p. 138

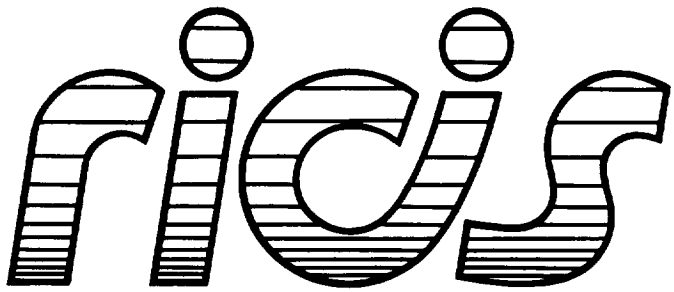
ART/Ada Design Project - Phase I Final Report

Inference Corporation

March 1989

Cooperative Agreement NCC 9-16
Research Activity No. SE.19

NASA Johnson Space Center
Information Systems Directorate
Information Technology Division



Research Institute for Computing and Information Systems
University of Houston - Clear Lake

T·E·C·H·N·I·C·A·L R·E·P·O·R·T

The RICIS Concept

The University of Houston-Clear Lake established the Research Institute for Computing and Information systems in 1986 to encourage NASA Johnson Space Center and local industry to actively support research in the computing and information sciences. As part of this endeavor, UH-Clear Lake proposed a partnership with JSC to jointly define and manage an integrated program of research in advanced data processing technology needed for JSC's main missions, including administrative, engineering and science responsibilities. JSC agreed and entered into a three-year cooperative agreement with UH-Clear Lake beginning in May, 1986, to jointly plan and execute such research through RICIS. Additionally, under Cooperative Agreement NCC 9-16, computing and educational facilities are shared by the two institutions to conduct the research.

The mission of RICIS is to conduct, coordinate and disseminate research on computing and information systems among researchers, sponsors and users from UH-Clear Lake, NASA/JSC, and other research organizations. Within UH-Clear Lake, the mission is being implemented through interdisciplinary involvement of faculty and students from each of the four schools: Business, Education, Human Sciences and Humanities, and Natural and Applied Sciences.

Other research organizations are involved via the "gateway" concept. UH-Clear Lake establishes relationships with other universities and research organizations, having common research interests, to provide additional sources of expertise to conduct needed research.

A major role of RICIS is to find the best match of sponsors, researchers and research objectives to advance knowledge in the computing and information sciences. Working jointly with NASA/JSC, RICIS advises on research needs, recommends principals for conducting the research, provides technical and administrative support to coordinate the research, and integrates technical results into the cooperative goals of UH-Clear Lake and NASA/JSC.

ART/Ada Design Project - Phase I
Final Report

Preface

This research was conducted under auspices of the Research Institute for Computing and Information Systems by Inference Corporation. Dr. Charles McKay served as RICIS research coordinator.

Funding has been provided by the Information Systems Directorate, NASA/JSC through Cooperative Agreement NCC 9-16 between the NASA Johnson Space Center and the University of Houston-Clear Lake. The NASA technical monitor for this activity was Robert T. Savely, of the Software Technology Branch, Information Technology Division, Information Systems Directorate, NASA/JSC.

ART/Ada Design Project - Phase I

Final Report

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Table of Contents

List of Figures

List of Tables

1. Introduction

Under subcontract to University of Houston - Clear Lake as part of the Cooperative Agreement between UHCL and NASA Johnson Space Center, Inference Corporation conducted an Ada-Based Expert System Building Tool Design Research Project. The goal of the research project was to investigate various issues in the context of the design of an Ada-based expert systems building tool. The research project attempted to achieve a comprehensive understanding of the potential for embedding expert systems in Ada systems, for eventual application in future projects.

This report will describe the current status of the project by introducing an operational prototype, ART/Ada. It will then explain how the project was conducted analyze the performance of the prototype, compare it with other related works, and suggest future research directions.

2. Project Goal

This chapter identifies the goal of the Ada-Based Expert System Building Tool Design Research Project.

This chapter is composed of three sections:

- Conventional Expert System Tools
- Considerations for Ada Environment
- Requirements for the Real-Time Embedded Systems

As the Department of Defense mandate to standardize on Ada as the language for embedded software systems development begins to be actively enforced, interest from developers of large-scale Ada systems in making expert systems technology readily available in Ada environments has increased.

Two examples of Ada applications that can benefit from the use of expert systems are monitoring and control systems and decision support systems. Monitoring and control systems demand real-time performance, small execution images, tight integration with other applications, and limited demands on processor resources; decision support systems have somewhat less stringent requirements. An example project which exhibits the need for both of these types of systems is NASA's Space Station Freedom. Monitoring and control systems that will perform fault detection, isolation and reconfiguration for various on-board systems are expected to be developed and deployed on the station either in its initial operating configuration or as the station evolves; decision support systems that will provide assistance in activities such as crew-time scheduling and failure mode analysis are also under consideration. These systems will be expected to run reliably on a standard data processor, currently envisioned as a 1-16 megabyte 386-based workstation. The Station is typical of the large Ada software development projects that will require expert systems in the 1990's.

2.1 Conventional Expert System Tools

Inference Corporation developed an expert system tool called Automated Reasoning Tool (ART) which has been commercially available for several years [8]. ART is written in Lisp and it supports various reasoning facilities such as rules, frames, truth maintenance, hypothetical reasoning, and object-oriented programming.

More recently, Inference introduced another expert system tool called ART-IM (Automated Reasoning Tool for Information Management) which is also commercially available [9]. ART-IM is written in C and it supports a subset of ART's reasoning facilities; ART-IM Version 1.5 supports forward-chaining rules, frames, truth maintenance, and basic object-oriented programming.

Both ART and ART-IM have been successfully used to develop many applications which are in daily use today.

2.2 Considerations for Ada Environment

This research project permitted Inference to study how to bring the ART and ART-IM features into Ada environments. Inference's approach in designing an Ada-based expert system tool is to use an existing architecture such as ART or ART-IM so that its input language would be identical to that of an existing tool.

Two approaches to implementing the existing architecture were considered:

1. To implement the whole system in Ada
2. To implement an Ada deployment compiler as part of an existing tool

Since the purpose of the project was to research operational issues such as those discussed below, it was decided to take approach number 2.

2.3 Requirements for Real-Time Embedded Systems

Laffey et. al. identified potential problems in using conventional expert system tools for real-time applications[Laffey88b]. Many of these problems are already solved by ART and ART-IM.

ART and ART-IM provide features for embedded environments such as

- They have facilities for handling asynchronous inputs.
- They have a standard call-in and call-out interface for various languages.
- They assign priorities to rules which can be used to focus attention on important events.
- They have interrupt capabilities.
- They can run continuously even if there is no rule to fire.

Among the problems that Laffey et. al. identified, ART and ART-IM do not address the following problems:

- Guaranteeing response times
- Temporal reasoning capability

Both ART and ART-IM are based on the Rete algorithm [5]. Laffey et. al. claim that in real-time applications, the knowledge base changes too rapidly for the Rete algorithm to be optimal [11]. Barachini

et. al. claim that an expert system tool based on the Rete Algorithm can be optimized to better support real-time expert systems [2]. The reported speed of their system, however, does not seem much faster than that of other C-based tools such as CLIPS or ART-IM. Some tools specialized in the monitoring and analysis applications do not use the Rete algorithm; they use a compiled, static knowledge base in which all variables used in the rules are resolved at compile time [12] [10]. While the speed of these tools seems faster than that of the Rete-based tools, these tools still cannot guarantee response times. The main drawback is that they may not be suitable for expert system application areas other than monitoring and analysis. An alternative approach to the compiled, static knowledge base is an object-oriented programming (OOP) facility that uses active values. The OOP facility is already implemented in ART, and it is being considered for ART-IM and ART/Ada.

A temporal reasoning capability refers to a way to invoke a rule at a regular time interval. For example, the following is a temporally driven rule:

```
Check the price of IBM stocks every hour.
If the price goes down more than five dollars in an hour,
then sell all shares.
```

The temporal reasoning capability can be directly supported, or it could be implemented as an Ada task outside of the inference engine. The task should be started during the initialization phase of the expert system as a demon that wakes up at a certain time interval. A built-in temporal reasoning capability, therefore, may not be as important as the issue of guaranteed response times.

There are two different levels of real-time requirements: *soft real-time* and *hard real-time* [12]. In a hard real-time system, the correctness of the system depends not only on the result of computation, but also on the time at which the results are produced. If these strict timing constraints are not met, the consequence may be disastrous. On the other hand, in a soft real-time system, disastrous consequences do not result if the dead-line is missed. While most expert system tools try to address the soft real-time issue today by improving their performance, they do not, yet, address the hard real-time issue.

The current generation embedded processors such as the MIL-STD-1750A have limited addressing capability of 2 megabytes. Medium size Ada-based expert systems may not fit into this limitation. It is also known that the size of the Ada-based expert systems is larger than that of C-based counterparts. While next-generation embedded processors such as the 80386 would alleviate the size problem, it would still be desirable to study how to optimize the size of the Ada-based inference engine.

3. Current Status

This chapter discusses the status of a prototype Ada-based expert system building tool, called *ART Ada* Version 1.0.

3.1 Overview

A primary goal of this research phase was to design an expert system tool that allowed applications to be deployed in Ada environments. In order to achieve this goal, three components were needed:

- Existing expert system tool as a baseline
- Application generator that generates Ada code
- Ada-based inference engine

After ART and ART-IM were reviewed carefully, ART-IM was selected as a baseline system because C was much closer to Ada than Lisp. ART/Ada, an Ada-based inference engine, was modeled after that of ART-IM Version 1.0 which supported forward chaining rules.

ART-IM has a deployment compiler that converts an application into C data structure definitions. An Ada deployment compiler was designed using the C deployment compiler as a model. The Ada deployment compiler converts C data structures specific to an application into Ada source code that would be used to initialize Ada data structures equivalent to the original C data structures. The Ada deployment compiler is written in C and is part of ART-IM.

3.2 Introduction to ART-IM

ART-IM is a general purpose expert system tool written in C. ART-IM version 1.0 implements a forward-chaining rule-based inference engine using on the Rete algorithm. It also has a truth maintenance system, called Logical Dependency.

ART-IM version 1.5 includes a frame system, called Schema system, which is fully integrated with the rule system. It also includes an explanation system, called Justifications. In addition, ART-IM version 1.5 for MS-DOS has a presentation manager style user interface, called Studio, that provides extensive capabilities for debugging ART-IM applications. An example of a Studio screen is shown in Figure 3-1.

