.585 P3 P2 P1))

E> (saved-activation-history)
#|Warning: No activation trace information available |#
NIL

E> (saved-activation-history)
#|Warning: get-module called with no current model. |#
#|Warning: No declarative module available for reporting activation trace. |#
NIL
```

Perceptual & Motor modules

The perceptual and motor modules provide a model with a way to interact with a world. The provided perceptual modules allow the model to attend to visual and aural stimuli and the given motor modules provide the model with hands and a voice. The perceptual and motor modules provided with ACT-R 6 are essentially updated versions of the modules which comprised those same components in the ACT-R/PM system. ACT-R/PM was developed by Mike Byrne as a combination of ACT-R, the Visual Interface for ACT-R created by Mike Matessa, and the EPIC cognitive architecture created by David Kieras and David Meyer. Providing a model access to an external world was an important development in the advancement of ACT-R modeling, and that integration lead to many of the changes that came about with the introduction of ACT-R 5. Those components are now fully integrated with ACT-R 6 - ACT-R/PM is no longer a separate system because the perceptual and motor modules which it contained are now integral components of the main ACT-R system.

Unlike the cognitive modules, the perceptual and motor modules each work with chunks of specific types and take specific request types as actions. Each module creates those chunk-types automatically, and it may also define some initial chunks. Those chunk-types and any such chunks will be listed with the modules' descriptions.

These modules also have more complicated internal states than the basic state free and state busy which can be queried for all modules. Each of these modules has three separate internal systems: preparation, processor, and execution. Each of those systems can be queried individually for being busy or free. Different requests to these modules may require the use of different internal systems and thus may not require that all internal states be free before being allowed to progress. This is particularly useful in the motor module to request an action before the previous has completed. How the modules respond to the queries and how that affects the requests which can be made to them vary from module to module.

Before describing the perceptual and motor modules themselves, however, the interface that they have to the world will be described.

The Device Module

The world with which a model interacts is called the device. The device defines the operations which the perceptual modules can use for gathering information and the operators available to the motor modules for manipulating that device. The device module provides a model with its interface to the device and provides the commands to the modeler for installing and configuring a device.

The typical device used for modeling is one where the model is operating a computer. Essentially, the model is sitting in front of a monitor, has its hands on a keyboard/mouse, and the computer has speaker outputs and an input microphone. That is the situation generally assumed by the device module, and the one for which many of the parameters are relevant. However it is not the only device with which a model can be interfaced. Models have also been situated within driving and flight simulation systems as well as in virtual worlds as provided by the game Unreal Tournament or the RoboCup soccer simulation and models have also been connected with devices that allow them to receive the inputs and control the actions of real robots.

In general, a device can be any Lisp object and the control of the device is handled by defining methods specific to that type of object. For this section and the description of the following modules, the assumption is that the world with which the model is interacting is the basic computer device created using one of the default devices included with ACT-R 6. Construction of custom devices is described in a later section.

The system includes devices for the basic GUI classes in MCL, LispWorks, ACL w/IDE as well as a "virtual" windowing system that works in any Lisp. There is a set of commands called the AGI (ACT-R GUI Interface) which can be used with any Lisp to create such an interface device. When used with the ACT-R Environment or in MCL, LispWorks, or ACL the AGI can create a "real" GUI with which a person or model can interact. The AGI is described in another section.

Parameters

:mouse-fitts-coeff

This parameter is the b coefficient in the Fitts's Law equation for aimed movements which is used when the model moves the mouse cursor. The default value is .1 and it can be set to any positive value.

:needs-mouse

This parameter controls whether or not the model will take control of the computer's mouse cursor when interacting with a real interface. If it is set to **t**, then the system will attempt to keep the mouse pointer located where the model has placed it within the current device. The default value is **t**. If the

model does not need to use the mouse, but is interacting with a real interface then setting this parameter to **nil** will prevent the system from taking over the mouse cursor.

:pixels-per-inch

This is the number of pixels/inch assumed for the device which the model is looking at. It is used in computations of the size of items in terms of degrees of visual angle. The default value is 72 and it can be set to any positive number.

:process-cursor

This parameter controls whether the mouse cursor should be included as a feature for the vision module when processing a display. If it is set to **t,** then a feature for the mouse will be generated. The default value is **nil**.

:show-focus

This parameter controls whether a red circle is drawn in a real device window to indicate where the model's visual attention is located. If it is set to **t**, then a red circle is drawn. The default is **nil**.

:stable-loc-names

When using the virtual device windows, this parameter determines whether the device sorts the items found in the window before generating the visual features. If the model is not using the virtual device windows, then this parameter has no effect. Setting the parameter to **t**, which is the default value, will force the items to be sorted which means that the same interface display will result in the same feature names each time it is run on all systems – it will be deterministic. If it is set to **nil** then the items in the interface will not be sorted and the names could vary among runs or across systems. Setting it to **nil** should not affect the model's performance and may improve the time it takes to run the simulation at the potential cost of debugging time needed to compare different model runs.

:trace-mouse

This parameter controls whether or not the device module maintains a record of where the model has moved the mouse. If it is set to **t** then one can use the get-mouse-trace command to access the history of mouse positions. The default value is **nil**.

:viewing-distance

This is the assumed distance between the model's eyes and the display in inches. It is used in determining the size of items in terms of degrees of visual angle. The default is 15 and it can be set to any positive number.

:vwt

The :vwt parameter (virtual window trace) controls whether the included virtual window devices report their interactions with the model in the trace. If the parameter is set to **t**, then virtual window interactions will be printed in the trace surrounded by "<<" and ">>" characters. The default value is **nil**.

Commands

These are the general commands relating to the device itself. Commands which are related to a specific module's interaction with the device will be described with that module. Methods necessary to implement a new device are described in another section.

install-device

Syntax:

install-device {*device*} -> [device | **nil**]

Arguments and Values:

device ::= any Lisp value for which the appropriate device methods have been defined

Description:

The install-device command takes one parameter which should be an item for which the appropriate methods have been defined. It makes that item the current device for the current model. The device itself is returned if no problems occurred. If there is no current model, then a warning is printed and **nil** is returned.

A model must have a device installed before it issues any requests to the perceptual or motor modules.

Examples:

```
> (install-device (make-instance 'my-device))
#<MY-DEVICE @ #x2b481f72>

> (install-device nil)
NIL

E> (install-device (make-instance 'my-device))
#|Warning: install-device called with no current model. |#
NIL
```

current-device

current-device -> [device | **nil**]

Arguments and Values:

device ::= the currently installed device

Description:

The current-device command takes no parameters. It returns the device which has been installed for the current model. If there is no current model, then a warning is printed and **nil** is returned.

Examples:

```
1> (install-device (make-instance 'my-device))
#<MY-DEVICE @ #x2b5a7972>

2> (current-device)
#<MY-DEVICE @ #x2b5a7972>

E> (current-device)
#|Warning: current-device called with no current model. |#
NIL
```

get-mouse-trace

get-mouse-trace -> [trace | **:mouse-trace-off** | **nil**]

Arguments and Values:

trace ::= a list of times and mouse positions

Description:

The get-mouse-trace command takes no parameters. If tracing of the mouse has been enabled by setting the :trace-mouse parameter to **t** then it returns a list of cons which record every time the model has moved the mouse and where it was moved to. The car of the cons is the time of the action and the cdr is a vector indicating the x and y coordinates (respectively). If the mouse tracing has not been enabled, then the keyword **:mouse-trace-off** is returned. If there is no current model, then a warning is printed and **nil** is returned.

Examples:

```
> (get-mouse-trace)
((0.909 . #(130 160)))

> (get-mouse-trace)
```

```
:MOUSE-TRACE-OFF

E> (get-mouse-trace)
#|Warning: get-module called with no current model. |#
#|Warning: No device interface found for get-mouse-trace. |#
NIL
```

model-generated-action

model-generated-action -> [model-name | **nil**]

Arguments and Values:

model-name ::= a symbol which names the model that generated the action

Description:

The model-generated-action command takes no parameters. It can be used in writing the methods for a device as a way to determine whether the model performed the action which caused the particular method to be called, and if so, which model it was if there are multiple models defined. If a model performed the action which triggered the method it returns the name of the model which generated the action. If the method was called other than through a model's action then it returns **nil**. Outside of a method called from a device interaction this command will always return **nil**. That last point is an important one and puts some limits on where this command can be used. It should only be used in the device's methods or those functions and methods which are called directly by those methods. If an interface method is called indirectly, for example the rpm-window-key-event-handler or button actions when using the native interface in ACL and LispWorks, because they get called after the model generates a real mouse or keyboard action which is indistinguishable from a person's action, then this is not guaranteed to work correctly, but it will work for the rpm-window handlers and button actions in visible virtual windows through the ACT-R environment because those are all handled directly.

Examples:

```
> (model-generated-action)
NIL
```

Vision module

The vision module is used to provide a model with information about what can be seen in the current device and provides a system for modeling visual attention. The vision module has two subsystems, a "where" system and a "what" system. The two subsystems work together, but each has its own buffer and accepts specific requests. The basic operations of the module are described in this section and more advanced topics will be covered in later sections.

One important thing to note is what the vision module does not do – it does not model eye movements. It is a model of visual attention abstracted away from what is occurring with the eyes. There has been work done by Dario Salvucci to create a more detailed vision module which takes into account eye movements and makes the time required for attention shifts dependent on the eccentricity between the requested location and the current point of gaze, with nearer objects taking less time than further objects. That work resulted in the creation of a system called EMMA (eye movements and movements of attention) which was built as a replacement for the default vision module of ACT-R. That module is not part of the default system and will not be described here.

The model's visual world

The vision module sees the features that are made available by the current device. The device provides a set of features to which a model may attend. That set of features is referred to as the visicon (visual icon). The features in the visicon are the items which can be found with the where system, and contain basic information about items like their general type, location and color. When one of those features is then attended by the what system the device produces a more detailed representation of the item that was attended. More details on the where and what systems are described in the next two sections.

The Where System

The where system takes requests through the visual-location buffer. A request to the visual-location buffer specifies a series of constraints, and the where system returns a chunk representing a location meeting those constraints. This is often referred to as "finding a location". Constraints are attribute-value pairs which can restrict the search based on visual properties of the object (such as "color red"), the spatial location of the object (such as "screen-y greater-than 153"), coarse temporal information such as whether it recently became visible, and tests of whether the model has previously attended to that location. This is akin to so-called "pre-attentive" visual processing (Triesman & Gelade, 1980) and supports visual pop-out effects. For example, if the display consists of one green object in a field of blue objects, the time to determine the location of the green object is constant regardless of the number of blue objects.

When such a request is made, if there is an object on the display that meets those constraints, then a chunk representing the location of that object is placed in the visual-location buffer. If multiple

objects meet the constraints, then the newest one (the one with the most recent onset time) will be returned. If multiple objects meet the constraints and they have the same onset, then one will be picked randomly. If there are no objects which meet the constraints, then the buffer will be left empty and an error will be indicated. See the section on the visual-location buffer for more details on how to use the where system.

Finsts

As noted above, one property of the objects in the visicon which can be tested is whether the item has been previously attended by the model. The vision module is able to keep track of a small number of locations to which it has attended. It does so using a set of markers called finsts which are limited both in number and in duration. When a location is attended to by the model using the what system (described below) a finst marker is placed upon it. The finst marker will remain until the finst's duration expires, at which time the location will revert to unattended, or until an attention shift requires a finst and there are none available. If all finsts are in use and a new one is needed then the oldest one which was assigned will be removed (thus forcing that location to revert to unattended) and reused for the newly attended location.

The What System

The what system takes requests through the visual buffer. Its primary use is to attended to locations which have been found using the where system. A request to the what system entails providing a chunk representing a visual location, which will cause the what system to shift visual attention to that location, process the object located there, and place a chunk representing the object into the visual buffer. If there is more than one object at the location specified when the attention shift completes, only one of them gets encoded and placed into the buffer. The vision module arbitrates among the objects by using the constraints last passed to the where system for that visual location. Thus, if the location passed in was constrained to be red, and there are three objects at the location, one of which is red, then the red one will be encoded.

The what system has a rudimentary tolerance for movement. That is, if the location chunk passed in to be attended specifies a location of (100 125) and the object there moves a little, there will be no error generated if the movement is small. Just how far an object can move and still be encoded is configurable with a parameter, and the default tolerance is 0.5 degrees of visual angle. That means the object can have moved by up to 0.5 degrees of visual angle and still be processed without finding a new location with the where system.

The basic assumption behind the vision module is that the visual-object chunks placed into the visual buffer as a result of an attention operation are episodic representations of the objects in the visual scene. Thus, a visual-object chunk with the value "3" represents a memory of the character "3" available via the eyes, not the semantic THREE used in arithmetic—a declarative retrieval would be necessary to make that mapping. Note also that there is no "top-down" influence on the creation of

these chunks; top-down effects are assumed to be a result of the system's processing of these basic visual chunks, not anything that's done by the vision module. (See Pylyshyn, 1999 for a clear argument about why it should work this way.)

Re-encoding

Once a location has been attended to, if the visual world changes at that location, the module will automatically update the chunk in the visual buffer. The module will register briefly as busy while it re-encodes the new object (or lack of one) at that location.

This behavior is sometimes undesirable. For instance, in response to the model clicking the mouse or typing a key, the stimulus disappears and a new one appears somewhere else. Attention cannot be shifted to that new location right away because the visual system is busy processing the current location. This could make a response to the new stimulus slower than desired.

If this is a problem, it is possible for the model to un-allocate visual attention after it has processed the visual chunk. The clear request to the visual buffer will cause the vision module to stop attending to the visual scene and then it will no longer re-encode until a new attention shift is performed.

Scene change

The vision module will signal when there is a significant change to the visual display. When there is a change to the visual world the module computes the proportion of the items which have changed. If that value is greater-than or equal to a threshold (set with the **:**scene-change-threshold parameter) then the module will signal that there has been a scene change. That signal will only last for a short time (controlled with the :visual-onset-span parameter). That signal of a scene change is made available to the model through the scene-change query of the **visual** buffer.

This is the calculation which computes the proportion of items which have changed:

$$Change = \frac{d + n}{o + n}$$

o: The number of features in the scene prior to the update
d : The number of features which have been deleted from the original scene
n: The number of features which are newly added to the scene by the update

Note: if both **o** and **n** are 0 then the change value will also be 0.

Tracking

The vision module has a rudimentary ability to track moving objects. The basic pattern is to attend the object, then issue a request to start tracking. While the module is tracking an object the chunks representing that item in the visual-location and visual buffers will be updated as the object moves, and the where system will remain busy. Tracking will continue until an explicit request to stop tracking is made or a new request is made of the what system.

Parameters

:auto-attend

This parameter controls whether or not a visual-location request results in an automatic move-attention action to the location which is found. This is designed as a modeling shortcut to allow one to skip productions which make move-attention requests when they will always follow visual-location requests in the model. It does not affect the timing of the model because there is a 50ms delay before the request to compensate for the skipped production's firing time. It is off by default (**nil**) but setting it to **t** will enable that functionality.

:optimize-visual

This parameter controls how text is processed with the default devices. If it is set to **t** (the default value), then each word in the text will be parsed into one feature for the visicon. If it is set to **nil**, then each letter is parsed into multiple features.

There are several options for what features will result from carving up the letters; there is no universally agreed-upon way to do this. The default option is to carve the letters into features consisting of a LED-type representation of the characters of the text. Different feature sets are also available, including Gibson's (1968) set and Briggs & Hochevar's (1975) set.

:scene-change-threshold

This parameter controls the smallest proportion of change in the visicon which will result in signaling that the scene has changed. It must be set to a number in the range [0.0 – 1.0] and defaults to .25.

:test-feats

This parameter controls how items in the visicon are compared on successive calls to proc-display to determine which items are the same between the two calls for purposes of maintaining the finsts and tracking information. If it is set to **nil** then the only test performed is whether the same chunk names

are used. If it is set to **t** then the items are also compared across all of their features (slot values). The default value is **t**.

Setting it to **nil** can allow for a significant performance improvement in proc-display. However, there are only certain circumstances where setting it to **nil** is safe i.e. if it is set to **nil** in other circumstances it may result in incorrect operation of the module. One safe situation is if all proc-display calls also specify ":clear t". In that case the screen is always considered as all new items and there is no need to perform the checks between the old and new visicon items. The other situation is if the device's build-vis-locs-for method(s) always return the same chunks for the visicon items (chunks with the same names). For the included devices the virtual windows meet that criteria, but the Lisp specific devices do not. So, this parameter should only be set to **nil** if proc-display is only called with "clear" screens, the model only uses the virtual windows without modifying the object features explicitly, or if a custom device is installed which satisfies the "same chunk name" constraint on visual items.

:visual-attention-latency

This parameter specifies how long a visual attention shift will take in seconds. The default value is .085.

:visual-finst-span

This parameter controls how long a finst marker will remain on a location. It is measured in seconds and default to 3.0.

:visual-movement-tolerance

This parameter controls how far an object can move and still being considered the same object by the vision module. It is measured in degrees of visual angle and defaults to 0.5.

:visual-num-finsts

This parameter controls how many finsts are available to the vision module. It can be set to any positive number and defaults to 4.

:visual-onset-span

This parameter specifies how long an item recently added to the visicon will be marked as new and how long a scene change notice will be available. It is measured in seconds, and the default value is 0.5.

Visual-location buffer

The visual-location buffer is used to access the where system of the vision module as described above. In addition to taking requests to find locations, the vision module will also place chunks into the visual-location buffer automatically without a model request (a process referred to as "buffer stuffing"). Whenever there is an update to the visual scene (as indicated to the model by calling proc-display), if the visual-location buffer is empty, a visual-location chunk of some visual feature will be placed into the visual-location buffer. The feature which gets "stuffed" into the buffer is chosen based on preferences which can be set either by the modeler or directly by the model. The default preference is for the left-most unattended item.

Activation spread parameter: :visual-location-activation
Default value: 0.0

Queries

'State busy' will always be **nil.**

'State free' will always be **t**.

'State error' will be **t** if the last visual-location request failed to find a matching visual-location and it will be **nil** in all other situations. Once it becomes **t** it will remain **t** until a new visual-location request is made or the explicit clear request is made of the visual buffer.

The visual-location buffer has an additional query that allows one to check the attended status of the location represented by the chunk in the visual-location buffer.

'Attended t' will be **t** if there is a chunk in the visual-location buffer and that location currently has a finst marker on it. Otherwise it will be **nil**.

'Attended nil' will be **t** if there is a chunk in the visual-location buffer and that location does not currently have a finst marker on it. Otherwise it will be **nil**.

'Attended new' will be **t** if there is a chunk in the visual-location buffer, that location does not currently have a finst marker, and that feature was added to the model's visicon within the :visual-onset-span. Otherwise it will be **nil**.

Requests

Isa *visual-location-type*
{{modifier} *valid-slot* [*value* | *variable*]}*
{:**nearest** *nearest-spec*}
{**:attended** [***t*** | ***nil*** | ***new***]}
{**:center** [*vis-loc* | *vis-obj*]}

visual-location-type ::= a chunk-type which is a subtype of visual-location
modifier ::= [= | - | > | < | >= | <=]
valid-slot ::= the name of a slot which exists in the type given for visual-location-type
value ::= any Lisp value, but the symbols **lowest**, **highest** and **current** have special meanings.
variable ::= a Lisp symbol which starts with the character &
nearest-spec ::= [vis-loc | **current** | **current-x** | **current-y** | **clockwise** | **counterclockwise**]
vis-loc ::= a chunk which has a type that is a subtype of visual-location
vis-obj ::= a chunk which has a type that is a subtype of visual-object

A visual-location request is an attempt to find an item in the visicon. The chunk-type of the request must be a subtype of the chunk-type visual-location. All of the items in the visicon are compared against the specification provided in the request and if there is an item which matches that specification a visual-location chunk describing that item is placed into the visual-location buffer. The specification given describes the properties which the item must have in order to match. If a property is not specified then its value is not considered for the matching.

Any of the slots may be specified using any of the modifiers (-, <, >, <=, or >=) in much the same way one specifies a retrieval request. Each of the slots may be specified any number of times. In addition, there are some special tests which one can use that will be described below. All of the constraints specified will be used to find a visual-location in the visicon to be placed into the visual-location buffer. If there is no visual-location in the visicon which satisfies all of the constraints then the visual-location buffer will indicate an error state.

When the slot being tested holds a number it is also possible to use the slot modifiers <, <=, >, and >= along with specifying the value. If the value being tested or the value specified is not a number, then those tests will result in warnings and are not considered in the matching.

You can use the values **lowest** and **highest** in the specification of any slot which has a numeric value. Of the chunks which match the other constraints the one with the numerically lowest or highest value for that slot will then be the one found. There is one note about using **lowest** and **highest** when more than one slot is specified in that way. First, all of the non-relative values are used to determine the set of items to be tested for relative values. Then the relative tests are performed one at a time in the order provided to reduce the matching set.

It is also possible to use the special value **current** in a slot of the request. That means the value of the slot must be the same as the value for the location of the currently attended object (the one attention was last shifted to with a move-attention request to the visual buffer). If the model does not have a currently attended object (it has not yet attended to anything or has cleared its attention) then the tests for current are ignored.

A newly added component of the visual-location requests is the ability to use variables to compare the particular values within a visual-location to each other in the same way that the LHS tests of a

production use variables to match chunks. If a value for a slot in a visual-location request starts with the character **&** then it is considered to be a variable in the request. The request variables can be combined with the modifiers and any of the other values allowed to be used in the requests.

The :nearest request parameter can be used to find the items closest to the currently attended location in some way, or closest to some other location. If there are constraints other than :nearest specified then they are all tested first. The nearest of the locations that matches all of the other constraints is the one that will be placed into the buffer. There are several options available for using the nearest request parameter. To find the location of the object nearest to the currently attended location (computed as the straight line distance based on screen-x, screen-y, and distance values) we can again use the value **current**. Alternatively, one can specify any location chunk for the nearest test, and the location of the object nearest to that location will be the one returned. It is also possible to find the locations of objects nearest to the current object along a particular axis by specifying either **current-x** or **current-y**. Finally, one can request locations which are nearest in angular distance relative to an arbitrary center point using either **clockwise** or **counterclockwise** as the nearest specification. The center point used for the calculation is the location specified using the :center request parameter (or the location of the object if a visual object is provided as the :center). If no :center is specified in the request then the most recent center specified by the set-visual-center-point command is used, or the default center point of 0,0 is used if set-visual-center-point has not been called.

If the :attended request parameter is specified, that is used as a test with the finsts: :attended **t** means that the item is currently marked with a finst, :attended **nil** means that it is not, and :attended **new** means that it is not currently marked and it has recently been added to the visicon (within the time specified by the :visual-onset-span parameter).

If there is more than one item which is found as a match, then the one which has been added to the visicon most recently will be the one chosen, and if there is more than one with the same recent onset time, then a random one of those will be chosen.

This request takes no time to return the resulting chunk and will show up with the following events when successful:

```
0.050   VISION                Find-location
0.050   VISION                SET-BUFFER-CHUNK VISUAL-LOCATION LOC1
```

When no location in the visicon matches the request a failure will be indicated in the trace with a find-loc-failure event:

```
0.755   VISION                FIND-LOC-FAILURE
```

When the :auto-attend parameter is set to **t** a move-attention request will follow all successful visual-location requests. The move-attention will occur 50ms after the find-location event and the vision

module will be busy during the entire time from the find-location request until the attention shift is completed:

```
0.050   VISION                Find-location
0.050   VISION                SET-BUFFER-CHUNK VISUAL-LOCATION VISUAL-LOCATION1-0
0.050   VISION                automatically attending VISUAL-LOCATION1-0
…
0.100   VISION                Move-attention VISUAL-LOCATION1-0
0.185   VISION                Encoding-complete VISUAL-LOCATION1-0 NIL
```

Isa *set-visloc-default-type*
{{*modifier*} *valid-slot* [*value* | *variable*]}*
{**type** *vis-loc-type*}
{:**nearest** *nearest-spec*}
{**:attended** [***t*** | ***nil*** | ***new***]}
{**:center** [*vis-loc* | *vis-obj*]}

set-visloc-default-type ::= a chunk-type which is a subtype of set-visloc-default
modifier ::= [= | - | > | < | >= | <=]
valid-slot ::= the name of a slot which exists in the type given for set-visloc-default-type except the slot named type
value ::= any Lisp value, but the symbols **lowest**, **highest** and **current** have special meanings.
variable ::= a Lisp symbol which starts with the character &
vis-loc-type ::= a symbol which names a chunk-type that is a subtype of visual-location
nearest-spec ::= [vis-loc | **current** | **current-x** | **current-y** | **clockwise** | **counterclockwise**]
vis-loc ::= a chunk which has a type that is a subtype of visual-location
vis-obj ::= a chunk which has a type that is a subtype of visual-object

A set-visloc-default request allows the model to change the constraints that are used when determining which (if any) chunk from the visicon will be stuffed into the visual-location buffer when the screen is updated. It works the same as the set-visloc-default command described below. The slot values provided can be specified in the same way that they can for a visual-location request.

The type slot may be specified only once to specify the chunk-type to test. If it is not given, then the default is a chunk of type visual-location.

This request does not directly place a chunk into the visual-location buffer. It works essentially as a delayed request – for each future screen change this specification will be used to determine if a chunk should be placed into the visual-location buffer.

This request will automatically trigger a check of the current visicon elements to determine if a chunk should be stuffed into the buffer based on the new specification.

It will generate an event in the trace which looks like this:

```
0.850   VISION                Set-visloc-default
```

Visual buffer

The visual buffer is used to access the what system of the vision module as described above. It takes requests to attend to locations, track features, or to stop attending to items. As described above under re-encoding, the chunk in the visual buffer may be updated even when there is no explicit request made to the module.

Activation spread parameter: :visual-activation
Default value: 0.0

Queries

'State busy' will be **t** between the time any visual request is started and the time it completes. It will also be **t** between when an unrequested re-encoding starts and it completes. It will be **nil** otherwise.

'State free' will be **nil** between the time any visual request is started and the time it completes. It will also be **nil** between when an unrequested re-encoding starts and it completes. It will be **t** otherwise.

'State error' will be **t** if the last visual request failed or **nil** otherwise. It will not change from **t** to **nil** until a successful request is completed -- any of the available visual requests will reset the error state to **nil** if completed.

'Scene-change t' will be **t** if there has been a detected scene change which has not been explicitly cleared within the past :visual-onset-span seconds. Otherwise it will be **nil**.

'Scene-change nil' will be **t** if there has not been a detected scene change within the past :visual-onset-span seconds or such a scene change has been explicitly cleared. Otherwise it will be **nil**.

'Scene-change-value *value*' will be **t** if *value* is a number and the last scene change had a proportion of change which is greater than or equal to value. Otherwise it will be **nil**. This query is intended primarily as a debugging aid so that a modeler can see the last change value via the buffer-status command, but there may be circumstances where it would be useful to test that directly within a model.

The visual buffer can be used to query the internal states of the vision module, but this is generally not needed since there is no benefit to doing so since the requests cannot be "pipelined" by checking for particular subsystems being free.

'Preparation busy' will be **t** during the time of a clear request and its completion and it will be **nil** otherwise.

'Preparation free' will be **nil** during the time of a clear request and its completion and it will be **t** otherwise.

'Processor busy' will be **t** between the time a move-attention request is started and the time it completes and it will be **nil** otherwise.

'Processor free' will be **nil** between the time a move-attention request is started and the time it completes and it will be **t** otherwise.

'Execution busy' will be **t** between the time of a move-attention or start-tracking request and its completion as well as during an unreqeusted re-encoding. It will be **nil** otherwise.

'Execution free' will be **nil** between the time of a move-attention or start-tracking request and its completion as well as during an unreqeusted re-encoding. It will be **t** otherwise.

'Last-command *command*' *command* should be a chunk-type which corresponds to one of the vision module's requests for either buffer. The query will be **t** if that is the name of the last request (the chunk-type) received by the vision module otherwise it will be **nil**. Note that it is requests to the module in general which are tested, not just requests to the visual buffer.

Requests

Isa move-attention
screen-pos *location*
{**scale** [**phrase** | **word**]}

The move-attention request moves the vision module's attention to the item at the location given, which must be a chunk which is a subtype of type visual-location. If there is an item at that location, then a chunk which represents that item is placed into the visual buffer after the attention shift time passes. The resulting chunk will be a subtype of the visual-object chunk-type – the specific type is controlled by how the device builds such representations. If there is no item there, then the buffer is left empty and the error state is set. The scale value has an impact on how the default devices' text items are parsed. If :optimize-visual is set to **t** (the default), then the basic unit is words, but specifying a scale of phrase will have the module attend to an entire phrase as a single item. If :optimize-visual is **nil**, then the default attention shift is to the letter which contains the LED style feature which is attended, but the module can be told to look for words, or phrases using the scale.

This results in the following events being displayed in the trace showing the move-attention event with the location to which attention was shifted and the scale used (shown as NIL here because no scale was specified), the encoding-complete occurring after the :visual-attention-latency time passes

(in this case the default .085 seconds), and then the buffer being set to the chunk that encodes the visual information:

```
0.100   VISION                Move-attention LOC1-0 NIL
...
0.185   VISION                Encoding-complete LOC1-0 NIL
0.185   VISION                SET-BUFFER-CHUNK VISUAL TEXT1
```

If no item is found, then the same first two events will be shown, but there will be no setting of a chunk in the buffer and instead an event will show that no object was found:

```
0.185   VISION                No visual-object found
```

There may also be maintenance events generated which have an action of unlock-device when the move-attention request comes from a production (to allow the visual scene to be processed after the request has been received – see the proc-display command).

If a move-attention request is received while the module is currently handling another request, then a warning is printed and the current request is ignored:

```
#|Warning: Attention shift requested at 0.8 while one was already in progress. |#
```

The timing of the encoding-complete event for this request uses the randomize-time command. So, if the :randomize-time parameter is set to non-**nil** the timing on that event will be randomized accordingly.

Isa start-tracking

The start-tracking request will make the vision module continue to "track" an item in the visicon as it moves and/or changes over time until the tracking is terminated. If there is an item currently attended by the vision module, then the start-tracking request will keep the vision module's attention focused on that item. Both the visual-location and visual buffers will be updated with changes to that item and if the buffers are empty new chunks will be placed into them representing any changes. The execution state will be busy while the model is tracking. This will show up in the trace as a start-tracking event and there will be subsequent set-buffer-chunk and mod-buffer chunk events to update the visual-location and visual buffers as necessary (note that the setting is marked as requested **nil** because the chunks are not a direct result of the request):

```
0.185   VISION                Start-tracking
...
0.185   VISION                SET-BUFFER-CHUNK VISUAL-LOCATION LOC3 REQUESTED NIL
0.185   VISION                SET-BUFFER-CHUNK VISUAL TEXT1 REQUESTED NIL
...
0.700   VISION                MOD-BUFFER-CHUNK VISUAL-LOCATION
0.700   VISION                MOD-BUFFER-CHUNK VISUAL
...
1.000   VISION                SET-BUFFER-CHUNK VISUAL-LOCATION LOC11 REQUESTED NIL
1.000   VISION                SET-BUFFER-CHUNK VISUAL TEXT5 REQUESTED NIL
```

If a request to start-tracking is made when there is no currently attended item a warning will be displayed and the module will not become busy:

```
#|Warning: Request to track object but nothing is currently being attended. |#
```

There is one minor issue which may be important in the model when using tracking. For the visual-location buffer to be updated it must either be empty when the start-tracking request is made or it must contain the visual-location chunk which was used when the object was first attended. However, buffer stuffing may place a different chunk into that buffer between the attention shift and the starting of tracking. So, if one wants to make sure that both buffers will be updated with tracking there should also be a -visual-location> action in the production which makes the start-tracking request.

Isa clear

A clear request can be used to clear the currently attended object from the vision module. That will stop the re-encoding from occurring until a new item is attended. A clear request will also stop the tracking of an item, it will also clear the error flags if set for either of the vision module's buffers and clear the change scene notice if one is set. A clear request will make the preparation state busy for 50ms.

Here are the events which will show for a clear request.

```
1.455   VISION                CLEAR
...
1.505   VISION                CHANGE-STATE LAST NONE PREP FREE
```

Note, that after the clear request completes the last-command recorded by the module will be none and not clear – the clear effectively clears the history of its own request as well.

Isa clear-scene-change

A clear-scene-change request can be used to clear any pending scene change notice from the module. It will not affect any other operation of the module. A clear-scene-change request will take no time and does not make any of the module's stages busy.

Here is the event which will show for a clear-scene-change request.