The ART-IM syntax is basically a subset of the ART syntax. An application written in ART, therefore, can be easily ported to ART-IM.

Figure 3-1: Composite ART-IM Screen

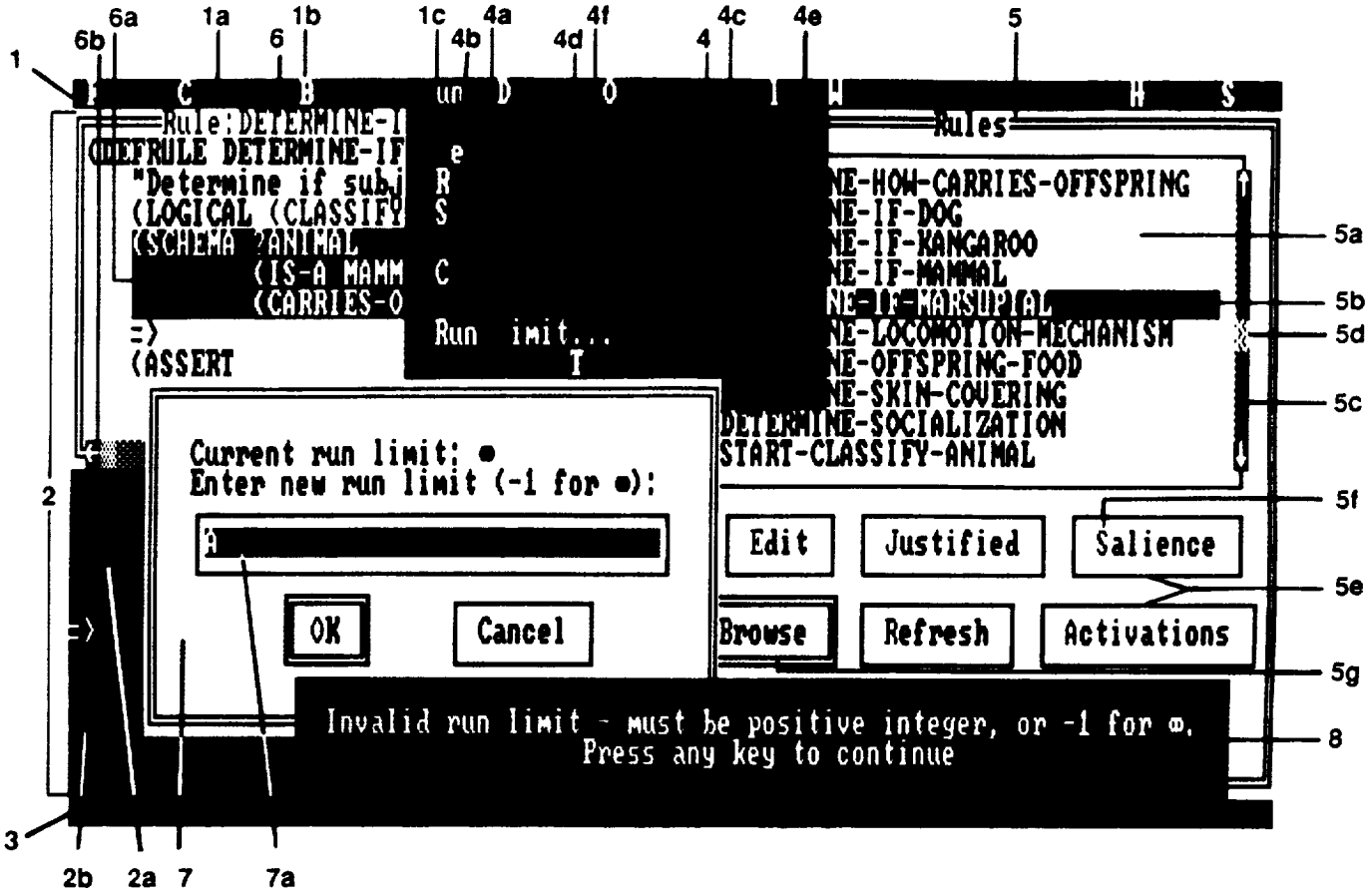

Figure Key:

1 - Menu Bar
- 1a - Menu Name
- 1b - Menu Name Mnemonic
- 1c - Highlighted Menu Name

2 - Interaction Window
- 2a - Display Area
- 2b - Command Area

3 - Status Line

4 - Menu
- 4a - Menu Item (Command)
- 4b - Menu Item Mnemonic
- 4c - Menu Item (Extended Command)
- 4d - Highlighted Menu Item
- 4e - Accelerator Key Designator
- 4f - Menu Separator

5 - Browser Dialog Box (Object-Type)
- 5a - List Box Control
- 5b - Highlighted List Box Item
- 5c - Vertical Scroll Bar
- 5d - Scroll Bar Elevator
- 5e - Push Button Controls
- 5f - Push Button Mnemonic
- 5g - Highlighted Push Button

6 - Browser Dialog Box (Individual-Object)
- 6a - Selectable Text Control
- 6b - Horizontal Scroll Bar

7 - Prompting Dialog Box
- 7a - Edit Control

8 - Message Box

3.3 ART-IM Ada Deployment Compiler

ART-IM Version 1.5 was augmented with an Ada Deployment Compiler to support the ART/Ada runtime system. As shown in figure 3-2, its input is an ART-IM source file, and its output is Ada source files. At any point after an ART-IM source file is loaded into ART-IM and reset, it can be invoked to generate the Ada source code that will be used to initialize ART internal data structures for the ART/Ada runtime system. The ART-IM program can be run up to any given point before the code generation takes place.

Since it is part of ART-IM, the Ada deployment compiler is written in C. In addition to generating Ada source code that represents the knowledge base, it also generates a call-out interface module that can be used to call user-defined Ada functions. ART-IM provides a powerful call-out specification language that can be used to call out from ART-IM or from ART/Ada to Ada.

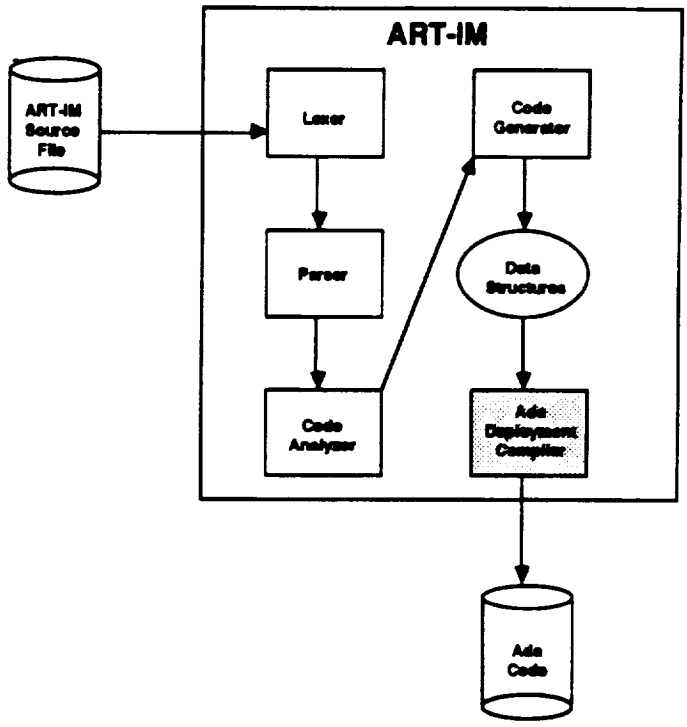

Figure 3-2: ART-IM Ada Deployment Compiler

3.4 ART/Ada Run-time System

The ART/Ada run-time system is composed of the following components:

- Inference engine
- Procedural Interface Package
- Memory management package
- Ada deployment compiler utilities
- User interface package

ART/Ada's inference engine is based on the Rete algorithm, and supports only forward chaining rules matching on facts as specified in the ART-IM Version 1.0 syntax.

ART/Ada supports a simplified version of the procedural language of ART-IM. ART/Ada's procedural interface can be used either in the rule right-hand side, or directly in user's Ada programs. The procedural interface includes data type conversions between the Ada data types and the ART data types, predicates, operations on ART objects, ART commands, I/O functions, and math functions. ART/Ada's I/O system supports simple input and output functions. Unlike ART-IM, stream are not supported in ART/Ada. All streams variables default to either standard output or input. File I/O is not supported in ART/Ada. ART/Ada's math package provides most mathematical functions except trigonometric functions.

ART/Ada's memory management package uses Ada the features **new** and **unchecked_deallocation** to allocate and deallocate memory. In phase II, the advantages and disadvantages of implementing a memory manager for ART/Ada will be investigated.

The ART/Ada run-time system contains utilities called by the Ada code that ART-IM Ada deployment compiler generates.

ART/Ada has an optional simple command interface that support rudimentary debugging features such as tracing/untracing rules, facts, activations, printing out facts and agenda, and running the program.

3.5 Deployment in Ada Environment

As shown in Figure 3-3. the following steps are needed to deploy an ART-IM application in Ada:

1. Develop an application in ART-IM using ART-IM's development environment.
2. If necessary, call out to Ada from ART-IM using the standard callout mechanism for both ART-IM and ART/Ada.

3. Generate Ada code from ART-IM using the Ada deployment compiler.

4. Compile the generated Ada code.

5. Link it with an Ada library of the ART/Ada runtime system and user's Ada code if any

6. Deploy the Ada executable image on a host computer or on a target system

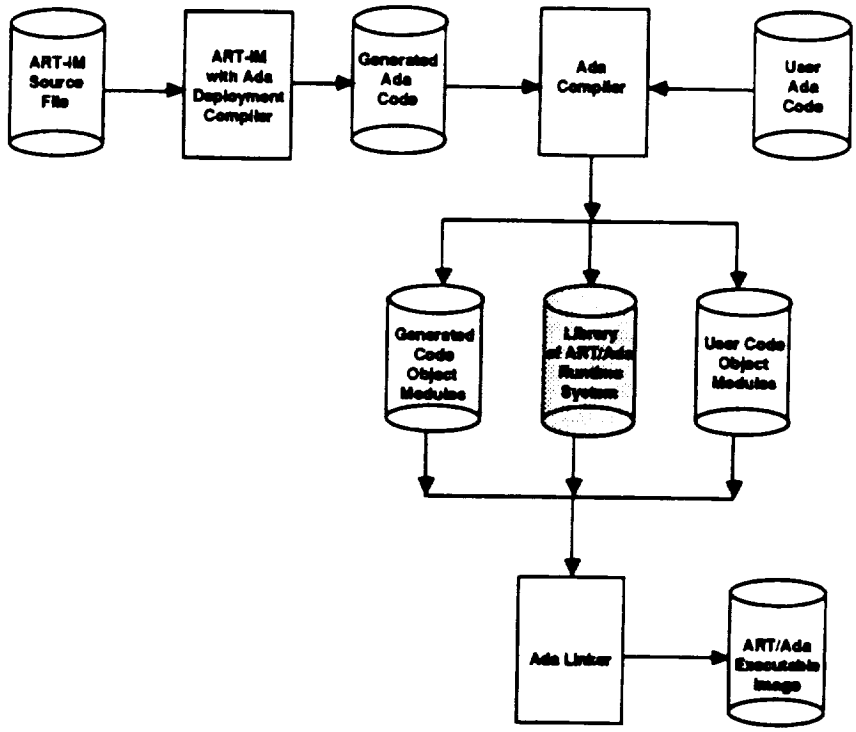

Figure 3-3: Ada Deployment Process

4. Prototype Development Process

This chapter discusses how the ART/Ada Version 1.0 prototype was developed.

4.1 Specification

ART-IM Version 1.0 was used as a functional specification for the ART/Ada Version 1.0 prototype. Some features in ART-IM 1.0 (e.g. Logical Dependency) that were not essential for the proof of concept were left out intentionally.

The ART-IM C source code was used as a detailed design specification for the ART/Ada run-time system. The ART-IM internal function definitions and data structures were converted to Ada package specifications which were compiled by an Ada compiler. The Ada package specification served as a detailed design specification of ART/Ada.

4.2 Object-Oriented Design

ART/Ada was designed using the object-oriented design (OOD) methodology. The object-oriented design is an approach to software design in which the system is decomposed into a set of objects. Each object is mapped to one or more Ada packages. Four different kinds of packages were used in the design:

- Abstract Data Object (ADO)
- Abstract Data Type (ADT)
- Package of subroutines (SUB)
- Package of declarations (DCL)

The Abstract Data Object is a package that contains encapsulated data and operations (expressed as subprograms) performed upon those data. These data are static and local to that package. They are known as state data.

The Abstract Data Type is a package that contains abstract types and operations performed on those abstract types. The operations are expressed as subprograms and the abstract types are declared as the Ada types.

The package of subroutines is a package of logically related subroutines. There exists no encapsulated data in this package.

The package of declarations is a package of logically related declarations. These declarations may be types, constants, or exceptions.

4.3 Implementation

Once package specifications for the Ada run-time system were laid out, the packages were divided among two programmers to be implemented. Again, the ART-IM C source code was used as a program design language (PDL). Despite the differences between C and Ada, it was relatively easy to port C code into Ada. In fact, productivity was as high as 500 to 1000 lines of code a week per person during the actual coding phase.

Perhaps it is worthwhile to describe the difficulties encountered while porting C to Ada. A lack of function pointers in Ada made it necessary to write a case statement which contains all the Ada subprograms that were called either by the system or by the user. This case statement was generated automatically by the Ada deployment compiler according to the call-out interface specification of system functions and user-defined functions.

In C, it is legal to treat an arbitrary memory location as a certain data type at run-time through type casting. For example, four bytes of memory could be used as a long integer or as a pointer depending on how it is casted. Similarly, a pointer to a data type can be casted to a pointer to another data type. Another example is bit manipulation operations such as bitwise exclusive OR which is useful in hashing. Ada does not allow such practices in general. Certainly they are not recommended if they are not prohibited. Since ART-IM uses many such C features to achieve the maximum efficiency, it was unavoidable to sacrifice some performance when it was ported to Ada.

4.4 Reuse

In order to reduce the development cost of the ART/Ada prototype, it was decided in the early phase of the project that the Booch components [4] would be used in the ART/Ada prototype. A linked-list package, a string package, and other utility packages are used by ART/Ada. The following is the full list:

- "vcalenut.a" -- package CALENDAR_UTILITIES
- "vcharuti.a" -- package CHARACTER_UTILITIES
- "vfixedut.a" -- generic package FIXED_POINT_UTILITIES
- "vfloatut.a" -- generic package FLOATING_POINT_UTILITIES
- "vintegrt.a" -- generic package INTEGER_UTILITIES
- "vlistsum.a" -- generic package LIST_SINGLE_UNBOUNDED_MANAGED
- "vstorage.a" -- generic package STORAGE_MANAGER_SEQUENTIAL

- "vstrings.a" -- generic package STRING_SEQUENTIAL_UNBOUNDED_MANAGED_ITERATOR
- "vstringt.a" -- package STRING_UTILITIES

Some of these packages had to be modified because they failed to compile on a certain compiler, or their functionality was not what was desired. The modified version of these components were successfully compiled on Alsys, Verdix, and DEC compilers. The package body of LIST_SINGLE_UNBOUNDED_MANAGED did not compile on the Sun Tartan compiler because of a bug in the compiler. Consequently, the Tartan compiler had to be excluded in the benchmark.

4.5 Testing

It was difficult to unit-test ART/Ada modules which were part of the inference engine kernel because these modules were highly interdependent. For example, it was impossible to test the join network module without the pattern network module. For this reason, test programs originally developed for ART-IM were modified and used to validate ART/Ada functionally as well as to do some unit testing. This validation and verification method turned out to be very effective. It is analogous to the Ada compiler validation test suite.

In the future, if an independent third party verification and validation contractor develops a set of test suites for a particular expert system tool, it would be an effective way to validate an expert system tool such as ART/Ada. It does not seem feasible to develop a general purpose test suite for several expert system tools because the input languages are usually very different. It may be possible to come up with a set of general requirements for developing such a test suite, though.

4.6 Debugging

In VLSI testing, a "golden device" that has been proven correct in advance is used to test chips in production. Likewise, ART-IM served as "golden software" while testing and debugging ART/Ada.

Many times, a source-level C debugger on a Sun, **dbxtool**, was used side by side with the Verdix Ada debugger to track down subtle bugs, which was very effective. While single-stepping through critical code segments, difficult bugs were easily isolated.

4.7 Summary

It was a great advantage to have a commercial expert system tool, ART-IM, and its source code throughout the development cycle of the ART/Ada prototype. During all phases of prototype development, it helped programmers greatly. As a result, it allowed high productivity among programmers and high quality in the prototype. It also reduced the development time greatly. Without it, it would have been impossible to develop an operational prototype in such a short time. With two programmers working on the project, coding was started in July 1988, and the prototype was fully operational in December 1988. A modified version of Boehm's spiral model [3] is used to show the ART/Ada 1.0 prototype life cycle in Figure 4-1.

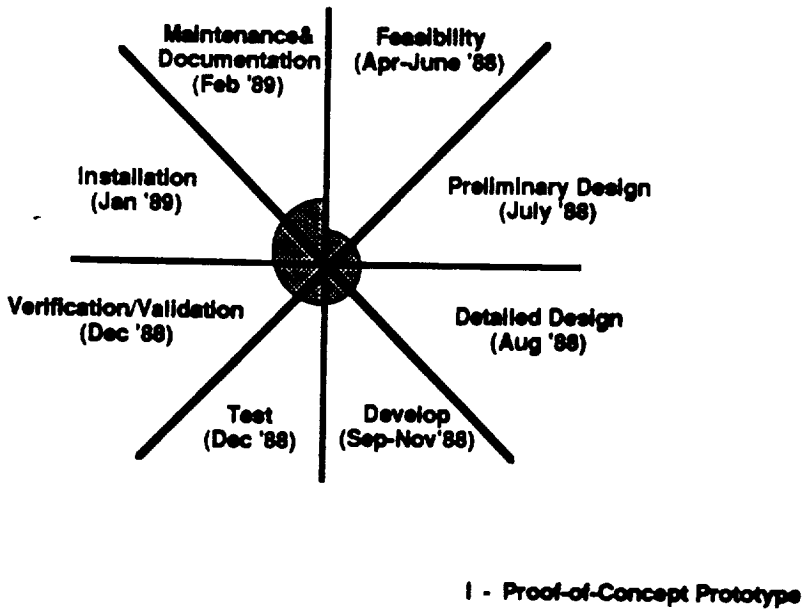

Figure 4-1: Spiral Life Cycle of the ART/Ada 1.0 prototype

5. Performance Analysis

This chapter analyzes the performance of the ART Ada 1.0 prototype.

The following programs were used to benchmark it. In both programs, I/O was suppressed so that the speed measured was not the speed of I/O, but that of the ART/Ada inference engine.

- Monkey and Banana: It fires 81 rules, and it has 13 facts in the knowledge base after it runs.
- N-Queens (6 Queens): It fires 515 rules, and it has 155 facts in the knowledge base after it runs.

ART/Ada code was successfully compiled on the following platforms:

- IBM PS/2 Model 70 using the Alsys 286 DOS Ada compiler Version 4.2
- Sun 3/260 using the Verdix Sun Ada compiler Version 5.5K.
- Sun 3/260 using the Alsys Sun Ada compiler Version 4.2 Beta
- VAXstation II using the DEC Ada compiler Version 1.5

As mentioned earlier, the package body of a Booch component, LIST_SINGLE_UNBOUNDED_MANAGED, did not compile on the Tartan Sun Ada compiler Version 2.0 because of a bug in the compiler. Consequently, the Tartan compiler was excluded in the benchmark.

Ada files were compiled with maximum suppression of error checks and maximum optimization. For the Verdix Sun Ada compiler, the following command was used:

```
a.make -S -O -v main -f *.a
```

For the Alsys compilers, the following default was used for compilation:

```
COMPILE (OPTIONS  => (CHECKS     => STACK),
         IMPROVE  => (CALLS      => INLINED,
                      REDUCTION  => EXTENSIVE)
         KEEP     => (DEBUG      => NO,
                      COPY       => NO));
```

In addition, the following default was used on the Alsys 286 DOS compiler for linking:

```
BIND PROGRAM=MAIN, EXECUTION=EXTENDED
```

5.1 Speed

The speed of ART/Ada is measured on the following platforms:

1. Sun 3/260 with 16 MBytes of memory using the Verdix Ada compiler
2. Sun 3/260 with 16 MBytes of memory using the Alsys Ada compiler
3. IBM PS/2 Model 70 386 20 MHz with 6 MBytes of memory using the Alsys Ada compiler

The speed is measured in the number of rules per second against a wall-clock time, not a CPU time. The PS/2 is a single user system. The Sun was connected to the network and was being used as a file server occasionally, but no other program was running while benchmark programs were running.