```
0.485   VISION                CLEAR-SCENE-CHANGE
```

Isa assign-finst
*[**object** obj | **location** loc]*

The assign-finst request can be used to explicitly tag a visual item as having been attended with a finst. The item can be specified using one of the chunks previously returned by the vision module

through either buffer. If it is a visual-object chunk then it must be specified using the object slot, and if it is a visual-location chunk it must be specified using the location slot. It takes no time to process the request and the module will not be marked as busy. An event like this will be shown in the trace indicating which slot was used to assign the finst:

```
    0.100   VISION ASSIGN-FINST #<VISION-MODULE> OBJECT NIL LOCATION VISUAL-LOCATION0-0-0
```

If the chunk provided represents an item in the current visicon then that item will have a finst marker placed on it in the same way as if it had been explicitly attended. If the item does not represent a feature in the visicon then a warning is printed and no action is performed:

```
#|Warning: X does not name an object or feature in the current visicon. No finst
created.|#
```

This request does not affect the status of any of the module's queries other than last-command.

Chunks & Chunk-types

Here are the chunk-type and chunk definitions that are effectively executed by the vision module:

```
(chunk-type visual-object screen-pos value status color height width)
(chunk-type abstract-object value line-pos bin-pos)
(chunk-type (abstract-letter (:include abstract-object)))
(chunk-type (abstract-number (:include abstract-object)))
(chunk-type (text (:include visual-object)))
(chunk-type (empty-space (:include visual-object)))

(chunk-type (line (:include visual-object)) end1-x end1-y end2-x end2-y)
(chunk-type (oval (:include visual-object)))
(chunk-type (cursor (:include visual-object)))
(chunk-type (phrase! (:include visual-object)) objects words)

(chunk-type visual-location screen-x screen-y distance kind color
            value height width size)

(chunk-type set-visloc-default type screen-x screen-y distance kind color
            value height width size)

(chunk-type (char-primitive (:include visual-location)) left right)

(chunk-type vision-command)
(chunk-type pm-constant))
(chunk-type color)

(chunk-type (move-attention (:include vision-command)) screen-pos scale)
(chunk-type (start-tracking (:include vision-command)))
(chunk-type (assign-finst (:include vision-command)) object location)
(chunk-type clear)


(define-chunks
  (lowest isa pm-constant)
  (highest isa pm-constant)
  (current isa pm-constant)
  (current-x isa pm-constant)
  (current-y isa pm-constant)
```

```
(clockwise isa pm-constant)
(counterclockwise isa pm-constant)
(external isa pm-constant)
(internal isa pm-constant)
(find-location isa vision-command)
(move-attention isa vision-command)
(assign-finst isa vision-command)
(start-tracking isa vision-command)

(black isa color)
(red isa color)
(blue isa color)
(green isa color)
(white isa color)
(magenta isa color)
(yellow isa color)
(cyan isa color)
(dark-green isa color)
(dark-red isa color)
(dark-cyan isa color)
(dark-blue isa color)
(dark-magenta isa color)
(dark-yellow isa color)
(light-gray isa color)
(dark-gray isa color)

(text isa chunk)
(box isa chunk)
(line isa chunk)
(oval isa chunk)

(new isa chunk)
(clear isa chunk))
```

Commands

proc-display

Syntax:

proc-display {**:clear** *clear*} -> [visicon-count | **nil**]

Arguments and Values:

clear ::= a generalized boolean which specifies whether to consider the visual scene to be all new
visicon-count ::= the number of features which are in the visicon

Description:

The proc-display command is used to have the vision module of the current model process the visual display of the currently installed device. This will create a new set of features for the visicon of the current model. By default or if the clear parameter is provided as **nil**, then objects which are

considered to be the same as those which were in the previous visicon will retain their finsts. If the clear parameter is provided as non-**nil**, then all objects are considered to be new items. Calling proc-display will trigger the where system to possibly stuff the visual-location buffer. It also triggers the what system to re-encode the currently attended item. It returns the number of items in the visicon unless there is no current model or no device currently installed for the current model in which case a warning is printed and **nil** is retuned.

If proc-display is called between the selection and firing of a production which is going to make a request to the visual buffer the vision module will delay the processing of the display until after the request has been received. If multiple calls to proc-display for a model are made at the same simulation time a model warning will be printed and the processing of all calls after the first one at that time will be postponed until the model has been run to provide an opportunity for the changes from that first call to be handled.

Because the vision module does not account for perception times one can adjust the timing of when the proc-display function is called relative to when visual changes occur in the device to account for that if needed. That is done in the sperling model of unit 3 in the tutorial to account for persistence of vision – the screen blanks after 50ms, but the proc-display is postponed for approximately a second to allow the vision module to continue attending to items.

Examples:

```
> (proc-display)
3

> (proc-display :clear t)
3

1> (proc-display)
1
2E> (proc-display)
#|Warning: Proc-display should not be called more than once at the same ACT-R time. |#
NIL

E> (proc-display)
#|Warning: Cannot process display--no device is installed. |#
NIL

E> (proc-display)
#|Warning: proc-display called with no current model. |#
NIL
```

remove-visual-finsts

Syntax:

remove-visual-finsts {**:set-new** *set-new*} {**:restuff** *restuff*} -> **nil**

Arguments and Values:

set-new ::= a generalized boolean which specifies whether to set all visual features to the new state
restuff ::= a generalized boolean which specifies whether to check for stuffing of the visual-location buffer after removing the finsts

Description:

The remove-visual-finsts command is used to have the vision module of the current model remove all of the finsts from the current set of visual features in the visicon. If the set-new parameter is true then the features will all be marked as attended new and have their onset times reset to the current time. If the set-new parameter is **nil** (the default value if not provided) then the features will be either attended **new** or attended **nil** based on their original onset time and whether they have been previously attended. In that case, any item which has been attended will be marked as attended **nil** and only those items which have not yet been attended and which have not been on the display longer than the module's new-span time will be marked as attended **new**. If the restuff parameter is true, then it will trigger the where system to possibly stuff the visual-location buffer after resetting the finsts. If the restuff parameter is **nil** (the default value if not provided) then it will not attempt to stuff the visual-location buffer. The command always returns **nil**. If there is no current model a warning is printed in addition to returning **nil**.

This command is not recommended as a plausible mechanism of the vision module, but may be useful in creating some experimental situations which would require reprocessing the whole display otherwise.

Examples:

```
1> (print-visicon)
Loc        Att   Kind          Value             Color          ID
---------  ---   ------------  ----------------  -------------  -------------
(130 160)  T     TEXT          "v"               BLACK          VISUAL-LOCATION0
NIL

2> (remove-visual-finsts)
NIL

3> (print-visicon)
Loc        Att   Kind          Value             Color          ID
---------  ---   ------------  ----------------  -------------  -------------
(130 160)  NIL   TEXT          "v"               BLACK          VISUAL-LOCATION0
NIL

4> (remove-visual-finsts :set-new t)
NIL

5> (print-visicon)
Loc        Att   Kind          Value             Color          ID
---------  ---   ------------  ----------------  -------------  -------------
(130 160)  NEW   TEXT          "v"               BLACK          VISUAL-LOCATION0
NIL

6> (buffer-chunk visual-location)
VISUAL-LOCATION: NIL
(NIL)
```

```
7> (remove-visual-finsts :restuff t)
NIL

8> (run .01)
     2.000   VISION     SET-BUFFER-CHUNK VISUAL-LOCATION VISUAL-LOCATION0-1 REQUESTED NIL
     2.000   PROCEDURAL CONFLICT-RESOLUTION
     2.000   ------     Stopped because no events left to process
0.0
3
NIL

9> (buffer-chunk visual-location)
VISUAL-LOCATION: VISUAL-LOCATION0-1-2 [VISUAL-LOCATION0-1]
VISUAL-LOCATION0-1-2
  ISA VISUAL-LOCATION
   SCREEN-X  130
   SCREEN-Y  160
   DISTANCE  15.0
   KIND  TEXT
   COLOR  BLACK
   VALUE  TEXT
   HEIGHT  10
   WIDTH  7
   SIZE  0.19999999

(VISUAL-LOCATION0-1-2)
```

set-visloc-default

Syntax:

set-visloc-default isa *chunk-type* {{*modifier*} *slot* [*value* | *variable*]}*
{:**nearest** *nearest-loc*} {**:attended** [***t* | *nil* | *new***]} -> [**t** | **nil**]
set-visloc-default-fct (isa *chunk-type* {{*modifier*} *slot* [*value* | *variable*]}*
{:**nearest** *nearest-loc*} {**:attended** [***t* | *nil* | *new***]**)** -> [**t** | **nil**]

chunk-type ::= a symbol which names a chunk-type which is a subtype of visual-location
modifier ::= [= | - | > | < | >= | <=]
slot ::= the name of a slot which exists in the chunk-type specified
value ::= any Lisp value
variable ::= a Lisp symbol which starts with the character &
nearest-loc ::= a symbol which names a chunk which is a subtype of visual-location or the symbol **current**

Description:

Set-visloc-default is used to set the values of the properties which are used when testing the items in the visicon to determine if a visual-location chunk should be stuffed into the visual-location buffer for the current model. The specification is the same as that which is used for a visual-location request.

If a property is not specified, then that property is not considered for purposes of stuffing the visual-location buffer.

The default specification is given by:

```
(set-visloc-default isa visual-location screen-x lowest :attended new)
```

The command returns **t** if a new specification is set. If any of the slots specified are invalid no change is made and **nil** is returned. If there is no current model or no vision module can be found, then it prints a warning and returns **nil**.

Examples:

```
> (set-visloc-default isa visual-location screen-x lowest :attended new)
T

1> ((chunk-type (new-vis-loc (:include visual-location)) extra-slot)
NEW-VIS-LOC

2> (set-visloc-default isa new-vis-loc extra-slot highest height &h width &h < screen-y
100)
T

> (set-visloc-default-fct '(isa visual-location :nearest current))
T

E> (set-visloc-default isa non-type screen-x 10)
#|Warning: Second element in define-chunk-spec isn't a chunk-type. (ISA NON-TYPE SCREEN-X
10) |#
#|Warning: slot-in-chunk-spec-p called with something other than a chunk-spec |#
#|Warning: slot-in-chunk-spec-p called with something other than a chunk-spec |#
#|Warning: Invalid chunk specification.  Default not changed. |#
NIL

E> (set-visloc-default isa visual-location bad-slot current)
#|Warning: Invalid slot-name BAD-SLOT in call to define-chunk-spec. |#
#|Warning: slot-in-chunk-spec-p called with something other than a chunk-spec |#
#|Warning: slot-in-chunk-spec-p called with something other than a chunk-spec |#
#|Warning: Invalid chunk specification.  Default not changed. |#
NIL

E> (set-visloc-default isa visual-location screen-x 10)
#|Warning: No current model.  Cannot set visloc defaults. |#
NIL
```

print-visicon

Syntax:

print-visicon -> nil

Description:

The print-visicon command will print out a description of the features which are currently in the visicon of the current model. Each feature will be printed on a separate line showing several of the basic parameters of the feature. It will always return **nil**. If there is no current model then it will print out a warning instead.

Examples:

```
> (print-visicon)

Loc        Att   Kind           Value             Color           ID
---------  ---   -------------  ----------------  --------------  -------------
(130  84)  T     TEXT           "c"               BLACK           TEXT0
( 80 184)  T     TEXT           "c"               BLACK           TEXT1
(178 184)  T     TEXT           "j"               BLACK           TEXT2
NIL

E> (print-visicon)
#|Warning: get-module called with no current model. |#
NIL
```

add-word-characters

Syntax:

add-word-characters *char** -> [word-char-list | **nil**]

Arguments and Values:

char ::= a character to be added to those used in the construction of words
word-char-list ::= a list of all the characters which have been specified with add-word-characters

Description:

The add-word-characters command can be used to adjust how the default text items processed by the vision module of the current model in the current meta-process get separated into separate visual words. By default, text is broken into words as collections of sequential characters which are either all alphanumericp or all not alphanumericp. Thus, this text string "one--word" would be broken into three separate visual items "one", "--", and "word". This command allows one to specify additional characters to group with the alphanumerics. Thus, if #\- were added using this command that string would instead be processed as a single word.

Add-word-characters takes any number of characters to add to those grouped with the alphanumerics. If there is a current model it returns a list of all the additional characters which have been added using this command. If there is no current model then a warning is printed and **nil** is returned.

Any characters added with this command are removed when the model is reset. Thus, if needed this command should probably be included in the model's definition.

Examples:

These examples assume that the model has a currently installed device that was created with the open-exp-window command.

```
1> (add-text-to-exp-window :text "split_on--dash+only")
#<STATIC-TEXT-VDI @ #x2539c3fa>
```

```
2> (proc-display)
7

3> (print-visicon)
Loc         Att   Kind           Value              Color           ID
---------  ---   -------------  -----------------  --------------  -------------
( 19  10)  NEW   TEXT           "split"            BLACK           VISUAL-LOCATION0
( 40  10)  NEW   TEXT           "_"                BLACK           VISUAL-LOCATION1
( 50  10)  NEW   TEXT           "on"               BLACK           VISUAL-LOCATION2
( 64  10)  NEW   TEXT           "--"               BLACK           VISUAL-LOCATION3
( 85  10)  NEW   TEXT           "dash"             BLACK           VISUAL-LOCATION4
(103  10)  NEW   TEXT           "+"                BLACK           VISUAL-LOCATION5
(120  10)  NEW   TEXT           "only"             BLACK           VISUAL-LOCATION6
NIL

1> (add-word-characters #\_ #\+)
(#\+ #\_)

2> (add-text-to-exp-window :text "split_on--dash+only")
#<STATIC-TEXT-VDI @ #x2541925a>

3> (proc-display)
3
CG-USER(50): (print-visicon)
Loc         Att   Kind           Value              Color           ID
---------  ---   -------------  -----------------  --------------  -------------
( 29  10)  NEW   TEXT           "split_on"         BLACK           VISUAL-LOCATION0
( 64  10)  NEW   TEXT           "--"               BLACK           VISUAL-LOCATION1
(103  10)  NEW   TEXT           "dash+only"        BLACK           VISUAL-LOCATION2
NIL

E> (add-word-characters #\_)
#|Warning: get-module called with no current model. |#
#|Warning: No vision module available could not add new word characters. |#
NIL
```

set-visual-center-point

Syntax:

set-visual-center-point *x y* -> [loc | **nil**]

Arguments and Values:

loc ::= a vector of the current center point in the order x y

Description:

The set-visual-center-point command is used to specify the center point used for the current model in the current meta-process when determining the nearest location in a visual-location request that specifies :nearest as **clockwise** or **counterclockwise** and which does not also specify a center with the :center request parameter. The x and y values provided must be numbers and they specify the coordinates of the center to use. The default center point is 0,0 if this command is not used. If x and y are both numbers then that point is used as the center and a vector of those values is returned. If either x or y is not a number or if there is no current model then a warning is printed and **nil** is returned.

Examples:

```
> (set-visual-center-point 100 75)
#(100 75)

E> (set-visual-center-point 10 :not-a-number)
#|Warning: X and Y values must be numbers for set-visual-center-point. |#
NIL

E> (set-visual-center-point 10 40)
#|Warning: get-module called with no current model. |#
#|Warning: No vision module available so cannot set center point. |#
NIL
```

Audio module

The audio module provides a model with rudimentary audio perception abilities and is very similar to the vision module. It has both a what and where system and two buffers which accept requests. It has a store of audio events called the *audicon*, and those are transformed into chunks which the model can use by requesting an attention shift to a particular event.

Auditory world

Unlike the visual portion of the device, there is no support for hearing "real" sounds generated by the computer. Instead, all of the sounds for the model must be simulated using the commands described later. There are commands for generating pure tones, spoken digits, spoken words, and a general command which allows one to specify all of the components of the sound directly. In addition, the model will also hear its own speech which it generates using the vocal module.

Sound events occur over time and are not immediately available for processing in the audicon. There are several attributes to a sound event which describe it and control the timing of the model's access to the sound.

Here are the attributes of a sound event:

- Onset: The time at which the sound began.
- Duration: The amount of time that the sound is present.
- Content delay: The amount of time between a sound's onset and when the content of the sound is accessible to the auditory system. No information can be extracted before this time has passed.
- Recode time: The amount of time (after the content is available) that it takes for the auditory system to construct a representation of the sound.
- Content: The value which will be made available to the model once the sound is attended.
- Kind: The basic description of the type of sound. The given commands create kinds of **tone**, **digit**, **word**, and **speech**.
- Location: An indication of where the sound originated. The built-in options are **external** for sounds generated by the simulated sound commands, **self** for words the model speaks, and **internal** for words the model subvocalizes. Other values may be provided when creating custom sounds with the commands described below.

The sound events are only available in the audicon for a short time before they decay. After a sound event ends and the decay time elapses (which defaults to 3 seconds), the sound event is deleted from the audicon.

The Where System

The where system takes requests through the aural-location buffer. A request to the aural-location buffer specifies a series of constraints. The constraints are attribute-value pairs which can restrict the search based on the event properties of the sound (such as “kind tone”). If there is a sound event in the audicon that meets those constraints, then a chunk representing that sound event is placed in the aural-location buffer. If multiple objects meet the constraints, then one will be picked randomly. If there are no objects which meet the constraints, then the buffer will be left empty and the state error query to the aural-location buffer will be true.

Like the vision and declarative modules, the audio module maintains a set of finsts which mark items that have been attended, and the attended status of an audio event can be a constraint in a request to the aural-location buffer. However, unlike those other modules, because the audicon is already time limited (audio events decay on their own) there is no limit on the number or duration of the auditory finsts.

The What System

The what system takes requests through the aural buffer. Its primary use is to attend to audio events which have been found using the where system. A request to the what system requires a chunk representing an audio event. In response to the request, the what system will shift aural attention to that audio event, process the sound, and place a chunk representing that sound into the aural buffer.

Like the vision module, the assumption behind the aural module is that the sound chunks placed into the aural buffer as a result of an attention operation are episodic representations of the sounds. Thus, a sound chunk with content "3" represents a memory of hearing the number "3" being spoken, not the semantic THREE used in arithmetic—a declarative retrieval would be necessary to make that mapping.

Parameters

:digit-detect-delay

This parameter controls the content delay time given to digit sounds created with the new-digit-sound command. It is measured in seconds. It can be set to any non-negative value and the default is 0.3.

:digit-duration

This parameter controls the duration given to digit sounds created with the new-digit-sound command in seconds. It can be set to any non-negative number and the default is 0.6.

:digit-recode-delay

This parameter controls the recode time given to digit sounds created with the new-digit-sound command in seconds. It is also the time that it takes for a failure to encode to occur when an audio event is no longer available. It can be set to any non-negative number and the default is 0.5.

:hear-newest-only

This parameter is no longer needed with the addition of the set-audloc-default command. It has been deprecated and has no effect other than to print a warning.

:sound-decay-time

This parameter controls how long sound events will stay in the audicon measured in seconds. It can be set to any non-negative number and the default is 3.0.

:tone-detect-delay

This parameter controls the content delay time given to tone sounds created with the new-tone-sound command measured in seconds. It can be set to any non-negative number and the default is 0.05.

:tone-recode-delay

This parameter controls the recode time given to tone sounds created with the new-tone-sound command measured in seconds. It can be set to any non-negative number and the default is 0.285.

The audio module has two buffers: aural-location and aural.

Aural-location buffer

The aural-location buffer is used to access the where system of the audio module as described above. In addition to taking requests to find sounds, the audio module will also place chunks into the aural-location buffer automatically without a model request (a process referred to as "buffer stuffing"). Whenever there is a new sound available to the model, if the aural-location buffer is empty, an audio-event chunk of a feature from the audicon will be placed into the aural-location buffer. The feature which gets "stuffed" into the buffer is chosen based on preferences which can be set by the modeler. The default preference is for any unattended item.

Activation spread parameter: :aural-location-activation
Default value: 0.0

Queries

'State busy' will always be **nil.**

'State free' will always be **t**.

'State error' will be **t** if the last aural-location request failed to find a matching audio-event and it will be **nil** in all other situations. Once it becomes **t** it will remain **t** until a new aural-location request is made or the explicit clear request is made of the aural buffer.

The aural-location buffer has two additional queries that allows one to check the attended and finished status of the audio-event represented by the chunk in the aural-location buffer.

'Attended t' will be **t** if there is a chunk in the aural-location buffer and that audio-event currently has a finst marker on it. Otherwise it will be **nil**.

'Attended nil' will be **t** if there is a chunk in the aural-location buffer and that location does not currently have a finst marker on it. Otherwise it will be **nil**.

'Finished t' will be **t** if there is a chunk in the aural-location buffer and that audio-event has finished playing (its offset time has been reached or passed). Otherwise it will be **nil**.

'Finished nil' will be **t** if there is a chunk in the aural-location buffer and that audio-event has not finished playing (its offset time has not been reached yet). Otherwise it will be **nil**.

Requests

Isa audio-event
{**kind** *value*}
{**location** *value* }
{**onset** *value* }
{**:attended** [**t** | **nil**]}
{**:finished** [**t** | **nil**]}

An aural-location request is an attempt to find an audio event in the audicon. All of the items in the audicon are compared against the values provided in the request and if there is an item which is detectable and matches that specification an audio-event chunk describing that item is placed into the aural-location buffer. The specification given describes the properties which the item must have in order to match. If a property is not specified then its value is not considered for the matching. The actual order in which the properties are provided does not matter.

Each of the properties may be specified at most once in the request. For the onset property the values of lowest and highest can be used to select the item which has the value that is numerically lowest (oldest) or highest (most recent) among all audio events.

If the attended value is specified, that is used as a test with the auditory finsts: :attended t means that the item is currently marked with a finst (has been attended) and :attended nil means that it is not marked (has not been attended).

The finished value can be used to test whether or not the sound is still 'playing' or not. That is determined by the offset time of the sound. If the current time is greater-than or equal to the offset time of the sound then it is considered to be finished, but if the current time is less-than the offset time of the sound it is not finished.

If there is more than one item which is found as a match then a random one of those will be chosen. This request takes no time to return the resulting chunk and will show up with the following events when successful:

```
0.100   AUDIO                   FIND-SOUND
0.100   AUDIO                   SET-BUFFER-CHUNK AURAL-LOCATION AUDIO-EVENT0
```

If no sound event which matches the request is found then the buffer will be left empty and the state error query of the buffer will be true. That will result in a find-sound-failure event showing up in the trace:

```
0.050   AUDIO                   find-sound-failure
```

The aural-location buffer may be set to a chunk even without a request being made. If the aural-location buffer is empty and a new sound event becomes detectable an audio-event chunk which represents it will be stuffed into the aural-location buffer. This is the event which will be generated in the trace indicating the chunk being set without being requested:

```
0.060   AUDIO               SET-BUFFER-CHUNK AURAL-LOCATION AUDIO-EVENT0 REQUESTED NIL
```

If a sound event which is not yet finished is placed into the aural-location buffer it will not have values for its offset or duration slots since the sound is still playing. If that audio event is attended with a request to the aural buffer (as described below) and remains in the buffer until the sound is completed then those slots will be updated to contain the appropriate values with an event that will look like this:

```
0.500   AUDIO                   AUDIO-EVENT-ENDED AUDIO-EVENT0
```

Aural buffer

The aural buffer is used to access the what system of the audio module as described above. It takes requests to attend to audio events. It attends to the event and creates a chunk to encode it which is placed into the buffer.

Activation spread parameter: :aural-activation

Default value: 0.0

Queries

'State busy' will be **t** between the time any aural request is started and the time it completes. It will be **nil** otherwise.

'State free' will be **nil** between the time any aural request is started and the time it completes. It will be **t** otherwise.

'State error' will be **t** if the last aural request failed or **nil** otherwise. It will not change from **t** to **nil** until a successful request is completed – either a sound or a clear request will reset it.

The aural buffer can be used to query the internal states of the audio module, but this is generally not needed since there is no benefit to doing so since the requests cannot be "pipelined" by checking for particular subsystems being free.

'Preparation busy' will be **t** during the time of a clear request and its completion and during a sound request if the sound is not yet available (the detect time has not passed since its entry into the audicon) and it will be **nil** otherwise.

'Preparation free' will be **nil** during the time of a clear request and its completion and during a sound request if the sound is not yet available (the detect time has not passed since its entry into the audicon) and it will be **t** otherwise.

'Processor busy' will always be **nil**.

'Processor free' will always be **t**.

'Execution busy' will be **t** between the start and end of a sound request. It will be **nil** otherwise.

'Execution free' will be **nil** between the start and end of a sound request. It will be **t** otherwise.

'Last-command *command*' *command* should be a chunk-type which corresponds to one of the audio module's requests for either buffer. The query will be **t** if that is the name of the last request (the chunk-type) received by the audio module otherwise it will be **nil**. Note that it is requests to the module in general which are tested, not just requests to the aural buffer.

Requests

Isa clear

A clear request can be sent to clear the error flags of both of the audio module's buffers. A clear request will make the preparation state busy for 50ms. These events will show in the trace for a clear request to the aural buffer:

```
0.485   AUDIO                   CLEAR
...
0.535   AUDIO                   CHANGE-STATE LAST NONE PREP FREE
```

Note, that after the clear request completes the last-command recorded by the module will be none and not clear – the clear has effectively cleared the history of its own request as well.

Isa sound
event *audio-event*

The sound request moves the audio module's attention to the sound event provided which should be a chunk of type audio-event. If that sound event is still available in the audicon then it will be marked as attended and a chunk which represents that sound will be placed into the aural buffer after the sound event's recode time has passed. The resulting chunk will be of the chunk-type sound. Its kind slot will have the same value as the audio-event that was used to attend to it. Its content slot will have the content of the sound event that was attended, and its event slot will be the name of the original sound event from the audicon.

This results in the following events being displayed in the trace showing the attention shift event with the audio-event listed, the audio-encoding-complete occurring after the sound event's recode time passes (in this case the default .285 seconds for a tone sound), and then the buffer being set to the sound chunk that encodes the visual information:

```
0.150   AUDIO                   ATTEND-SOUND AUDIO-EVENT0-1
...
0.435   AUDIO                   AUDIO-ENCODING-COMPLETE #<TONE-SOUND-EVT>
0.435   AUDIO                   SET-BUFFER-CHUNK AURAL TONE0
```

If there is no corresponding sound available in the audicon, then the buffer is left empty and the error state is set to **t**. This event will show that no object was found after taking the amount of time required to recode a digit (the time to fail is always the same regardless of the type of sound the event represents):

```
0.585   AUDIO                   ATTEND-SOUND AUDIO-EVENT0-1
...
1.085   AUDIO                   attend-sound-failure
```

If a sound request is received while the module is currently handling another sound request, then a warning is printed and the newer request is ignored:

```
#|Warning: Auditory attention shift requested at 0.6 while one was already in progress. |#
```

The timing of the audio-encoding-complete and attend-sound-failure events for this request use the randomize-time command. Thus, if the :randomize-time parameter is set to non-nil the timing on those events will be randomized accordingly.

Chunks & Chunk-types

Here are the chunk-type and chunk definitions that are effectively executed by the audio module:

```
(chunk-type audio-event onset offset duration pitch kind location id)
(chunk-type sound kind content event)
(chunk-type audio-command)
(chunk-type clear)

(define-chunks
  (digit isa chunk)
  (speech isa chunk)
  (tone isa chunk)
  (word isa chunk))
```

Commands

new-digit-sound/new-tone-sound/new-other-sound/new-word-sound

Syntax:

new-digit-sound *digit* {*onset*} -> [**t** | **nil**]
new-tone-sound *freq duration* {*onset*}-> [**t** | **nil**]
new-word-sound *word* {[*onset* | *onset location*]}-> [**t** | **nil**]
new-other-sound *content duration delay recode* {[*onset* | *onset location* | *onset location kind*]}-> [**t** | **nil**]

Arguments and Values:

digit ::= a number representing the digit to be heard
onset ::= a number which is the time at which the sound will begin
freq ::= a number representing the frequency of the tone to be heard
duration ::= a number which is the amount of time between the onset and when the sound stops
word ::= a string which is the word (or words) which will be heard
location ::= any Lisp value this will be the sound event's location value
content ::= any Lisp value the content for a new sound event
delay ::= a number which is the content delay for the sound
recode ::= a number which is the recode time for the sound
kind ::= a symbol which will be used as the sound event's kind value

Description:

The new-*-sound commands are used to create new sound events for the audicon of the current model. The newly created sound event will be placed into the audicon at the onset time of the sound event with the other properties of that event being set based on which command was used to create it. Here is how those values are set based on the command:

new-digit-sound

Onset: as provided or the current time if not provided
Duration: set using randomize-time on the value of :digit-duration
Content delay: set using randomize-time on the value of :tone-detect-delay
Recode time: the value of :digit-recode-delay
Content: the provided digit
Kind: **digit**
Location: **external**

new-tone-sound

Onset: as provided or the current time if not provided
Duration: as provided
Content delay: set using randomize-time on the value of :tone-detect-delay
Recode time: the value of :tone-recode-delay
Content: the provided frequency
Kind: **tone**
Location: **external**

new-word-sound

Onset: as provided or the current time if not provided
Duration: computed using the get-articulation-time command of the speech module
Content delay: set using randomize-time on the value of :digit-detect-delay
Recode time: the maximum between the duration/2 and the duration - .15 seconds
Content: the provided string
Kind: **word**
Location: as provided, or **external** if not provided

new-other-sound

Onset: as provided or the current time if not provided
Duration: as provided
Content delay: as provided
Recode time: as provided
Content: as provided
Kind: as provided, or **speech** if not provided
Location: as provided, or **external** if not provided

Each new sound will generate a maintenance event which will not be shown in the trace. It will have an action of stuff-sound-buffer and no parameters. It will occur at the time the sound event becomes

detectable, and this is where the testing is done to determine whether or not a new sound should be stuffed into the aural-location buffer.

If a sound is successfully created and added to the audicon of the model then **t** is returned. If there is no current model or an invalid parameter is provided a warning will be displayed and **nil** will be returned.

Examples:

```
> (new-tone-sound 400 .75)
T

> (new-digit-sound 6 1.0)
T

> (new-word-sound "Hello" .25 'left)
T

> (new-other-sound 'new-content 1.5 .2 .25)
T

E> (new-tone-sound 'high .2)
#|Warning: Freq must be a number.  No new tone sound created. |#
NIL

E> (new-digit-sound 3)
#|Warning: No current model found.  Cannot create a new sound. |#
NIL
```

print-audicon

Syntax:

print-audicon -> nil

Description:

The print-audicon command will print out a description of the features which are currently in the audicon of the current model. Each feature will be printed on a separate line showing several of the basic parameters of the audio event. It will always return **nil**. If there is no current model then it will print out a warning instead.

Examples:

```
> (print-audicon)

Sound event  Att  Kind           Content           location     onset     offset    Sound
ID
-----------  ---  -------------  ----------------  --------     -----     ------   -------
AUDIO-EVENT5 NIL  WORD           Hi                INTERNAL     0.700      0.800    WORD1
AUDIO-EVENT4 NIL  SPEECH         other             EXTERNAL     0.600      0.800    SOUND1
AUDIO-EVENT3 NIL  WORD           Hello             EXTERNAL     0.450      0.700    WORD0
```

```
AUDIO-EVENT1 NIL  DIGIT          3                EXTERNAL     0.011      0.611    DIGIT0
AUDIO-EVENT0 T    TONE           500              EXTERNAL     0.010      0.210    TONE0
NIL

E> (print-audicon)
#|Warning: get-module called with no current model. |#
#|Warning: No audio module found |#
NIL
```

set-audloc-default

Syntax:

set-audloc-default {*spec default-value*}* -> [**t** | **nil**]
set-audloc-default-fct ({*spec default-value*}***)** -> [**t** | **nil**]

Arguments and Values:

spec ::= [**:kind** | **:attended** | **:onset** | **:pitch** | **:location** | **:finished**]
default-value ::= a Lisp value which specifies the default value to use for the preceding spec

Description:

The set-audloc-default command is used to set the values of the properties which are used when testing the items in the audicon to determine if an audio-event chunk should be stuffed into the aural-location buffer for the current model. Each parameter can be specified once and the values are similar to those that are available for an aural-location request.

If a property is not specified, then that property is not considered for purposes of stuffing the aural-location buffer.

The default specification is ":attended nil".

The command returns **t** if a new specification is set. If there is no current model or no audio module can be found then it prints a warning and returns **nil**. If there are an odd number of parameters provided then no changes are made to the current default spec and **nil** is returned.

If there are any invalid specifications provided a warning is printed and those specifications are ignored. If all of the specifications are invalid then no changes are made and **nil** is returned.

Examples:

```
> (set-audloc-default :onset lowest :attended nil)
T

> (set-audloc-default-fct (list :kind 'word :location 'external))
T

E> (set-audloc-default :onset highest)
```

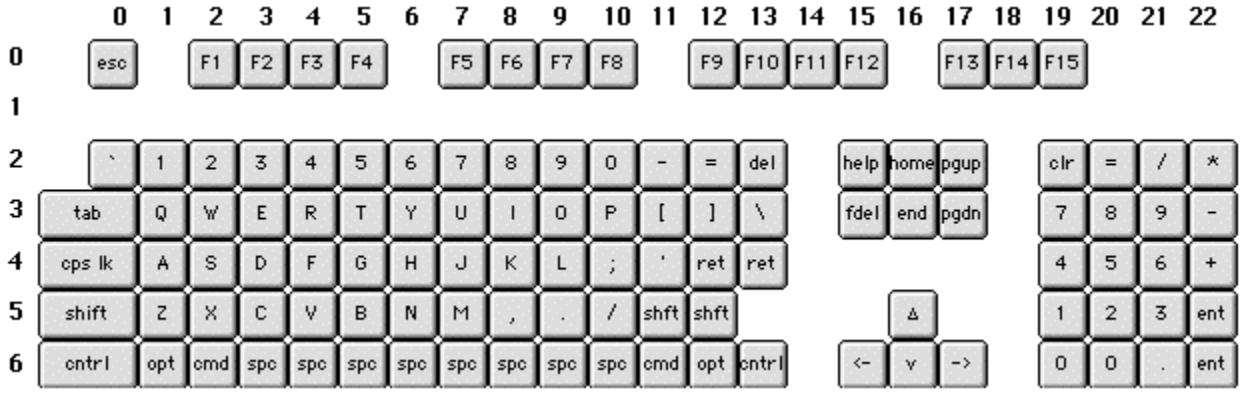
```
#|Warning: No current model.  Cannot set audloc defaults. |#
NIL

E> (set-audloc-default :onset lowest :onset highest)
#|Warning: Each property can only be used once.  Ignoring duplicate setting :ONSET
HIGHEST. |#
T

E> (set-audloc-default :bad-value highest :onset lowest)
#|Warning: Property :BAD-VALUE is not valid as an audio spec.  It is being ignored. |#
T

E> (set-audloc-default :bad-value highest)
#|Warning: Property :BAD-VALUE is not valid as an audio spec.  It is being ignored. |#
#|Warning: No valid specs provided so defaults are unchanged. |#
NIL
```

Motor module

The motor module functions as a model's hands. It is conceptually based on EPIC's Manual Motor Processor (Kieras & Meyer, 1996) and is quite similar in many respects. It provides a model with the ability to operate a virtual keyboard and mouse by default, but it is possible to extend the actions and devices with which the model can interact. It has one buffer through which it accepts requests and it does not generate any chunks in response.

Physical world

The model's hands are assumed to be operating a keyboard having this two-dimensional layout:



The mouse has one button and is controlled by the model's right hand when used (considered to be located at location (28 2) relative to the keyboard layout shown above). The default devices accept the input from the model's virtual keyboard and mouse and pass it along as if it was from a real user (including moving the actual mouse cursor for some devices). By default, the model's hands start at the home row positions – left and right index fingers positions over the F and J keys respectively, with the other fingers positioned over the correspondingly adjacent keys and the thumbs placed two rows down and one row "in" from the index fingers. The model's hand positions are tracked with the corresponding index finger. Thus, the starting position for the left hand is (4 4) and for the right hand is (7 4).

Operation

In general, movement requests require specification of a movement type, called a style (which is specified by the chunk-type of the request) and one or more parameters, such as the hand/finger that is to make the movement. The motor module includes several movement styles based on EPIC's Motor Processor. They are:

- Punch. This is a simple downstroke followed by an upstroke of a finger, for pressing a key that is already directly below a given finger.

- Peck. This is a directed movement of a finger to a location followed by a keystroke, all as one continuous movement.
- Peck-recoil. Same as "peck" above, but the finger moves back to the location at which it started its movement.
- Ply. Moves a device (e.g. a mouse) to a given location in space.
- Point-hand. Moves the hand to a new location.

There are also more complex movements which are built out of these basic movement styles. For example, there is a move-cursor request which is translated into a “ply" movement for the right hand, and a press-key request which translates the key to be pressed into either a "punch" or a "peck-recoil" for the appropriate hand and finger (assuming that the hands are starting from the home row).

The motor module does not place any chunks into its buffer in response to the requests. The buffer should always be empty, and it is the state of the module that is most important to the model in this case. As described above for all the perceptual and motor modules, the motor module has three internal states: preparation, processor, and execution. When a request is received by the motor module, it goes through three phases: preparation, initiation, and execution which correspond to those internal states.

In the preparation phase, it builds a list of "features" which guide the actual movement. The amount of time that preparation takes depends on the number of features that need to be prepared - the more that need to be prepared, the longer it takes. The motor module maintains a history of the last set of features that it prepared. The actual number of features that need to be prepared depends upon two things: the complexity of the movement to be made and the difference between that movement and the previous movement. On one end of the scale, the motor module is simply repeating the previous movement, then all the relevant features will already be prepared and do not require preparation. On the other end, a request could specify a movement that requires a full five features and they may not overlap with the features in the motor module's history, in which case all five features would need to be prepared.

Movement features are organized into a hierarchy, with the movement style at the top of the hierarchy. If the movement style changes, then all of the features required for a movement must be prepared over again. Then, if the movement styles are the same but the hand for the movement differs, all features at and below the hand level require preparation. All actions will have a style and a hand, but below that the features vary by request. If the action requires a finger, then it is the next level in the hierarchy. Any other features for an action are considered equal and at the bottom of the hierarchy.

When feature preparation is complete, the motor module makes the specified movement. The first 50 ms (by default) of the movement is movement initiation. During this interval, the preparation state becomes free and the processor and execution states become busy. After initiation ends, the processor state becomes free. The amount of time that a movement takes to execute depends on the type and possibly the distance the movement will traverse. Simple movements have a minimum execution

time and more complex movements (such as pointing with the mouse) have a longer execution time based on Fitts's Law:

$$T = b * \log_2(D/W + 0.5)$$

T := the time of the movement in seconds
b := a parameter dependent on the type of motor action
D := the distance to the target
W := the width of the target

The motor module can only prepare one movement at a time (though it can be preparing features for one movement while executing another movement). If the motor module is in the process of preparing a movement and another request is sent, the later request will be ignored and the motor module is said to be "jammed." When the module is jammed it will output a warning to indicate when the jamming occurred like this:

```
#|Warning: Module :MOTOR jammed at time 0.68 |#
```

The way to avoid jamming, as with all modules, is to test the state of the module before making a request. Testing that state free is true will avoid jamming the module, but it is possible to issue motor requests faster than that – because the state will not be free until the previous request has been completed. Instead, one only needs to test that the preparation state is free to be able to issue a new request to the motor module. A slightly more conservative approach would be to test the processor state because it is still busy during the initiation time of the last movement request.

Finally, it is possible to prepare movements in advance without executing them, and then execute them later. For instance, let's say the model is one of a subject doing simple reaction time: whenever anything appears on the screen, press the key under the right index finger. The time at which something will appear is unknown. To minimize the model's response time, the movement to press the key could be prepared in advance and then executed as soon as the visual object is detected.

Parameters

:cursor-noise

If this is set to **nil** (which is the default) then the mouse movements by the model will be made to the exact pixel location requested. If it is set to **t** then there will be noise added to the location to which the cursor is moved.

:default-target-width

This is the effective width, in degrees visual angle, of targets with undefined widths when computing the Fitts's law computation. The default value is 1.0.

:incremental-mouse-moves

When set to **t**, this will update the mouse location approximately every 50 ms when it is in motion. When set to **nil** (which is the default value) it will update the mouse location only at the end of each mouse move. If it is set to a number then that is considered as a time in seconds between the updates and replaces the time of .05 used when it is set to **t**. The incremental positions are calculated along the line between the old and new points using a minimum jerk velocity profile.

:motor-burst-time

This is the minimum time required for the execution of any motor module movement in seconds. the default is .05.

:motor-feature-prep-time

The time in seconds that it takes to prepare each movement feature. The default is .05.

:min-fitts-time

The minimum movement time in seconds required to perform an aimed movement (one for which the Fitts's law timing is applied). The default value is 0.1.

:motor-initiation-time

This is the length of the initiation time for motor actions in seconds. The default is .05.

:peck-fitts-coeff

The b coefficient in the Fitts's equation for the timing of peck style movements. The default is .075.

Manual Buffer

The motor module does not place any chunks into the manual buffer - it is only used for requests.

Almost all of the timing for the requests to the manual buffer (everything except for a clear request) are randomized using randomize-time if the :randomize-time parameter is set to **t**.

Activation spread parameter: :manual-activation

Default value: 0.0

Queries:

'State busy' will be **t** when any of the internal states of the module (listed below) also report as being busy. Essentially, it will be **t** while there is any request to the manual buffer that has not yet completed. It will be **nil** otherwise.

'State free' will be **t** when all of the internal states of the module (listed below) also report as being free. Essentially, it will be **t** only when all requests to the manual buffer have completed. It will be **nil** otherwise.

'State error' will always be **nil**.

Unlike the perceptual modules, the internal states of the motor module may be useful to track in a model because it is possible to send new requests while the module is partially busy. Only the preparation stage of the module needs to be free to avoid jamming. For each request that is received the module will progress through three stages as described above: preparation, initiation, and execution.

'Preparation busy' will be **t** after a request has been received and until it completes the preparation of the features needed for that request which depends on how many features there are and whether or not they overlap with the last features prepared. It will be **nil** otherwise.

'Preparation free' will be **nil** after a request has been received and until it completes the preparation of the features needed for that request which depends on how many features there are and whether or not they overlap with the last features prepared. It will be **t** otherwise.

'Processor busy' will be **t** while preparation is busy and will continue to be **t** after the features have been prepared until the additional initiation time (set with the :motor-initiation-time parameter) has passed. It will be **nil** otherwise.

'Processor free' will be **nil** while preparation is busy and will continue to be **nil** after the features have been prepared until the additional initiation time (set with the :motor-initiation-time parameter) has passed. It will be **t** otherwise.

'Execution busy' will be **t** once the preparation of a request's features has completed and will remain **t** until the time necessary to complete the action has passed. It will be **nil** otherwise.

'Execution free' will be **nil** once the preparation of a request's features has completed and will remain **nil** until the time necessary to complete the action has passed. It will be **t** otherwise.

'Last-command *command*' *command* should be a chunk-type which corresponds to one of the manual buffer's requests. The query will be **t** if that is the name of the last request (the chunk-type) received by the manual buffer otherwise it will be **nil**.

Here is a summary indicating the state transitions for a single movement request assuming that the module is entirely free at the start of the request:

Preparation state	**Processor state**	**Execution state**	**When**
FREE	FREE	FREE	Before event arrives
BUSY	BUSY	FREE	When event is received
FREE	BUSY	BUSY	After preparation of movement
FREE	FREE	BUSY	After initiation movement
FREE	FREE	FREE	When movement is complete

Requests

Isa clear

A clear request can be sent to clear the history of prepared features. A clear request varies from the other requests in that it will make only make the preparation state busy for 50ms and not the processor or execution states. These events will show in the trace for a clear request to the manual buffer:

```
0.050   MOTOR                 CLEAR
...
0.100   MOTOR                 CHANGE-STATE LAST NONE PREP FREE
```

Note, that after the clear request completes the last-command recorded by the module will be none and not clear – the clear has effectively cleared the history of its own request as well.

Isa punch
hand [***left*** | ***right***]
finger [***index*** | ***middle*** | ***ring*** | ***pinkie*** | ***thumb***]

This request will execute a punch action for the specified finger on the specified hand. This will result in pressing the key that is directly under that finger (or the mouse button if it is the right index finger and the hand is currently located on the mouse). The time to execute this action is controlled by the initiation and burst times set for the module. These are the actions which will be shown in the trace for a punch action indicating the request being received, the preparation of the features completing, the initiation time having passed, the actual striking of the key which is under that finger

currently (showing the coordinates on the virtual keyboard), and the time to finish the execution of the action (returning the finger to a position where it is ready to act again):

```
0.050   MOTOR                   PUNCH HAND LEFT FINGER INDEX
...
0.200   MOTOR                   PREPARATION-COMPLETE
...
0.250   MOTOR                   INITIATION-COMPLETE
...
0.260   MOTOR                   OUTPUT-KEY #(4 4)
...
0.350   MOTOR                   FINISH-MOVEMENT
```

Isa click-mouse

If the model's right hand is located on the virtual mouse, then this request will result in a punch action (as described above) by the right index finger pressing the primary mouse button. These are the events which one will see for such an action showing the progression through the stages of the motor module and the pressing of the mouse button (which is considered to be located at (28 2) relative to the virtual keyboard):

```
0.050   MOTOR                   CLICK-MOUSE
...
0.200   MOTOR                   PREPARATION-COMPLETE
...
0.250   MOTOR                   INITIATION-COMPLETE
...
0.260   MOTOR                   OUTPUT-KEY #(28 2)
...
0.350   MOTOR                   FINISH-MOVEMENT
```

If the model's right hand is not on the virtual mouse then a warning will be printed and no action taken:

```
#|Warning: CLICK-MOUSE requested when hand not at mouse! |#
```

Isa peck
hand [***left*** | ***right***]
finger [***index*** | ***middle*** | ***ring*** | ***pinkie*** | ***thumb***]
r *distance*
theta *direction*

This request will result in the model making a peck style movement with the indicated finger on the specified hand. That finger will be moved the specified distance and direction from where it currently is and then press the key at that new location. The finger will then remain over that new key until moved elsewhere. The distance is measured in "keys" on the virtual keyboard which is the distance between two adjacent keys in the same row or the same column. The direction is an angle measured in radians with 0 being movement along the x axis to the right and increasing with

clockwise rotation. The time taken to execute this action is controlled by Fitts's law as described above. These are the events which one will see for such an action showing the progression through the stages of the motor module and the pressing of the corresponding key location on the virtual keyboard (in this case moving one key to the right from the default home location):

```
0.050   MOTOR                 PECK HAND LEFT FINGER INDEX R 1 THETA 0
...
0.300   MOTOR                 PREPARATION-COMPLETE
...
0.350   MOTOR                 INITIATION-COMPLETE
...
0.450   MOTOR                 OUTPUT-KEY #(5 4)
...
0.500   MOTOR                 FINISH-MOVEMENT
```

There are no constraints on how far or in which direction a model's finger can move relative to the other fingers. Thus, at this time, the model may be able to make finger movements which would be impossible for a real person to make and it is up to the modeler to consider such issues.

If the movement takes the model's finger to an invalid location for a key then it effectively presses a key with the value **nil** and a warning will be printed:

```
#|Warning: Invalid key location pressed #(4 7) |#
```

Isa peck-recoil
hand [***left*** | ***right***]
finger [***index*** | ***middle*** | ***ring*** | ***pinkie*** | ***thumb***]
r *distance*
theta *direction*

A peck-recoil is effectively the same as a peck, except that the finger is returned to where it started after the key has been pressed. The indicated finger on the specified hand is moved the specified distance and direction from where it currently is and then it presses the key at that new location. The finger will then return to where it was prior to the peck-recoil request. The distance is measured in "keys" on the virtual keyboard which is the distance between two adjacent keys in the same row or the same column. The direction is an angle measured in radians with 0 being movement along the x axis to the right and increasing with clockwise rotation. The time taken to move the finger is controlled by Fitts's law as described above. These are the events which one will see for such an action showing the progression through the stages of the motor module and the pressing of the corresponding key location on the virtual keyboard (in this case moving one key up from the default home location):

```
0.050   MOTOR                 PECK-RECOIL HAND LEFT FINGER INDEX R 1 THETA -1.57
...
0.300   MOTOR                 PREPARATION-COMPLETE
...
0.350   MOTOR                 INITIATION-COMPLETE
```

```
...
0.450   MOTOR                   OUTPUT-KEY #(4 3)
...
0.600   MOTOR                   FINISH-MOVEMENT
```

There are no constraints on how far or in which direction a model's finger can move relative to the other fingers. Thus, at this time, the model may be able to make finger movements which would be impossible for a real person to make and it is up to the modeler to consider such issues.

If the movement takes the model's finger to an invalid location for a key then it effectively presses a key with the value **nil** and a warning will be printed:

```
#|Warning: Invalid key location pressed #(4 7) |#
```

Isa press-key
key *key*

The press-key request is essentially a programming convenience for typing. It assumes that the model's hands are in the home positions and translates from the specified key to either a punch or a peck-recoil request as needed to press that key. The key can be specified using either a symbol or string that specifies the name of a key to press. It should be the single character for the alpha-numeric keys or one of these symbols for the punctuation and special keys: space, backquote, tab, comma, period, semicolon, slash, hyphen, quote, return, or enter.

If the model's hands have been moved off of the home row, then the model will strike the wrong key. This request does not represent an ACT-R theory of typing. A more ideal theory of typing would be based on a model learning how to type - the model would have to look at the keyboard to determine where each key is, then acquire chunks that encode which keys map to which locations, through practice it would learn specific productions that handle these, and would also involve learning in the motor system itself. Until such a mechanism is implemented, press-key should be able to handle basic typing assuming a moderately skilled touch typist.

Here are the events which will show in the trace for a press-key request indicating the key that was specified, the progression through the stages of the action, and indicating the location of the key which was pressed:

```
0.050   MOTOR                   PRESS-KEY COMMA
...
0.300   MOTOR                   PREPARATION-COMPLETE
...
0.350   MOTOR                   INITIATION-COMPLETE
...
0.450   MOTOR                   OUTPUT-KEY #(8 5)
...
0.600   MOTOR                   FINISH-MOVEMENT
```

If an invalid key is specified then a warning is printed and no action is taken:

```
     0.050   MOTOR                   PRESS-KEY BAD-KEY
#|Warning: No press-key mapping available for key BAD-KEY. |#
```

Isa move-cursor
 [**object** *object* | **loc** *location*]
 {**device** [**mouse** | **joystick-1** | **joystick-2**]}

This request will result in a ply style movement of the model's right hand if it is currently located on the mouse. That ply will move the cursor to either the object (which must be a chunk which is a subtype of visual-object) or location (which must be a chunk which is a subtype of visual-location) given taking time based on Fitts's Law. If device is not specified then the assumption is that the cursor is positioned with a mouse, but if one of the joystick values is specified that indicates the pointing is done with either a first or second order joystick respectively which increases the Fitts's coefficient for the movement. The coefficient is multiplied by 2 for a first-order joystick and by 4 for a second-order joystick.

If the :cursor-noise parameter is **nil** then the cursor will be positioned exactly at the coordinates provided – either the screen-x and screen-y coordinates of the location given or the screen-x and screen-y coordinates of the location of the object provided. If :cursor-noise is **t** then a very simplified noise component is added to the target point to determine where the cursor is moved to. An offset distance is computed using the effective width of the target – it's width along the vector of approach as used in the Fitts's Law calculation. The offset is computed using the act-r-noise command with an s value that results in it being on the object (along the approach vector) 96% of the time. That offset is applied in a random direction from the target chosen from a uniform distribution.

Here are the events which show for a move-cursor action showing the module progressing through the internal states and indicating the final position of the cursor:

```
0.050   MOTOR                   MOVE-CURSOR OBJECT NIL LOC LOC1
...
0.250   MOTOR                   PREPARATION-COMPLETE
...
0.300   MOTOR                   INITIATION-COMPLETE
...
0.661   MOTOR                   MOVE-CURSOR-ABSOLUTE #(100 200)
...
0.711   MOTOR                   FINISH-MOVEMENT
```

If the :incremental-mouse-moves parameter is specified as **t**, then there may be multiple smaller mouse movements leading up to the final position which are spaced approximately 50 ms apart. The individual movements indicate the distance and direction of the smaller movements:

```
0.050   MOTOR                   MOVE-CURSOR OBJECT NIL LOC LOC1
...
0.250   MOTOR                   PREPARATION-COMPLETE
0.250   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.300   MOTOR                   INITIATION-COMPLETE
...
0.301   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
```

```
...
0.353   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.404   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.455   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.507   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.558   MOTOR                   MOVE-CURSOR-POLAR #(28 1.1071488)
...
0.661   MOTOR                   MOVE-CURSOR-ABSOLUTE #(100 200)
...
0.711   MOTOR                   FINISH-MOVEMENT
```

If the model's right hand is not on the mouse a warning is printed and no action is taken:

```
#|Warning: MOVE-CURSOR requested when hand not at mouse! |#
```

Isa hand-to-mouse

The hand-to-mouse request will move the model's right hand from where ever it is to the virtual mouse's location using a ply style movement (the target location for the mouse is (28 2)). These are the events which will show the action progressing through the stages of a motor action along with final movement indicating the distance and direction the right hand moved:

```
0.050   MOTOR                   HAND-TO-MOUSE
...
0.250   MOTOR                   PREPARATION-COMPLETE
...
0.300   MOTOR                   INITIATION-COMPLETE
...
0.553   MOTOR                   MOVE-A-HAND RIGHT 21.095022 -0.094951704
...
0.603   MOTOR                   FINISH-MOVEMENT
```

If the model's hand is already on the virtual mouse it will acknowledge the request, but no actions are taken and the module does not become busy. There will only be the one acknowledgement event in the trace:

```
0.050   MOTOR                   HAND-TO-MOUSE
```

Isa hand-to-home

The hand-to-home request will move the model's right hand from where ever it is to the home position on the virtual keyboard using a ply style movement (the target location for the home position is (7 4))). These are the events which will show the action progressing through the stages of a motor action along with final movement indicating the distance and direction the hand moved:

```
0.653   MOTOR                   HAND-TO-HOME
```

```
...
0.703   MOTOR                   PREPARATION-COMPLETE
...
0.753   MOTOR                   INITIATION-COMPLETE
...
1.006   MOTOR                   MOVE-A-HAND RIGHT 21.095022 3.0466409
...
1.056   MOTOR                   FINISH-MOVEMENT
```

Even if the model's hand is already at the home location it will still progress through all if the stages of the movement to move the hand:

```
0.000   MOTOR                   HAND-TO-HOME
...
0.200   MOTOR                   PREPARATION-COMPLETE
...
0.250   MOTOR                   INITIATION-COMPLETE
...
0.350   MOTOR                   MOVE-A-HAND RIGHT 0.0 0.0
...
0.400   MOTOR                   FINISH-MOVEMENT
```

Isa point-hand-at-key
hand [**left** | **right**]
to-key *key*

key ::= either a symbol or string that specifies the name of a key to press. It should be the single character for the alpha-numeric keys or one of these symbols for the punctuation and special keys: space, backquote, tab, comma, period, semicolon, slash, hyphen, quote, return, or enter.

This request will move the hand on the virtual keyboard causing all of the fingers to be repositioned using a ply style movement. The index finger of the specified hand is positioned over that key with the other fingers being positioned to the left or right as appropriate.

The key can be specified using either a symbol or string that specifies the name of a key to press. It should be the single character for the alpha-numeric keys or one of these symbols for the punctuation and special keys: space, backquote, tab, comma, period, semicolon, slash, hyphen, quote, return, or enter.

Here are the events which will show in the trace for a point-hand-at-key request indicating the hand and key that were specified, the progression through the stages of the action, and indicating the distance and direction the hand was moved:

```
0.050   MOTOR                   POINT-HAND-AT-KEY HAND LEFT TO-KEY a
...
0.250   MOTOR                   PREPARATION-COMPLETE
...
0.300   MOTOR                   INITIATION-COMPLETE
...
0.481   MOTOR                   MOVE-A-HAND LEFT 3.0 3.1415927
...
0.531   MOTOR                   FINISH-MOVEMENT
```

As with the hand-to-home request, even if the hand is already located over the requested key the module will still progress through the movement stages:

```
     0.600   MOTOR                  POINT-HAND-AT-KEY HAND RIGHT TO-KEY J
     0.600   MOTOR                  PREPARATION-COMPLETE
     ...
     0.650   MOTOR                  INITIATION-COMPLETE
     ...
     0.750   MOTOR                  MOVE-A-HAND RIGHT 0.0 0.0
     ...
     0.800   MOTOR                  FINISH-MOVEMENT
```

If an invalid key is specified then a warning is printed and no action is taken:

```
     0.050   MOTOR                  POINT-HAND-AT-KEY HAND LEFT TO-KEY BAD-KEY
#|Warning: No key mapping available for key BAD-KEY |#
```

Isa prepare
style [*punch* | *peck* | *peck-recoil* | *ply* | *hand-ply*]
{**hand** [***left*** | ***right***] }
{**finger** [***index*** | ***middle*** | ***ring*** | ***pinkie*** | ***thumb***] }
{**r** *distance*}
{**theta** *direction*}

The prepare request can be used to have the module prepare but not immediately execute a set of features. Those features are stored the same way that the features for a previously executed action are, and thus will decrease the preparation time of a subsequent action which shares those features. Using the execute request (described next) it is also possible to perform the action specified by the history of features, so a prepare could be used to set up an action which one may execute later. For instance, if you know the next motor action is going to be a punch of the right index finger, but you're not sure when, you can prepare the movement in advance and then execute it later.

You must specify a style to prepare, and then you may specify any of the parameters that are relevant for that style.

Here is the trace showing a preparation for a ply style action (movement of the left index finger two keys to the right) which shows that only the preparation step occurs for a prepare request:

```
     0.050   MOTOR                  PREPARE PLY HAND LEFT FINGER INDEX R 2 THETA 0
     ...
     0.300   MOTOR                  PREPARATION-COMPLETE
```

If that is followed by an execute action there is no preparation step at that time, and the previously prepared action is executed. Here is a continuation of that trace showing an execute request occurring next:

```
     0.350   MOTOR                  EXECUTE
     ...
     0.400   MOTOR                  INITIATION-COMPLETE
     ...
```

```
0.500   MOTOR                 MOVE-A-FINGER LEFT INDEX 2 0
...
0.550   MOTOR                 FINISH-MOVEMENT
```

Isa execute

The execute request causes the model to execute the last movement which was prepared. That will either be a movement which was specified by an explicit prepare request or the last action which was requested. Because all of the features are already prepared there is no preparation step required as shown in the sequence of events (in this case the last prepared features were for a click-mouse action):

```
0.400   MOTOR                 EXECUTE
...
0.450   MOTOR                 INITIATION-COMPLETE
...
0.460   MOTOR                 OUTPUT-KEY #(28 2)
...
0.550   MOTOR                 FINISH-MOVEMENT
```

If there are no currently prepared features then the execute command prints a warning and no action is taken:

```
#|Warning: Motor Module has no movement to EXECUTE. |#
```

Chunks & Chunk-types

Here are the chunk-type definitions that are effectively executed by the motor module:

```
(chunk-type motor-command)
(chunk-type (click-mouse (:include motor-command)))
(chunk-type (hand-to-mouse (:include motor-command)))
(chunk-type (hand-to-home (:include motor-command)))
(chunk-type (move-cursor (:include motor-command)) object loc device)
(chunk-type (peck (:include motor-command)) hand finger r theta)
(chunk-type (peck-recoil (:include motor-command)) hand finger r theta)
(chunk-type (point-hand-at-key (:include motor-command)) hand to-key)
(chunk-type (press-key (:include motor-command)) key)
(chunk-type (punch (:include motor-command)) hand finger)
(chunk-type (prepare (:include motor-command)) style hand finger r theta)
(chunk-type (execute (:include motor-command)))
(chunk-type clear)
```

Commands

start-hand-at-mouse

Syntax:

start-hand-at-mouse -> [**t** | **nil**]

Description:

The start-hand-at-mouse command is used to position the right hand of the current model on the virtual mouse. It should be called before running the model – it is not intended for moving the model's hand only specifying its initial location. If the model's hand is successfully placed on the mouse, then **t** is returned. If there is no current model, then no change is made, a warning is printed, and **nil** is returned.

Examples:

```
> (start-hand-at-mouse)
T

E> (start-hand-at-mouse)
#|Warning: No current model.  Cannot set hand at mouse. |#
NIL
```

set-cursor-position

Syntax:

set-cursor-position *x y* -> [xy-loc | **nil**]
set-cursor-position-fct *new-loc* -> [xy-loc | **nil**]

Arguments and Values:

x ::= a number specifying the starting x coordinate for the mouse cursor
y ::= a number specifying the starting y coordinate for the mouse cursor
new-loc ::= a vector of two values representing a new location for the mouse cursor
xy-loc ::= a vector of two values representing the current location of the mouse cursor

Description:

The set-cursor-position command can be used to set the initial position of the mouse cursor for the current device of the current model. It should be called before running the model – it is not intended for moving the mouse cursor during a model's run. If the position of the mouse cursor is set for the device, the a vector with the current mouse coordinates is returned. If there is no current model then no change is made, a warning is printed, and **nil** is returned.

Examples:

```
> (set-cursor-position 10 20)
#(10 20)

> (set-cursor-position-fct #(20 30))
#(20 30)

E> (set-cursor-position 10 20)
#|Warning: No current model.  Cannot set cursor position. |#
NIL
```

set-hand-location

Syntax:

set-hand-location [***left*** | ***right***] *x y* -> [**t** | **nil**]
set-hand-location-fct [***left*** | ***right***] *xy-loc* -> [**t** | **nil**]

Arguments and Values:

x ::= a number specifying the starting x coordinate on the virtual keyboard for the specified hand
y ::= a number specifying the starting y coordinate on the virtual keyboard for the specified hand
xy-loc ::= a vector or list of two numbers specifying the starting x and y coordinates respectively on the virtual keyboard for the specified hand

Description:

The set-hand-location command can be used to set the initial position of the specified hand of the current model on the virtual keyboard. It should be called before running the model – it is not intended for moving the hand during a model's run. The x and y coordinates specify the key over which the index finger of the hand is placed, and the other fingers will be located over the keys to the left or right of that location as appropriate. If the position of the hand is set for the model then **t** is returned. If there is no current model then no change is made, a warning is printed, and **nil** is returned.

Examples:

```
> (set-hand-location left 0 3)
T

> (set-hand-location-fct 'right '(8 2))
T

E> (set-hand-location left 5 1)
#|Warning: No current model.  Cannot set hand location. |#
NIL
```

extend-manual-requests

Syntax:

extend-manual-requests *chunk-type request-function* -> [**t** | **nil**]
extend-manual-requests-fct *chunk-type request-function* -> [**t** | **nil**]

Arguments and Values:

chunk-type ::= a list with a valid definition for a new chunk-type (not including the call to chunk-type)
request-function ::= a symbol which is the name of a function to call to handle the new request

Description:

The extend-manual-requests command allows one to add new requests to those which are accepted by the manual buffer. Extend-manual-requests only needs to be called once for each new request being added, and it does not have to occur within the context of a model. The chunk-type parameter must be a list which is valid for passing to chunk-type-fct and specifies the new chunk-type that all models will now have available for making the request. When a request to the manual buffer is made with that chunk-type the function specified by request-function will be called with the current model's motor module as the first parameter and the chunk-spec of the request as the second parameter. There are no restrictions on what the new request may do, nor are there any default operations performed – it is entirely up to the extension to handle all scheduling of events as necessary to change the state of the motor module and perform the actions necessary.

Once a new request has been added it cannot be overwritten by a new request with the same chunk-type. However, it can be removed using the remove-manual-request command and then be defined again.

If chunk-type is not a list, request-function does not name a currently defined function or the chunk-type being specified is already used for an extension then extend-manual-requests will print a warning, no new request extension will be made, and **nil** will be returned.

Otherwise, the new request will be available to all models from that point on and **t** will be returned.

The recommended use of this command is to place a file which has the necessary request function and any support code needed along with a call to extend-manual-requests into one of the directories for which the files are loaded automatically. That way the request function is compiled with the rest of the sources and is made available to all models right from the start. If it is called while there are models already defined the new request will not be available to those models until they are reset.

Examples:

These examples assume that there are functions named handle-right-click and handle-hold already defined.

```
> (extend-manual-requests (right-click) handle-right-click)
T

1> (extend-manual-requests-fct '((hold-key (:include motor-command)) key) 'handle-hold)
T

2E> (extend-manual-requests-fct '((hold-key (:include motor-command) key)) 'handle-hold)
#|Warning: Request HOLD-KEY is already an extension of the manual buffer.  To redefine you
must remove it first with remove-manual-request. |#
NIL

E> (extend-manual-requests bad-type handle-right-click)
#|Warning: Invalid chunk-type specification BAD-TYPE.  Manual requests not extended. |#
NIL

E> (extend-manual-requests-fct '(chord finger1 finger2) 'not-a-function)
#|Warning: NOT-A-FUNCTION does not name a function.  Manual requests not extended. |#
NIL
```

remove-manual-request

Syntax:

remove-manual-request *chunk-type-name* -> [**t** | **nil**]
remove-manual-request-fct *chunk-type-name* -> [**t** | **nil**]

Arguments and Values:

chunk-type-name ::= a symbol which is the name of a chunk-type used to extend the manual requests

Description:

Remove-manual-request is used to remove a request that has been added to the manual buffer through the use of extend-manual-requests. The chunk-type-name parameter should be the name of a chunk-type which was defined in a call to extend-manual-requests. The request of that chunk-type will be removed from the set of requests that the manual buffer will process for all models and that chunk-type will no longer be defined in any new models (its definition will still remain in any existing models until they are reset).

If chunk-type-name does name an extended request, then after removing the request this command will return **t**. If chunk-type-name is not the name of a previously extended request then a warning will be printed and **nil** will be returned.

This command is typically only needed when one is developing some extensions to the manual module and needs to change some of the requests under development. It is not recommended for use in other situations.

Examples:

These examples assume that there are functions named handle-right-click and handle-hold already defined.

```
1> (extend-manual-requests (right-click) handle-right-click)
T

2> (extend-manual-requests-fct '((hold-key (:include motor-command)) key) 'handle-hold)
T

3> (remove-manual-request-fct 'right-click)
T

4> (remove-manual-request hold-key)
T

5E> (remove-manual-request hold-key)
#|Warning: HOLD-KEY is not a previously extended request for the manual module. |#
NIL

E> (remove-manual-request-fct 'bad-chunk-name)
#|Warning: BAD-CHUNK-NAME is not a previously extended request for the manual module. |#
NIL
```

Speech module

The Speech Module gives a model a rudimentary ability to speak. This system is not designed to provide a sophisticated simulation of human speech production, but to allow a model to speak words and short phrases for simulating verbal responses in experiments and for subvocalizing text internally. The module has one buffer, vocal, and works in much the same way as the motor module.

The vocal world

The model's speech output is fairly limited. When it speaks or subvocalizes it will hear its own words through the auditory system. That is the only result from subvocalizing. When the model speaks, then the device will detect the output as well. Essentially, the device has a microphone which detects the onset of the speech and can record the content of what was said.

Operation

Like the motor module, the speech module takes requests that specify a style of action and the parameters to control that style. There are only two styles available for the speech module:

- Speak. This is a normal speech output.
- Subvocalize. This is internal speech – the model speaking to itself with no external output.

The only parameter for both of those styles is a string of text to speak.

The speech module does not place any chunks into its buffer in response to the requests. The vocal buffer should always be empty, and it is the state of the module that is most important to the model in this case. As described above for all the perceptual and motor modules, the speech module has three internal states: preparation, processor, and execution. How a request progresses through those states is described in detail below.

An important thing to note is that while the vocal buffer does not receive a chunk in response to a speech action the aural-location buffer might. Because the model hears its own speech acts the automatic buffer stuffing of the aural-location buffer may occur as a result of a vocal request.

When a request is received by the speech module, it goes through three phases: preparation, initiation, and execution. The amount of time that speech output preparation takes depends on the history of previous speech acts. The speech module records the last string which it has output. If there is no previous string which has been spoken, then the module takes .15 seconds in preparation. If there is a previously spoken string, then the preparation time is 0 seconds if the same string is being output again and .1 seconds if it is a different string.

After preparation is complete, the speech module makes the specified vocal output. The first 50 ms (by default) of that output is initiation. During this interval, the preparation state becomes free and the processor and execution states become busy. After initiation ends, the processor state becomes free. It is at that time that speech output is made available to the device and the auditory system. Note that the typical detection delay and recoding times still apply for the encoding of sounds as described in the audio module, but speech output though subvocalizing has a separate parameter for the detection delay and a recoding time of 0 seconds. The amount of time that the speech takes to finish after initiation depends on the articulation time of the string which defaults to .15 seconds per assumed syllable, but can be changed in various ways (see the get-articulation-time command below for details).

The speech module can only prepare one output at a time. If the speech module is in the process of preparing a movement and another request is received, the later request will be ignored and the speech module is said to be "jammed." When the module is jammed it will output a warning indicating when the jamming occurred like this:

```
#|Warning: Module :SPEECH jammed at time 0.1 |#
```

The way to avoid jamming, as with all modules, is to test the state of the module before making a request. Testing that state free is true will avoid jamming the module, but it is possible to issue speech requests faster than that – because the state will not be free until the previous output has been completed. Instead, one only needs to test that the preparation state is free to be able to issue a new request to the speech module. A slightly more conservative approach would be to test the processor state because it is still busy during the initiation time of the last output request.

Parameters

:syllable-rate

This parameter controls the time it takes the model to articulate each syllable in a text string and is measured in seconds (see the get-articulation-time below for how it applies). It can be set to any non-negative number and defaults to 0.15.

:char-per-syllable

This parameter controls how the model breaks a text string into syllables and is measured in a number of characters (see the get-articulation-time below for how it applies). It can be set to any positive number and defaults to 3.

:subvocalize-detect-delay

This parameter sets the detect delay timing for the sound events generated by a subvocalize action (see the audio module for details on the detect delay). It is measured in seconds and can be set to any non-negative value. It defaults to .3 (which is the same value that normal text has).

Vocal buffer

The speech model does not place any chunks into the vocal buffer. The preparation timing for the actions will be set using the randomize-time function if the :randomize-time parameter is set, but all other action times will be fixed regardless of the randomize-time setting.

Activation spread parameter: :vocal-activation
Default value: 0.0

Queries

'State busy' will be **t** when any of the internal states of the module (listed below) also report as being busy. Essentially, it will be **t** while there is any request to the vocal buffer that has not yet completed. It will be **nil** otherwise.

'State free' will be **t** when all of the internal states of the module (listed below) also report as being free. Essentially, it will be **t** only when all requests to the vocal buffer have completed. It will be **nil** otherwise.

'State error' will always be **nil**.

Unlike the perceptual modules, the internal states of the speech module may be useful to track in a model because it is possible to send new requests while the module is partially busy. Only the preparation stage of the module needs to be free to avoid jamming. For each request that is received the module will progress through three stages as described above: preparation, initiation, and execution.

'Preparation busy' will be **t** after a request has been received and until it completes the preparation of the features needed for that request which depends on how many features there are and whether or not they overlap with the last features prepared. It will be **nil** otherwise.

'Preparation free' will be **nil** after a request has been received and until it completes the preparation of the features needed for that request which depends on how many features there are and whether or not they overlap with the last features prepared. It will be **t** otherwise.

'Processor busy' will be **t** while preparation is busy and will continue to be **t** after the features have been prepared until the additional initiation time (fixed at .05 seconds) has passed. It will be **nil** otherwise.

'Processor free' will be **nil** while preparation is busy and will continue to be **nil** after the features have been prepared until the additional initiation time (fixed at .05 seconds) has passed. It will be **t** otherwise.

'Execution busy' will be **t** once the preparation of a request's features has completed and will remain **t** until the time necessary to complete the action has passed. It will be **nil** otherwise.

'Execution free' will be **nil** once the preparation of a request's features has completed and will remain **nil** until the time necessary to complete the action has passed. It will be **t** otherwise.

'Last-command *command*' *command* should be a chunk-type which corresponds to one of the vocal buffer's requests. The query will be **t** if that is the name of the last request (the chunk-type) received by the vocal buffer otherwise it will be **nil**.

Here is a summary indicating the state transitions for a single vocal request assuming that the module is entirely free at the start of the request:

Preparation state	**Processor state**	**Execution state**	**When**
FREE	FREE	FREE	Before event arrives
BUSY	BUSY	FREE	When event is received
FREE	BUSY	BUSY	After preparation time
FREE	FREE	BUSY	After initiation (.05 seconds)
FREE	FREE	FREE	When speech completes (articulation time)

Requests

Isa clear

A clear request can be sent to clear the history of the last string vocalized. A clear request will make the preparation state busy for 50ms. These events will show in the trace for a clear request to the vocal buffer:

```
0.050   SPEECH                CLEAR
...
0.100   SPEECH                CHANGE-STATE LAST NONE PREP FREE
```

Note, that after the clear request completes the last-command recorded by the module will be none and not clear – the clear request has effectively cleared the history of its own request as well.

Isa speak

string *text*

A speak request causes the model to generate vocal output. The output that is made is the Lisp string specified by text. That output is sent to the current device and thus may be heard/recorded externally. It is also made available to the model's audio module as a word sound with a location of self. That will trigger buffer stuffing of the aural-location buffer.

Here are the events which will show in the trace for a speak request showing the text that is to be output and the progression through the stages of the action:

```
0.050   SPEECH                  SPEAK TEXT Hello
...
0.200   SPEECH                  PREPARATION-COMPLETE
...
0.250   SPEECH                  INITIATION-COMPLETE
0.250   SPEECH                  OUTPUT-SPEECH Hello
...
0.500   SPEECH                  FINISH-MOVEMENT
```

If an invalid text value is given this warning will show in the trace and no action will be taken by the module:

```
#|Warning: String slot in a speak request must be a Lisp string. |#
```

Isa subvocalize
string *text*

A subvocalize request causes the current model to generate a internal speech (the model is talking to itself). That output is not made available to the device, but it is made available to the model's audio module as a word sound with an internal location. That will trigger buffer stuffing of the aural-location buffer.

Here are the events which will show in the trace for a subvocalize request showing the text that is to be subvocalized and the progression through the stages of the action:

```
0.050   SPEECH                  SUBVOCALIZE TEXT hello
...
0.200   SPEECH                  PREPARATION-COMPLETE
...
0.250   SPEECH                  INITIATION-COMPLETE
...
0.500   SPEECH                  FINISH-MOVEMENT
```

If an invalid text value is given this warning will show in the trace and no action will be taken by the module:

```
#|Warning: String slot in a subvocalize request must be a Lisp string. |#
```

Chunks & Chunk-types

Here are the chunk-type and chunk definitions that are effectively executed by the speech module:

```
(chunk-type speech-command)
(chunk-type (speak (:include speech-command)) string)
(chunk-type (subvocalize (:include speech-command)) string)
(chunk-type clear)
(chunk-type pm-constant)

(define-chunks
  (self isa pm-constant))
```

Commands

get-articulation-time/register-articulation-time

Syntax:

get-articulation-time *string* -> [time | **nil**]
register-articulation-time *string time* -> [time | **nil**]

Arguments and Values:

string ::= a Lisp string for which a specific articulation time is required
time ::= a non-negative number indicating the time it takes to articulate the string specified

Description:

These commands are used to get the articulation time for a text string and to set an explicit time to articulate a string in the current model. That time will be used by the audio module as the duration of such a string if it is heard by the model and will be the length of time that the model requires to speak such a string using the speech module.

Register-articulation-time sets the articulation time for the provided string in the current model. If such a value is set then time is returned. If there is no current model or one of the parameters is invalid, then a warning is printed and **nil** is returned.

Get-articulation-time returns the time it takes to articulate a string of text for the current model. That time will be either the explicit time that was set using register-articulation-time if one was set, or computed based on the length of the string and the values of the parameters :syllable-rate and :char-per-syllable using this equation:

$$AT = r * L / c$$

AT := articulation time for the string
r := value of the :syllable-rate parameter
L := the length of the string
c := value of the :char-per-syllable parameter

If the string is invalid or there is no current model then a warning is printed and **nil** is returned instead.

Examples:

```
1> (sgp :char-per-syllable :syllable-rate)
:CHAR-PER-SYLLABLE 3 (default 3) : Characters per syllable.
:SYLLABLE-RATE 0.15 (default 0.15) : Seconds per syllable.
(3 0.15)

2> (get-articulation-time "Hello")
0.25

3> (get-articulation-time "Goodbye")
0.35

4> (get-articulation-time "A")
0.05

5> (register-articulation-time "Hello" .185)
0.185

6> (get-articulation-time "Hello")
0.185

E> (register-articulation-time "Hello" .25)
#|Warning: No current model.  Cannot set articulation time. |#
NIL

E> (get-articulation-time "Hello")
#|Warning: No current model.  Cannot get articulation time. |#
NIL

E> (get-articulation-time 'hello)
#|Warning: Must specify a string for which to get the articulation time. |#
NIL

E> (register-articulation-time 'hello .2)
#|Warning: Must specify a string for which the articulation time is to be set. |#
NIL

E> (register-articulation-time "Hello" -1)
#|Warning: Articulation time must be a non-negative number. |#
NIL
```

Temporal Module

The temporal module provides a model with a means of determining time intervals and is based on research by Taatgen, van Rijn, & Anderson (2007). It does so by providing a timer which counts the number of "ticks" which have passed since the timer was started. The tick lengths are noisy and also increase in duration as time progresses. Thus it is more accurate for timing shorter intervals than longer ones. The current tick count is available to the model via a chunk in the temporal buffer. The chunk is of a type called time and the count is in a slot called ticks. Once the timer is started the module will continue to update the ticks slot of the chunk in the buffer with the current count automatically. The timer can be explicitly reset to start a new count or stopped by the model at any time, and if the time chunk is removed from the buffer it will implicitly stop the count from incrementing.

The tick lengths are generated based on the following equations for the nth tick (where the 0^{th} tick is the time between the count of 0 and the count of 1):

$$t_0 = start + \varepsilon_1$$

$$t_n = a \cdot t_{n-1} + \varepsilon_2$$

start := value of the :time-master-start-increment parameter (default 0.011 seconds)
a := value of the :time-mult parameter (default 1.1)
b := value of the :time-noise parameter (default 0.015)
ε_1 := noise generated with the act-r-noise command with an s of b * 5 * start
ε_2 := noise generated with the act-r-noise command with an s of b * a * t_{n-1}

Parameters

:record-ticks

This parameter controls whether or not the time incrementing event generates an action which the buffer tracing tools (which are used to create the BOLD predictions for a model and to generate the graphic traces in the ACT-R Environment) can detect. If it is set to **t** then there will be an extra event in the trace which will be associated with activity in the temporal buffer. It can be set to **t** or **nil** and the default value is **t**.

:time-master-start-increment

This parameter controls the length of the 0^{th} tick in seconds. It can be set to any positive number and defaults to 0.011.

:time-mult

This parameter sets the multiplier for increasing the tick length. It can be set to any positive number and defaults to 1.1.

:time-noise

This parameter scales the s value of the noise added to the tick lengths. It can be set to any positive number and defaults to 0.015.

Temporal buffer

The temporal module sets the temporal buffer to **not** be strict harvested.

Activation spread parameter: :temporal-activation
Default value: 0.0

Queries

The temporal buffer only responds to the default queries and does so like the goal module i.e. always available and never in an error state.

'State busy' will always be **nil**.

'State free' will always be **t**.

'State error' will always be **nil**.

Requests

Isa time

There are no slots allowed in the time request.

The time request will reset the tick counter to 0, put a chunk of type time into the temporal buffer holding that count of 0 in the ticks slot, and start a timer to increment that tick count as described above. These actions will happen at the time of the request:

```
0.050   PROCEDURAL              MODULE-REQUEST TEMPORAL
0.050   TEMPORAL                create-new-buffer-chunk isa time
0.050   TEMPORAL                SET-BUFFER-CHUNK TEMPORAL TIME0
```

The updating of the timer will happen at the appropriate times in the future and will generate multiple events in the trace for each update. If the :record-ticks parameter is set to **t** then there will be three events for each update like this:

```
0.063   TEMPORAL              Incrementing time ticks to 1
0.063   TEMPORAL              MODULE-MOD-REQUEST TEMPORAL
0.063   TEMPORAL              MOD-BUFFER-CHUNK TEMPORAL
```

whereas if :record-ticks is set to **nil** there will only be two events like this:

```
0.063   TEMPORAL              Incrementing time ticks to 1
0.063   TEMPORAL              MOD-BUFFER-CHUNK TEMPORAL
```

Isa clear

There are no slots allowed in the clear request.

The clear request will stop a temporal counter which is running. This is generally done in a model when a time estimation finishes (the ticks count is no longer needed) to improve performance of the system and keep the trace cleaner. Though as long as the model is no longer using the temporal buffer whether the timer is left running or stopped should not affect the operation of the model. The clear action will occur at the time of the request and will generate an event like this in the trace:

```
15.559   TEMPORAL              Clear
```

Modification requests

Technically, the temporal module allows modification requests because it is used internally to update the tick count when the :record-ticks parameter is set to t. However, that capability is not intended for general use and modification requests should not be made to the temporal buffer.

Chunks & Chunk-types

Here are the chunk-type definitions that are effectively executed by the temporal module:

```
(chunk-type time ticks)
(chunk-type clear)
```

Advanced Topics

The previous sections of the manual have covered the basic operation of the system and the operation of the modules that are provided. That is the information which should be of general use to those using ACT-R to produce models. However, there are other capabilities which one can use in the system in addition to being able to extend the system itself. The following sections will describe more of the low level subsystems that are available for working with ACT-R and will cover more advanced topics in using the system like running multiple models, defining new modules for the model to use and creating new devices with which a model can interact. These sections will assume that one has a good grasp of the concepts from the earlier sections and some moderate experience with Lisp programming.

One note about the advanced topics is that the purpose is to describe the components that the system makes available. Because the system is provided as Lisp code it is entirely possible for the user to modify or change the definition of the system itself. That is not the sort of thing that will be covered in this, or any, section of the reference manual.

Chunk-Specs

The first advanced component to describe will be the chunk-spec. A chunk-spec is an internal representation for the specification of a chunk (*chunk-spec*ification). Chunk-specs consist of a chunk-type, a set of constraints on the slots of that chunk-type and a set of request parameters. They can be used for a variety of purposes and are a key component in the communication between modules. They were used implicitly in several of the commands of the modules described above and occasionally showed up in the text of a warning message. The most obvious use of chunk-specs shown in the modules described is in the commands for defining productions. The LHS buffer tests and RHS requests are both direct instances of chunk-specs. That also describes the two primary uses of chunk-specs: testing or finding chunks that match a specification and making a request to a module.

The description of a chunk in a chunk-spec can use modifiers and variables in much the same way that the production pattern matching does. The same modifiers used in productions are available in a chunk-spec: =,-,<,>,<=, and >=. The default behavior is the same as used in productions: = means that the slots must be equal, - means they must differ, and the inequality tests are only valid for numbers. However, one is not restricted to only that usage. How each of those modifiers is used to match or find a chunk with a chunk-spec can be controlled individually in the commands which do so. One example where one might want to change that would be to allow using the inequality tests among some particular set of symbolic qualitative sizes like {tiny, small, normal, big, gigantic} or other non-numeric quantities.

Similarly, the character used to denote that a slot value in a chunk-spec is a variable can also be controlled when using the matching and finding commands. As with productions, it defaults to '=', but any character which is valid for the first element in a symbol name may be used. An example where changing the character used to denote a variable is seen in the visual-location requests to the visual-location buffer. For those requests the '&' character is used to denote a variable in the request to differentiate it from the specific variables used in the production itself which would substitute their bindings into the request instead of leaving it as a variable.

The most common place where one will need to use chunk-specs is when developing a new module. All requests to the module will be encoded as chunk-specs. Thus any module which accepts requests will have to process chunk-specs. If the module also holds a set of chunks internally for some purpose, like the vision module does for the features of the visual scene, then one may also find the matching and search commands which are available via chunk-specs to be useful.

Because the semantics of the modifiers are not fixed and the specification of a variable is configurable, a chunk-spec does not really have any particular meaning on its own. Without knowing the context in which the chunk-spec will be used it is difficult to know what it really represents, and thus the chunk-specs are going to be specific to the module or code which uses them.

The internal representation of a chunk-spec is not part of the API for the system, and the commands for creating and destructuring them will be described in detail below. There are also several special purpose commands for testing and reforming a chunk-spec which can make things easier when writing a new module.

Commands

define-chunk-spec

Syntax:

define-chunk-spec *specification* -> [chunk-spec | **nil**]
define-chunk-spec-fct *(specification)* -> [chunk-spec | **nil**]

Arguments and Values:

specification ::= [chunk-name | **isa** chunk-type {{modifier} slot value}*]
chunk-name ::= a symbol which names a chunk in the current model
chunk-type ::= a symbol which names a chunk-type in the current model
modifier ::= [**=** | **-** | **<** | **>** | **<=** | **>=**]
slot ::= [valid-slot | request-param]
valid-slot ::= a symbol which names a slot in the specified chunk-type
request-param ::= a Lisp keyword
value ::= any Lisp value

Description:

The define-chunk-spec command is used to create a chunk-spec. There are two ways to define chunk-spec. If a chunk-name is given as the only parameter then a chunk-spec will be created that matches that chunk exactly. It will specify the chunk-type of the named chunk and for each valid slot in that chunk-type it will use the = modifier to test the slot for the current slot value of that slot in the chunk given. Alternatively, a chunk-type must be provided and then any number of slot and request parameters may be specified for the chunk-spec.

If the syntax of the specification is correct and all of the components are valid then a chunk- spec is returned.

If the syntax is incorrect, any of the components are invalid, or there is not a current model then a warning is displayed and **nil** is returned.

As indicated in the general description of a chunk-spec, the chunk-spec representation itself is not part of the API. Thus the specific return value of this command should not be used directly and is only intended to be passed to other chunk-spec processing commands.

Examples:

```
1> (chunk-type goal value state)
```

```
GOAL

2> (define-chunks (g isa goal value 2 state start))
 (G)

3> (chunk-type compare val1 val2)
COMPARE
```

The following two chunk-specs would be functionally equivalent:

```
4> (define-chunk-spec g)
#S(ACT-R-CHUNK-SPEC ...)

5> (define-chunk-spec-fct '(isa goal = value 2 = state start))
#S(ACT-R-CHUNK-SPEC ...)
```

The purpose of the next chunk-spec is ambiguous without knowing a context in which it will be used because the @ may be used to represent a variable, or perhaps the symbol @value has a particular meaning for where it will be used:

```
6> (define-chunk-spec isa compare val1 @value <= val2 @value - :param t)
#S(ACT-R-CHUNK-SPEC ...)

E> (define-chunk-spec isa bad-type)
#|Warning: Second element in define-chunk-spec isn't a chunk-type. (ISA BAD-TYPE) |#
NIL

E> (define-chunk-spec-fct '(bad-name))
#|Warning: define-chunk-spec's 1 parameter doesn't name a chunk: (BAD-NAME) |#
NIL

E> (define-chunk-spec isa goal)
#|Warning: define-chunk-spec-fct called with no current model. |#
NIL
```

pprint-chunk-spec

Syntax:

define-chunk-spec *chunk-spec* -> **nil**

Arguments and Values:

chunk-spec ::= a valid chunk-spec

Description:

The pprint-chunk-spec command can be used to print a chunk-spec to the model's command output stream. If the chunk-spec provided is valid a description of that chunk-spec will be output on the model's command output stream. The chunk-type, each slot and request parameter specification will be output on a separate line. Note that the = modifier will not be printed in the output, but all other modifiers will be. If the provided parameter is not a valid chunk-spec, then no output will be

performed. If there is no current model then a warning will be printed and no output will occur. The command will always return **nil**.

Examples:

```
1> (chunk-type goal value state)
GOAL

2> (define-chunks (g isa goal value 2 state start))
 (G)

3> (chunk-type compare val1 val2)
COMPARE

4> (defparameter *spec* (define-chunk-spec g))
*SPEC*

5> (pprint-chunk-spec *spec*)
    ISA GOAL
    STATE START
    VALUE 2
NIL

6> (setf *spec* (define-chunk-spec isa goal = value 2 = state start))
#S(ACT-R-CHUNK-SPEC ...)

7> (pprint-chunk-spec *spec*)
    ISA GOAL
    VALUE 2
    STATE START
NIL

8> (setf *spec* (define-chunk-spec isa compare val1 @value <= val2 @value - :param t))
#S(ACT-R-CHUNK-SPEC ...)

9> (pprint-chunk-spec *spec*)
    ISA COMPARE
    VAL1 @VALUE
 <= VAL2 @VALUE
 -  :PARAM T
NIL

E> (pprint-chunk-spec nil)
NIL

E> (pprint-chunk-spec *spec*)
#|Warning: get-module called with no current model. |#
NIL
```

match-chunk-spec-p

Syntax:

match-chunk-spec-p *chunk-name chunk-spec* {**:=test** *test-fn*} {**:-test** *test-fn*} {**:<=test** *test-fn*} {**:>=test** *test-fn*} {**:>test** *test-fn*} {**:<test** *test-fn*} {**:variable-char** *var*} -> result

Arguments and Values:

chunk-name ::= a symbol which should name a chunk in the current model
chunk-spec ::= a valid chunk-spec
test-fn ::= a function designator which must take two parameters and return a generalized boolean
var ::= a Lisp character
result ::= a generalized boolean indicating whether or not the match was a success

Description:

The match-chunk-spec-p command is used to determine if a chunk matches the chunk-spec. If it matches, then a true value is returned and if it does not match **nil** is returned.

A chunk matches the chunk-spec if it is a subtype of the chunk-type in the chunk-spec and the test of every slot in the specification with the corresponding slot value in the chunk results in a true value. Any request parameters which are a part of the chunk-spec are ignored for the purposes of matching the chunk with this command. To test the slot values, the test function which corresponds to the modifier on that slot in the chunk-spec will be called with the slot value as the first parameter and the chunk-spec's value as the second parameter unless the slot value specified is a variable. If the chunk-spec's value is a variable, then the value bound to that variable (as described next) will be passed to the testing function.

If there are any variables in the chunk-spec they are first tested for consistency and to determine their bindings before performing the slot tests. Each variable in the chunk-spec must appear in at least one slot test which uses the = modifier. If there is a variable which does not meet that requirement the match fails. For each variable in the chunk-spec in a slot test which uses the = modifier the corresponding chunk slot value must not be **nil** or the match will fail. If more than one slot test using the = modifier contains the same variable, then all slots where the = test is used with that variable must have the same value (using the function for the = test) or the match will fail. If those conditions are true, then the value in that slot will be bound to the variable for the remainder of the slot tests in the chunk-spec.

If there is not a variable-character provided then the default character of #\= is used to denote variables in the chunk-spec.

If no test functions are specified then the default chunk matching functions are used. Those functions work as follows:

- The = test is done based on the type of the items.
  - If they are strings they are compared with string-equal.
  - If they are symbols then they are tested with eq-chunks.
  - All other types are tested with equalp.
- The – test is the result of negating the = test for the items.
- All of the inequality tests are true if
  - Both values are numbers and

- The specified inequality holds between them with the chunk's slot value being the left of the items in the test and the chunk-spec's slot value the right.

If chunk-name, chunk-spec or one of the testing functions is invalid or there is no current model then a warning is displayed and **nil** is returned.

Examples:

```
1> (chunk-type test value1 value2)
TEST

2> (chunk-type (subtest (:include test)) value3)
SUBTEST

3> (define-chunks (a isa test value1 10 value2 5)
                  (b isa test value1 large value2 small)
                  (c isa subtest value1 medium value2 small value3 tiny))
 (A B C)

4> (defun x-smaller-than-y (x y)
     (let ((valid '(tiny small medium large huge)))
       (and (find x valid)
            (find y valid)
            (< (position x valid) (position y valid)))))
X-SMALLER-THAN-Y

4> (match-chunk-spec-p 'a (define-chunk-spec isa test - value1 7 >= value2 1))
T

5> (match-chunk-spec-p 'a (define-chunk-spec isa test value1 4))
NIL

6> (match-chunk-spec-p 'a (define-chunk-spec isa test value1 =val < value2 =val))
T

7> (match-chunk-spec-p 'a (define-chunk-spec isa test value1 10 :arbitrary-param t))
T

8> (match-chunk-spec-p 'b (define-chunk-spec isa test value1 =val < value2 =val))
NIL

9> (match-chunk-spec-p 'b (define-chunk-spec isa test value1 =val < value2 =val)
                       :<test 'x-smaller-than-y)
T

10> (match-chunk-spec-p 'c (define-chunk-spec isa test value1 =val < value2 =val)
                         :<test 'x-smaller-than-y)
T

11> (match-chunk-spec-p 'b (define-chunk-spec isa test value1 @val < value2 @val)
                         :<test 'x-smaller-than-y)
NIL

12> (match-chunk-spec-p 'b (define-chunk-spec isa test value1 @val < value2 @val)
                         :<test 'x-smaller-than-y :variable-char #\@)
T

E> (match-chunk-spec-p 'bad-name (define-chunk-spec isa chunk))
#|Warning: BAD-NAME does not name a chunk in call to match-chunk-spec-p. |#
NIL

E> (match-chunk-spec-p 'a 'bad-spec)
#|Warning: BAD-SPEC is not a valid chunk-spec in call to match-chunk-spec-p. |#
```

```
NIL

E> (match-chunk-spec-p 'b (define-chunk-spec isa test value1 =val < value2 =val)
                          :<test 'bad-function-name)
#|Warning: Error #<UNDEFINED-FUNCTION @ #x2685e6ba> encountered in matching chunk B. |#
NIL

E> (match-chunk-spec-p 'a nil)
#|Warning: Match-chunk-spec-p called with no current model. |#
NIL
```

find-matching-chunks

Syntax:

find-matching-chunks *chunk-spec* {**:chunks** [**:all** | (*chunk**)]} {**:=test** *test-fn*} {**:-test** *test-fn*} {**:<=test** *test-fn*} {**:>=test** *test-fn*} {**:>test** *test-fn*} {**:<test** *test-fn*} {**:variable-char** *var*} -> result-list

Arguments and Values:

chunk-spec ::= a valid chunk-spec
chunk ::= a symbol which should name a chunk in the current model
test-fn ::= a function designator which must take two parameters and return a generalized boolean
var ::= a Lisp character
result ::= (chunk*)

Description:

The find-matching-chunks command tests each chunk provided in the list given as the :chunks keyword parameter, or all chunks in the current model if it is omitted or specified as :all, against the chunk-spec provided. It returns the list of chunk names which match the chunk-spec using the same matching as described in match-chunk-spec-p which includes the possibility of specifying alternate testing functions and a variable character other than the default of #\=.

If the chunks list contains items which do not name chunks, then for each such item a warning will be printed and that item will be ignored, but the matching will still occur for the valid chunks.

If chunk-spec, chunks, or a testing function is invalid or there is no current model then a warning is displayed and **nil** is returned.

Examples:

```
> (find-matching-chunks (define-chunk-spec isa chunk))
(FREE REQUESTED LINE TONE SPEECH BOX CLEAR DIGIT ERROR UNREQUESTED ...)

1> (chunk-type test slot1)
TEST

2> (chunk-type (sub-test (:include test) slot2))
#|Warning: Too many options specified for chunk-type SUB-TEST. NO chunk-type created. |#
NIL

3> (chunk-type (sub-test (:include test)) slot2)
```

```
SUB-TEST
4> (define-chunks (a isa test slot1 4)
                  (b isa test slot1 6)
                  (c isa sub-test slot1 7 slot2 10)
                  (d isa sub-test slot1 12 slot2 b))
(A B C D)

5> (find-matching-chunks (define-chunk-spec isa test))
(B A D C)

6> (find-matching-chunks (define-chunk-spec isa chunk) :chunks '(a b c d))
NIL

7> (find-matching-chunks (define-chunk-spec isa test >= slot1 6) :chunks '(a b c))
(C B)

E> (find-matching-chunks 'not-a-chunk-spec)
#|Warning: NOT-A-CHUNK-SPEC is not a valid chunk-spec in call to find-matching-chunks. |#
NIL

E> (find-matching-chunks (define-chunk-spec isa chunk) :chunks '(bad-name1 free))
#|Warning: BAD-NAME2 does not name a chunk in call to match-chunk-spec-p. |#
(FREE)

E> (find-matching-chunks (define-chunk-spec isa chunk) :chunks 'not-a-list)
#|Warning: NOT-A-LIST isa not a valid value for the :chunks keyword parameter to find-
matching-chunks. |#
NIL

E> (find-matching-chunks (define-chunk-spec isa chunk))
#|Warning: Find-matching-chunks called with no current model. |#
NIL
```

chunk-spec-chunk-type

Syntax:

chunk-spec-chunk-type *chunk-spec* -> [chunk-type | **nil**]

Arguments and Values:

chunk-spec ::= a valid chunk-spec
chunk-type ::= a symbol which names a chunk-type in the current model

Description:

The chunk-spec-chunk-type command is used to get the name of the chunk-type out of a chunk-spec i.e. the isa constraint.

If chunk-spec is not a valid chunk-spec then a warning is printed and **nil** is returned.

Examples:

```
> (chunk-spec-chunk-type (define-chunk-spec isa chunk))
CHUNK

> (chunk-spec-chunk-type (define-chunk-spec isa visual-location))
VISUAL-LOCATION
```

```
E> (chunk-spec-chunk-type 'not-a-chunk-spec)
#|Warning: chunk-spec-chunk-type called with a non-chunk-spec |#
NIL
```

chunk-spec-slots

Syntax:

chunk-spec-slots *chunk-spec* -> (slot*)

Arguments and Values:

chunk-spec ::= a valid chunk-spec
slot ::= a symbol which names a slot or request parameter specified in chunk-spec

Description:

The chunk-spec-slots command returns a list of the names of the slots and request parameters that are used in the provided chunk-spec. Each slot will occur only once in the return list no matter how many times it may be tested in chunk-spec, and the list is in no particular order.

If chunk-spec is not a valid chunk-spec then a warning is displayed and **nil** is returned.

Examples:

```
> (chunk-spec-slots (define-chunk-spec isa chunk))
NIL

> (chunk-spec-slots (define-chunk-spec isa press-key key "x"))
(KEY)

> (chunk-spec-slots (define-chunk-spec isa visual-location > screen-x 10 < screen-x 20
:attended nil))
(SCREEN-X :ATTENDED)

E> (chunk-spec-slots 'not-a-chunk-spec)
#|Warning: chunk-spec-slots called with something other than a chunk-spec |#
NIL
```

slot-in-chunk-spec-p

Syntax:

chunk-spec-slots *chunk-spec slot* -> result

Arguments and Values:

chunk-spec ::= a valid chunk-spec
slot ::= a symbol which names a slot or request parameter
result ::= a generalized boolean indicating whether slot was found in chunk-spec

Description:

The slot-in-chunk-spec-p command tests whether the given slot occurs in a condition of the chunk-spec specified. It returns true if that slot is specified in chunk-spec or **nil** if it is not.

If chunk-spec is not a valid chunk-spec then a warning is printed and **nil** is returned.

Examples:

```
> (slot-in-chunk-spec-p (define-chunk-spec isa chunk) 'slot)
NIL

> (slot-in-chunk-spec-p (define-chunk-spec isa visual-location - screen-x 10) 'screen-x)
SCREEN-X

> (slot-in-chunk-spec-p (define-chunk-spec isa visual-location :attended nil) :attended)
:ATTENDED

> (slot-in-chunk-spec-p (define-chunk-spec isa visual-location - screen-x 10) 'screen-y)
NIL

E> (slot-in-chunk-spec-p 'not-a-chunk-spec 'slot)
#|Warning: slot-in-chunk-spec-p called with something other than a chunk-spec |#
NIL
```

chunk-spec-slot-spec

Syntax:

chunk-spec-slot-spec *chunk-spec {slot}* -> (spec-list*)

Arguments and Values:

chunk-spec ::= a valid chunk-spec
slot ::= [slot-name | **nil**]
slot-name ::= a symbol which names a slot or request parameter specified in chunk-spec
spec-list ::= (modifier slot-name value)
modifier ::= [**=** | **-** | **<** | **>** | **<=** | **>=**]
value ::= any Lisp value

Description:

The chunk-spec-slot-spec command is used to extract the slot specifications from a chunk-spec. It returns a list of specification lists. A specification list is a list of three elements. The first item in a specification list is a modifier for the constraint, the second element is the slot to be tested, and the third element is the value for the test. If no slot is specified, then a specification list is returned for each constraint in the chunk-spec and the specification lists will be in the same order as the constraints were provided when the chunk-spec was defined.

If a slot is specified, then only the specification lists which reference that slot are returned, again in the order that they were provided when the chunk-spec was defined. Note that if a slot is specified

for chunk-spec-slot-spec and there are no constraints in the chunk-spec which use that slot then a warning will be printed and **nil** will be returned. Thus, before using chunk-spec-slot-spec for a specific slot, one may want to first test the slot with slot-in-chunk-spec-p or only use slots returned by chunk-spec-slots.

If chunk-spec is not a valid chunk-spec then a warning is printed and **nil** is returned.

Examples:

```
1> (defvar *test-spec* (define-chunk-spec isa visual-location
                                          < screen-x 10
                                          > screen-x 0
                                          screen-x =var
                                          color blue
                                          - screen-y =var
                                          :attended t))
*TEST-SPEC*

2> (chunk-spec-slot-spec *test-spec*)
((< SCREEN-X 10) (> SCREEN-X 0) (= SCREEN-X =VAR) (= COLOR BLUE) (- SCREEN-Y =VAR)
 (= :ATTENDED T))

3> (chunk-spec-slot-spec *test-spec* 'color)
((= COLOR BLUE))

4> (chunk-spec-slot-spec *test-spec* 'screen-x)
((< SCREEN-X 10) (> SCREEN-X 0) (= SCREEN-X =VAR))

5> (chunk-spec-slot-spec *test-spec* :attended)
((= :ATTENDED T))

6E> (chunk-spec-slot-spec *test-spec* 'size)
#|Warning: Slot SIZE is not specified in the chunk-spec. |#
NIL

E> (chunk-spec-slot-spec 'not-a-chunk-spec 'color)
#|Warning: chunk-spec-slot-spec called with something other than a chunk-spec |#
NIL
```

chunk-spec-variable-p

Syntax:

chunk-spec-variable-p *value* {*var*} -> result

Arguments and Values:

value ::= any Lisp value
var ::= a Lisp character
result ::= a generalized boolean

Description:

The chunk-spec-variable-p command can be used to determine if a value would be considered as a variable in a chunk-spec. If the value is a symbol with a symbol-name longer than one character and

the first character of the symbol-name is var (or **#\=** if var is not specified) then true is returned otherwise **nil** is returned.

This will typically only be needed when explicitly decoding a chunk-spec through the use of chunk-spec-slot-spec.

Examples:

```
> (chunk-spec-variable-p 'value)
NIL

> (chunk-spec-variable-p '=value)
T

> (chunk-spec-variable-p '@value #\@)
T

> (chunk-spec-variable-p '=value #\@)
NIL

> (chunk-spec-variable-p "=value")
NIL

1> (defvar *test-spec* (define-chunk-spec isa visual-location
                                          < screen-x 10
                                          > screen-x 0
                                          screen-x =var
                                          color blue
                                          - screen-y =var
                                          :attended t))
*TEST-SPEC*

2> (dolist (spec (chunk-spec-slot-spec *test-spec*))
     (format t "Slot: ~10s value: ~8S variable?: ~s~%" (second spec) (third spec)
       (chunk-spec-variable-p (third spec))))
Slot: SCREEN-X   value: 10       variable?: NIL
Slot: SCREEN-X   value: 0        variable?: NIL
Slot: SCREEN-X   value: =VAR     variable?: T
Slot: COLOR      value: BLUE     variable?: NIL
Slot: SCREEN-Y   value: =VAR     variable?: T
Slot: :ATTENDED  value: T        variable?: NIL
NIL
```

strip-request-parameters-from-chunk-spec

Syntax:

strip-request-parameters-from-chunk-spec *chunk-spec* -> [result-spec | **nil**]

Arguments and Values:

chunk-spec ::= a valid chunk-spec
result-spec ::= a chunk-spec which has no request parameters in it

Description:

The strip-request-parameters-from-chunk-spec command can be used to convert a general chunk-spec into one which has all of the same conditions for the slots but which does not have any request parameters from the original. There are likely very few circumstances where one would need to do this, but just in case this function is available.

If chunk-spec is a valid chunk-spec then this command returns a new chunk-spec which has the same slot conditions as chunk-spec but none of the request parameters it may have. If chunk-spec is not a valid chunk-spec then a warning is printed and **nil** is returned.

Examples:

```
1> (defvar *test-spec* (define-chunk-spec isa visual-location
                                          < screen-x 10
                                          > screen-x 0
                                          screen-x =var
                                          color blue
                                          - screen-y =var
                                          :attended t))
*TEST-SPEC*

2> (pprint-chunk-spec *test-spec*)
    ISA VISUAL-LOCATION
 <  SCREEN-X 10
 >  SCREEN-X 0
    SCREEN-X =VAR
    COLOR BLUE
 -  SCREEN-Y =VAR
    :ATTENDED T
NIL

3> (pprint-chunk-spec (strip-request-parameters-from-chunk-spec *test-spec*))
    ISA VISUAL-LOCATION
 <  SCREEN-X 10
 >  SCREEN-X 0
    SCREEN-X =VAR
    COLOR BLUE
 -  SCREEN-Y =VAR
NIL

E> (strip-request-parameters-from-chunk-spec 'not-a-chunk-spec)
#|Warning: strip-request-parameters-from-chunk-spec called with something other than a
chunk-spec. |#
NIL
```

chunk-spec-to-chunk-def

Syntax:

chunk-spec-to-chunk-def *chunk-spec* -> [chunk-def | **nil**]

Arguments and Values:

chunk-spec ::= a valid chunk-spec
chunk-def ::= a chunk definition list which is valid for passing to define-chunks

Description:

The chunk-spec-to-chunk-def command can be used to convert a chunk-spec into a list which can be passed to define-chunks for creating a chunk. To be able to create such a chunk specification the chunk-spec must meet the following conditions:

- It must not have any request parameters
- It must only specify each slot at most once
- It must not have any slot modifiers other than =
- There must not be any variables in the conditions

This command is used by modules like goal and imaginal which create new chunks based on requests.

If chunk-spec is a valid chunk-spec and meets the criteria necessary then this command returns a list which contains a definition for a chunk based on the conditions in the chunk-spec. If chunk-spec is not a valid chunk-spec then a warning is printed and **nil** is returned.

Examples:

```
> (chunk-spec-to-chunk-def (define-chunk-spec isa chunk))
(ISA CHUNK)

1> (define-chunks-fct
     (list (chunk-spec-to-chunk-def (define-chunk-spec isa visual-location screen-x 10))))
(VISUAL-LOCATION7)

2> (pprint-chunks visual-location7)
VISUAL-LOCATION7
  ISA VISUAL-LOCATION
   SCREEN-X  10
   SCREEN-Y  NIL
   DISTANCE  NIL
   KIND  NIL
   COLOR  NIL
   VALUE  NIL
   HEIGHT  NIL
   WIDTH  NIL
   SIZE  NIL

(VISUAL-LOCATION7)

E> (chunk-spec-to-chunk-def 'not-a-spec)
#|Warning: chunk-spec-to-chunk-def called with something other than a chunk-spec. |#
NIL

E> (chunk-spec-to-chunk-def (define-chunk-spec isa visual-location - screen-x 10))
#|Warning: A chunk creation request may only use the = modifier. |#
NIL

E> (chunk-spec-to-chunk-def (define-chunk-spec isa visual-location :attended nil))
#|Warning: A chunk creation request may not have request parameters. |#
NIL

E> (chunk-spec-to-chunk-def (define-chunk-spec isa visual-location size 10 size 20))
#|Warning: A chunk creation request can only specify a slot once. |#
NIL
```

```
E> (chunk-spec-to-chunk-def (define-chunk-spec isa visual-location size =var))
#|Warning: A chunk creation request may not have variables in the slots. |#
NIL
```

Using Buffers

In the earlier section on buffers their role in the system was described and the commands that allow a user to inspect and query the buffers were presented. This section is going to provide the commands that allow one to use the buffer as will be necessary to create new modules and to interact with existing modules directly.

There are several things which one can do with a buffer. They are: read the chunk that it holds, test if the buffer is empty, request the state of the buffer's module, request an action of the buffer's module (either a request that it update the buffer or that it modify the chunk currently in the buffer), modify the chunk in the buffer, clear the chunk from the buffer, or place a new chunk into the buffer. The commands for performing those actions will be detailed below. Creation of buffers is not described in this section because buffers are only created when modules are defined – buffers only exist in conjunction with a module. Thus buffer creation will be described in the section on defining modules.

Any buffer may be accessed for any of the operations at any time. With the provided modules, only the procedural module accesses buffers of other modules, but there is nothing that prevents other module-to-module communication. Modules accept the requests sent to them regardless of how they are created. One warning however is that most modules only accept one request at a time and the procedural module's requests from the productions are delayed relative to their testing of a module's state i.e. a production queries the module to determine if it is free to accept requests but does not send a request until 50ms later (by default). So, if you plan on using the buffers for requests between modules you may want to take care in how the productions in any models which operate in that situation also issue requests.

Also, while it is possible to write to any buffer at any time, generally only the owning module should be storing chunks into its buffer. Often the module responds to a request by placing a chunk into the buffer, and thus if one were to arbitrarily write a chunk into the buffer while it was processing a request it could confuse the module which made that request and was expecting a particular result. Again, the procedural module's productions are typically the primary source of requests and also usually written to expect a result consistent with the request. Thus, if you write a module or other code which modifies buffers explicitly care must be taken when using that with a normal model's production processing.

For most of these commands there are two versions. One which makes an immediate action and one which schedules the action to occur as an event. In general, the scheduled versions of the requests and modifications are preferable to the non-scheduled ones because they will then be recorded in the trace and thus be detectable by other things and also be ordered appropriately. However, sometimes it may be necessary to use the immediate version, and in particular, the reading and testing functions often need to be done immediately because the result is what is important.

In addition to the commands for using the buffers, there are also some additional command described below for accessing other buffer information. The first allows one to find the name of the buffer's owning module. This may be useful when implementing tracing tools or other event monitoring utilities which might have access to only the buffer names. The other allows one to find the value of the buffer's activation spread parameter without knowing what the name of the parameter the module has made available for that purpose. That may be useful when developing alternative equations for the spreading activation calculation or for creating tools for monitoring and tracking the activation calculations.

Commands

buffer-read

Syntax:

buffer-read *buffer* -> [chunk-name | **nil**]
schedule-buffer-read *buffer time-delta* {**:module** *module*} {**:priority** *priority*} {**:output** *output*} -> [event | **nil**]
buffer-read-report *buffer* {**:module** *module*} -> [chunk-name | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-name ::= a symbol that names the chunk which is in the buffer
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The buffer-read commands are used to read the name of the chunk which is currently in the named buffer of the current model.

For buffer-read, the name of the chunk is returned directly. If the buffer is empty the return value is **nil.** If the buffer named is invalid or there is no current model then a warning is printed and **nil** is returned.

Schedule-buffer-read is used to record a buffer reference in the trace of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'buffer-read-action
                         :module module
                         :priority priority
                         :params (list buffer)
                         :output output)
```

The default values for the parameters are **:none** for module, 0 for priority, and **t** for output if not provided. The buffer-read-action function essentially does nothing and is only there to record a reference for the trace. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Buffer-read-report is used to read a buffer's chunk and have a record of the buffer-read recorded in the trace of the model. It is essentially a combination of buffer-read and schedule-buffer-read. It schedules an event to occur as if the following were executed:

```
(schedule-event-relative time-delta 'buffer-read-action
                         :module module
                         :priority :max
                         :params (list buffer-name)
                         :output t)
```

The name of the chunk currently in the named buffer is returned. If the buffer is empty then **nil** is returned. If the buffer named is invalid or there is no current model then a warning is printed and **nil** is returned.

Examples:

This example assumes that the model starts with no chunk in the goal and buffer and has the :trace-detail parameter set to **high**.

```
1> (buffer-read 'goal)
NIL

2> (goal-focus free)
FREE

3> (run .1)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FREE REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   ------                Stopped because no events left to process
0.0
3
NIL

4> (buffer-read 'goal)
FREE-0

5> (schedule-buffer-read 'goal .2)
#S(ACT-R-EVENT ...)

6> (mp-show-queue)
Events in the queue:
     0.200   NONE                  BUFFER-READ-ACTION GOAL
     0.200   PROCEDURAL            CONFLICT-RESOLUTION
2

7> (run .2)
     0.200   NONE                  BUFFER-READ-ACTION GOAL
     0.200   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   ------                Stopped because time limit reached
0.2
2
```

```
NIL

8> (buffer-read-report 'goal :module 'test-module)
FREE-0

9> (mp-show-queue)
Events in the queue:
     0.200   TEST-MODULE            BUFFER-READ-ACTION GOAL
     0.200   PROCEDURAL             CONFLICT-RESOLUTION
2

E> (buffer-read 'bad-name)
#|Warning: Buffer-read called with an invalid buffer name BAD-NAME |#
NIL

E> (schedule-buffer-read 'bad-name .1)
#|Warning: schedule-buffer-read called with an invalid buffer name BAD-NAME |#
NIL

E> (schedule-buffer-read 'goal 'bad-time)
#|Warning: schedule-buffer-read called with a non-number time-delta: BAD-TIME |#
NIL

E> (schedule-buffer-read 'goal '.1 :priority 'bad)
#|Warning: schedule-buffer-read called with an invalid priority BAD |#
NIL

E> (buffer-read-report 'bad-name)
#|Warning: buffer-read-report called with an invalid buffer name BAD-NAME |#
NIL

E> (buffer-read 'goal)
#|Warning: buffer-read called with no current model. |#
NIL
```

query-buffer

Syntax:

query-buffer *buffer query-list* -> [**t** | **nil**]
schedule-query-buffer *buffer query-list time-delta* {**:module** *module*} {**:priority** *priority*}
{**:output** *output*} -> [event | **nil**]
query-buffer-report *buffer query-list* {**:module** *module*} -> [**t** | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
query-list ::= (<query value>*)
query ::= a symbol which names a query to test
value ::= a Lisp value to test for with the associated query
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The query-buffer commands are used to query the state of the buffer and its module in the current model.

For query-buffer each of the queries specified is tested from left to right and if they all return true then query-buffer returns **t**. If any query fails, then **nil** is returned without making any more queries. If the buffer named is invalid, any of the queries are not valid for the buffer or module, or there is no current model then a warning is printed and **nil** is returned.

Schedule-query-buffer is used to record buffer querying in the trace of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'query-buffer-action
                         :module module
                         :priority priority
                         :params (list buffer query-list)
                         :output output
                         :details (format nil "query-buffer-action ~a" buffer))
```

The default values for the parameters are **:none** for module, 0 for priority, and **t** for output if not provided. The query-buffer-action function essentially does nothing and is only there to record a reference for the trace. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Query-buffer-report is used to query the buffer and have a record of the querying recorded in the trace of the model. It is essentially a combination of query-buffer and schedule-query-buffer. It schedules an event to occur as if the following were executed:

```
(schedule-event-relative time-delta 'query-buffer-action
                         :module module
                         :priority :max
                         :params (list buffer query-list)
                         :output t
                         :details (format nil "query-buffer-action ~a" buffer))
```

The result of performing the queries is returned in the same way that it is for query-buffer. If the buffer named is invalid, any of the queries are invalid for the buffer, or there is no current model then a warning is printed and **nil** is returned.

Examples:

This example assumes that the model starts with no chunk in the goal and buffer and has the :trace-detail parameter set to **high**.

```
> (query-buffer 'goal '((state . free)))
T

> (query-buffer 'goal '((state . busy)))
NIL
```

```
> (query-buffer 'goal '((buffer . empty) (state . free)))
T

> (query-buffer 'goal nil)
T

1> (schedule-query-buffer 'goal '((buffer . empty)) .1 )
#S(ACT-R-EVENT ...)

2> (mp-show-queue)
Events in the queue:
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.100   NONE                   QUERY-BUFFER-ACTION GOAL
2

3>
 (run .1)
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.100   NONE                   QUERY-BUFFER-ACTION GOAL
     0.100   PROCEDURAL             CONFLICT-RESOLUTION
     0.100   ------                 Stopped because time limit reached
0.1
3
NIL

4> (query-buffer-report 'goal '((buffer . full) (state . free)) :module 'test-name)
NIL

5> (mp-show-queue)
Events in the queue:
     0.100   TEST-NAME              QUERY-BUFFER-ACTION GOAL
     0.100   PROCEDURAL             CONFLICT-RESOLUTION
2

6> (run .1)
     0.100   TEST-NAME              QUERY-BUFFER-ACTION GOAL
     0.100   PROCEDURAL             CONFLICT-RESOLUTION
     0.100   ------                 Stopped because no events left to process
0.0
2
NIL

E> (query-buffer 'bad-name nil)
#|Warning: query-buffer called with an invalid buffer name BAD-NAME |#
NIL

E> (query-buffer 'goal '((bad-query . t)))
#|Warning: Invalid query-buffer ((BAD-QUERY . T)).  Available queries to buffer GOAL are
(STATE BUFFER ERROR). |#
NIL

E> (schedule-query-buffer 'bad-name nil .1)
#|Warning: schedule-query-buffer called with an invalid buffer name BAD-NAME |#
NIL

E> (schedule-query-buffer 'goal nil 'bad-time)
#|Warning: schedule-query-buffer called with non-nimber time-delta: BAD-TIME |#
NIL

E> (schedule-query-buffer 'goal nil .1 :priority 'bad-priority)
#|Warning: schedule-query-buffer called with an invalid priority BAD-PRIORITY |#
NIL

E> (query-buffer-report 'bad-name '((state . free)))
#|Warning: query-buffer-report called with an invalid buffer name BAD-NAME |#
NIL
```

```
E> (query-buffer 'goal '((state . free)))
#|Warning: query-buffer called with no current model. |#
NIL
```

clear-buffer

Syntax:

clear-buffer *buffer* -> [chunk-name | **nil**]
schedule-clear-buffer *buffer time-delta* {**:module** *module*} {**:priority** *priority*} {**:output** *output*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-name ::= a symbol that names the chunk which is in the buffer
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The clear-buffer commands are used to clear any chunk which may be in a buffer which will leave the buffer empty. Any module which is monitoring for buffer clearing will be notified that the chunk has been cleared – in particular the declarative module will merge the cleared chunk into the model's declarative memory.

For clear-buffer, the buffer is cleared immediately and the name of the chunk which is in the buffer currently is returned. If the buffer is empty the return value is **nil.** If the buffer named is invalid or there is no current model then a warning is printed and **nil** is returned.

Schedule-clear-buffer is used to schedule the clearing of the buffer such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'clear-buffer
                         :module module
                         :priority priority
                         :params (list buffer)
                         :output output)
```

The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Examples:

This example assumes that the model starts with no chunk in the goal buffer.

```
1> (clear-buffer 'goal)
NIL

2> (goal-focus free)
FREE

3> (run 1)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FREE REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.000   ------                Stopped because no events left to process
0.0
3
NIL

4> (clear-buffer 'goal)
FREE-0

5> (buffer-read 'goal)
NIL

6> (goal-focus free)
FREE

7> (schedule-clear-buffer 'goal .2 :module 'test-name )
#S(ACT-R-EVENT ...)

8> (run 1)
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL FREE REQUESTED NIL
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   TEST-NAME             CLEAR-BUFFER GOAL
     0.200   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   ------                Stopped because no events left to process
0.2
5
NIL

9> (buffer-read 'goal)
NIL

E> (clear-buffer 'bad-name)
#|Warning: clear-buffer called with an invalid buffer name BAD-NAME |#
NIL

E> (clear-buffer 'goal)
#|Warning: clear-buffer called with no current model. |#
NIL

E> (schedule-clear-buffer 'bad-name .1)
#|Warning: schedule-clear-buffer called with an invalid buffer name BAD-NAME |#
NIL

E> (schedule-clear-buffer 'goal 'bad-time)
#|Warning: schedule-clear-buffer called with a non-number time-delta: BAD-TIME |#
NIL

E> (schedule-clear-buffer 'goal .2 :priority 'bad)
#|Warning: schedule-clear-buffer called with an invalid priority BAD |#
```

set-buffer-chunk

Syntax:

set-buffer-chunk *buffer chunk-name* {**:requested** *requested*}-> [new-chunk-name | **nil**]
schedule-set-buffer-chunk *buffer time-delta* {**:module** *module*} {**:priority** *priority*}
{**:output** *output*} {**:requested** *requested*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-name ::= a symbol which should name a chunk
new-chunk-name ::= a symbol which will name a new chunk
requested ::= a generalized boolean
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The set-buffer-chunk commands are used to copy a chunk into a buffer. It will always make a copy of the chunk specified, and then place that copy into the buffer. Before it places the new chunk into the buffer, it will first clear the buffer. Thus, any chunk which may be there will be cleared as described for the clear-buffer command. The buffer clearing is not scheduled, thus there will not be an event in the trace to indicate explicitly that the buffer was cleared.

For set-buffer-chunk, the buffer is cleared and then set immediately and the name of the copy of the chunk which is placed into the buffer is returned. If either the buffer or chunk named is invalid or there is no current model then a warning is printed and **nil** is returned.

The requested keyword parameter specifies whether the buffer will indicate that the chunk was requested or not. If requested is specified as **t** (which is the default) or any other true value, then the setting of the chunk is to be interpreted as being the result of a request to a module and the query of that buffer for "buffer requested" will be true. If the requested keyword parameter is specified as **nil**, which should be done when the setting of the chunk is not the result of a module request, then the "buffer requested" query for the buffer will be **nil** and the "buffer unrequested" query will be true. An example of when the requested value should be **nil** is the buffer stuffing which the visual-location buffer performs when there is a screen change. That does not happen because of an explicit request to the module, and thus if a chunk is placed into the buffer it should be marked accordingly.

Schedule-set-buffer-chunk is used to schedule the setting of the buffer such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'set-buffer-chunk
                         :module module
                         :priority priority
                         :params (list buffer chunk-name :requested requested)
                         :output output)
```

The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Examples:

```
1> (define-chunks (a isa chunk) (b isa color) (c isa text))
(a b c)

2> (dm)
nil

3> (set-buffer-chunk 'goal 'a)
a-0

4> (buffer-chunk goal)
goal: a-0 [a]
a-0
  ISA chunk

(a-0)

5> (dm)
nil

6> (schedule-set-buffer-chunk 'goal 'b 0.1)
#S(act-r-event ...)

7> (dm)
nil

8> (run 1.0)
     0.000   procedural             conflict-resolution
     0.100   none                   set-buffer-chunk goal b
     0.100   procedural             conflict-resolution
     0.100   ------                 Stopped because no events left to process
0.1
3
nil

9> (dm)
a-0
  ISA chunk

(a-0)

10> (buffer-chunk goal)
goal: b-0 [b]
b-0
  ISA color

(b-0)

11> (schedule-set-buffer-chunk 'goal 'c 0.05 :requested nil)
#S(act-r-event ...)

12> (run 1.0)
     0.150   none                   set-buffer-chunk goal c requested nil
     0.150   procedural             conflict-resolution
     0.150   ------                 Stopped because no events left to process
0.05
2
```

```
nil

13> (buffer-chunk goal)
goal: c-0 [c]
c-0
  ISA text
   screen-pos  nil
   value  nil
   status  nil
   color  nil
   height  nil
   width  nil

(c-0)

14> (dm)
b-0
  ISA color

a-0
  ISA chunk

(b-0 a-0)

15> (query-buffer 'goal '((buffer . requested)))
nil

E> (set-buffer-chunk 'bad-buffer 'green)
#|Warning: set-buffer-chunk called with an invalid buffer name bad-buffer |#
nil

E> (set-buffer-chunk 'goal 'bad-chunk)
#|Warning: set-buffer-chunk called with an invalid chunk name bad-chunk |#
nil

E> (schedule-set-buffer-chunk 'goal 'blue 'bad)
#|Warning: schedule-set-buffer-chunk called with time-delta that is not a number: bad |#
nil

E> (schedule-set-buffer-chunk 'goal 'free 0 :priority 'bad)
#|Warning: schedule-set-buffer-chunk called with an invalid priority bad |#
nil

E> (schedule-set-buffer-chunk 'goal 'free 0)
#|Warning: set-buffer-chunk called with no current model. |#
nil
```

overwrite-buffer-chunk

Syntax:

overwrite-buffer-chunk *buffer chunk-name* {**:requested** *requested*} -> [new-chunk-name | **nil**]
schedule-overwrite-buffer-chunk *buffer time-delta* {**:module** *module*} {**:priority** *priority*}
{**:output** *output*} {**:requested** *requested*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-name ::= a symbol which should name a chunk
requested ::= a generalized boolean

new-chunk-name ::= a symbol which will name a new chunk
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The overwrite-buffer-chunk commands are used to copy a chunk into a buffer like set-buffer-chunk. It will always make a copy of the chunk specified, and then place that copy into the buffer. The difference between overwrite-buffer-chunk and set-buffer-chunk is that the overwrite operation does not clear the buffer first. Thus, if there is a chunk in the buffer when the overwrite-buffer-chunk command is issued there will be no clearing of that chunk and no modules will be notified that it has been cleared. One specific consequence of that is that the previous chunk in the buffer, if there was one, will not be collected by the declarative module and added to the model's declarative memory.

Typically, one will use set-buffer-chunk when building a module or otherwise working with the buffers. However, there are rare situations where the model or a module may want to destructively erase a chunk which is in a buffer with this command.

The requested keyword parameter specifies whether the buffer will indicate that the chunk was requested or not. If requested is specified as **t** or any other true value, then the setting of the chunk is to be interpreted as being the result of a request to a module and the query of that buffer for "buffer requested" will be true. If the requested keyword parameter is specified as **nil** (which is the default value), which should be done when the setting of the chunk is not the result of a module request, then the "buffer requested" query for the buffer will be **nil** and the "buffer unrequested" query will be true.

For overwrite-buffer-chunk, the buffer is set immediately to hold the newly copied chunk and the name of the copy of the chunk which is placed into the buffer is returned. If either the buffer or chunk named is invalid or there is no current model then a warning is printed and **nil** is returned.

Schedule-overwrite-buffer-chunk is used to schedule the setting of the buffer such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'overwrite-buffer-chunk
                         :module module
                         :priority priority
                         :params (list buffer chunk-name :requested requested)
                         :output output)
```

The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Examples:

```
1> (define-chunks (a isa chunk) (b isa color))
(a b)

2> (buffer-chunk goal)
goal: nil
(nil)

3> (overwrite-buffer-chunk 'goal 'a)
a-0

4> (buffer-chunk goal)
goal: a-0 [a]
a-0
  ISA chunk

(a-0)

5> (dm)
nil

6> (buffer-status goal)
goal:
  buffer empty          : nil
  buffer full           : t
  buffer requested      : nil
  buffer unrequested    : t
  state free            : t
  state busy            : nil
  state error           : nil
(goal)

7> (schedule-overwrite-buffer-chunk 'goal 'b .05 :requested t)
#S(act-r-event ...)

8> (run 1.0)
     0.000   procedural             conflict-resolution
     0.050   none                   overwrite-buffer-chunk goal b requested t
     0.050   procedural             conflict-resolution
     0.050   ------                 Stopped because no events left to process
0.05
3
nil

9> (dm)
nil

10> (buffer-chunk goal)
goal: b-0 [b]
b-0
  ISA color

(b-0)

11> (buffer-status goal)
goal:
  buffer empty          : nil
  buffer full           : t
  buffer requested      : t
  buffer unrequested    : nil
  state free            : t
  state busy            : nil
  state error           : nil
(goal)
```

```
E> (overwrite-buffer-chunk 'bad-name 'a)
#|Warning: overwrite-buffer-chunk called with an invalid buffer name bad-name |#
nil

E> (overwrite-buffer-chunk 'goal 'bad-chunk)
#|Warning: overwrite-buffer-chunk called with an invalid chunk name bad-chunk |#
nil

E> (schedule-overwrite-buffer-chunk 'goal 'a 'bad)
#|Warning: schedule-overwrite-buffer-chunk called with a non-number time-delta: bad |#
nil

E> (schedule-overwrite-buffer-chunk 'goal 'a 0.5 :priority 'bad)
#|Warning: schedule-overwrite-buffer-chunk called with an invalid priority bad |#
nil

E> (overwrite-buffer-chunk 'goal 'b)
#|Warning: overwrite-buffer-chunk called with no current model. |#
nil
```

mod-buffer-chunk

Syntax:

mod-buffer-chunk *buffer* **(**{*slot-name slot-value* }***)** -> [chunk-name | **nil**]
schedule-mod-buffer-chunk *buffer* **(**{*slot-name slot-value* }***)** *time-delta* {**:module** *module*} {**:priority** *priority*}
{**:output** *output*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-name ::= a symbol which will be the name of the chunk in the buffer named
slot-name ::= a symbol that should be the name of a slot of the chunk in the named buffer
slot-value ::= a Lisp value to set for the corresponding slot-name of the chunk in the named buffer
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The mod-buffer-chunk commands are used to make modifications to the chunk which is in a buffer. It works the same as the mod-chunk command except instead of providing the name of the chunk a buffer is named and the chunk which is in that buffer is modified.

If there is a chunk in the buffer which is named, and there are an even number of items specified in the list of modifications to make i.e. the slot-name and slot-values in the list provided pair up, then those items are considered pair-wise to be the name of a slot in that chunk and a new value for that slot.

Each slot name may only be specified once in the set of slot-names. If any slot-value is a symbol and not the name of a chunk in the current model then it is created as a new chunk of chunk-type chunk and a warning is displayed.

For mod-buffer-chunk, if there is not a chunk in the named buffer, there is no current model, there are an odd number of items provided in the modifications list, or any of the slot names are invalid or duplicated then a warning is displayed, no changes are made, and **nil** is returned.

If there is a chunk in the buffer and the modifications are valid, then the chunk is modified and the name of that chunk is returned.

Schedule-mod-buffer-chunk is used to schedule the modifications to the chunk in the buffer such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'mod-buffer-chunk
                         :module module
                         :priority priority
                         :params (list buffer modifications)
                         :output output)
```

Where modifications is the list of slot-name and slot-values provided. The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled.

Examples:

```
1> (define-chunks (a isa visual-location screen-x 10))
(a)

2> (set-buffer-chunk 'imaginal 'a)
a-0

3> (buffer-chunk imaginal)
imaginal: a-0 [a]
a-0
  ISA visual-location
   screen-x  10
   screen-y  nil
   distance  nil
   kind  nil
   color  nil
   value  nil
   height  nil
   width  nil
   size  nil

(a-0)

4> (mod-buffer-chunk 'imaginal '(screen-y 20 color blue))
a-0

5> (buffer-chunk imaginal)
imaginal: a-0
```

```
a-0
  ISA visual-location
   screen-x  10
   screen-y  20
   distance  nil
   kind  nil
   color  blue
   value  nil
   height  nil
   width  nil
   size  nil

(a-0)

6> (schedule-mod-buffer-chunk 'imaginal '(value text) 0)
#S(act-r-event ...)

7> (run 1)
     0.000   none                    MOD-BUFFER-CHUNK IMAGINAL
     0.000   procedural              conflict-resolution
     0.000   ------                  Stopped because no events left to process
0.0
2
nil

8> (buffer-chunk imaginal)
imaginal: a-0
a-0
  ISA visual-location
   screen-x  10
   screen-y  20
   distance  nil
   kind  nil
   color  blue
   value  text
   height  nil
   width  nil
   size  nil

(a-0)

E> (mod-buffer-chunk 'bad-name '(screen-x 10))
#|Warning: mod-buffer-chunk called with an invalid buffer name bad-name |#
nil

E> (mod-buffer-chunk 'imaginal '(bad-slot 20))
#|Warning: mod-buffer-chunk called with an invalid modification (bad-slot 20) |#
nil

E> (mod-buffer-chunk 'imaginal '(slot-only))
#|Warning: mod-buffer-chunk called with an invalid modification (slot-only) |#
nil

E> (mod-buffer-chunk 'imaginal '(screen-x 1 screen-x 2))
#|Warning: mod-buffer-chunk called with an invalid modification (screen-x 1 screen-x 2) |#
nil

E> (schedule-mod-buffer-chunk 'imaginal '(screen-x 20) 'bad)
#|Warning: schedule-mod-buffer-chunk called with non-number time-delta: bad |#
nil

E> (schedule-mod-buffer-chunk 'imaginal '(screen-x 20) 0 :priority 'bad)
#|Warning: schedule-mod-buffer-chunk called with an invalid priority bad |#
nil

E> (mod-buffer-chunk 'imaginal '(screen-x 20))
#|Warning: mod-buffer-chunk called with no current model. |#
```

nil

module-request

Syntax:

module-request *buffer chunk-spec* -> [**t** | **nil**]
schedule-module-request *buffer chunk-spec time-delta* {**:module** *module*} {**:priority** *priority*}
{**:output** *output*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
chunk-spec ::= an ACT-R chunk-spec
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The module-request commands are used to send a request to a module through its buffer. This is the only recommended way to interact with a module to make requests.

If the buffer name is valid and a chunk-spec is provided, then that chunk-spec will be sent to the buffer's module as a request. Note that the command does not implicitly clear the buffer as occurs for requests from the productions of a model. If the buffer should be cleared that must be done explicitly in conjunction with the request.

For module-request, if the buffer name and chunk-spec are valid and the named buffer's module accepts requests then a value of **t** is returned. If the buffer name is invalid, an invalid chunk-spec is provided, or the buffer's module does not accept requests then a warning is displayed and **nil** is returned.

There is no test performed by module-request to determine if the valid chunk-spec provided is acceptable to the module prior to sending it. All processing of that nature is done by the module once it has received the request.

When using module-request, even though the request itself is not scheduled the actions performed by the module in response to the request should be (at least if the module is written according to the recommended guidelines). Thus, it is likely that no changes will occur until the model is run.

It is recommended that all requests be scheduled using schedule-module-request.

Schedule-module-request is used to schedule the sending of the request to the buffer's module such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'module-request
                         :module module
                         :priority priority
                         :params (list buffer chunk-spec)
                         :output output)
```

The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled. Note that for schedule-module-request the test whether the module accepts requests is not performed until the event occurs. Thus the warning will not occur until during the model run.

Examples:

Note that these examples assume that there is a module called dummy with a buffer called dummy which does not accept requests.

```
1> (module-request 'goal (define-chunk-spec isa chunk))
T

2> (buffer-chunk goal)
goal: nil
(nil)

3> (run 1)
     0.000   goal                    set-buffer-chunk goal chunk0
     0.000   procedural              conflict-resolution
     0.000   ------                  Stopped because no events left to process
0.0
4
nil

4> (buffer-chunk goal)
goal: chunk0-0
chunk0-0
  ISA chunk

(chunk0-0)

1> (schedule-module-request 'goal (define-chunk-spec isa chunk) 0 )
#S(act-r-event ...)

2> (run 1)
     0.000   none                    MODULE-REQUEST GOAL
     0.000   goal                    set-buffer-chunk goal chunk1
     0.000   procedural              conflict-resolution
     0.000   ------                  Stopped because no events left to process
0.0
5
nil

E> (module-request 'dummy (define-chunk-spec isa chunk))
#|Warning: Module dummy does not handle requests. |#
nil
```

```
1E> (schedule-module-request 'dummy (define-chunk-spec isa chunk) 0)
#S(act-r-event ...)

2E> (run 1)
     0.000   none                    MODULE-REQUEST DUMMY
#|Warning: Module dummy does not handle requests. |#
     0.000   procedural              conflict-resolution
     0.000   ------                  Stopped because no events left to process
0.0
2
nil

E> (module-request 'bad-buffer (define-chunk-spec isa chunk))
#|Warning: module-request called with an invalid buffer name bad-buffer |#
nil

E> (module-request 'goal 'bad-spec)
#|Warning: module-request called with an invalid chunk-spec bad-spec |#
nil

E> (schedule-module-request 'goal (define-chunk-spec isa chunk) 'bad)
#|Warning: schedule-module-request called with a non-number time-delta: bad |#
nil

E> (schedule-module-request 'goal (define-chunk-spec isa chunk) 0 :priority 'bad)
#|Warning: schedule-module-request called with an invalid priority bad |#
nil

E> (module-request 'goal (define-chunk-spec isa chunk))
#|Warning: define-chunk-spec-fct called with no current model. |#
#|Warning: module-request called with no current model. |#
nil
>
```

module-mod-request

Syntax:

module-mod-request *buffer* **(**{*slot-name slot-value* }***)** {*verify*}-> [**t** | **nil**]
schedule-module-mod-request *buffer* **(**{*slot-name slot-value* }***)** *time-delta* {**:module** *module*}
{**:priority** *priority*} {**:output** *output*} {**:verify** *verify*} -> [event | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
slot-name ::= a symbol that should be the name of a slot of the chunk in the named buffer
slot-value ::= a Lisp value to set for the corresponding slot-name of the chunk in the named buffer
verify ::= a generalized boolean indicating whether or not to test the slot-names
time-delta ::= a number in seconds indicating when to schedule the event
module ::= a symbol which will be used to as the module of the event and in the trace
priority ::= [**:max** | **:min** | priority-val]
priority-val ::= a number indicating the priority to use for the event
output ::= [**t** | **high** | **medium** | **low** | **nil**]
event ::= an ACT-R scheduler event

Description:

The module-mod-request commands are used to send a modification request to a module through its buffer. This is the only recommended way to interact with a module to make modification requests.

For module-mod-request, if the buffer name is valid and either valid is provided as **nil** or the modification list is valid (only specifies slots which exist for the chunk currently in the named buffer), and the named buffer's module accepts requests then a value of **t** is returned. If the buffer name is invalid, an invalid modification list is provided when valid is true (the default if not given), or the buffer's module does not accept modification requests then a warning is displayed and **nil** is returned.

There is no test performed by module-request to determine if the modification list provided is acceptable to the module prior to sending it. All processing of that nature is done by the module once it has received the modification request.

When using module-mod-request, even though the request itself is not scheduled the actions performed by the module in response to the request should be (at least if the module is written according to the recommended guidelines). Thus, it is likely that no changes will occur until the model is run.

It is recommended that all modification requests be scheduled using schedule-module-mod-request.

Schedule-module-mod-request is used to schedule the sending of the modification request to the buffer's module such that it occurs during the running of the model. It schedules an event to occur as if the following was executed:

```
(schedule-event-relative time-delta 'module-mod-request
                         :module module
                         :priority priority
                         :params (list buffer modifications valid)
                         :output output)
```

Where modifications is the list of slot-name and slot-values provided. The default values for the parameters are **:none** for module, 0 for priority, and **low** for output if not provided. It returns the event that is scheduled. If any of the parameters are not valid or there is no current model then a warning is printed, **nil** is returned and nothing is scheduled. Note that for schedule-module-mod-request the test whether the module accepts modification requests is not performed until the event occurs. Thus the warning will not occur until during the model run.

Examples:

```
1> (define-chunks (a isa visual-location))
(a)

2> (set-buffer-chunk 'goal 'a)
a-0

3> (set-buffer-chunk 'retrieval 'a)
a-1
```

```
4> (clear-buffer 'imaginal)
nil

5> (module-mod-request 'goal '(screen-x 10 screen-y 20))
t

6> (buffer-chunk goal)
goal: a-0 [a]
a-0
  ISA visual-location
   screen-x  nil
   screen-y  nil
   distance  nil
   kind  nil
   color  nil
   value  nil
   height  nil
   width  nil
   size  nil

(a-0)

7> (run 1.0)
     0.000   goal                    MOD-BUFFER-CHUNK GOAL
     0.000   procedural              conflict-resolution
     0.000   ------                  Stopped because no events left to process
0.0
2
nil

8> (buffer-chunk goal)
goal: a-0
a-0
  ISA visual-location
   screen-x  10
   screen-y  20
   distance  nil
   kind  nil
   color  nil
   value  nil
   height  nil
   width  nil
   size  nil

(a-0)

9> (schedule-module-mod-request 'goal '(color green) .1)
#S(act-r-event ...)

10> (run 1.0)
     0.100   none                    MODULE-MOD-REQUEST GOAL
     0.100   goal                    MOD-BUFFER-CHUNK GOAL
     0.100   procedural              conflict-resolution
     0.100   ------                  Stopped because no events left to process
0.1
3
nil

11> (buffer-chunk goal)
goal: a-0
a-0
  ISA visual-location
   screen-x  10
   screen-y  20
   distance  nil
   kind  nil
```

```
   color  green
   value  nil
   height  nil
   width  nil
   size  nil

(a-0)

12E> (module-mod-request 'retrieval '(screen-x 10))
#|Warning: Module declarative does not support buffer modification requests. |#
nil

13E> (module-mod-request 'imaginal '(screen-x 10))
#|Warning: module-mod-request called with no chunk in buffer imaginal |#
nil

E> (module-mod-request 'bad nil)
#|Warning: module-mod-request called with an invalid buffer name bad |#
nil

E> (module-mod-request 'goal '(bad-slot 10))
#|Warning: module-mod-request called with an invalid modification (bad-slot 10) |#
nil

E> (module-mod-request 'goal '(color blue color red))
#|Warning: module-mod-request called with an invalid modification (color blue color red)|#
nil

E> (schedule-module-mod-request 'goal '(screen-x 10) 0 :priority 'bad)
#|Warning: schedule-module-mod-request called with an invalid priority bad |#
nil

E> (module-mod-request 'goal '(screen-x 10))
#|Warning: module-mod-request called with no current model. |#
nil
```

buffer-spread

Syntax:

buffer-spread *buffer* -> [spread-value | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
spread-value ::= a number indicating the buffer spreading parameter value for the buffer

Description:

For the spreading activation calculation in declarative memory each buffer has associated with it a value for the amount of activation it can spread. Each module may specify a particular name for that parameter for each buffer which it owns. This command allows one to get the value of that parameter for any buffer without knowing the specific name of the parameter which the module assigned for it.