Here it should be noted that ART/Ada on a PS/2 uses different table sizes. A direct comparison, therefore, between the speed of ART/Ada on a Sun ant that on a PS/2 is not possible.

Platform	Monkey	6 Queens
Sun/Verdix	38.2 Rules/Sec	42.7 Rules/Sec
Sun/Alsys	46.4 Rules/Sec	62.4 Rules/Sec
PS/2/Alsys	37.4 Rules/Sec	49.9 Rules/Sec

Table 5-1: Speed of ART/Ada in Rules/Second

5.2 Size

The size of ART/Ada is measured on the following platforms:

1. Sun 3/260 with 16 MBytes of memory using the Verdix Ada compiler
2. Sun 3/260 with 16 MBytes of memory using the Alsys Ada compiler

Since multiprocessing is not supported in MS-DOS, size of the ART/Ada process could not be measured. On a Sun workstation, size of the ART/Ada process was measured in KBytes using a Unix command, "ps aux", after the program finished running and just before it was exited.

Platform	Monkey	6 Queens
Sun/Verdix	968 KBytes	1232 KBytes
Sun/Alsys	768 KBytes	944 KBytes

Table 5-2: Size of ART/Ada in KBytes

5.3 Discussion

The benchmark results reported should be considered as preliminary results because of the following reasons:

- No effort was made to optimize the performance of the ART/Ada prototype due to the time limitation.
- More compilers should be included in the benchmark.
- More hardware platforms should be included in the benchmark.
- Better monitoring tools are necessary. One problem with Ada is that it does not support CPU time; it only supports wall-clock time. Therefore, the benchmark result is subject to many variables such as the load on the system, network activities, etc.

The size limitation of current generation embedded processors such as the MIL-STD-1750A is 1 megaword (2 megabytes) within which all software systems including the operating system have to run. This might be too restrictive for medium size expert systems. New generation embedded processors such as the 80386 would be adequate for many expert systems developed using an Ada-based expert system tool such as ART/Ada. The speed of the ART/Ada prototype seems comparable to other tools, especially C-based tools, although it is slower.*

It is interesting that both speed and size of ART/Ada vary significantly depending on which Ada compiler is used. It is known that Ada compilers are not very efficient [6]. As the Ada compiler technology advances, the ART/Ada performance would be improved.

*The unoptimized ART/Ada prototype is about 2-3 times slower in execution speed and about 2-3 times larger in process size than ART-IM.

6. Related Work

This chapter compares the ART/Ada prototype with other similar systems such as

- CLIPS/Ada [1]
- PAMELA [2]
- FLAC [10]
- L*STAR [12]

CLIPS (C Language Production System) is a C-based forward-chaining rule-based expert system tool whose syntax is very close to ART and ART-IM. It has been reported that CLIPS is being ported to Ada. Unlike ART/Ada, the whole system is being reimplemented in Ada. CLIPS does not have a frame system, a truth maintenance system, and an explanation system. Its only knowledge representation method is a forward-chaining rule system.

It is claimed that PAMELA (PAttern Matching Expert system LAnguage) uses the Rete algorithm improved with optimizations and extensions that could satisfy the requirements of many real-time applications. Unlike ART/Ada, PAMELA does not seem to support deployment in Ada environments. It is implemented in CHILL(Communication HIgh Level Language). PAMELA is similar to ART Ada because it is based on the Rete algorithm. In addition to PAMELA, other optimizations on the Rete algorithm have been proposed and implemented by Gupta [7] Schor et. al. [14] and Miranker [13].

FLAC (Ford Lisp-Ada Connection) uses a Lisp environment to develop an expert system application, and generates Ada code to be deployed in Ada environments [10]. Its knowledge base is specified using a graphical representation similar to that of VLSI design (e.g. OR gates and AND gates), which gets compiled into a *static* knowledge base. Because of this compiled, static knowledge base, high performance of 1500 rules per second on a VAX 11/780 was achieved, perhaps, at the cost of flexibility. It still does not guarantee response times.

FLAC is similar to ART/Ada because its development environment is not implemented in Ada, but the Ada deployment is supported. The difference is, however, that FLAC's development environment is based on Lisp, while ART/Ada uses that of ART-IM which is written in C. The C and Ada development environments coexist on the same hardware platforms more often than the Lisp and Ada development environments do. FLAC, for example, uses a special purpose Lisp machine for the front-end, and a VAX for the Ada deployment. Both ART-IM and ART/Ada run on the same hardware. Another difference is that FLAC's input is graphically oriented while ART/Ada is language-oriented. FLAC's pre-compiled, static knowledge base imposes restrictions on the reasoning capability which do not exist in the inference engines based on the Rete algorithm such as ART-IM and ART/Ada.

L*STAR (Lockheed Satellite Telemetry Analysis in Real time) is designed for real-time monitoring and analysis expert systems. L*STAR has a built-in feature for temporal reasoning. All data is archived and time-tagged into a ring buffer. The ring buffer consists of a compressed format which keeps track of the last time the datum was updated and each time it changed over a user-specified time period. ART/Ada does not support temporal reasoning. It could be implemented, however, using ART/Ada's asynchronous function capability. An asynchronous function is an Ada procedure that gets invoked between rule firings. It can be implemented to achieve the same behavior as L*STAR's temporal reasoning facility.

Unlike ART/Ada and PAMELA, L*STAR is not based on the Rete algorithm. In L*STAR, not all the rules are continually checked. Some of the rules are triggered by the test clock at regular time intervals. Other rules are checked only when data changes that is used in one of its IF clauses, or when they are needed to achieve a goal. Rules are compiled into an intermediate postfix format or optionally into C. Because all variables are resolved at compile time, multiple variables in a single rule can result in a combinatoric increase in the number of rules generated. In this sense, it is similar to FLAC. While it achieves the performance of about 1000 rules per second on a VAX 8650, L*STAR still cannot guarantee response times. Although it seems to work well for the real-time monitoring and analysis applications, it is unclear whether this architecture would satisfy the requirements of other expert system application areas besides the monitoring and analysis applications. L*STAR is written in C, and does not support deployment in Ada environments.

Tools like FLAC and L*STAR seem to achieve high performance because they have a static knowledge base in which variables are resolved at the compile time. It might be possible to achieve the same level of performance if object-oriented programming (OOP) facilities such as active values are used to invoke actions from objects which represent those variables. When the active value capability is added to ART-IM and ART/Ada, the performance of the OOP methodology could be compared to that of the static knowledge base.

7. Future Work

This chapter suggests the future directions for the Ada-Based Expert System Building Tool Design Research Project.

The current prototype system supports only forward-chaining rules. There are multiple knowledge representation techniques one or more of which are usually used for a particular application. To support various application, an expert system tool should support more than one paradigm. It would be useful, therefore, to enhance the ART/Ada prototype with a frame system, a truth maintenance system, and a explanation system which exist in ART-IM 1.5. This enhanced prototype will be called ART/Ada 1.5. ART-IM will be still used as a development environment and as an Ada deployment compiler. A modified version of Boehm's spiral model [3] is used to show the proposed ART/Ada 1.5 prototype life cycle in Figure 7-1.

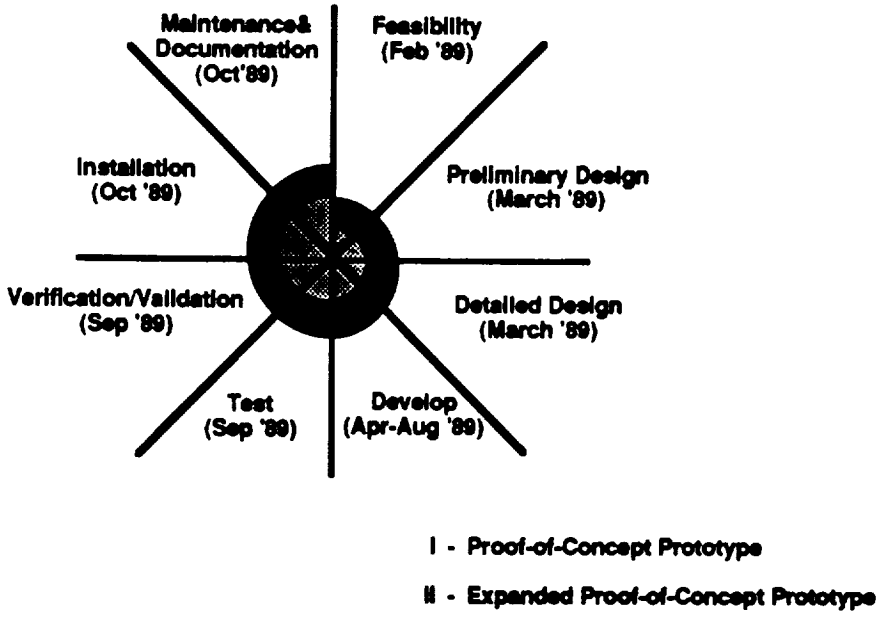

Figure 7-1: Proposed Spiral Life Cycle of the ART/Ada 1.5 prototype

Once the ART/Ada 1.5 prototype is completed, significant effort should be dedicated to understand the operational issues and potential uses of the prototype. This may involve a joint effort with potential users who use the ART/Ada 1.5 prototype to implement prototype expert systems for the Space Station Freedom.

Additional research effort would be necessary to enhance ART/Ada 1.5 to better support the real-time embedded applications. The following issues need be investigated further:

- To meet the soft and hard real-time requirements,
- To support the distributed environments such as parallel processors [7].
- To fit into the embedded processors.

It is feasible to reimplement all of ART-IM in Ada including the front-end and the development environment. The following modules would be required:

- Front-end: a lexer, a parser, a semantic analyzer, a code generator, etc.
- User interface: a graphical debugging tool and debugging-oriented functions to browse various knowledge base objects
- New Ada deployment compiler written in Ada
- Miscellaneous: the Clear and Reset commands, an error handling system, etc.

It would not be easy to reimplement ART-IM's development environment in Ada because most graphics packages are written in C. An Ada binding would have to be used to interface ART/Ada with existing C-based graphics packages. Despite standardization efforts such as X windows, graphics applications are not very portable today. It might be necessary, therefore, that the multiple graphics packages (e.g. X Windows and Presentation Manager) be supported. Integration and testing would also require significant effort.

7.1 Summary

In summary, the following projects are recommended as future projects:

- To implement the ART/Ada 1.5 prototype (compatible with ART-IM 1.5)
- To study the operational issues and potential uses of the ART/Ada 1.5 prototype
- To enhance the current architecture to better support real-time applications
- To implement the whole ART/Ada 1.5 in Ada including the development environment and integrate it with an existing APSE (Ada Programming Support Environment)

8. Conclusion

As shown in the preliminary benchmark results of the operational prototype, this project succeeded in proving that the conventional expert system tool could be used to deploy its applications in Ada environments with efficient use of time and space.

Another important goal of this project was to reuse existing software. During the prototype development, software reuse techniques were practiced at all levels.

- A commercially available software component library, the Booch Components, was used to implement data structures.
- A commercial software system, ART-IM, was reused for various purposes: as a functional specification and a detailed design of the ART/Ada run-time system; as a development environment for ART/Ada applications; and as an Ada deployment compiler.
- The ART-IM test programs were also reused to test the whole Ada deployment process; to debug the ART-IM Ada deployment compiler and the ART/Ada run-time system.

The reuse practice of the project, especially the reuse of ART-IM, contributed greatly to the high productivity in coding, testing, and integration and the high quality of the ART/Ada prototype. During the coding phase, productivity was as high as 1000 lines of code a week per person, and was in average about 500 lines of code a week per person. Thanks to the ART-IM test programs, it took only about a month to fully validate the prototype. Testing and integration would have taken much longer if no test programs had been available. The source listings of the test programs are available in the appendix.

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I. Detailed Description of ART/Ada Implementation

In this chapter, the ART/Ada prototype will be described in greater detail.

I.1 Deploying an ART-IM application in Ada

The following steps are necessary to deploy an ART-IM application in an Ada environment:

1. Load an application into ART-IM. This can be achieved either through the ART-IM Studio menus or by entering a command. When the menu is used, select **File**, **Load** and an appropriate filename. When a command is used, enter

```
(load "<filename>")
```

2. Reset the application. This can be achieved either through the Studio menus or by entering a command. When the menu is used, select **Run** and then **Reset**. When a command is used, enter

```
(reset)
```

3. Generate Ada code for the application. This can be achieved either through the Studio menus or by entering a command. When the menu is used, select **File** and then **Ada Generate**. When a command is used, enter

```
(load "buildada.art")                    ; load call-out definitions
(set-generate-options 1000 25)           ; set generate options
(generate-ada "<filename-prefix>")       ; generate Ada code
```

   The menu command **Ada Generate** executes the first two commands automatically. The file **buildada.art** contains Ada call-out definitions used by ART/Ada internally. If there exists user's Ada code to be called from ART/Ada, the call-out interface should be defined either in this file or in a separate file, and loaded into ART-IM. The function, **set-generate-options**, sets maximum number of source lines per Ada source file and maximum number of source lines per Ada subprogram. For example, (set-generate-options 1000 25) set the maximum lines per file to 1000, and the maximum number of lines per subprogram to 25. These numbers were found optimal for some Ada compilers. ART-IM will generate multiple files:

   - funcall.a --- procedure FUNCALL for calling out to Ada
   - <filename-prefix>.a --- specification and body of a package, <filename-prefix>
   - <filename-prefix>1.a, <filename-prefix>2.a, ... --- separate procedures contained in the package, <filename-prefix>
   - <filename-prefix>.com. -- a command file to compile Ada source files.

4. Compile the Ada source files using an Ada compiler using <filename-prefix>.com which might have to be customized for each compiler. So far, only Alsys compiler has been used on a PS/2.

5. Write the main program. A simple command loop may or may not be included in the main program.

6. Link the Ada executable image.

7. Run the Ada executable image.

I.1.1 Ada Source Code Generated by the Ada Deployment Compiler

The generated Ada code includes a procedure called INIT which initializes an application in the ART/Ada knowledge base.

Below is the package specification generated by the Ada Generator for an application, MAB:

```
package MAB is
  procedure INIT;
end MAB;

with GEN_UTIL_ADO, GLOBAL_DCL;
package body MAB is

  procedure MAB0 is separate;
  procedure MAB1 is separate;
  procedure MAB2 is separate;
  procedure MAB3 is separate;
  procedure MAB4 is separate;
  procedure MAB5 is separate;
  procedure MAB6 is separate;

  procedure INIT is
  begin
    GEN_UTIL_ADO.INIT_INIT;
    MAB1;
    MAB2;
    MAB3;
    MAB4;
    MAB5;
    MAB6;
    GEN_UTIL_ADO.CROSS_REF;
    MAB0;
    GEN_UTIL_ADO.CLEANUP;
    GEN_UTIL_ADO.SYSTEM_INIT;
  end INIT;

end MAB;
```

In addition to generating a package specification for an application, the Ada deployment compiler also generates the separate procedure body for INTERPRETER_SUB.FUNCALL. This procedure is the top-level procedure called by the function call interpreter to call out to Ada subprograms. These Ada subprograms consist of those used internally by ART/Ada and those defined by the user. All user-defined Ada subprograms should be defined in the package USER_SUB.

I.1.2 ART/Ada User Interface Command Loop

A simple command loop is included in the ART/Ada run-time system. It supports a minimum subset of the ART-IM command syntax which is necessary for simple tracing and debugging. The following syntax is supported:

```
<art_cmd>        ::= (<command>)

<command>        ::= <trace_cmd>   | <untrace_cmd> | <run_cmd>   |
                     <agenda_cmd>  | <facts_cmd>   | <exit_cmd>

<untrace_cmd>    ::= untrace <untrace_arg>

<untrace_arg>    ::= rules | facts | activations | all

<trace_cmd>      ::= trace <trace_arg>

<trace_arg>      ::= <untrace_arg> | status

<run_cmd>        ::= run | run <integer>

<agenda_cmd>     ::= agenda

<facts_cmd>      ::= facts

<exit_cmd>       ::= exit
```

I.1.3 Example Main Programs

Two examples of the ART/Ada main programs are included in this section: one that includes the command loop, and one that does not. Although the main program should be defined by the user for each application because the name of the package that contains the application specific procedures varies, it would be easy to modify the standard one.

The following is an example of the main program that includes the user interface by calling COMMAND_LOOP:

```
with USER_INTERFACE_SUB, ERROR_HDL_SUB, MAB;
procedure MAIN is
begin
  MAB.INIT;
  USER_INTERFACE_SUB.COMMAND_LOOP;
exception
  when CONSTRAINT_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.CONSTRAINT_ERR);
  when PROGRAM_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.PROGRAM_ERR);
  when STORAGE_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.STORAGE_ERR);
  when TASKING_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.TASKING_ERR);
  when ERROR_HDL_SUB.TIME_ERROR       =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.TIME_ERR);
  when ERROR_HDL_SUB.INTERNAL_ERROR   =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.INTERNAL_ERR);
  when ERROR_HDL_SUB.RETRACT_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.RETRACT_ERR);
  when ERROR_HDL_SUB.INTERPRETER_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.INTERPRETER_ERR);
  when ERROR_HDL_SUB.USER_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.USER_ERR);
  when ERROR_HDL_SUB.USER_DEFINED_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.USER_DEFINED_ERR);
end MAIN;
```

This main program initializes an expert system application called MAB, and prompts the user for a command. The USER_INTERFACE package is with'ed to gain access to the COMMAND_LOOP procedure.

The following is an example of the main program that is tailored for an embedded application:

```
with ART, ERROR_HDL_SUB, MAB;
procedure MAIN is
begin
  MAB.INIT;
  ART.RUN(-1);
exception
  when CONSTRAINT_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.CONSTRAINT_ERR);
  when PROGRAM_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.PROGRAM_ERR);
  when STORAGE_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.STORAGE_ERR);
  when TASKING_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.TASKING_ERR);
  when ERROR_HDL_SUB.TIME_ERROR       =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.TIME_ERR);
  when ERROR_HDL_SUB.INTERNAL_ERROR   =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.INTERNAL_ERR);
  when ERROR_HDL_SUB.RETRACT_ERROR    =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.RETRACT_ERR);
  when ERROR_HDL_SUB.INTERPRETER_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.INTERPRETER_ERR);
  when ERROR_HDL_SUB.USER_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.USER_ERR);
  when ERROR_HDL_SUB.USER_DEFINED_ERROR =>
    ERROR_HDL_SUB.PROCESS_ERROR(ERROR_HDL_SUB.USER_DEFINED_ERR);
end MAIN;
```

This main program initializes and runs an expert system application, called MAB. The USER_INTERFACE package is not with'ed by the main program.

I.2 Public Packages in ART/Ada

The ART/Ada runtime system is composed of public Ada packages and internal Ada packages. The following is a list of public packages that can be with'ed and, in some cases, modified by the user:

- ART
- ERROR_HDL_SUB
- USER_INTERFACE_SUB

I.2.1 ART

The package, ART, contains public subprograms to be used to call into ART/Ada from user's Ada program. This package should be with'ed by the user program whenever subprograms in this package are called. The ART package contains the following:

- Data types: Integer_Type, Natural_Type, Positive_Type, Float_Type, ART_Object
- Type conversions: ART_Symbol, ART_String, ART_Integer, ART_Float, Ada_Symbol, Ada_String, Ada_Integer, Ada_Float
- Predicates: Symbolp, Stringp, Integerp, Floatp, Numberp, Sequencep, Factp

- Operations: Eq, Equal, Type_of, Gentemp, Length, Position, Member, Nth, Set_Nth, Find_Fact, Fact_Number, Register_ART_Object, Unregister_ART_Object, Make_Template, Free_Template, Sequence

- ART commands: Assert, Retract, Run, Halt, Get_Async_Fun, Set_Async_Fun, Get_Salience_Threshold, Set_Salience_Threshold, Get_Limit_Default, Set_Limit_Default, Get_Print_Messages, Set_Print_Messages

- I/O Functions: Print, Prin1, Princ, Read

In ART/Ada, all integer numbers are INTEGER_TYPE which is a 32 bit integer, and all float numbers are FLOAT_TYPE which is a 64 bit float. ART_Object is a generic data type which could be one of the following: integer, float, string, symbol, fact, or sequence.

Data type conversion functions are provided to convert ART data types to Ada data types or to convert Ada data types to ART data types.

Predicate functions are similar to Lisp predicates. They return T or NIL depending on the result of the predicate.

The ART package provides various operations on ART_Object.

The ART package also includes ART-IM commands such as Run and Halt as well as functions to change the defaults of ART/Ada.

Simple I/O functions are provided to handle basic input and output. File I/O is not supported.

I.2.2 ERROR_HDL_SUB

The package, ERROR_HDL_SUB, contains subprograms for error handling. It contain two separate procedures, PROCESS_ERROR and WARNING, that can be modified to customize the behavior of the error handler. For example, the default behavior is to print the error or warning messages on the screen. It could be changed, however, to print it on the line printer in an embedded environment. This package also defines exceptions one of which is USER_DEFINED_ERROR. It is a generic exception that can be raised by the user.