If the buffer name given is the name of a buffer in the current model, then the value of that buffer's activation spread parameter will be returned. If the buffer name is invalid or there is no current model then a warning will be printed and **nil** will be returned.

This command is not likely to be used by the typical modeler or module developer, but it may be useful when investigating alternative equations for implementing the spreading activation and is used internally by the declarative module.

Examples:

```
1> (sgp :ga 1.5 :imaginal-activation 2.0)
(1.5 2.0)

2> (buffer-spread 'goal)
1.5

3> (buffer-spread 'imaginal)
2.0

4> (buffer-spread 'retrieval)
0

E> (buffer-spread 'bad)
#|Warning: buffer-spread called with an invalid buffer name bad |#
nil

E> (buffer-spread 'goal)
#|Warning: buffer-spread called with no current model. |#
nil
```

buffers-module-name

Syntax:

buffers-module-name *buffer* -> [name | **nil**]

Arguments and Values:

buffer ::= a symbol which should name a buffer
name ::= a symbol which names the module that owns the buffer specified

Description:

The buffers-module-name command can be used to find the name of a module when you know the name of a buffer. If the buffer name given names a valid buffer in the current model then the symbol which is the name of the module which owns that buffer is returned. If the buffer name is not valid or there is no current model then **nil** is returned.

This command will typically be used if one is building general tools for tracing events or otherwise producing code which will be monitoring the model's event stream and need to determine module names from buffer actions.

Examples:

```
> (buffers-module-name 'goal)
goal

> (buffers-module-name 'visual-location)
:vision

E> (buffers-module-name 'bad)
#|Warning: invalid buffer name bad |#
nil

E> (buffers-module-name 'goal)
#|Warning: buffer-instance called with no current model. |#
#|Warning: invalid buffer name goal |#
nil
```

Adding New Parameters to Chunks

Sometimes it may be convenient to associate supporting information with chunks i.e. information which is not appropriate to encode within the chunk using the slots. This is often useful when creating a new module. As noted in the general description of chunks, each chunk has associated with it a set of parameters which can be used to hold such information. This section will describe how to add and use new chunk parameters.

The command to add a new parameter to chunks is called extend-chunks and will be described in detail below. Here the general concepts and support for chunk parameters will be described.

The first thing to note is that extending chunks is a system wide operation. Once the parameter is added all chunks in all models will have such a parameter available. Thus, extending chunks is a one-time operation. It is recommended that chunk parameters be added when there are no models defined and thus no preexisting chunks. If there are chunks defined when a new parameter is added, then an attempt to access that new parameter value in one of those existing chunks will have unpredictable consequences and could result in errors. The recommended way to add a new parameter is to place the extend-chunks call at the top-level in a file that is loaded automatically by ACT-R at initial load time. That will ensure that the functions for setting and accessing the parameter value are compiled with the rest of the code and that there will be no problems or warnings with attempts to redefine that parameter. There is no mechanism provided for removing a chunk parameter once it has been added and redefinition of an existing chunk parameter is not allowed.

Adding a new chunk parameter causes two functions to be created. The first one is the accessor for the parameter, and the other is an update function so that one can use setf with the accessor. Only the accessor is intended for direct use. That accessor function will have the name **chunk-***param* where param is the name of the parameter which was added. Thus, if you were to add a parameter named foo to chunks the accessor for that parameter would be **chunk-foo**. The accessor takes one parameter which should be the name of a chunk in the current model and it will return the current value of that parameter for that chunk. To change the parameter you can use setf in conjunction with the accessor. Thus, assuming one has added a parameter called foo this shows how one could get and set the value of that parameter for a chunk named free:

```
> (chunk-foo 'free)
NIL

> (setf (chunk-foo 'free) 10)
10

> (chunk-foo 'free)
10
```

The accessor function will test that there is a current model and that the chunk name is valid and it will report a warning and return **nil** if there is a problem:

```
E> (chunk-foo 'bad-name)
#|Warning: Chunk BAD-NAME does not exist in attempt to access CHUNK-FOO. |#
NIL

E> (chunk-foo 'free)
#|Warning: get-chunk called with no current model. |#
#|Warning: Chunk FREE does not exist in attempt to access CHUNK-FOO. |#
NIL
```

After adding the parameter, it will be shown when the pprint-chunks-plus command is called and will display the current value just like all of the other chunk parameters which are currently defined:

```
> (pprint-chunks-plus free)
FREE
  ISA CHUNK

  --chunk parameters--
   FOO  10
   FAN-LIST  (FREE)
   ACTIVATION  0
   ...
```

When creating a parameter for the chunks it is also possible to control how that parameter is treated under the following conditions:

- How it is initially set when a chunk is created
- How it is set in the copy when a chunk is copied
- How it is set when two chunks are merged

The details of how to specify those controls when creating a chunk parameter and examples of their use are provided with the details of the extend-chunks command. How they apply to the operation of the system will be described here.

There are two possible ways one can specify the initial value for the parameter. If neither is used, then the initial value for the parameter when a chunk is created will be **nil**. The first option is to specify a default value. The parameter will be set to that value for each new chunk created. The other method for setting the initial value is to provide a function to set the value. If a default value function is provided, then that function will be called to get the initial value for the parameter. The function will be called with one parameter, which will be the name of the chunk in which the default value is being set. The return value of that function call will be the initial setting of that chunk parameter. The parameters for a chunk will be initialized in no particular order, and thus the initialization function should not rely on any other parameters of the chunk having been set. Also, the initialization function will not be called until the first time that the chunk's parameter value is requested. Thus, it may not be called for every chunk and may not be called until well after the initial creation time of the chunk.

When a chunk is copied using the copy-chunks command the settings of the parameters for the new copy are determined as follows. By default, the parameter will be set in the same manner as the initial value for a newly created chunk i.e. either **nil**, the specified default value, or the result of

calling the default value function. However, it is possible to also specify a function to use to set the value for the copy which is different from the function used to set the initial value (if such a function was also provided). There are two options available for setting how the copy gets created. It can be copied based on the value of the current chunk's parameter (the parameter's copy function) or by accessing the current chunk (the parameter's copy from chunk function). Only one of the copying mechanisms will be used. If both are specified then the copy function will be the one that gets used. The parameter's copy function will be passed one value which will be the current value of that parameter for the chunk which is being copied. The parameter's copy from chunk function will be passed one value which will be the name of the chunk which is being copied. In both cases, the return value of that function will be the value set for the parameter in the new copy of the chunk. As with the initialization function, the parameter's copying function is likely to be called very often in the system and should be made reasonably efficient to avoid performance issues. If one wants to have the copied chunk's parameter set the same as the original chunk's parameter specifying the copy function as the Lisp function identity is recommended.

When two chunks are merged using the merge-chunks command (which can happen automatically when the declarative module collects chunks cleared from the buffers) the values of the parameters for the merged chunk after the merging are set by default to the values that existed for the primary chunk (the first one in the call to merge-chunks) prior to the merge. That can be overridden by providing a merge function for the parameter. If a merge function is provided then when two chunks are merged that function will be called with the names of the chunks being merged as its only two parameters. They will be passed to the parameter's merge function in the same order as they were given to merge-chunks. The return value of that function will be the setting of that parameter in the merged chunk.

Commands

extend-chunks

Syntax:

extend-chunks *parameter-name* {**:default-value** *value*} {**:default-function** *def-fn*} {**:copy-function** *copy-fn*} {**:copy-from-chunk-function** *copy-from-fn*} {**:merge-function** *merge-fn*} -> [accessor | **:duplicate-parameter**]

Arguments and Values:

parameter-name ::= a symbol which will be the name of the new parameter for the chunk
value ::= any Lisp value
def-fn ::= a function designator for a function which takes one parameter
copy-fn ::= a function designator for a function which takes one parameter
copy-from-fn ::= a function designator for a function which takes one parameter
merge-fn ::= a function designator for a function which takes two parameters
accessor ::= a symbol which names the accessor function for the new parameter

Description:

The extend-chunks command is used to add a new parameter to chunks. If chunks do not already have a parameter by that name, then an accessor called chunk-*parameter-name* (where *parameter-name* is the parameter-name symbol provided) will be created which takes one parameter which should always be a chunk name. That accessor can be used to get the corresponding parameter of a chunk or used with setf to change the value of that parameter for the chunk.

The initial value for the new parameter when a chunk is created will be **nil** unless either the default-value or default-function keyword parameter is provided. If a default-value is specified then that will be set as the value of the parameter for a newly created chunk. If a default-function is specified, then that function will be called with the name of the chunk as its only parameter and the return value of that function call will be used as the initial value. If both a default-value and default-function are given, then the function will be used.

When a copy of a chunk is being made the parameter value for the new copy of the chunk will be set to the default value as determined above unless either a copy-function or a copy-from-chunk-function is provided. If one of those functions is provided, then the new chunk will have its value set to the value returned from calling that function. The difference between the copying functions is that the copy-function is called with the current parameter value of the chunk which is being copied and the copy-from-chunk-function gets called with the name of the chunk which is being copied.

If a merge-function is provided, then when two chunks are being merged that function will be called with the names of those chunks and the value it returns will be the setting for the parameter in the merged chunk. If no merge-function is given, then the merged chunk will take the value of the parameter from the first of the two chunk names specified in the merging.

If a new parameter is created, then the name of that accessor is returned.

If a parameter by that name already exists, then a warning will be printed and the keyword **:duplicate-parameter** will be returned.

If parameter-name is not a valid symbol or other problems occur with creating the parameter it will likely result in an error during the loading – there is no extra error correction code in extend-chunks to handle such situations.

If there is already a function with the same name as the accessor or the update function created then a warning will be printed to indicate that and those functions will be redefined as needed for the chunk parameter. In some cases, that warning will appear during initial loading of the ACT-R system or if a file containing an extend-chunks call is compiled and then loaded. In those circumstances the warning can typically be safely ignored and there is a note to that effect printed with the warning:

```
#|Warning: The following 2 warnings can be ignored for the main ACT-R modules provided,
but may be a serious problem if seen otherwise. |#
```

```
#|Warning: Function CHUNK-FOO already exists and is being redefined. |#
#|Warning: Function CHUNK-FOO-SETF already exists and is being redefined. |#
```

One final note on this command is that it is a macro which does not evaluate its arguments and it does not have a corresponding function.

Examples:

```
1> (defun count-copies (n) (1+ n))
COUNT-COPIES

2> (defun merge-use-second (a b) b)
MERGE-USE-SECOND

3> (defun start-with-name (x) (string x))
START-WITH-NAME

4> (extend-chunks simple)
CHUNK-SIMPLE

5> (extend-chunks counter :default-value 0 :copy-function count-copies)
CHUNK-COUNTER

6> (extend-chunks merge-demo :default-function start-with-name
                             :merge-function merge-use-second)
CHUNK-MERGE-DEMO

7> (define-chunks (a isa chunk))
(A)

8> (pprint-chunks-plus a)
A
  ISA CHUNK

  --chunk parameters--
   MERGE-DEMO  "A"
   COUNTER  0
   SIMPLE  NIL
   ...

(A)

9> (copy-chunk a)
A-0

10> (pprint-chunks-plus a-0)
A-0
  ISA CHUNK

  --chunk parameters--
   MERGE-DEMO  "A-0"
   COUNTER  1
   SIMPLE  NIL
   ...

(A-0)

11> (merge-chunks a a-0)
A

12> (pprint-chunks-plus a)
A
  ISA CHUNK

  --chunk parameters--
```

```
   MERGE-DEMO  A-0
   COUNTER  0
   SIMPLE  NIL
   ...

(A)

13E> (extend-chunks simple)
#|Warning: Parameter SIMPLE already defined for chunks. |#
:DUPLICATE-PARAMETER
```

Defining New Modules

The primary means of extending the system, both in terms of extending the cognitive capabilities of models and extending the software system itself, is through adding new modules. This section will describe the mechanism for defining a new module and detail how it interacts with the system.

To create a new module one uses the define-module command which is described in detail below. A module can only be defined when there are currently no models in the system. The typical way to do that is to place the file with the module definition into one of the directories from which all of the .lisp files are loaded automatically at startup. That way the new module will be compiled and loaded with the rest of the ACT-R files. However it is not necessary to do it that way, and one can define modules by loading files or calling the define-module command at any time when there are no models defined.

When a module is defined it must be given a name. That name must be unique among the currently defined modules i.e. only one module with a given name may exist in the system. Once a module is defined it cannot be overwritten with a new definition for a module with the same name. However, one can use the undefine-module command to explicitly remove a module from the system if it is necessary to replace it. Undefining a module can also only happen when there are no models defined.

Once a module is defined every model which gets defined will have its own instance of that module. What constitutes an "instance" is determined by the module's creation function (described in detail below). The recommendation is that a new instance should be created for each model and that there should be no sharing of state between module in separate models, particularly for the cognitive modules. However, there is nothing which prevents such operation and in some circumstances that may be a useful, for example, a module might make one connection to an external simulation and then allow all the models to access that same connection through their own instances of the module.

There are several components which may be specified when defining a module. It is not necessary for a module to specify all of them, and other than a name no others are required. All of these components will be described in the following sections.

Documentation

When the module is defined one should provide a string for the version number of the module and a string containing the description of the module. These strings are displayed when the system is initially loaded and when the mp-print-versions command is called. There are no requirements on what the string must contain, but the recommendation is to provide some sort of number for the version string and a one sentence description of the module for the documentation. If documentation strings are not provided then a warning will be displayed indicating that they should be, but that will not prevent the module from being created.

Buffers

When the model is defined it may have any number of buffers associated with it. This is the only way to add new buffers to the system – they do not exist independently of a module. The buffers for a module will provide the main way for other modules to interact with that module. The buffers provide the means of making requests and queries to the module, and it may respond to requests or other actions by placing a chunk into those buffers. Note that every module has access to all of the buffers of the system and can place chunks into any of them, but the recommendation is that a module should only manipulate its own buffers. Of the default modules, the only one which does not follow that recommendation is the procedural module where the productions are allowed to manipulate, clear, or place chunks in any buffer.

There are several options which can be given when creating a new buffer. The only required component is a name. Each buffer must be given a name and that name must be unique in the system – there is can only be one buffer with any given name. The other components are described in the following sections.

spreading activation weight

The name of the parameter used to set that buffer's weight for the spreading activation calculation and the default value for that parameter may be specified. If they are not specified then the parameter will be named *buffer*-activation where *buffer* is the name of the buffer and the default value for the parameter will be 0.

request parameters

Any request parameters which are to be used with the buffer must be specified when the module is defined. Only those request parameters which are specified when the module is created will be considered valid within the production definition syntax. However, there is no constraint placed on the generation of a chunk-spec since it does not make reference to any buffer at its creation time. Therefore, it is possible for an explicit buffer request generated either by a direct call by the modeler or the action of some other module to send an invalid request parameter to the module during a request. So, when writing the request handling function for the module one may not want to assume that all request parameters which are included in the chunk-spec provided as the request are actually valid for the module.

queries

Any queries which the module will accept through the buffer other than the default query of state must be specified when the module is defined. Only those queries which are specified at this time will be accepted as valid within the production definition syntax. However, as with the request parameters, there is no constraint or check placed on the user commands like query-module. Thus,

the module's function which handles the queries may receive queries other than those specified for the buffer when it was defined and it should not assume that all queries are valid.

query printing

The last component which may be specified for a buffer is a function for printing its query information when the buffer-status command is called. By default, buffer-status will print out the results of querying the buffer's buffer and state queries (those to which every buffer must respond). If the module has other queries that one would like to show when buffer-status is called that can be done by providing a function to do so. That function should use the command-output command to print any additional status information desired for the buffer.

Parameters

Each module may specify a set of parameters which it will use. Those parameters can be either new parameters which the module will "own" and make available to the system, or existing parameters owned by other modules which it would like to be notified about as well. Whenever a parameter is changed through the use of the sgp command the module which owns that parameter is given the new value specified in the sgp call. The module is responsible for recording that new value, or whatever value it wants to use based on that value, and then return the current value for the parameter. If any other modules are watching that parameter, then they are notified of the new value which the owning module has reported.

The parameters are specified using the define-parameter command described in detail below. Here the components of a parameter which may be specified by the module.

name

Each defined parameter must specify the name of the parameter. The name must be a Lisp keyword. If it is the name of a parameter that has already been defined by another module then it is only valid if this definition explicitly claims that it is not the "owner" of that parameter. If it specifies that it is the owner of the parameter, then that name must not already be taken by a parameter of another module.

owner

When defining the parameter it must be specified whether it should be created as a new parameter or one which is to be watched and assumed to already exist. If it is being specified as a new parameter, that is, the specification claims that it is being defined by its owner, then the remaining properties may also be specified for the parameter. If the specification claims to not be the owner of the parameter then only the name of the parameter is relevant.

documentation

A string describing the parameter can be specified. That string will be printed by the sgp command when displaying the details of the parameter.

default-value

The value the parameter will have by default. If no default value is given then the default value will be **nil**.

valid-test

A function, or the name of a function, may be given to use when testing the parameter values set by the sgp command. If a valid-test is specified, then that function is passed one value, which is the requested setting in the sgp call. If the function returns a non-**nil** value then the setting is passed on to the module to handle. If the valid-test function returns **nil** then a warning is displayed and that parameter setting is not passed to the module.

warning

If a parameter value fails the valid-test the warning which is printed is constructed based on the warning string provided when the parameter is defined. The warning will always be of this form:

#|Warning: Parameter *param* cannot take value *val* because it must be *warn*. |#

where *param* is the name of the parameter, *val* is the invalid value given and *warn* is the warning string specified when defining the parameter.

Interface functions

A module interacts with the rest of the system by providing functions to be called at the appropriate times. There are several situations for which a module can provide a function. None of these functions are required unless the module also provides one or more buffers or one or more parameters for the system. If the module has a buffer then it must provide a function to handle queries of the buffer, and if it has any parameters then it must provide a function for setting and getting the parameter values.

Here are the possible situations for which a module may provide a function and the parameters which it will be passed.

creation

Whenever a new model is defined it will create an instance of each module in the system. To create that instance each module's creation function is called. That function will be passed one parameter which will be the name of the model being created. The value returned by that function will be saved as the instance of that module in that model. The module's instance should be a data structure

capable of holding any parameter values and state information necessary for the module to operate. That instance will be passed to all of the other interface functions which the module provides. If a module does not provide a creation function then its instance will be the value **nil** for the purpose of calling any of its other interface functions.

reset

The module may specify one, two or three functions to call when a model is reset. Those functions will be called with the instance of the module as their only parameter. The three reset functions are called at different times during the resetting of a model and a module may use any or all of them if needed. The primary reset function is called before the parameters get reset to their default values. The secondary reset gets called after the default parameters have been set and before any user code is evaluated. The tertiary reset gets called after the user code of the model definition has been evaled. Most modules are likely only going to need one of the reset functions, and typically only the primary reset is necessary. However, if a module needs to modify the value of another module's parameter at reset time it will have to do so in a secondary or tertiary reset function, otherwise any change will be overwritten. Although using the secondary or tertiary reset function is necessary to adjust another module's parameter from the default value, it may not be sufficient because other modules may also have secondary or tertiary reset functions which will also adjust or restore that value. In such cases, watching the parameter, by adding it to the module as a parameter which it does not own, will allow for more control and monitoring of the changes.

delete

The module may specify a function to be called when the model in which it has been created is deleted. The delete function will be passed the instance of the module in the model being deleted as its only parameter. The instance of the module will not be referenced by the given system code after it has been deleted and thus may be destructively modified, deallocated, or any other explicit cleanup as needed may be performed upon it. To ensure that deleted module instances are not referenced, one should not access any parameters using sgp in a module's delete method.

parameters

If the module makes parameters available to the system or is monitoring the parameters of other modules then it must provide a function for setting and getting those parameter values. The module's parameter function will be called with two parameters. The first will be the instance of the module in the current model. The second will be either a keyword which names a parameter, in which case this is a request for the current value of the parameter which the function should return, or it will be a cons of a keyword parameter name and a value. When a cons is provided as the second parameter it is a request to change the current value of the parameter to the one provided. The module should set the parameter as needed based on that value and then return the current value of the parameter (which may or may not be the same as the value which was provided). A module's parameter function will

only be called with parameters which the module has specified when it was defined. For those which it owns it will get both requests for the current value and requests to change the value. If a module does not own the parameter it will only be sent notifications of changes to the parameter and the return value from the function in those cases is ignored.

queries

If the module has one or more buffers, then it must provide a function to handle queries of those buffers. The module's query function will be called whenever a query-buffer or query-module command is issued. With the typical operation of the system there will also be queries made through the productions of the procedural module during conflict-resolution events. The query function will be called with four parameters. The first will be the instance of the module in the current model. The second will be the name of the buffer being queried. The third will be one of the valid queries for the module – either state, which all modules must accept, or one of the ones given when the buffer was specified. The fourth parameter will be the value of the query to test. There are no constraints on the values which may be used. Thus, a module should be able to handle any value which is provided, but it does not have to consider them all valid and may display warnings when invalid values are given. Every module is expected to respond to queries of state with values of free, busy, or error, but other than those there are no prespecified queries to which a module must respond. The return value of the query function is considered as a generalized boolean. If the query of the given value is true then the module should return a true value and if the query of the given value is not true the function should return **nil**.

requests

If the module has one or more buffers then it may provide a function to handle requests to those buffers, but it is not required that a module with buffers accept requests. If a request function is specified for the module then it will be called whenever the module-request command is called for the module's buffer, and with the typical operation of the system, the firing of productions by the procedural module will also generate request to the buffers. The module's request function will be called with three parameters. The first will be the instance of the module in the current model. The second will be the name of the buffer to which the request was made, and the third will be a chunk-spec which represents the request being made. The chunk-spec provided may be of any chunk-type and may include any number of slot tests and request parameters. The module-request command does not verify that request parameters are among those specified when the buffer was defined, though the procedural module's production syntax will prevent invalid request parameters from being used. Thus, the module's request function is responsible for all testing and verification of whether the request being made is something which the module is able to handle and should signal warnings to indicate invalid or malformed requests.

What a module does in response to a request is entirely up to the module writer – there are no mandatory actions which must occur. It is recommended however that the module should schedule

events to handle all of the actions which it performs in response to the request. By doing so, the trace will show those actions, other modules will be able to detect that they have occurred (for instance the procedural module may schedule another conflict-resolution event if there is not one pending), the model debugging tools will allow one to see that the events have been scheduled, and the stepping tools can be used for testing and debugging of the module's actions.

buffer modification requests

If the module has one or more buffers then it may provide a function to handle buffer modification requests, but a module is not required to handle such requests. If a function for buffer modification requests is provided for the module then it will be called whenever the module-mod-request command is called for one of the module's buffers, and with the typical operation of the system, the firing of productions may also generate buffer modification requests. The module's buffer modification request function will be called with two parameters. The first will be the instance of the module in the current model. The second will be a chunk modification list – an even length list where the items are taken in pairs as a slot name and then the value for that slot (the same format as would be used with the mod-chunk-fct command). A buffer modification request will only occur when there is a chunk in the buffer, but the slots specified may or may not be valid for that chunk. This allows the module to provide functionality which can extend chunk-types or other requests which may have other effects. With the normal components of the system the only time that an invalid slot can occur will be through an action in a production created with p*, but invalid requests could be made directly to the module-mod-request command by other code.

What a module does in response to a buffer modification request is entirely up to the module writer – there are no mandatory actions which must occur. It is recommended however that the module should schedule events to handle all of the actions which it performs in response to the request. The general purpose of the modification request is to allow the module to perform an action like mod-chunk which has a time cost during which time the module will be busy and unable to handle other requests. However, it does not have to be used that way and may be used to perform other module actions.

notify upon clearing

A module may specify a function to be called when any buffer is cleared. If a module provides a function to be notified when buffers clear that function will be called with three parameters after every buffer clearing occurs. The first parameter will be the instance of the module in the current model. The second parameter will be the name of a buffer, and the third parameter will be the name of the chunk which was cleared from the buffer. The module may use that information however it wants, but the one thing that it should not do is modify the chunk which was cleared from the buffer because other module may also need the information which was in that chunk or may have already used it as it was. In particular, the declarative memory module will merge all of the chunks that are cleared out of buffers with identical chunks that are in the model's declarative memory or add the

new chunk to the model's declarative memory if it does not match an existing one and modification of chunks in the model's declarative memory is not a recommended practice and may lead to problems with the declarative module's retrieval mechanisms.

notify at the start of a new call to run the system

A module may specify a function to be called whenever one of the system running commands is called. If a module provides a function to be notified when a run starts then that function will be called with one parameter before the first event of the run is executed. That parameter will be the instance of the module in the current model. This notification function is not recommended for the normal operations of a module because it should not depend on how or when the system is run. The intended use of this notification is to allow a module an opportunity to perform some safety or verification tests before the system runs.

The only current use of this notification is by the procedural module. It uses this to make sure that there is always a conflict-resolution or other appropriate procedural event scheduled or waiting. This avoids a problem that can occur because of an unusual run termination (a Lisp break while the Environment's stepper is open for example) that leaves the procedural module without any events on the queue and thus unable to fire any more productions until it is reset.

notify upon a completion of a call to run the system

A module may also specify a function to be called whenever one of the system running commands is finished running the system. If a module provides a function to be notified when a run ends then that function will be called with one parameter after the last event of the run is executed. That parameter will be the instance of the module in the current model. Like the run start notification, this is not recommended for the normal operations of a module because it should not depend on how or when the system is run. The intended use of this notification is to allow a module an opportunity to perform some safety or verification tests after the system runs.

None of the current modules use this notification, but the ACT-R Environment connection code may be changed to use the run start and stop notifications to better protect things since the environment evaluates ACT-R commands in background threads which is something that the main code base was not designed for and things like capturing the output of an ACT-R command can cause problems if there's also a trace being displayed while the model runs.

warning of an upcoming request

A module may specify a function which may be called to provide the module with a warning of an upcoming request. If a warning function is provided that function will be called with three parameters. The first parameter will be the instance of the module. The second will be the name of one of the module's buffers and the third will be the name of a chunk-type. The procedural module will call a module's warning function, if it has one, at production selection time to warn about any

requests which will be made when the selected production fires. This is the only time that the warning function will be called – requests from other modules or from direct requests of the modeler will not be preceded by warnings. Having a warning function allows a module to know that a production will be making a request which may be dependent on information which was true at the time the production was selected. The module gets called at the selection time and thus may suspend pending actions or note the relevant information necessary at that time to use when handling the request.

The only module which currently uses a warning function is the vision module. It allows the vision module to suspend the processing of a screen update during a production which will be making a move-attention request so that the visual-location chunk which is used in the production does not get invalidated by a change in the display before the request is handled.

Common Class of Modules – Goal Style

There is a particular type of module which modelers often find useful to create for specific situations. That type of module is one which works like the goal and imaginal modules where a request is a direct specification of a chunk to create and place into the buffer. There are referred to as "goal style" modules. There are three functions which exist to make creating such modules easy. Those functions can be used as the query, request and modification request functions for creating such a module. They are described in the commands section below and are the functions goal-style-query, goal-style-request and goal-style-mod-request.

Using those functions, one can create a new module which acts just like the default goal module and buffer using something like this:

```
(define-module name (name) nil :version "1.0" :documentation "Example"
               :query goal-style-query
               :request goal-style-request
               :buffer-mod goal-style-mod-request)
```

Where *name* is the name you want to give to the module and buffer, which need to be the same for the assumptions in the goal-style-* functions.

Those commands do not have to only be used in that manner, and it is possible to call them from other functions. For example, one could specify a different request function when creating the module which performs some error checking or possible restrictions on the requests which can be made to the module before then calling goal-style-request to do the rest of the work.

The file which defines the goal-style components is included in the support directory of the distribution. Therefore it is not loaded automatically when the system loads. So, any file which uses those commands should include this line near the top of the file:

```
(require-compiled "GOAL-STYLE-MODULE" "ACT-R6:support;goal-style-module")
```

That will ensure that the goal style support code is loaded appropriately. Typically, the main goal module will already have loaded that support, but it is best to be sure when creating modules or other code which may be shared with others who may have made other changes to the modules or default system.

Writing Module Code

When writing code to handle the module's operations there are some assumptions which can be made and practices which should be followed. This section will cover those assumptions and recommended practices.

Because the module functions which one provides will always be passed the current model's instance of the module one can assume that there is a current model in handling those calls. However, if one has additional functions which go along with the module that may be called at other times, or without requiring an instance of the module as a parameter then the use of the get-module command is recommended to get the current model's instance of the module to work with. The get-module command takes one parameter which should be the name of a module and it returns the instance of that module in the current model. If there is no current model then get-module will print a warning and return **nil**.

When a module performs actions in the running model, particularly actions relating to the buffers, it should always schedule those as events instead of directly calling commands which make those changes. When scheduling such events, it should always indicate the module's name when the event is generated. Doing those things makes it much easier to debug a model which uses the new module and also makes it easier to integrate new modules from different sources because any unexpected interactions should then be detectable in a model's trace.

If a module needs to reference the values of parameters of other modules then it is recommended that they be specified as non-owned parameters for the module. Those parameters' values should then be recorded in some way in the instance of the module with the module's parameter function even if the module has no parameters of its own. That is recommended for performance reasons because using sgp to get parameter values is a relatively slow process and often also requires suppressing the output which also may have a significant cost to performance relative to the work done by the module.

Any chunk-types and any constant chunks which a module is going to need should be defined in the module's reset function. If the module depends on the chunk-types of other modules it should not

reference those chunk-types during the primary reset function because there is no guarantee that the other module's primary reset function will be called prior to the new module's.

If the module will be extending the chunks or productions with new parameters for its use that should be done at the top level in the module's definition file because extending those items should only occur once. Thus such calls do not belong in either the creation or reset function for the module.

Module examples

The commands section will have examples showing the basic syntax of the commands, but will not have "working" module definitions as examples because the necessary support code is outside of the scope of the examples for the reference manual. Also, one often needs a model which uses the module to really have an example that shows the components in operation. In the examples directory of the source code distribution one can find a directory called creating-modules. In that directory are new module definition files which implement modules along with the corresponding models which use the features provided by those modules. The documentation for the modules and how to run the associated models are included in the comments of those files.

Commands

get-module

Syntax:

get-module *name* -> [instance | **nil**] [**t** | **nil**]
get-module-fct *name* -> [instance | **nil**] [**t** | **nil**]

Arguments and Values:

name ::= a symbol which should be the name of a module
instance ::= the named module's instance in the current model

Description:

The get-module command is used to get the instance of a module in the current model. It returns two values. If there is a module with that name in the system then the first return value is the instance of that module and the second return value will be **t**. If that name does not name a module in the current model or there is no current model then a warning will be printed and both return values will be **nil**.

Examples:

```
> (get-module goal)
#S(GOAL-MODULE ...)
T

> (get-module-fct 'imaginal)
#S(IMAGINAL-MODULE ...)
```

```
T

E> (get-module foo)
#|Warning: FOO is not the name of a module in the current model. |#
NIL
NIL

E> (get-module-fct 'goal)
#|Warning: get-module called with no current model. |#
NIL
NIL
```

define-parameter

Syntax:

define-parameter *param-name* {**:owner** *owner*} {**:default-value** *default*} {**:documentation** *docs*}
{**:valid-test** *test*} {**:warning** *warn*} -> [parameter | **nil**]

Arguments and Values:

param-name ::= a keyword for the name of the parameter being defined
owner ::= a generalized boolean indicating whether this definition is specifying the parameter's owner
default ::= a value which will be the default value for the parameter
docs ::= a string describing the parameter
test ::= a function, function name or nil used to test value for this parameter through sgp
warn ::= a string to print when an invalid parameter value is detected
parameter ::= an instance of an ACT-R internal parameter item

Description:

The define-parameter command is used to create a parameter for a module. The value returned from this function has no use in the system other than as a member of the list of parameters when defining a module. A parameter defined through this command will not be available to the system until it is part of a module which owns it.

The only parameter required when calling define-parameter is the name of the parameter which must be a Lisp keyword.

The owner parameter specifies whether the module which uses this parameter definition is to be considered the owner of that parameter. If not provided the default value is **t**.

The default parameter specifies the value the parameter should have as its default when the system is reset. If not provided, then the default value for the parameter will be **nil**. The only restriction on the default value is that it cannot be a Lisp keyword because it is not possible to use sgp to set a single parameter to a keyword value.

The docs parameter should be a string which describes the parameter. That string is printed by sgp when the parameter value is displayed.

The valid test may be specified as a function or the name of a function. That function is called whenever this parameter's value is changed using the sgp command. The test function will be passed the new value specified in the sgp call. If the test function returns a true value then the new value is considered valid and it is passed on to the owning module's parameter function to set. If the test function returns **nil** then a warning is printed and the parameter value is left unchanged. If no test is specified in the definition for the parameter then no testing is performed on the values for it which are given in sgp.

If a test function is provided, then when it reports an invalid value the warning which gets printed will look like this:

#|Warning: Parameter *param-name* cannot take value *val* because it must be *warn*. |#

where *param-name* is the name of the parameter, *val* is the invalid value given and *warn* is the warn string specified when defining the parameter. If no warn string is provided, then it defaults to an empty string.

If any of the parameters passed to define-parameter are invalid then a warning will be displayed and **nil** will be returned.