I.2.3 USER_INTERFACE_SUB

The package, USER_INTERFACE_SUB, contains a simple user interface that can be invoked by a procedure, COMMAND_LOOP. It also include debugging functions such as FACTS, AGENDA, and TIMED_RUN. It is not necessary to with this package when the presence of the user interface is not needed (i.e. embedded applications).

I.3 Ada Call-In and Call-Out Specification for ART/Ada and ART-IM

This section describes a portable call-in/call-out interface specification for ART Ada and ART-IM.

I.3.1 Interface Types

The following types may be passed between ART and Ada:

:INTEGER (INTEGER_TYPE) This type is an 32 bit integer in Ada and an integer in ART (INTEGER_TYPE in ART/Ada and long in ART-IM).

:BOOLEAN (BOOLEAN) In ART, this type is either NIL or non-NIL. In Ada, this type is BOOLEAN which is TRUE or FALSE. When translating from Ada to ART, TRUE will translate to T.

:FLOAT (FLOAT_TYPE) In Ada, this type is FLOAT_TYPE which is double precision float. For ART-IM, this is a C double.

:STRING (STRING) In Ada, this type is represented as a STRING. In ART, this type is represented as an ART string. ART may or may not copy the string being passed by this mechanism when passing a string from ART to Ada. Thus, it is an error to destructively modify a string passed with this mechanism. ART is responsible for freeing any space necessary for the string after exiting the current scope. The actual implementation will be based upon constraints of the underlying architecture. When transferring a string from Ada to ART, ART will always copy the string, allowing the Ada programmer to free the string at his leisure.

:SYMBOL (STRING) In Ada, this type is represented as a STRING. In ART, this type is a symbol. Case is preserved when interning an STRING as an ART symbol, just as case is preserved when passing a string to the Lisp function INTERN.

:ART-OBJECT (ART_OBJECT) This type is any ART type in ART. It is represented as a pointer to a discriminant record in ART/Ada. For ART-IM, it is an integer type which represents a C pointer to a C structure art_object. A set of Ada functions is provided to operate on these ART objects from Ada.

I.3.2 Scope of Objects

This section gives a detailed description of the scope of objects communicated from ART to Ada and objects communicated from Ada to ART. In both cases the prime motivation for scoping is that the caller should free all objects it allocates, (thus it should not allocate objects which it intends that the callee free). Additionally, the callee should not destructively modify objects which it did not allocate.

All objects that are not immediate fall under these constraints. For example, strings and art-objects passed from ART to Ada conform to the following semantics.

When an ART_OBJECT or string is passed from ART by call out to an Ada function, the object is automatically reclaimed when the Ada function returns to ART. At this point, the Ada ART_OBJECT data structure is no longer valid for use in Ada code. It is an error to retain a pointer to an automatically reclaimed ART_OBJECT in Ada once the Ada call has returned.

When an ART_OBJECT or string is returned from ART to Ada, it is automatically reclaimed when control returns to ART from Ada. In those implementations where Ada can start up and call ART as a subroutine so that a returned value may never be reclaimed, the returned ART_OBJECT is allocated permanently and must be freed using a freeing function supplied in Ada.

A function is supplied in Ada that accepts an ART_OBJECT as argument and returns a permanent copy of that ART_OBJECT. This object must be explicitly freed when no longer useful.

I.3.3 Call-Out from ART to Ada

The following is a grammar for def-user-fun which should used to call out to Ada from ART:

```
(def-user-fun <fun-name> {<comment>}
        <function-spec>*)

<function-spec> ::=
        :compiler <compiler-name>      |
        :returns <return-data-type>    |
        :epname <link-editor-symbol>   |
        :args (<arg-spec>*)

<fun-name> ::= <art-symbol>

<comment>  ::= <art-string>

<compiler-name> ::=
        :VERDIX-ADA
        :DEC-ADA
        :ALSYS-ADA

<internal-data-type> ::=
        :SYMBOL
        :STRING
        :FLOAT
        :INTEGER
        :BOOLEAN
        :ART-OBJECT

<return-data-type> ::=
        :VOID | <internal-data-type>

<link-editor-symbol> ::=
        <art-symbol> | <art-string>
```

```
<arg-spec> ::=
        (<name> <internal-data-type> <arg-attribute>*) |
        (<internal-data-type> <arg-attribute>*) |
        <internal-data-type>

<name>  ::= <art-symbol>

<arg-attribute> ::=
        <convention>    |
        <status>

<convention> ::=
        :OBJECT-POINTER |
        :VALUE-POINTER  |
        :VALUE

<status> ::=
        <optional>      |
        <rest>

<optional>  ::=
        :optional       |
        (:optional <default>)

<default>  ::= art-object

<rest> ::= :rest                ; Must be the last arg
```

For example, in order to call out to an Ada function, CALC_STD_DEV, using an ART function, calc-std-dev, define the following in ART-IM before the Ada code is generated:

```
(def-user-fun calc-std-dev
        :epname "CALC_STD_DEV"
        :args ((sx :float) (ssq :float) (n :integer))
        :returns :float
        :compiler :alsys-ada)
```

An Ada package called USER_SUB should be also defined as follows:

```
with ART,MATH_LIB,TEXT_IO;
use  ART,TEXT_IO;
package USER_SUB is
  type REAL_TYPE is digits 15;
  package MY_MATH_LIB is new MATH_LIB(REAL_TYPE);
  use MY_MATH_LIB;
  function CALC_STD_DEV(SX   : FLOAT_TYPE;
                        SSQ  : FLOAT_TYPE;
                        N    : INTEGER_TYPE) return FLOAT_TYPE;

end USER_SUB;

package body USER_SUB is

  function CALC_STD_DEV(SX   : FLOAT_TYPE;
                        SSQ  : FLOAT_TYPE;
                        N    : INTEGER_TYPE) return FLOAT_TYPE is
    SD: FLOAT_TYPE;
  begin
    SD := (SSQ - ((SX * SX) /FLOAT_TYPE(N))) / FLOAT_TYPE(N - 1);
    return FLOAT_TYPE(MY_MATH_LIB.SQRT(REAL_TYPE(SD)));
  end CALC_STD_DEV;

end USER_SUB;
```

I.3.4 Call-In from Ada to ART/Ada

The ART package of ART/Ada is the public package for the ART/Ada users to call in from Ada to ART/Ada. The specification of the ART package will serve as the standard Ada call-in interface specification.

II. Difference between ART-IM 1.5 and ART/Ada 1.0

Among the ART-IM 1.5 features that are missing in ART/Ada, the following features will be implemented in phase II:

- Schema System - a frame system
- Logical Dependency - a truth maintenance system
- Justification System - an explanation system

The following features were not implemented during the phase I due to time limitation, but will be implemented during phase II.

- some string functions
- some I/O functions
- some math functions
- procedural iterators
- asynchronous function

The following features are not planned to be supported in ART/Ada:

- streams
- external data interface functions (e.g. def-external-data, def-map-fun, etc.) which are useful for building database interfaces.
- Trigonometric functions (e.g. sin, cos, etc) which are not part of standard Ada.