Examples:

```
> (define-parameter :new :documentation "A new parameter")
#S(ACT-R-PARAMETER ...)

> (define-parameter :count :valid-test 'fixnump :warning "a fixnum")
#S(ACT-R-PARAMETER ...)

> (define-parameter :bll :owner nil)
#S(ACT-R-PARAMETER ...)

E> (define-parameter 'not-a-keyword)
#|Warning: Parameter name must be a keyword. |#
NIL

E> (define-parameter :new :documentation 'not-a-string)
#|Warning: documentation must be a string. |#
NIL

E> (define-parameter :new :valid-test 'not-a-function)
#|Warning: valid-test must be a function, the name of a function, or nil. |#
NIL

E> (define-parameter :new :default-value :keywords-not-allowed)
#|Warning: default-value cannot be a keyword. |#
NIL

E> (define-parameter :new :warning 'not-a-string)
#|Warning: warning must be a string. |#
NIL
```

define-module

Syntax:

define-module *module-name* (*buffer-def**) (*param**) {**:version** *version*} {**:documentation** *doc-string*}
{**:creation** *create*} {**:reset** *reset*} {**:request** *request*} {**:query** *query*} {**:buffer-mod** *mod*}
{**:params** *params*} {**:delete** *delete*} {**:notify-on-clear** *clear*} {**:warning** *warn*}
{**:run-start** *run-start*} {**:run-end** *run-end*}
-> [module-name | **nil**]

define-module-fct *module-name* (*buffer-def**) (*param**) {**:version** *version*} {**:documentation** *doc-string*}
{**:creation** *create*} {**:reset** *reset*} {**:request** *request*} {**:query** *query*} {**:buffer-mod** *mod*}
{**:params** *params*} {**:delete** *delete*} {**:notify-on-clear** *clear*} {**:warning** *warn*}
{**:run-start** *run-start*} {**:run-end** *run-end*}
-> [module-name | **nil**]

Arguments and Values:

module-name ::= a symbol which will be the name for the module being defined
buffer-def ::= [buffer-name |
([buffer-name |
buffer-name buff-params |
buffer-name buff-params (req-param*) |
buffer-name buff-params (req-param*) (query-names*) |
buffer-name buff-params (req-param*) (query-names*) [print-status | **nil**]])
buffer-name ::= a symbol which names the buffer being defined
buff-params ::= [pname | (pname pdefault) | (**nil** pdefault) | (pname **nil**) | **nil**]
pname ::= a keyword which names the parameter to create for the buffer's spreading activation value
pdefault ::= a number which will be the default for the buffer's spreading activation value parameter
req-param ::= a keyword which names a request parameter this buffer will accept
query-names ::= a symbol which names a new query which is valid for this buffer
print-status ::= a function or name of a function to be called when buffer-status reports on this buffer
param ::= a parameter item as returned by the define-parameter command
version ::= a string providing version information for the module
doc-string ::= a string to provide a brief description of the module
create ::= a function or the name of a function to handle the module creation
reset ::= [primary-reset | ([primary-reset | **nil**] [secondary-reset| **nil**] {[tertiary-reset| **nil**]})]
primary-reset ::= a function or the name of a function to handle the module's primary reset
secondary-reset ::= a function or the name of a function to handle the module's secondary reset
tertiary-reset ::= a function or the name of a function to handle the module's tertiary reset
request ::= a function or the name of a function to handle module requests
query ::= a function or the name of a function to handle module queries
mod ::= a function or the name of a function to handle module modification requests
params ::= a function or the name of a function to handle the module's parameter
delete ::= a function or the name of a function to handle the deletion of the module
clear ::= a function or the name of a function to call whenever a buffer is cleared
warn ::= a function or the name of a function to be called to warn of a future request to the module
run-start ::= a function or the name of a function to be called each time a running command is called
run-end ::= a function or the name of a function to be called each time a running command finishes

Description:

The define-module command is used to add a new module to the system. A new module may only be added if there are currently no models defined and only the default meta-process is defined. The first

parameter to define-module must be a symbol that names the new module being defined. If there is not already a module defined with that name and all of the remaining parameters provided to describe the module are valid (as described below) then a new module is added to the system and the name of the module is returned. Otherwise, a warning is printed and **nil** is returned.

The second parameter must be a list of the buffer descriptions for the buffers of the module. It may be an empty list, in which case the module has no buffers. If it is not an empty list, then the elements of that list must be either symbols or lists.

If an element of the buffer definition list is a symbol, then that symbol names a buffer which the module will have and that buffer will be given the default values for its components. If a list is provided then one can specify the other components of the buffer as well. The list may be up to five elements long and the components of the list are as follows:

- The first element must be a symbol which names the buffer.
- The second element specifies the name of the spreading activation parameter to add to the system for this buffer and the default value for the buffer's spreading activation parameter. If it is a keyword which is not already the name of a parameter in the system then that name will be used for the parameter and it will have a default value of 0. If it is a list, then the first element of the list is the name of the parameter and the second element is the default value, which should be a number. If the name is specified as **nil** then the default name for the parameter is used.
- The third element is the list of request parameters which the buffer will accept. It must be a list of keywords or **nil**. Only those items specified in this list will be considered as valid request parameters by the production parsing system.
- The fourth element is the list of queries which may be made to the module in addition to the standard query for state. It must be a list of symbols or **nil**. Only those items specified in this list will be considered as valid queries by the production parsing system.
- The fifth element should be a function or the name of a function. This function will be called when the buffer-status command after it has printed the default query information for the buffer. This is typically added when one provides additional queries so that their status may be displayed for the user along with the normal queries.

If a module has one or more buffers then it must provide a query function. It is not required to provide a request or modification request function.

The third parameter to define-module must be a list of parameters as returned by the define-parameter command. If the list is non-empty, then they must be valid parameters and meet the this additional restriction. If a parameter in the list is created as being owned by the module then it must not be owned by any other module, and if a parameter is created as not being owned that parameter must be owned by some other module. A module which specifies parameters must also provide a params function to support them.

The remaining parameters to define-module are keyword parameters and may occur in any order. None of the keyword parameters are required except when the module has buffers and/or parameters as described above.

The version and documentation parameters should be strings and are used to display information about the module when the mp-print-versions command is called and after initially loading the system. They are not required, but if either is not provided a warning will be displayed before defining the module.

The rest of the keyword parameters are used to specify the functions to call for interfacing the module to the rest of the system. How they interface to the system is described in detail above in the "interface functions" section. Here the details of the parameters they will be passed and expected return values will be described.

The create function will be passed one parameter. That will be the symbol naming the model in which a new instance of the module is being created. The return value of the module's create function will be the instance used for calling all of the module's other functions from that model.

The module's reset function (or functions) are called with one parameter. That parameter will be the instance of the module in the current model. The return values of the reset functions are ignored by the system.

The request function will be passed three parameters. The first will be the instance of the module in the current model. The second will be a symbol naming one of the module's buffers indicating to which buffer the request was made. The third parameter will be the chunk-spec which describes the request. The return value of the request function is ignored by the system.

The query function will be passed four parameters. The first will be the instance of the module in the current model. The second will be a symbol naming one of the module's buffers indicating which buffer is being queried. The third will be the symbol naming the query being made and the fourth will be the value being queried. The return value of the query function will be considered as a generalized boolean and should indicate whether the value specified for the query was true or false.

The mod function will be passed three parameters. The first will be the instance of the module in the current model. The second will be a symbol naming one of the module's buffers indicating to which buffer the modification request was made. The third will be the list of modifications indicated in the request. The list of modifications will be an even length list as would be provided to mod-chunk or schedule-mod-buffer-chunk i.e. the elements in the even indices are slot names and the corresponding elements after each slot name is a value for that slot. The return value of the mod function is ignored by the system.

The params function will be passed two parameters. The first will be the instance of the module in the current model. The second will be either a keyword naming one of the module's owned

parameters or a cons of a keyword naming a parameter specified for the module and a new value for that parameter. If the second parameter is a keyword then that indicates that the current value for that parameter is being asked for and the return value of the function should be that parameter's current value in the current model. If the second parameter is a cons then that means sgp has been called to change that parameter's value. If this module owns the parameter being changed then the return value of the params function will be considered the current value of that parameter. If the module does not own the parameter being changed then the return value of the params function is ignored.

The delete function will be passed one parameter. That parameter will be the instance of the module in the model being deleted. The return value of the delete function is ignored by the system.

The clear function will be passed three parameters. The first will be the instance of the module in the current model. The second will be a symbol naming the buffer which is being cleared. The third will be a symbol naming the chunk which is being cleared from that buffer. The return value of the clear function is ignored by the system.

The warn function will be passed three parameters. The first will be the instance of the module in the current model. The second will be a symbol naming one of the module's buffers indicating to which buffer the request will be made. The third will be a symbol naming the chunk-type which will be in the request that the production will make. The return value of the warn function is ignored by the system.

The run-start function will be passed one parameter. That parameter will be the instance of the module in the current model. The return value of the run function is ignored by the system.

The run-end function will be passed one parameter. That parameter will be the instance of the module in the current model. The return value of the run function is ignored by the system.

Examples:

Examples of modules along with demo models which use them can be found in the examples/creating-modules directory of the distribution. The examples here are only to show the syntax of the command and some of the warnings and errors which may occur.

```
> (define-module foo nil nil)
#|Warning: Modules should always provide a version and documentation string. |#
FOO

1> (define-module bar nil nil :version "" :documentation "")
BAR

2E> (define-module bar nil nil :version "" :documentation "")
#|Warning: Module BAR already exists and cannot be redefined.  Delete it with undefine-
module first if you want to redefine it. |#
```

```
NIL

> (define-module-fct 'foo '(foo-1 (foo-2 (:foo-spread 1.5)))
               (list (define-parameter :foo-value))
               :version "0.3"
               :documentation "example"
               :params 'foo-param-function
               :query 'foo-query-function)

FOO

E> (define-module-fct nil nil nil)
#|Warning: Modules should always provide a version and documentation string. |#
#|Warning: Nil is not a valid module-name. No module defined. |#
NIL

E> (define-module-fct 'bad '(buffer-1) nil)
#|Warning: Modules should always provide a version and documentation string. |#
#|Warning: A module with a buffer must support queries.
Module BAD not defined. |#
NIL

E> (define-module-fct 'bad nil (list 'bad-parameter))
#|Warning: Modules should always provide a version and documentation string. |#
#|Warning: Invalid params-list (BAD-PARAMETER).
Module BAD not defined. |#
NIL

E> (define-module-fct 'bad '(buffer-1 (buffer-2 bad-param-name)) nil :query 'query-fn)
#|Warning: Modules should always provide a version and documentation string. |#
#|Warning: Invalid buffer specification: (BUFFER-2 BAD-PARAM-NAME) |#
#|Warning: Error in module buffer definitions.
Module BAD not defined. |#
NIL
```

undefine-module

Syntax:

undefine-module *module-name* -> [**t** | **nil**]
undefine-module-fct *module-name* -> [**t** | **nil**]

Arguments and Values:

module-name ::= a symbol which should name a module

Description:

The undefine-module command is used to remove a module from the system. It takes one required parameter which is the name of the module to remove. If that names a module in the system and there are no models defined and there are no meta-processes defined other than the default then that module, all of its buffers, and all of its parameters are removed from the system and the value **t** will be returned.

If the name does not name a module in the system or there is a model defined or a meta-process other than default defined then a warning is printed and a value of **nil** is returned.

There are typically two reasons for using this command. The first is when first writing and debugging a module. Often one finds that they need to change something with it and this command is the only way to remove a broken or incomplete module without quitting the system and reloading everything. The other is when one has built a module which is a replacement for an existing module. In that case, the file with the new version uninstalls the default version of the module before defining the replacement.

Examples:

```
1> (define-module bar nil nil :version "" :documentation "")
BAR

2> (define-module foo nil nil :version "" :documentation "")
FOO

3> (undefine-module bar)
T

4> (undefine-module-fct 'foo)
T

5E> (undefine-module-fct 'foo)
#|Warning: FOO is not the name of a currently defined module. |#
NIL

E> (undefine-module goal)
#|Warning: Cannot delete a module when there are models defined. |#
NIL

E> (undefine-module goal)
#|Warning: Cannot delete a module when there is a meta-process other than the default
defined. |#
NIL
```

goal-style-query

Syntax:

goal-style-query *instance buffer slot value* -> [**t** | **nil**]

Arguments and Values:

instance ::= this parameter is ignored
buffer ::= a symbol which names the buffer being queried
slot ::= this parameter is ignored
value ::= a symbol for the value of the query

Description:

The goal-style-query command is designed to be used as the query function for a module's definition. It will respond to the default queries for a module and assumes that only the state slot will be queried. It responds to those queries as follows: a state busy query will always return **nil**, a state free query

will always return **t**, and a state error query will always return **nil**. For any other values it will print a warning indicating that the query was invalid and return **nil**.

Examples:

```
> (goal-style-query nil 'goal 'state 'free)
T

> (goal-style-query nil 'goal 'state 'busy)
NIL

> (goal-style-query nil 'goal 'state 'error)
NIL

E> (goal-style-query nil 'goal 'state 'bad)
#|Warning: Unknown state query BAD to GOAL buffer |#
NIL
```

goal-style-request

Syntax:

goal-style-request *instance buffer chunk-spec* {*delay*} -> [event | **nil**]

Arguments and Values:

instance ::= this parameter is ignored
buffer ::= a symbol which names the buffer to which the request was made
chunk-spec ::= a chunk-spec of the request
delay ::= a number indicating how many seconds to wait before creating the chunk
event ::= the scheduled event which will create the new chunk in the buffer

Description:

The goal-style-request command is designed to be used as the request function for a module's definition, but it may also be called by a more specific request function to handle the final creation of a chunk in the buffer and provides an optional delay for such use. If the chunk-spec provided is valid for the chunk-spec-to-chunk-def command, then this command schedules an event to create a chunk using that chunk definition and place that chunk into the specified buffer after the provided delay time has passed. If no delay time is provided, then it default to 0 seconds. The event scheduled is returned. If the chunk-spec is invalid then a warning is printed and **nil** is returned.

Examples:

```
1> (goal-style-request nil 'goal (define-chunk-spec isa chunk))
#S(ACT-R-EVENT ...)

2> (goal-style-request nil 'goal (define-chunk-spec isa chunk) .2)
#S(ACT-R-EVENT ...)
3> (run .25)
     0.000   GOAL                  CREATE-NEW-BUFFER-CHUNK GOAL ISA CHUNK
     0.000   GOAL                  SET-BUFFER-CHUNK GOAL CHUNK0
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.200   GOAL                  CREATE-NEW-BUFFER-CHUNK GOAL ISA CHUNK
```

```
     0.200   GOAL                    SET-BUFFER-CHUNK GOAL CHUNK1
     0.200   PROCEDURAL              CONFLICT-RESOLUTION
     0.200   ------                  Stopped because no events left to process
0.2
9
NIL

E> (goal-style-request nil 'goal 'bad-spec)
#|Warning: chunk-spec-to-chunk-def called with something other than a chunk-spec. |#
#|Warning: Invalid request made of the GOAL buffer. |#
NIL
```

goal-style-mod-request

Syntax:

goal-style-request *instance buffer mods* {*delay*} -> [event | **nil**]

Arguments and Values:

instance ::= this parameter is ignored
buffer ::= a symbol which names the buffer to which the request was made
mods ::= a chunk modification list
delay ::= a number indicating how many seconds to wait before creating the chunk
event ::= the scheduled event which will create the new chunk in the buffer

Description:

The goal-style-mod-request command is designed to be used as the buffer modification request function for a module's definition, but it may also be called by a more specific function to handle the modification of a chunk in the buffer and provides an optional delay for such use. If the modifications provided in mods are a valid chunk modification list as used by mod-chunk for the chunk which is in the named buffer at the time of the call, then this command schedules an event to modify that chunk in the buffer with those modifications after the provided delay time has passed. If no delay time is provided, then it default to 0 seconds. The event scheduled is returned. If the modifications provided are invalid or the buffer is empty then a warning is printed and **nil** is returned.

Examples:

```
1> (chunk-type goal state)
GOAL

2> (set-buffer-chunk 'goal (car (define-chunks (g isa goal))))
G-0

3> (goal-style-mod-request nil 'goal '(state start))
#S(ACT-R-EVENT ...)

4> (goal-style-mod-request nil 'goal '(state done) .5)
#S(ACT-R-EVENT ...)

5> (run .5)
     0.000   GOAL                    MOD-BUFFER-CHUNK GOAL
     0.000   PROCEDURAL              CONFLICT-RESOLUTION
```

```
     0.500   GOAL                    MOD-BUFFER-CHUNK GOAL
     0.500   PROCEDURAL              CONFLICT-RESOLUTION
     0.500   ------                  Stopped because time limit reached
0.5
5
NIL

E> (goal-style-mod-request nil 'goal '(state start))
#|Warning: schedule-mod-buffer-chunk called with no chunk in buffer GOAL |#
NIL

E> (goal-style-mod-request nil 'goal '(bad-slot nil))
#|Warning: schedule-mod-buffer-chunk called with an invalid modification (BAD-SLOT NIL) |#
NIL
```

Multiple Models

In the model and meta-process sections it indicates that it is possible to run more than one model at a time, but it does not cover the details on how to do so. This section will describe how to create and use multiple models and show the commands that are available for working with them.

The first thing to discuss is the notion of the current model and the current meta-process. Those terms were introduced in the model and meta-process sections above and most of the commands described in this manual indicate that they only work with respect to those current items. When there is only one meta-process and one model defined then those will always be the current ones. However if more than one of either is defined which one is the current one will typically need to be specified by the user. If there are multiple meta-processes then the user must always specify the current one – there will not be a current meta-process otherwise. If there is more than one model defined within a meta-process (each meta-process has its own set of models) then which one is the current model will be set either by the user or by the system. When a model is initially defined and whenever the model is reset the code provided in the model's definition will be executed with that model set to the current one. If the meta-process is not running the models, then, as with meta-processes, there will not be a current model unless specified by the user. When the meta-process is running the models the current model will be set based on the events being executed. When each event is executed the meta-process will set the current model to be the model which generated that event before it performs the event's action. After an event's action is complete the meta-process will return to not having a current model. It is possible for the code in the event's action to also modify which model is current if necessary, for example to send a notice to some other model.

Because the meta-process maintains the current model automatically based on the events, user defined modules (or other code) which generate events to perform their actions should not need to have any changes made to them to be able to work with multiple models. The only thing that would be important for a module is that if it has any internal state it would need to generate a unique instance for each model when it is created. Thus, as long as the creation function for the module returns a new "instance" (structure, class, vector, etc.) for each model and doesn't rely on globally defined objects it should work with multiple models without any modifications. All of the standard modules provided with the system will work as described in this manual whether there is only one model defined or if there are multiple models defined.

The next thing to discuss is the two ways in which multiple models can be run. The choice is whether they are to be run synchronously (at the same time with one clock) or asynchronously (individually with their own clocks). The distinction is important because it is determined at the time the models are defined and cannot be changed. Note however that those are not mutually exclusive and it is possible to use both mechanisms with different models all simultaneously defined where there are distinct sets of models which run synchronously within a set, but asynchronously between the sets.

What determines how the models will run is whether or not they are defined within the same meta-process. If there is only one meta-process defined then all models will be defined within that meta-process and will run synchronously – any call to run will run all of those models. However, if there are multiple meta-processes defined then each meta-process will run the models defined within it on its own clock which will be independent of the clocks in other meta-processes. Those meta-processes can only be run one at a time, since there is only ever one current meta-process which can be run.

[It is worth noting that the ACT-R system is only designed to be run single threaded. When a meta-process is running multiple models they are all being run in one thread and all of their events are being executed off of a single event queue. Similarly, when there are multiple meta-processes defined only one should ever be run at a time. Even though in a threaded Lisp system it would be possible to spawn separate threads with different current meta-processes to run, the ACT-R code has no protection to prevent unintended interactions in such a situation and doing so will likely lead to improper operations and errors.]

When working with multiple models one thing to be aware of is that the system does not come with any built in ways for those models to interact. Other than sharing a clock in the case of synchronous models there is no interaction among the models. Each one has its own set of modules, chunk-types, chunks, and parameters and unless there is some interaction implemented by the user the models will run the same when they are run together as each would run on its own because they are not aware of the other models' existence. In particular, they do not "see" the other models' events in the queue. Thus, events waiting to be scheduled will not be removed from the waiting queue until an appropriate trigger from the same model occurs.

Synchronous models

Synchronous models are usually easier to work with since they are all defined within the same meta-process, and if there is only one such meta-process that simplifies things even more. For this section the assumption will be that there is only one meta-process. These same principles would also apply to a situation with multiple meta-processes if one wants to create asynchronous sets of synchronous models. The only difference would be the need to specify the appropriate current meta-process when defining the models, as described in the asynchronous section.

To create synchronous models all one needs to do is define them. There is no special syntax needed, and the standard define-model command will create each model the same as it would if that were the only model being defined. Each model defined will exist within the current meta-process and they will all run when that meta-process is run.

An example of defining multiple synchronous models can be found in the examples directory of the distribution in the file called "unit-1-together-1-mp.cl". That file contains the definitions for all three of the example models from unit 1 of the tutorial (count, addition, and semantic). Each of the model definitions is just copied from the corresponding tutorial model file. The only difference between loading that file with all three defined and loading the individual model files is that the individual

model files each call clear-all when loaded which results in removing all models and all meta-processes except for the default one before defining the model. The combined file only calls clear-all once to remove other models and meta-processes and then defines each of the models one after the other. That model file will be used to create some of the examples when describing the additional commands available for working with multiple models.

After loading that file one can run it just as one would have run any of the individual models by calling the run command. Here is the beginning of the trace of a run of those models:

```
> (run 10)
     0.000  COUNT     GOAL                SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000  SEMANTIC  GOAL                SET-BUFFER-CHUNK GOAL G1 REQUESTED NIL
     0.000  ADDITION  GOAL                SET-BUFFER-CHUNK GOAL SECOND-GOAL REQUESTED NIL
     0.000  COUNT     PROCEDURAL          CONFLICT-RESOLUTION
     0.000  SEMANTIC  PROCEDURAL          CONFLICT-RESOLUTION
     0.000  ADDITION  PROCEDURAL          CONFLICT-RESOLUTION
     0.050  COUNT     PROCEDURAL          PRODUCTION-FIRED START
     0.050  COUNT     PROCEDURAL          CLEAR-BUFFER RETRIEVAL
     0.050  SEMANTIC  PROCEDURAL          PRODUCTION-FIRED INITIAL-RETRIEVE
     0.050  SEMANTIC  PROCEDURAL          CLEAR-BUFFER RETRIEVAL
     0.050  ADDITION  PROCEDURAL          PRODUCTION-FIRED INITIALIZE-ADDITION
     0.050  ADDITION  PROCEDURAL          CLEAR-BUFFER RETRIEVAL
     ...
```

When there are multiple models running there will be an additional column shown in the trace indicating which model is performing the action. Here we see actions from each of the count, semantic, and addition models occurring.

Commands

current-model

Syntax:

current-model -> [name | **nil**]

Arguments and Values:

name ::= a symbol which will be the name of the current model in the current meta-process

Description:

The current-model command can be used to get the name of current model in the current meta-process. If there is a current model then that model's name will be returned. If there is no current model in the current meta-process or there is no current meta-process then **nil** will be returned.

This command is likely to be used when one has code which can be called for different models and it's important to know which model is the current one. An example of that would be the event handler methods for a device which may be called for different models using the same type of device.

Examples:

```
1> (clear-all)
NIL

2> (current-model)
NIL

3> (define-model m1)
M1

4> (current-model)
M1

5> (define-model m2)
M2

6> (current-model)
NIL

7> (define-model m3 (format t "Current-model is: ~S~%" (current-model)))
Current-model is: M3
M3

8> (current-model)
NIL
```

mp-models

Syntax:

mp-models -> (name*)

Arguments and Values:

name ::= a symbol which will be the name of a model in the current meta-process

Description:

The mp-models command can be used to get the names of all of the models defined in the current meta-process. If there is a current meta-process then a list with the names of all the currently defined models will be returned. If there is no current meta-process then a warning will be printed and **nil** will be returned.

This command is likely to be used when one has code which needs to do something for all the current models (like provide some external percept) or perhaps to send a message from one model to all the others in some action (like a vocal speech act).

Examples:

```
1> (clear-all)
NIL

2> (mp-models)
NIL
```

```
3> (define-model m1)
M1

4> (mp-models)
(M1)

5> (define-model m2)
M2

6> (mp-models)
(M2 M1)

E> (mp-models)
#|Warning: mp-models called with no current meta-process. |#
NIL
```

delete-model

Syntax:

delete-model {*name*} -> [**t** | **nil**]
delete-model-fct *name* -> [**t** | **nil**]

Arguments and Values:

name ::= a symbol which should name a model in the current meta-process

Description:

The delete-model command can be used to completely remove a model from the current meta-process. When a name is provided and that name names a model in the current meta-process that model will be completely removed from the meta-process and **t** will be returned. If name does not name a model in the current meta-process or there is no current meta-process then a warning will be printed and **nil** will be returned.

If no name is provided to delete-model then the current model in the current meta-process will be removed from that meta-process. If there is a current model and a current meta-process then that model is removed and **t** will be returned. If no name is provided and there is no current model or no current meta-process then a warning will be printed and **nil** will be returned.

Examples:

```
1> (clear-all)
NIL

2> (define-model m1)
M1

3> (delete-model m1)
T

4> (define-model m2)
```

```
M2

5> (delete-model)
T

6> (define-model m3)
M3

7> (define-model m4)
M4

8> (delete-model-fct 'm3)
T

9> (mp-models)
(M4)

E> (delete-model foo)
#|Warning: No model named FOO in current meta-process. |#
NIL

E> (delete-model)
#|Warning: No current model to delete. |#
NIL

E> (delete-model)
#|Warning: delete-model called with no current meta-process.
No model deleted. |#
NIL
```

with-model

Syntax:

with-model *name form** -> [result | **nil**]
with-model-eval *name form** -> [result | **nil**]
with-model-fct *name* (*form**) -> [result | **nil**]

Arguments and Values:

name ::= a symbol which should name a model in the current meta-process
form ::= a valid Lisp expression to evaluate
result ::= the value returned from the last form evaluated

Description:

The with-model commands are used to set a model to be the current model and then execute some commands. If the name provided is the name of a model in the current meta-process then that model will be set as the current model before evaluating the forms provided. After those forms have been evaluated the current model will be returned to whichever model was the current one before with-model was called. The return value from the last form evaluated will be returned by with-model. If the name provided does not name a model in the current meta-process then a warning will be printed and **nil** will be returned without evaluating any of the forms.

In addition to the usual macro and functional versions of the command there is an additional macro version for with-model – with-model-eval. That command is a hybrid of the functional and macro versions and probably the one which is most likely to be used in code. The difference between with-model and with-model-eval is that with-model-eval will evaluate the expression provided for the name position to determine the name of the model to use.

Examples:

These examples assume that the "unit-1-together-1-mp.cl" example file has been loaded.

```
> (dolist (model (mp-models))
    (format t "Model: ~s~%" model)
    (with-model-eval model
      (goal-focus)))
Model: ADDITION
Will be a copy of SECOND-GOAL when the model runs
SECOND-GOAL
  ISA ADD
   ARG1  5
   ARG2  2
   SUM  NIL
   COUNT  NIL

Model: SEMANTIC
Will be a copy of G1 when the model runs
G1
  ISA IS-MEMBER
   OBJECT  CANARY
   CATEGORY  BIRD
   JUDGMENT  NIL

Model: COUNT
Will be a copy of FIRST-GOAL when the model runs
FIRST-GOAL
  ISA COUNT-FROM
   START  2
   END  4
   COUNT  NIL

NIL

1> (run 10)
     0.000  COUNT     GOAL                SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000  SEMANTIC  GOAL                SET-BUFFER-CHUNK GOAL G1 REQUESTED NIL
     0.000  ADDITION  GOAL                SET-BUFFER-CHUNK GOAL SECOND-GOAL REQUESTED NIL
     0.000  COUNT     PROCEDURAL          CONFLICT-RESOLUTION
     0.000  COUNT     PROCEDURAL          PRODUCTION-SELECTED START
     0.000  COUNT     PROCEDURAL          BUFFER-READ-ACTION GOAL
     0.000  SEMANTIC  PROCEDURAL          CONFLICT-RESOLUTION
     0.000  ADDITION  PROCEDURAL          CONFLICT-RESOLUTION
     0.050  COUNT     PROCEDURAL          PRODUCTION-FIRED START
     0.050  COUNT     PROCEDURAL          MOD-BUFFER-CHUNK GOAL
     0.050  COUNT     PROCEDURAL          MODULE-REQUEST RETRIEVAL
     0.050  COUNT     PROCEDURAL          CLEAR-BUFFER RETRIEVAL
     ...
     0.500  -         ------              Stopped because no events left to process
0.5
144
NIL

2> (with-model semantic
     (goal-focus g2))
```

```
G2

3> (run 10)
     0.500  SEMANTIC  GOAL                  SET-BUFFER-CHUNK GOAL G2 REQUESTED NIL
     0.500  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.550  SEMANTIC  PROCEDURAL            PRODUCTION-FIRED INITIAL-RETRIEVE
     0.550  SEMANTIC  PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.550  SEMANTIC  DECLARATIVE           START-RETRIEVAL
     0.550  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.600  SEMANTIC  DECLARATIVE           RETRIEVED-CHUNK P14
     0.600  SEMANTIC  DECLARATIVE           SET-BUFFER-CHUNK RETRIEVAL P14
     0.600  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.650  SEMANTIC  PROCEDURAL            PRODUCTION-FIRED CHAIN-CATEGORY
     0.650  SEMANTIC  PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.650  SEMANTIC  DECLARATIVE           START-RETRIEVAL
     0.650  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.700  SEMANTIC  DECLARATIVE           RETRIEVED-CHUNK P20
     0.700  SEMANTIC  DECLARATIVE           SET-BUFFER-CHUNK RETRIEVAL P20
     0.700  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.750  SEMANTIC  PROCEDURAL            PRODUCTION-FIRED DIRECT-VERIFY
     0.750  SEMANTIC  PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.750  SEMANTIC  PROCEDURAL            CONFLICT-RESOLUTION
     0.750  -         ------                Stopped because no events left to process
0.25
36
NIL

4> (with-model-fct 'count
     '((goal-focus)))
Goal buffer is empty
NIL

E> (with-model foo (goal-focus))
#|Warning: FOO does not name a model in the current meta-process |#
NIL
```

Asynchronous models

Asynchronous models are probably a little trickier to work with than synchronous models because they require having multiple meta-processes. When there is more than one meta-process there will not be a current meta-process available to work with. Thus, all interactions with the system will require specifying which meta-process to use as the current one.

To create asynchronous models one needs to define the additional meta-processes and then define the models within the appropriate meta-processes. To do that one will need to use the define-meta-process and with-meta-process commands described below along with the define-model command as would normally be used to create a model.

There are some other things to consider when creating additional meta-processes. First, each model only exists in one meta-process – the meta-process in which it is defined. The names for models are only required to be unique within a meta-process (each meta-process has its own model name set). Thus, it is possible to have models with the same name defined in different meta-processes, but that does not create any sort of link or connection between those models. Similarly, the current model is relative to the current meta-process because each meta-process has its own set of models and thus its own current model. If there is only one model defined in each meta-process then it will not be

necessary to also specify which model to use because specifying the meta-process will be sufficient. However, if you have multiple meta-processes defined and more than one model within a meta-process you will have to specify both which meta-process and which model to make current.

An example of defining multiple asynchronous models can be found in the examples directory of the distribution in the file called "unit-1-together-3-mp.cl". That file contains the definitions for all three of the example models from unit 1 of the tutorial (count, addition, and semantic) each being defined within a different meta-process.

After loading that file one cannot just run it using the run command as would be done with the models individually or with the synchronously defined version of the three models described above. Trying to do so would result in this warning with nothing having run:

```
> (run 10)
#|Warning: run called with no current meta-process. |#
NIL
```

Instead, one must specify a current meta-process and then run it. Here is an example running the count model (which is defined in the meta-process named default):

```
> (with-meta-process default
    (run 10))
     0.000 DEFAULT   GOAL                  SET-BUFFER-CHUNK GOAL FIRST-GOAL REQUESTED NIL
     0.000 DEFAULT   PROCEDURAL            CONFLICT-RESOLUTION
     0.000 DEFAULT   PROCEDURAL            PRODUCTION-SELECTED START
     0.000 DEFAULT   PROCEDURAL            BUFFER-READ-ACTION GOAL
     0.050 DEFAULT   PROCEDURAL            PRODUCTION-FIRED START
     0.050 DEFAULT   PROCEDURAL            MOD-BUFFER-CHUNK GOAL
     0.050 DEFAULT   PROCEDURAL            MODULE-REQUEST RETRIEVAL
     0.050 DEFAULT   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     ...
     0.300 DEFAULT   ------                Stopped because no events left to process
0.3
47
NIL
```

To run one of the other models one would then need to specify that meta-process and run it as well. Here is the semantic model being run using the meta-process named semantic in which it was defined:

```
> (with-meta-process semantic
    (run 10))
     0.000 SEMANTIC   GOAL                  SET-BUFFER-CHUNK GOAL G1 REQUESTED NIL
     0.000 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.050 SEMANTIC   PROCEDURAL            PRODUCTION-FIRED INITIAL-RETRIEVE
     0.050 SEMANTIC   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.050 SEMANTIC   DECLARATIVE           START-RETRIEVAL
     0.050 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.100 SEMANTIC   DECLARATIVE           RETRIEVED-CHUNK P14
     0.100 SEMANTIC   DECLARATIVE           SET-BUFFER-CHUNK RETRIEVAL P14
     0.100 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.150 SEMANTIC   PROCEDURAL            PRODUCTION-FIRED DIRECT-VERIFY
     0.150 SEMANTIC   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.150 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.150 SEMANTIC   ------                Stopped because no events left to process
```

```
0.15
24
NIL
```

When there are multiple meta-processes defined the trace will include an additional column to indicate which meta-process is running.

Commands

define-meta-process

Syntax:

define-meta-process *name* -> [name | **nil**]
define-meta-process-fct *name* -> [name | **nil**]

Arguments and Values:

name ::= a symbol which be the name for a meta-process

Description:

The define-meta-process command is used to create a new meta-process. If the name given is a symbol which doesn't name an existing meta-process then a new meta-process with that name is created and that name is returned. If there is already a meta-process with that name or if the name is not a symbol then no meta-process is created, a warning will be printed and **nil** will be returned.

Examples:

```
> (define-meta-process new)
NEW

> (define-meta-process-fct 'another)
ANOTHER

E> (define-meta-process "what")
#|Warning: "what" is not a symbol and thus not valid as a meta-process name. |#
NIL

E> (define-meta-process-fct 'default)
#|Warning: There is already a meta-process named DEFAULT. |#
NIL
```

meta-process-names

Syntax:

meta-process-names -> (name^{+})

Arguments and Values:

name ::= a symbol which will be the name of a meta-process

Description:

The meta-process-names command can be used to get the names of all of the currently defined meta-processes. A list with the names of all the defined meta-process will be returned. There will always be at least one member in the list because the default meta-process will always exist.