III. ART/Ada Public Packages

III.1 Specification of ART Package

```
------------------------------------------------------------------------
--
--                C O P Y R I G H T   N O T I C E
--
--      1) COPYRIGHT (C) 1988
--      INFERENCE CORPORATION,
--      5300 W. Century Blvd.,
--      Los Angeles, California 90045.
--      AN UNPUBLISHED WORK - - ALL RIGHTS RESERVED.
--
--      2) Restricted Rights Notice (Short Form) (April 1984)
--
--              Use, reproduction, or disclosure is
--      subject to restrictions set forth in
--      Government Cooperative Agreement Number NCC-
--      9-16 between the National Aeronautics and
--      Space Administration and the University of
--      Houston-Clear Lake and a subcontract
--      thereunder, Number 015 between the University
--      of Houston-Clear Lake and Inference
--      Corporation.
--
--      3) Restricted Rights Notice (ART/Ada)
--
--              These data constitute Inference
--      Corporation trade secrets and/or information
--      that is commercial or financial and
--      confidential or privileged.  They are
--      submitted to the Government under NASA
--      Cooperative Agreement NCC-9-16 with the
--      University of Houston-Clear Lake Research
--      Institute for Computing and Information
--      Systems (RICIS) with the understanding that
--      they will not, without the permission of
--      Inference Corporation, be used or disclosed
--      for other than evaluation purposes.
--
------------------------------------------------------------------------
-- Author: S. Daniel Lee
--
-- Package: ART
--
-- Function: This package contains subprograms for the user to call into
--           ART/Ada.  This package is the top-level public package which
--           contains all the operations on ART/Ada.  This package should
--           always be with'ed in the user's program.
--
-- State Variables:
--           None
--
-- State Variable Initialization:
--           None
--
-- Change Log:
--
------------------------------------------------------------------------

with STRUCT_DCL, ART_OBJECT_SUB, DATABASE_SUB, INFER_ENG_SUB, CALLIO_SUB,
  ALLOC_SUB, IO_SUB, AGENDA_SUB;
use STRUCT_DCL;
package ART is

   ---------------------------------------------------------------------
   -- Public Types for Ada Callout
```

```
------------------------------------------------------------------

subtype INTEGER_TYPE  is STRUCT_DCL.INTEGER_TYPE;       -- For :INTEGER
-- Use BOOLEAN                                          -- For :BOOLEAN
subtype FLOAT_TYPE    is STRUCT_DCL.FLOAT_TYPE;         -- For :FLOAT
-- Use STRING                                           -- For :STRING
subtype ART_OBJECT    is STRUCT_DCL.ART_OBJECT;         -- For :ART-OBJECT

subtype NATURAL_TYPE  is STRUCT_DCL.NATURAL_TYPE;
subtype POSITIVE_TYPE is STRUCT_DCL.POSITIVE_TYPE;

------------------------------------------------------------
-- Operations on ART objects
------------------------------------------------------------

------------------------------------------------------------------------
-- Returns a new, permanent art_object reference to the ART object
-- referred to by reference.  Reference may be either a permanent
-- or automatically allocated art_object.
------------------------------------------------------------------------
function REGISTER_ART_OBJECT(REFERENCE : ART_OBJECT) return ART_OBJECT
   renames ART_OBJECT_SUB.REGISTER_ART_OBJECT;

------------------------------------------------------------------------
-- Frees the permanent or temporary reference to an art_object;
-- it is an error to continue to use an art_object after freeing the
-- reference to it.
------------------------------------------------------------------------
procedure UNREGISTER_ART_OBJECT(REFERENCE : ART_OBJECT)
   renames ART_OBJECT_SUB.UNREGISTER_ART_OBJECT;

------------------------------------------------------------------------
-- Returns TRUE if the two art_objects X and Y are the same object.
-- EQ and EQUAL are equivalent.
------------------------------------------------------------------------
function EQ(X: ART_OBJECT;
            Y: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.EQ;

------------------------------------------------------------------------
-- Returns TRUE if the two art_objects X and Y are the same object.
-- EQ and EQUAL are equivalent.
------------------------------------------------------------------------
function EQUAL(X: ART_OBJECT;
               Y: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.EQUAL;

------------------------------------------------------------------------
-- Returns the type of an object, as a symbol.
------------------------------------------------------------------------
function TYPE_OF(OBJ: ART_OBJECT) return ART_OBJECT
   renames ART_OBJECT_SUB.TYPE_OF;

------------------------------------------------------------------------
-- A_GENTEMP: Creates a new, previously
-- unused symbol.
------------------------------------------------------------------------
function GENTEMP(STR : STRING) return ART_OBJECT
   renames ART_OBJECT_SUB.GENTEMP;

------------------------------------------------------------------
-- Calls the Ada procedure PROCESS once for each permanent OBJECT
-- that has been allocated passing each permanent art_object
-- as the argument to PROCESS in turn.  If PROCESS returns FALSE
```

```
-- at any time, then the iteration is terminated at that point.
-------------------------------------------------------------
-- generic
--    with procedure PROCESS (THE_ITEM : in  ART_OBJECT;
--                            CONTINUE : out BOOLEAN);
-- procedure FOR_ALL_PER_ART_OBJECTS;

-------------------------------------------------------------
-- Returns an ART_OBJECT for the symbol resulting from performing a
-- intern operation on the string str.  Case is presered in str.
-------------------------------------------------------------
function ART_SYMBOL(STR : STRING) return ART_OBJECT
   renames ART_OBJECT_SUB.ART_SYMBOL;

-------------------------------------------------------------
-- Returns an ART_OBJECT that represents the string specified.
-- Case is preserved.
-------------------------------------------------------------
function ART_STRING(STR : STRING) return ART_OBJECT
   renames ART_OBJECT_SUB.ART_STRING;

-------------------------------------------------------------
-- Returns an ART_OBJECT that represents the number specified.
-------------------------------------------------------------
function ART_INTEGER(NUM: INTEGER_TYPE) return ART_OBJECT
   renames ART_OBJECT_SUB.ART_INTEGER;

-------------------------------------------------------------
-- Returns an ART_OBJECT that represents the number specified.
-------------------------------------------------------------
function ART_FLOAT(NUM: FLOAT_TYPE) return ART_OBJECT
   renames ART_OBJECT_SUB.ART_FLOAT;

-------------------------------------------------------------
-- Returns a STRING that is the print name of the symbol.
-------------------------------------------------------------
function ADA_SYMBOL(SYMBOL: ART_OBJECT) return STRING
   renames ART_OBJECT_SUB.ADA_SYMBOL;

-------------------------------------------------------------
-- Returns a STRING that represents the ART_OBJECT specified.
-------------------------------------------------------------
function ADA_STRING(STR: ART_OBJECT) return STRING
   renames ART_OBJECT_SUB.ADA_STRING;

-------------------------------------------------------------
-- Returns the number represented by the ART_OBJECT specified.
-------------------------------------------------------------
function ADA_INTEGER(NUM: ART_OBJECT) return INTEGER_TYPE
   renames ART_OBJECT_SUB.ADA_INTEGER;

-------------------------------------------------------------
-- Returns the number represented by the ART_OBJECT specified.
-------------------------------------------------------------
function ADA_FLOAT(NUM: ART_OBJECT) return FLOAT_TYPE
   renames ART_OBJECT_SUB.ADA_FLOAT;

-------------------------------------------------------------
-- Predicates
-------------------------------------------------------------

-------------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a symbol, otherwise FALSE.
-------------------------------------------------------------------
```

```
function SYMBOLP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.SYMBOLP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a string, otherwise FALSE.
-----------------------------------------------------------------
function STRINGP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.STRINGP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is an integer, otherwise FALSE
-----------------------------------------------------------------
function INTEGERP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.INTEGERP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a float, otherwise FALSE.
-----------------------------------------------------------------
function FLOATP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.FLOATP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a number, otherwise FALSE.
-----------------------------------------------------------------
function NUMBERP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.NUMBERP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a sequence, otherwise FALSE.
-----------------------------------------------------------------
function SEQUENCEP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.SEQUENCEP;

-----------------------------------------------------------------
-- Returns TRUE if the ART_OBJECT, OBJ, is a fact, otherwise FALSE.
-----------------------------------------------------------------
function FACTP(OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.FACTP;

-------------------------------------------------------------
-- Fact and Sequence Manipulation
-------------------------------------------------------------

-----------------------------------------------------------------
-- Returns the fact with fact number n.  If no fact has that number,
-- returns NULL.
-----------------------------------------------------------------
function FIND_FACT(N: INTEGER_TYPE) return ART_OBJECT
   renames DATABASE_SUB.FIND_FACT;

-------------------------------------------------------
-- INT_FIND_FACT: Finds a fact based on a ID, and returns NIL instead of NULL.
-------------------------------------------------------
function INT_FIND_FACT(ID: INTEGER_TYPE) return ART_OBJECT
   renames DATABASE_SUB.INT_FIND_FACT;

-------------------------------------------------------
-- Returns the fact number of fact.
-------------------------------------------------------
function FACT_NUMBER(FACT: ART_OBJECT) return NATURAL_TYPE
   renames DATABASE_SUB.FACT_NUMBER;

-----------------------------------------------------------------------------------------
-- FOR_ALL_FACTS: Iterates over all the facts in the current database, calling a given
```

```
-- procedure once for each fact.
-------------------------------------------------------------------------------
-- generic
--   with procedure PROCESS (THE_ITEM : in  ART_OBJECT;
--                           CONTINUE : out BOOLEAN);
-- procedure FOR_ALL_FACTS;

-------------------------------------------------------------
-- Returns length of obj.
-------------------------------------------------------------
function LENGTH(OBJ: ART_OBJECT) return NATURAL_TYPE
   renames ART_OBJECT_SUB.LENGTH;

-------------------------------------------------------------------
-- Returns the position of the first occurrence of value in obj.  If
-- value is not in obj, returns 0.
-------------------------------------------------------------------
function POSITION(VALUE: ART_OBJECT;
                  OBJ: ART_OBJECT) return NATURAL_TYPE
   renames ART_OBJECT_SUB.POSITION;

-------------------------------------------------------------------
-- Returns TRUE if value is in obj, and FALSE otherwise.
-------------------------------------------------------------------
function MEMBER(VALUE: ART_OBJECT;
                  OBJ: ART_OBJECT) return BOOLEAN
   renames ART_OBJECT_SUB.MEMBER;

-------------------------------------------------------------
-- Returns the nth element of obj.
-------------------------------------------------------------
function NTH(OBJ: ART_OBJECT;
             INDEX: NATURAL_TYPE) return ART_OBJECT
   renames ART_OBJECT_SUB.NTH;

-------------------------------------------------------------
-- Fact and Sequence Creation
-------------------------------------------------------------

-----------------------------------------------------------------------
-- Constructs an "empty" fact template and returns a pointer to it as an
-- ART object which may later be asserted.  It is an error to assert a
-- template without inserting something into each of the size slots
-- allocated in it.  All templates are permanent.  Additionally they should
-- not be freed with unregister_art_object.  They should only be freed
-- with free_template
-----------------------------------------------------------------------
function MAKE_TEMPLATE(SIZE: NATURAL_TYPE) return TEMPLATE_TYPE
   renames CALLIO_SUB.MAKE_TEMPLATE;

-----------------------------------------------------------------------
-- This function sets the element of template specified by
-- index to be value.  It is an error to attempt to modify a fact
-- not created with MAKE_TEMPLATE.  The first element of the fact (the
-- relation) is indexed by index 1.  The other elements of the fact
-- have indices 2 through the length of the fact.
-----------------------------------------------------------------------
procedure SET_NTH(TEMPLATE: in out TEMPLATE_TYPE;
                  INDEX: in INTEGER_TYPE;
                  VALUE: in ART_OBJECT)
   renames CALLIO_SUB.SET_NTH;

-----------------------------------------------------------------------
-- Frees the TEMPLATE_TYPE template.  It is an error to continue to refer to
```

```
   -- template after freeing.
   ------------------------------------------------------------------------
   procedure FREE_TEMPLATE(TEMPLATE: in out TEMPLATE_TYPE)
      renames CALLIO_SUB.FREE_TEMPLATE;

   ------------------------------------------------------------------------
   -- Asserts a fact from the contents of template into the ART database.
   -- Template must be constructed using the functions and macros below
   -- prior to assertion.  It is an error to assert a fact with an empty fact
   -- slot.  A template may be used for any number of assertions.
   ------------------------------------------------------------------------
   function ASSERT(TEMPLATE: in TEMPLATE_TYPE) return ART_OBJECT
      renames CALLIO_SUB.ASSERT;

   ------------------------------------------------------------------------
   -- This function takes a template and returns a sequence matching the
   -- template.  The sequence returned will not incorporate or alter the
   -- template.
   ------------------------------------------------------------------------
   function SEQUENCE(TEMPLATE: in TEMPLATE_TYPE) return ART_OBJECT
      renames CALLIO_SUB.SEQUENCE;

   ------------------------------------------------------------
   -- ART Control
   ------------------------------------------------------------

   ------------------------------------------------------------
   -- Retracts fact from the ART database.
   ------------------------------------------------------------
   procedure RETRACT(FACT: in out ART_OBJECT)
      renames DATABASE_SUB.RETRACT;

   ------------------------------------------------------------------------
   -- Function: Runs the inference engine (match-select-act cycle) LIMIT
   --           number of times.  Continue to run until the agenda is
   --           empty, until the HALT is encountered on the rhs of a rule,
   --           until a salience threshold is reached, or until a breakpoint
   --           is triggered.
   --
   -- Parameters: LIMIT - Number of inference engine cycles. (Or number of rules
   --             allowed to fire.
   --                     >   0   fire that many rules
   --                     =   0   then No rules fire
   --                     =  -1   then LIMIT := current default limit
   --                     <= -2   fire until agenda becomes empty
   ------------------------------------------------------------------------
   function RUN(RUN_LIMIT: in INTEGER_TYPE) return INTEGER_TYPE
      renames INFER_ENG_SUB.RUN;

   ------------------------------------------------
   -- Returns TRUE if the agenda is empty.  Otherwise, FALSE.
   ------------------------------------------------
   function AGENDA_EMPTY_P return BOOLEAN
      renames AGENDA_SUB.AGENDA_EMPTY_P;

   ------------------------------------------------------------------------
   -- Function: Complete the execution of all rhs actions of the current
   --           rule and halts the inference engine.
   --
   ------------------------------------------------------------------------
   procedure HALT
       renames INFER_ENG_SUB.HALT;

    ------------------------------------------------------------------------
```

```
-- Function: It sets the asynchronous Ada function.
--           The asynchronous function should be defined in the USER_SUB
--           package.  ART/Ada will intern this function and assign it
--           a function ID.
-------------------------------------------------------------------------
procedure SET_ASYNCH_FUN(FUN : STRING)
   renames INFER_ENG_SUB.SET_ASYNCH_FUN;

-------------------------------------------------------------------------
-- Function: It returns the name of the asynchronous Ada function.
-------------------------------------------------------------------------
function GET_ASYNCH_FUN return STRING
   renames INFER_ENG_SUB.GET_ASYNCH_FUN;

-----------------------------------------------------------
-- Returns the minimum salience below which rules may not fire.
-----------------------------------------------------------
function GET_SALIENCE_THRESHOLD return SALIENCE_TYPE
   renames INFER_ENG_SUB.GET_SALIENCE_THRESHOLD;

-------------------------------------------------------------------------
-- Set the minimum salience below which rules may not fire.  The constant
-- min_salience may be used to reset salience to the initial default.
-------------------------------------------------------------------------
function SET_SALIENCE_THRESHOLD(SALIENCE: in INTEGER_TYPE) return INTEGER_TYPE
   renames INFER_ENG_SUB.SET_SALIENCE_THRESHOLD;

-------------------------------------------------------------------------
-- Returns the default limit on rule firings for run.  If the returned value
-- is negative, the default is to let ART run indefinitely.
-------------------------------------------------------------------------
function GET_LIMIT_DEFAULT return INTEGER_TYPE
   renames INFER_ENG_SUB.GET_LIMIT_DEFAULT;

-----------------------------------------------------------
-- Sets the default limit on rule firings for run.  If limit is
-- negative, the default is to let ART run indefinitely.
-----------------------------------------------------------
function SET_LIMIT_DEFAULT(LIMIT: in INTEGER_TYPE) return INTEGER_TYPE
   renames INFER_ENG_SUB.SET_LIMIT_DEFAULT;

-------------------------------------------------------------------------
-- Returns a boolean that tells whether ART prints informational messages.
-- TRUE means they are printed; FALSE means they are suppressed.
-------------------------------------------------------------------------
function GET_PRINT_MESSAGES return BOOLEAN
   renames INFER_ENG_SUB.GET_PRINT_MESSAGES;

-----------------------------------------------------------
-- Controls whether ART prints informational messages.  TRUE means
-- to print messages; FALSE to suppress printing of messages.
-- TRUE is the default.
-----------------------------------------------------------
function SET_PRINT_MESSAGES(VALUE: BOOLEAN) return BOOLEAN
   renames INFER_ENG_SUB.SET_PRINT_MESSAGES;

-----------------------------------------------------------
-- Convert INTEGER_TYPE to BOOLEAN.  If 0, then FALSE. TRUE, otherwise.
-----------------------------------------------------------
function INTEGER_TO_BOOLEAN(STATUS : INTEGER_TYPE) return BOOLEAN
   renames CALLIO_SUB.INTEGER_TO_BOOLEAN;

-----------------------------------------------------------
-- Convert BOOLEAN to INTEGER_TYPE.  If TRUE, then 1. If FALSE, then 0.
```

```
-------------------------------------------------------------------
function BOOLEAN_TO_INTEGER(STATUS : BOOLEAN) return INTEGER_TYPE
   renames CALLIO_SUB.BOOLEAN_TO_INTEGER;

-------------------------------------------------------------------------
-- Function: It frees a sequence
-------------------------------------------------------------------------
procedure FREE_SEQUENCE(X : in out ART_OBJECT)
   renames ALLOC_SUB.FREE_SEQUENCE;

-------------------------------------------------------------------------
-- Function: Prints the object followed by a CR LF to the standard output.
--           Standard output is, by default, the screen.
--
-- Parameters: OBJECT - The object to be printed
-------------------------------------------------------------------------
function PRINT(OBJECT: ART_OBJECT;
               STREAM: ART_OBJECT := null) return ART_OBJECT
  renames IO_SUB.PRINT;

-------------------------------------------------------------------------
-- Function: Prints the ART Object to the standard output.
--           Standard output is, by default, the screen.
--           Puts quotes around the string being printed.
--
-- Parameters: OBJECT - The ART Object to be printed
-------------------------------------------------------------------------
function PRIN1(OBJECT: ART_OBJECT;
               STREAM: ART_OBJECT := null) return ART_OBJECT
  renames IO_SUB.PRIN1;

-------------------------------------------------------------------------
-- Function: Prints the object to the standard output.
--           Standard output is, by default, the screen.
--
-- Parameters: OBJECT - The object to be printed
-------------------------------------------------------------------------
function PRINC(OBJECT: ART_OBJECT;
               STREAM: ART_OBJECT := null) return ART_OBJECT
  renames IO_SUB.PRINC;

-------------------------------------------------------------------------
-- Function: Prints a CR to the standard output
--           Standard output is, by default, the screen.
-------------------------------------------------------------------------
procedure TERPRI(STREAM: ART_OBJECT := null)
  renames IO_SUB.TERPRI;

-------------------------------------------------------------------------
-- Prints out a list of objects to the given stream.  The symbol T indicates
-- that a newline should be emitted.  The symbol T as the stream argument
-- indicates that stdout should be used as the stream (for compatibility with
-- big Art).  Conceptually, the argument list of printout is:
--
--   printout(stream &rest args)
--
-- For now, ignore the first arg, STREAM.
-------------------------------------------------------------------------
function PRINTOUT(STREAM : ART_OBJECT;
                  REST   : ART_OBJECT_ARRAY_PTR_TYPE) return BOOLEAN
  renames IO_SUB.PRINTOUT;

-------------------------------------------------------------------------
-- Function: Read from standard output.
```

```
    --
    -- Parameters: OBJECT - The ART_OBJECT being read.
    ------------------------------------------------------------------------
    function READ_INTERFACE(STREAM: ART_OBJECT := null) return ART_OBJECT
      renames IO_SUB.READ_INTERFACE;

end ART;
```