Examples:

```
1> (clear-all)
NIL

2> (meta-process-names)
(DEFAULT)

3> (define-meta-process new)
NEW

4> (meta-process-names)
(DEFAULT NEW)
```

delete-meta-process

Syntax:

delete-meta-process *name* -> [**t** | **nil**]
delete-meta-process-fct *name* -> [**t** | **nil**]

Arguments and Values:

name ::= a symbol which should name a meta-process

Description:

The delete-meta-process command is used to delete a meta-process. When the name provided names a meta-process that meta-process and all models defined within it will be removed from the system and **t** will be returned. If name does not name a meta-process then a warning will be printed and **nil** will be returned.

Note that the default meta-process cannot be deleted. If an attempt to delete it is made a warning will be printed and **nil** will be returned.

Examples:

```
1> (clear-all)
NIL

2> (meta-process-names)
(DEFAULT)

3> (define-meta-process new)
```

```
NEW

4> (define-meta-process x)
X

5> (meta-process-names)
(DEFAULT X NEW)

6> (delete-meta-process x)
T

7> (meta-process-names)
(DEFAULT NEW)

8> (delete-meta-process-fct 'new)
T

9> (meta-process-names)
(DEFAULT)

10E> (delete-meta-process new)
#|Warning: NEW does not name a meta-process. |#
NIL

E> (delete-meta-process-fct 'default)
#|Warning: Cannot delete the default meta-process. |#
NIL
```

current-meta-process

Syntax:

current-meta-process -> [name | **nil**]

Arguments and Values:

name ::= a symbol which will be the name of the current meta-process

Description:

The current-meta-process command can be used to get the name of the current meta-process. If there is a current meta-process then that meta-process's name will be returned. If there is no current meta-process then **nil** will be returned.

Examples:

```
1> (clear-all)
NIL

2> (current-meta-process)
DEFAULT

3> (define-meta-process new)
NEW

4> (current-meta-process)
NIL
```

```
5> (delete-meta-process new)
T

6> (current-meta-process)
DEFAULT
```

with-meta-process

Syntax:

with-meta-process *name form** -> [result | **nil**]
with-meta-process-eval *name form** -> [result | **nil**]
with-meta-process-fct *name* (*form**) -> [result | **nil**]

Arguments and Values:

name ::= a symbol which should name a meta-process
form ::= a valid Lisp expression to evaluate
result ::= the value returned from the last form evaluated

Description:

The with-meta-process commands are used to set the current meta-process and then execute some commands. If the name provided is the name of a meta-process then that meta-process will be set as the current one before evaluating the forms provided. After those forms have been evaluated the current meta-process will be returned to whichever meta-process was the current one before with-meta-process was called. The return value from the last form evaluated will be returned by with-meta-process. If the name provided does not name a meta-process then a warning will be printed and **nil** will be returned without evaluating any of the forms.

In addition to the usual macro and functional versions of the command there is an additional macro version for with-meta-process – with-meta-process-eval. That command is a hybrid of the functional and macro versions. The difference between with-meta-process and with-meta-process-eval is that with-meta-process-eval will evaluate the expression provided for the name position to determine the name of the model to use.

Examples:

These examples assume that the “unit-1-together-3-mp.cl” example file has been loaded.

```
> (dolist (mp (meta-process-names))
    (with-meta-process-eval mp
     (format t "Meta-process ~s has current model ~s~%" mp (current-model))))

Meta-process DEFAULT has current model COUNT
Meta-process SEMANTIC has current model SEMANTIC
Meta-process ADDITION has current model ADDITION
NIL

> (with-meta-process semantic
    (run 10))
```

```
     0.000 SEMANTIC   GOAL                  SET-BUFFER-CHUNK GOAL G1 REQUESTED NIL
     0.000 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.050 SEMANTIC   PROCEDURAL            PRODUCTION-FIRED INITIAL-RETRIEVE
     0.050 SEMANTIC   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.050 SEMANTIC   DECLARATIVE           START-RETRIEVAL
     0.050 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.100 SEMANTIC   DECLARATIVE           RETRIEVED-CHUNK P14
     0.100 SEMANTIC   DECLARATIVE           SET-BUFFER-CHUNK RETRIEVAL P14
     0.100 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.150 SEMANTIC   PROCEDURAL            PRODUCTION-FIRED DIRECT-VERIFY
     0.150 SEMANTIC   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.150 SEMANTIC   PROCEDURAL            CONFLICT-RESOLUTION
     0.150 SEMANTIC   ------                 Stopped because no events left to process
0.15
24
NIL

> (with-meta-process-fct 'addition
    '((goal-focus)))
Will be a copy of SECOND-GOAL when the model runs
SECOND-GOAL
  ISA ADD
   ARG1  5
   ARG2  2
   SUM  NIL
   COUNT  NIL

SECOND-GOAL

E> (with-meta-process x
     (goal-focus))

#|Warning: No actions taken in with-meta-process because X does not name a meta-process |#
```

Combining synchronous and asynchronous models

It is possible to use both synchronous and asynchronous models together by defining multiple models synchronously within different meta-processes. There are no additional commands necessary for doing so, but there are a couple of things worth noting about such situations. First, as was indicated in the asynchronous section it will require specifying both a current meta-process and a current model when interacting with the models. Also, when running synchronous models in asynchronous meta-processes there will be a additional column shown in the trace because it will show both the current meta-process and the current-model.

There is an example file called “unit-1-together-2-mp.cl” in the examples directory of the distribution. It define all three example models from unit 1 of the tutorial together split between two different meta-processes. The count model is defined in the default meta-process and the semantic and addition models are defined in a meta-process named others. Here is some of the trace from running the others meta-process:

```
> (with-meta-process others
    (run 10))
     0.000 OTHERS  SEMANTIC  GOAL         SET-BUFFER-CHUNK GOAL G1 REQUESTED NIL
     0.000 OTHERS  ADDITION  GOAL         SET-BUFFER-CHUNK GOAL SECOND-GOAL REQUESTED NIL
     0.000 OTHERS  SEMANTIC  PROCEDURAL   CONFLICT-RESOLUTION
```

```
     0.000 OTHERS  ADDITION  PROCEDURAL   CONFLICT-RESOLUTION
     0.050 OTHERS  SEMANTIC  PROCEDURAL   PRODUCTION-FIRED INITIAL-RETRIEVE
     0.050 OTHERS  SEMANTIC  PROCEDURAL   CLEAR-BUFFER RETRIEVAL
     ...
     0.500 OTHERS  -         ------       Stopped because no events left to process
0.5
97
NIL
```

There we can see the additional columns indicating the meta-process being run and then the model for which the event occurred.

Other multiple model examples

There are two other example models which define multiple synchronous models available in the examples directory. Each will be described briefly here and more details can be found in the comments in those files.

The "multi-model-talking.cl" file shows a custom device being defined which allows multiple models to hear each other as they speak. It also creates three models which can be run to show some very simple interaction among them using that device.

The "game-of-life.cl" file uses multiple models along with a custom device and the AGI to display a set of cells following the rules of Conway's Game of Life. Each cell is controlled by a separate model. The custom device allows them to see how many neighbors they have and provides a way for them to announce any change to the cell vocally each cycle.

Multi-buffers

A new addition to the system is what is being called a multi-buffer. The multi-buffers add some new possibilities to how a module can use its buffer as well as possibly changing how the procedural module will interact with that buffer. These changes are currently of an experimental nature and thus the primary sections on buffers, modules, and procedural matching are not going to be updated to reflect this information until the multi-buffers have had some use and further evaluation. If you do use multi-buffers in your own modules please let me know of any problems you encounter or suggestions for improvements which you have.

The multi-buffers have been introduced as a general mechanism to allow for the implementation of modules which do things which were not easy to do with the system previously. One such module was the threaded cognition module by Salvucci and Taatgen. Prior to the introduction of the multi-buffers, the implementation of the threaded cognition module required making changes to many internal functions of the system. That made that module difficult to maintain since it had to be updated often to stay in line with updates and changes to the main system. Those changes also had the potential to interfere with modules written by other people which could lead to problems integrating different new mechanisms. The current conception of the multi-buffers is sufficient to allow threaded cognition to be implemented as a module which does not require changing any of the main system code. The hope is that the multi-buffer concept may be useful in other areas as well.

The difference between a multi-buffer and a "normal" buffer is that a module with a multi-buffer may specify a set of chunks which can be placed into the buffer without being copied first. As with a normal buffer the multi-buffer is still restricted to only holding one chunk at any time. For chunks which are not in the "buffer set" of a multi-buffer, it will work like a normal buffer and copy the chunk first.

The other possibility with a multi-buffer is to allow the procedural module to search the buffer set to find a matching chunk during production matching. Allowing the search is optional – one can have a multi-buffer which is not searched in which case only the chunk currently in the buffer will be considered for procedural matching just like a normal buffer. The basic multi-buffer will be described here and the additional information needed for a searched buffer will be in the next section.

Not every chunk can be added to the buffer set of a multi-buffer. Essentially, only those chunks which are created by the module itself are valid members of the multi-set. Chunks which are, or could potentially be, referenced by other modules are generally invalid as members of a buffer set. In particular, chunks which have been cleared from a buffer and chunks which have been explicitly added into declarative memory cannot be put into a buffer set. Additionally, there is a way to mark a chunk as explicitly unavailable for the buffer set of a multi-buffer which a module may want to do to avoid outside modifications of its chunks. The buffer-set-invalid parameter of a chunk can be set to **t** to make it invalid for a buffer-set:

(setf (chunk-buffer-set-invalid *chunk*) **t**)

If a chunk is already in a buffer set when it is marked as invalid then it will remain in the buffer set, but will be copied into the buffer from that point forward.

Several of the existing buffer related commands have been modified to work with multi-buffers. The set-buffer-chunk and overwrite-buffer-chunk commands have been modified to work with multi-buffers to handle the skipping of the copying. When putting a chunk into a multi-buffer with those commands if the buffer is a multi-buffer and if the chunk is not marked as invalid for a buffer set then the buffer-set of that multi-buffer will be checked and if the chunk is a member it will not be copied. The clear-buffer command has been modified so that if the chunk being cleared from a buffer is coming from a multi-buffer and that chunk is a member of that multi-buffer's buffer set then it will also be removed from the buffer set. Finally, the buffer-chunk command has been changed to now show the buffer set of a multi-buffer when that buffer's information is displayed. The buffer set will be shown in curly braces after the name of the chunk in the buffer if it contains any chunks.

When working with a multi-buffer a module should be careful to not allow chunks which it wants to remain in the buffer set to be cleared from the buffer. The module should probably use overwrite-buffer-chunk instead of set-buffer-chunk to avoid clearing the current chunk first. Similarly, the module may want to turn off strict-harvesting for the multi-buffer to avoid the automatic clearing that the procedural module may perform. Note however that a request to the multi-buffer from a production will still clear the buffer. Thus, care may be required in how a model's productions interact with the multi-buffer if the buffer set is to be maintained.

To create a multi-buffer the module needs to provide a sixth item in the buffer definition list for the buffer in the module definition. A value of the keyword :multi will make the buffer a multi-buffer. There are other keyword values which create a searchable buffer described in the section below. If an invalid sixth item is given then a warning will be printed and the module will not be created.

There are four new commands that are used to work with the buffer set of a multi-buffer and one new general buffer command which should be useful for multi-buffers. For all of the examples shown in the new commands this module with two multi-buffers, foo and bar, is assumed to exist:

```
(define-module :foo ((foo nil nil nil nil :multi)(bar nil nil nil nil :multi)) nil
               :query goal-style-query :version "" :documentation "")
```

As is this model which creates some initial chunks to use in the examples:

```
(define-model foo (sgp :v t)
  (define-chunks (a isa chunk) (b isa chunk) (c isa chunk))
  (add-dm (d isa chunk)))
```

Commands

store-m-buffer-chunk

Syntax:

store-m-buffer-chunk *buffer chunk* -> [chunk | **nil**]

Arguments and Values:

buffer ::= a symbol which is the name of a multi-buffer
chunk ::= a symbol which is the name of a chunk to add to the buffer set of buffer

Description:

The store-m-buffer-chunk command is used to add a chunk to the buffer set of a multi-buffer. If the buffer name given is the name of a multi-buffer and the chunk names a chunk defined in the current model of the current meta-process which is not marked as invalid for a buffer set then that chunk will be added to the buffer set of that multi-buffer in the current model and the chunk name chunk will be returned. If the chunk is already a member of the buffer set then no change to the buffer set is made and the chunk name is still returned.

If there is no current model, no current meta-process, buffer does not name a multi-buffer, chunk is not a valid chunk name, or chunk names a chunk which is marked as invalid for a buffer set then there will be a warning printed and the value **nil** will be returned.

Examples:

These examples assume the module and model shown above have been defined.

```
1> (reset)
DEFAULT

2> (buffer-chunk foo bar)
FOO: NIL
BAR: NIL
(NIL NIL)

3> (store-m-buffer-chunk 'foo 'a)
A

4> (store-m-buffer-chunk 'foo 'b)
B

5> (store-m-buffer-chunk 'bar 'b)
B

6> (buffer-chunk foo bar)
FOO: NIL  {A B}
BAR: NIL  {B}
(NIL NIL)

7> (set-buffer-chunk 'foo 'a)
A
```

```
8> (buffer-chunk foo)
FOO: A  {A B}
A
  ISA CHUNK

(A)

9> (set-buffer-chunk 'foo 'b)
B

10> (buffer-chunk foo)
FOO: B  {B}
B
  ISA CHUNK

(B)

11> (setf (chunk-buffer-set-invalid 'b) t)
T

12> (overwrite-buffer-chunk 'foo 'b)
B-0

13> (buffer-chunk foo)
FOO: B-0 [B] {B}
B-0
  ISA CHUNK

(B-0)

E> (store-m-buffer-chunk 'goal 'a)
#|Warning: store-m-buffer-chunk cannot store a chunk in buffer GOAL because it is not a
multi-buffer |#
NIL

E>: (store-m-buffer-chunk 'foo 'd)
#|Warning: store-m-buffer-chunk cannot store D in a buffer set because it has been marked
as invalid for a buffer set most likely because it has been previously cleared from a
buffer |#
NIL
```

get-m-buffer-chunks

Syntax:

get-m-buffer-chunks *buffer* -> (chunk*)

Arguments and Values:

buffer ::= a symbol which is the name of a multi-buffer
chunk ::= a symbol which is the name of a chunk in the buffer set of buffer

Description:

The get-m-buffer-chunks command is used to get the buffer set of a multi-buffer. If the buffer name given is the name of a multi-buffer then a list of the chunks which are in the buffer set of that multi-buffer in the current model of the current meta-process will be returned. There is no specification for

the ordering of the chunks in the list which is returned. Thus, one should not assume anything about the buffer set based on that ordering.

If there is no current model, no current meta-process, or buffer does not name a multi-buffer a warning printed and the value **nil** will be returned.

Examples:

These examples assume the module and model shown above have been defined.

```
1> (reset)
DEFAULT

2> (store-m-buffer-chunk 'foo 'a)
A

3> (store-m-buffer-chunk 'foo 'c)
C

4> (store-m-buffer-chunk 'bar 'a)
A

5> (store-m-buffer-chunk 'bar 'b)
B

6> (get-m-buffer-chunks 'foo)
(A C)

7> (get-m-buffer-chunks 'bar)
(A B)

E> (get-m-buffer-chunks 'goal)
#|Warning: get-m-buffer-chunks cannot return a chunk set for buffer GOAL because it is not
a multi-buffer |#
NIL
```

remove-m-buffer-chunk

Syntax:

remove-m-buffer-chunk *buffer chunk* -> [chunk | **nil**]

Arguments and Values:

buffer ::= a symbol which is the name of a multi-buffer
chunk ::= a symbol which is the name of a chunk to remove from the buffer set of buffer

Description:

The remove-m-buffer-chunk command is used to remove a chunk from the buffer set of a multi-buffer. If the buffer name given is the name of a multi-buffer and the chunk names a chunk defined in the current model of the current meta-process which is currently in the buffer set of that multi-buffer then that chunk will be removed from that buffer set and the chunk name will be returned. If

the chunk is not a member of the buffer set then no change to the buffer set is made and the chunk name is still returned.

If there is no current model, no current meta-process, buffer does not name a multi-buffer, or chunk is not a valid chunk name then there will be a warning printed and the value **nil** will be returned.

Examples:

These examples assume the module and model shown above have been defined.

```
1> (reset)
DEFAULT

2> (store-m-buffer-chunk 'foo 'a)
A

3> (store-m-buffer-chunk 'foo 'c)
C

4> (store-m-buffer-chunk 'bar 'a)
A

5> (store-m-buffer-chunk 'bar 'b)
B

6> (get-m-buffer-chunks 'foo)
(A C)

7> (get-m-buffer-chunks 'bar)
(A B)

8> (remove-m-buffer-chunk 'foo 'a)
A

9> (remove-m-buffer-chunk 'bar 'b)
B

10> (get-m-buffer-chunks 'foo)
(C)

11> (get-m-buffer-chunks 'bar)
(A)

12> (remove-m-buffer-chunk 'bar 'd)
D

13> (get-m-buffer-chunks 'bar)
(A)

E> (remove-m-buffer-chunk 'goal 'a)
#|Warning: remove-m-buffer-chunk cannot remove a chunk from buffer GOAL because it is not
a multi-buffer |#
NIL

E> (remove-m-buffer-chunk 'bar :not-a-chunk)
#|Warning: remove-m-buffer-chunk cannot remove :NOT-A-CHUNK from the buffer set because it
does not name a chunk |#
NIL
```

remove-all-m-buffer-chunks

Syntax:

remove-all-m-buffer-chunks *buffer* -> [**t** | **nil**]

Arguments and Values:

buffer ::= a symbol which is the name of a multi-buffer

Description:

The remove-all-m-buffer-chunks command is used to remove all of the chunks from the buffer set of a multi-buffer. If the buffer name given is the name of a multi-buffer then the buffer set of that multi-buffer in the current model of the current meta-process will be cleared and the value **t** will be returned.

If there is no current model, no current meta-process, or buffer does not name a multi-buffer then there will be a warning printed and the value **nil** will be returned.

Examples:

These examples assume the module and model shown above have been defined.

```
1> (reset)
DEFAULT

2> (store-m-buffer-chunk 'foo 'a)
A

3> (store-m-buffer-chunk 'foo 'b)
B

4> (get-m-buffer-chunks 'foo)
(A B)

5> (remove-all-m-buffer-chunks 'foo)
T

6> (get-m-buffer-chunks 'foo)
NIL

E> (remove-all-m-buffer-chunks 'goal)
#|Warning: remove-all-m-buffer-chunks cannot remove a chunk from buffer GOAL because it is
not a multi-buffer |#
NIL
```

erase-buffer

Syntax:

erase-buffer *buffer* -> [chunk | **nil**]

Arguments and Values:

buffer ::= a symbol which is the name of a multi-buffer
chunk ::= a symbol which is the name of a chunk

Description:

The erase-buffer command is used to remove a chunk from a buffer without notifying other modules. It is similar to clear-buffer except that it skips the notification step. That will prevent the chunk from being collected by declarative memory and thus being marked as invalid for a buffer set. Thus, erase-buffer is to clear-buffer as overwrite-buffer-chunk is to set-buffer-chunk. If the buffer name given is the name of a buffer then if there is a chunk in that buffer that chunk will be removed from the buffer and the chunk name will be returned. If the buffer is already empty then **nil** will be returned.

If there is no current model, no current meta-process, or buffer does not name a buffer then there will be a warning printed and the value **nil** will be returned.

Examples:

These examples assume the module and model shown above have been defined.

```
1> (reset)
DEFAULT

2> (store-m-buffer-chunk 'foo 'a)
A

3> (store-m-buffer-chunk 'foo 'c)
C

4> (set-buffer-chunk 'foo 'a)
A

5> (set-buffer-chunk 'goal 'a)
A-0

6> (buffer-chunk foo goal)
FOO: A  {A C}
A
  ISA CHUNK

GOAL: A-0 [A]
A-0
  ISA CHUNK

(A A-0)

7> (erase-buffer 'foo)
A

8> (buffer-chunk foo)
FOO: NIL  {A C}
(NIL)

9> (erase-buffer 'goal)
A-0
```

```
10> (set-buffer-chunk 'foo 'a)
A

11> (buffer-chunk foo)
FOO: A  {A C}
A
  ISA CHUNK

(A)

12> (clear-buffer 'foo)
A

13> (buffer-chunk foo)
FOO: NIL  {C}
(NIL)

E> (erase-buffer :not-a-buffer)
#|Warning: erase-buffer called with an invalid buffer name :NOT-A-BUFFER |#
NIL
```

Searchable buffers

A searchable buffer is a multi-buffer which the procedural module will treat differently than other buffers. Except for the different treatment from the procedural module, a searchable buffer operates like a multi-buffer as described in the previous section (with one optional exception described later). When the procedural module matches a production's condition against a searchable buffer it does not restrict the matching to the chunk which is in the buffer. Instead, it will search the buffer set of that buffer to find a chunk which matches. How that search takes place and how the module participates in the search will be detailed in this section.

An important consideration in the development of the searchable buffers was to maintain plausibility. That means avoiding the potential multiple instantiation issues as well as the ability to solve NP-hard problems within a single production. The concept that seems to best fit with those constraints is to limit the search such that it is performed in parallel for all searchable buffers within a production, each search buffer may only have one set of conditions in a single production (i.e. only one chunk match is allowed), and then to limit that search to the first chunk found to match.

The testing of the conditions for a production then follows these steps:

- Normal buffer's conditions are tested and variable bindings occur
    - If it is a dynamic production this includes bindings from the variableized slots
- Other conditions which use only those variables (or none) are tested (!eval!, !bind!, queries)
- Each search buffer has its buffer set searched to find a chunk which matches all of the conditions that are currently defined i.e. involve constants or already bound variables
- Bind all of the variables necessary from the search buffer chunks found
- Test all remaining condition

There are a couple of additional details to add to that. One important issue is that if there is more than one search buffer tested within a production this is not guaranteed to find a set of chunks which satisfy all of the conditions in that production because tests among the search buffer chunks is performed after the search has completed. It will not go back and search again to find other chunks if those conditions fail to match.

Another thing to note relates to dynamic productions. Because the variablized slot bindings occur before the search, a variable bound in a search buffer condition cannot be used as a variablized slot. However, a search buffer could test variablized slots that were bound in the normal buffer conditions. This is the result of generalizing the constraint of dynamic testing which only allows one level of indirection to include the search as a level of indirection.

Once the conflict set has been determined the production with the highest utility in the set will be selected and fired. If that production involved one or more search buffers, then the chunk(s) found during the search will be placed into the appropriate buffer(s) at the time it is selected.

There are two ways for the module which owns the search buffer to effect the search and selection process. First, the module may specify the order in which to search the buffer set and possibly exclude some members. The module can add a search function by specifying a function with the :search keyword in the module definition. The search function will be called once during each conflict-resolution event. It will be passed the module instance and the symbol naming a search buffer of the module. It should return a list of chunks from the buffer set in the order that they are to be searched. Any chunks in the list returned which are not in the buffer set will be ignored in the search. If no search function is provided for the module then the whole buffer set will be searched in an arbitrary order.

The other thing the module can do is specify a preference for each of the chunks which have matched to offset the utilities of the productions which matched them. To do that the module must specify an offset function with the :offset keyword in the module definition. The offset function will be called once during each conflict-resolution event in which the conflict set is non-empty. The function will be passed three parameters: the module instance, a symbol naming a search buffer of the module, and a list of the chunks from the buffer set of that buffer which were found as matches in some production. The return value from that function should be a list of numbers of the same length as the list of chunks it was passed where each number will be the offset for the corresponding chunk's matching in a production. Those offset values will be added to the utility of a production which matched that chunk before determining which production to fire. To recommendation for offsets is to return 0 for a preferred chunk and significantly large negative values for non-preferred chunks.

To create a search buffer for a module one must specify a sixth parameter in the buffer definition similar to how a multi-buffer is specified. For search buffers there are actually two options available. The first is to specify the keyword :search. That will create a multi-buffer which has the search capability described above. The other option is to specify the value :search-copy. This will create a

special variation of a multi-buffer. A buffer created with :search-copy will actually have the chunks from the buffer set copied into the buffer like a normal buffer does. Otherwise, the search-copy buffer operates just like a standard searchable buffer. The advantage of using a search-copy buffer is that the chunks in the buffer set are then protected from being unintentionally cleared from the buffer (and thus being removed from the buffer set) via a production which finds them as a match.

Configuring Real Time Operation

When a meta-process is run with the real-time flag set to true the system is run in step with an external clock. By default, the clock used is the Lisp get-internal-real-time function, but the user can change that default behavior to specify an alternate clock as well as customize some other features of how the meta-process executes in real time mode. The command mp-real-time-management, described below, is the mechanism for changing the operation, but before describing that command how the meta-process runs in real-time will be described.

When a meta-process is not run in real time mode, as described in the running section, the scheduled events drive the clock directly and there is no delay between event executions regardless of the difference in time between them. When the meta-process runs in real time mode the "ACT-R time" is still determined by the events on the queue, but their execution is delayed, if necessary, so as to not run ahead of the real time clock provided. Here is some Lisp pseudo-code that describes the operation of the meta-process running in real time mode:

```
(let ((actr-start (mp-time))
      (real-start (funcall real-time-clock)))

  (loop

    (when (run-end-conditions-satisfied) (return))

    (when (and (numberp max-delta) (> (- (evt-time (next-event)) (mp-time)) max-delta))
      (dolist (model (mp-models))
        (with-model-eval model
          (schedule-event-relative max-delta 'dummy-event-function
                                   :priority :max
                                   :details "A dummy event to prevent model skip ahead"
                                   :output nil))))

    (do* ((current-real-time (funcall real-time-clock))
                             (funcall real-time-clock)))
          (delta-model (- (evt-time (next-event)) actr-start)
                       (- (evt-time (next-event)) actr-start))
          (delta-real (/ (- current-real-time real-start) real-units-per-second)
                      (/ (- current-real-time real-start) real-units-per-second)))
        ((>= delta-real delta-model))
      (funcall real-time-slack (- delta-model delta-real) (evt-time (next-event))))

    (setf (mp-time) (evt-time (next-event)))

    (execute (next-event))))
```

The functions in blue are not real ACT-R commands, but should be assumed to work as follows:

run-end-conditions-satisfied returns true when conditions specified for the current run have been met.

next-event returns the next event from the event queue.

execute performs all the actions necessary to deal with an event (calling the event hooks, printing the trace, calling the function, etc.).

The variables in red are items that can be set by the user to control how real time runs using the mp-real-time-management function. How to set them is described with the command's details below. Their general usage is shown in the pseudo-code above and here are some more details:

real-time-clock this must be a function that takes no parameters. It should return a number which represents a time. The time reference is not used as an absolute time, but an interval timer to pace the model. It should return non-decreasing values for time in any units desired. The default function for this value is the Lisp function **get-internal-real-time**.

real-units-per-second this should be a number which is used to scale the return value from the real-time-clock function into seconds. The default value is the value of the Lisp variable **internal-time-units-per-second**.

max-delta is used to set a maximum time interval between events in the meta-process. If it is set to a number, then that is assumed to be the maximum time in seconds allowed between successive events. If there is not an event scheduled within that amount of time from the current time, then a dummy event is scheduled for every model max-delta seconds from now. Note that if there are multiple models running in the meta-process then this does not impose a bound on the amount of time that a single model may go without an event, just how long the meta-process will go without processing one. The default value for this is **nil** which means there is no bound placed on the interval between events.

real-time-slack this must be a function which accepts two parameters. It is called whenever the next model event is "ahead" of the current interval length as reported by the real-time-clock i.e. when the model must wait before executing the event. The function is passed two values. The first is the duration which the model must wait in seconds, and the second is the ACT-R time of that next event in seconds. The function should perform some appropriate action to allow the time to pass cleanly which may involve calling some Lisp implementation specific functions to handle system events if necessary. The default value for this function is one which calls the Lisp function **sleep** with the duration which the model must wait if it is greater than .15 seconds.

Dynamic events

Both the real-time-clock and real-time-slack functions may schedule new ACT-R events. This is the recommended way to place events from an external simulation into the event queue. This is especially true if the external communication is being handled in a separate Lisp process because the ACT-R scheduling commands are not "thread safe" and thus should only be called by code running in the main ACT-R process. [How such a process communicates with these functions to schedule events should be properly protected, and such mechanisms are up to the user to implement since the requirements may vary among Lisp implementations.] Those external events may occur before the

current “next event” in some circumstances as well, though it is not possible to schedule an event for a time which has already past. Because the real time operation always checks for the next event it will properly detect any events which occur earlier than the current next event and use that to determine the appropriate waiting time.

The most likely situation where an event would be entered prior to the current next one would happen when the model is “waiting” for a long request to finish before the next production will match i.e. conflict-resolution fails and thus gets scheduled for after that next event. When not in real time mode that works fine because nothing else could happen during that period, but when connecting to an external simulation some external event could happen during that interval and the model should be able to detect that. If such events could occur in a simulation and the modeler wants the model to be sensitive to those events then there are two things that need to be done. First, when configuring the real time control with mp-real-time-management the :allow-dynamics parameter should be specified as true. This lets the meta-process know that events may be scheduled prior to the current next event and that they are important to the model. With that setting enabled, events which were scheduled based on the contents of the event queue (those scheduled with schedule-event-after-* commands) may be reevaluated and rescheduled based on newly scheduled events. Only events which are specified as being dynamic when created will be reconsidered when new events are scheduled. Of the events generated by the standard modules of the system, only the procedural module currently schedules dynamic events. The conflict-resolution events that it generates are specified as dynamic. Thus, conflict-resolution events will be rescheduled to occur after newer events which are added to the queue. That may be all that is needed in many situations, but if the modeler creates other events for the simulation or model which are to be sensitive to newly scheduled events then those events need to have the dynamic flag set to true when they are scheduled.

Commands

mp-real-time-management

Syntax:

mp-real-time-management {**:time-function** *timefct*} {**:units-per-second** *ups*} {**:slack-function** *slackfct*} {**:max-time-delta** *delta*} {**:allow-dynamics** *dynamics*} -> [**t** | **nil**]

Arguments and Values:

timefct ::= a function or a symbol which names a function to use as the real time clock (default is **get-internal-real-time)**

ups ::= a positive number specifying the number of units returned by timefct in a second (default is **internal-time-units-per-second)**

slackfct ::= a function or a symbol which names a function to call when the model needs to wait (default is **real-time-slack**)

delta ::= **nil** or a positive number specifying the maximum time in seconds allowed between events (default is **nil**)

dynamics ::= a generalized boolean indicating whether to reschedule dynamic events (default is **nil**)

Description:

The mp-real-time-management command is used to modify how the current meta-process will operate when run with the real-time flag set to true. The real time controls for the current meta-process are set to the provided values and default settings for those parameters not provided. How those controls affect the operation of the system is described in the Configuring Real Time Operation section above.

If there is no current meta-process or one or more of the parameters are invalid then no changes will be made, there will be a warning printed, and the value **nil** will be returned.

Examples:

These first two examples show how the real time running could be made faster or slower than real time (respectively) without adjusting any other values.

```
> (mp-real-time-management :units-per-second (/ internal-time-units-per-second 2))
T

> (mp-real-time-management :units-per-second (* internal-time-units-per-second 2))
T
```

The next examples show max-time-delta causing intermediate events to be scheduled and by enabling or disabling the allow-dynamics setting how that affects when conflict-resolution occurs. To do that this model is assumed to be defined prior to these actions:

```
(define-model test-model
  (sgp :esc t :lf 1.0 :trace-detail medium)

  (p start
     ?goal>
       buffer empty
    ==>
     +goal>
       isa chunk
     +retrieval>
       isa chunk))

1> (reset)
DEFAULT

2> (run 10 :real-time t)
     0.000   PROCEDURAL            CONFLICT-RESOLUTION
     0.050   PROCEDURAL            PRODUCTION-FIRED START
     0.050   PROCEDURAL            CLEAR-BUFFER GOAL
     0.050   PROCEDURAL            CLEAR-BUFFER RETRIEVAL
     0.050   GOAL                  SET-BUFFER-CHUNK GOAL CHUNK0
     0.050   DECLARATIVE           START-RETRIEVAL
     0.050   PROCEDURAL            CONFLICT-RESOLUTION
     1.050   DECLARATIVE           RETRIEVAL-FAILURE
     1.050   PROCEDURAL            CONFLICT-RESOLUTION
     1.050   ------                Stopped because no events left to process
1.05
17
```

```
NIL

3> (reset)
DEFAULT

4> (mp-real-time-management :allow-dynamics nil :max-time-delta 0.5)
T

5> (run 10 :real-time t)
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.050   PROCEDURAL             PRODUCTION-FIRED START
     0.050   PROCEDURAL             CLEAR-BUFFER GOAL
     0.050   PROCEDURAL             CLEAR-BUFFER RETRIEVAL
     0.050   GOAL                   SET-BUFFER-CHUNK GOAL CHUNK0
     0.050   DECLARATIVE            START-RETRIEVAL
     0.050   PROCEDURAL             CONFLICT-RESOLUTION
     1.050   DECLARATIVE            RETRIEVAL-FAILURE
     1.050   PROCEDURAL             CONFLICT-RESOLUTION
     1.050   ------                 Stopped because no events left to process
1.05
18
NIL
```

Notice that an extra event occurred in the second run relative to the first although there was nothing different displayed in the trace. A non-printing event occurred at time .550 because the gap between events at .05 and 1.0 was greater than the maximum time of .5 specified by :max-time-delta.

```
5> (reset)
DEFAULT

6> (mp-real-time-management :allow-dynamics t :max-time-delta 0.5)
T

6> (run 10 :real-time t)
     0.000   PROCEDURAL             CONFLICT-RESOLUTION
     0.050   PROCEDURAL             PRODUCTION-FIRED START
     0.050   PROCEDURAL             CLEAR-BUFFER GOAL
     0.050   PROCEDURAL             CLEAR-BUFFER RETRIEVAL
     0.050   GOAL                   SET-BUFFER-CHUNK GOAL CHUNK0
     0.050   DECLARATIVE            START-RETRIEVAL
     0.050   PROCEDURAL             CONFLICT-RESOLUTION
     0.550   PROCEDURAL             CONFLICT-RESOLUTION
     1.050   DECLARATIVE            RETRIEVAL-FAILURE
     1.050   PROCEDURAL             CONFLICT-RESOLUTION
     1.050   ------                 Stopped because no events left to process
1.05
19
NIL
```

This time because :allow-dynamics was set to t a conflict-resolution event occurred at time .550 because it was allowed to be moved back when the event generated because of the time delta was scheduled.

```
E> (mp-real-time-management :max-time-delta t)
#|Warning: Max-time-delta T is not a positive number or nil |#
NIL

E> (mp-real-time-management :allow-dynamics nil :max-time-delta 0.5)
#|Warning: mp-real-time-management called with no current meta-process. |#
NIL
```

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