III.2 Specification of ERROR_HDL_SUB Package

```
------------------------------------------------------------------------
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--      Inference Corporation, be used or disclosed
--      for other than evaluation purposes.
--
------------------------------------------------------------------------
-- Author: Jim Badura
--
-- Package: ERROR_HDL_SUB
--
-- Function:  This package contains a procedure that performs error
--            recovery for internal ART errors.
--
-- State Variables: None
--
-- State Variable Initialization: None
--
-- Change Log:
--
------------------------------------------------------------------------------
with STRUCT_DCL, CALENDAR;
use STRUCT_DCL;

package ERROR_HDL_SUB is

  type ERROR_LOC is (LHS_LOC, RHS_LOC, TOPLEVEL_LOC, ASYNC_LOC);

  type ERROR_TYPE is (CONSTRAINT_ERR,NUMERIC_ERR,PROGRAM_ERR,STORAGE_ERR,
                      TASKING_ERR, TIME_ERR,
                      INTERNAL_ERR, RETRACT_ERR, INTERPRETER_ERR,
                      USER_ERR,
                      USER_DEFINED_ERR);
```

```
   TIME_ERROR          : exception renames CALENDAR.TIME_ERROR;
   INTERNAL_ERROR      : exception;
   RETRACT_ERROR       : exception;
   INTERPRETER_ERROR   : exception;      -- Error in the interpreter.
   USER_ERROR: exception;      -- The User can use this exception.
   USER_DEFINED_ERROR: exception;      -- The User can use this exception.

   ------------------------------------------------------------------------
   -- Function: This procedure invokes the appropriate Ada routine for
   --           recovering from the current internal ART error.
   --           This procedure should be separate.
   --
   -- Parameters: ERROR - The current error being handled
   --
   ------------------------------------------------------------------------
   procedure PROCESS_ERROR(ERROR: in ERROR_TYPE);

   ------------------------------------------------------------------------
   -- Function: This procedure stores an error message into a buffer
   --           so that the error message could be printed by PROCESS_ERROR later.
   --
   -- Parameters: MESSAGE - The error message.
   --
   ------------------------------------------------------------------------
   procedure ERROR(MESSAGE: in STRING);

   ------------------------------------------------------------------------
   -- Function: This procedure handles an warning message.
   --           This procedure should be separate.
   --
   -- Parameters: MESSAGE - The warning message.
   --
   ------------------------------------------------------------------------
   procedure WARNING(MESSAGE: in STRING);

end ERROR_HDL_SUB;
```

III.3 Body of ERROR_HDL_SUB Package

```
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--      for other than evaluation purposes.
--
------------------------------------------------------------------------
-- Author: Jim Badura
--
-- Package: ERROR_HDL_SUB
--
-- Function:  This package contains a procedure that performs error
--            recovery for internal ART errors.
--
-- State Variables: None
--
-- State Variable Initialization: None
--
-- Change Log:
--
------------------------------------------------------------------------
with GLOBAL_DCL;
use GLOBAL_DCL;
package body ERROR_HDL_SUB is
  ----------------------------------------------------------------------------
  -- Function: This procedure invokes the appropriate Ada routine for
  --           recovering from the current internal ART error.
  --
  -- Parameters: ERROR - The current error being handled
  --
  ----------------------------------------------------------------------------
  procedure PROCESS_ERROR(ERROR: in ERROR_TYPE) is separate;
```

```
    ------------------------------------------------------------------------
    -- Function: This procedure stores an error message into a buffer
    --           so that the error message could be printed by PROCESS_ERROR later.
    --
    -- Parameters: MESSAGE - The error message.
    --
    ------------------------------------------------------------------------
    procedure ERROR(MESSAGE: in STRING) is
    begin
      CHARACTER_STRING_COPY(MESSAGE, CUR_USER.ERROR_BUFFER);
    end ERROR;

    ------------------------------------------------------------------------
    -- Function: This procedure handles the warning message.
    --
    -- Parameters: MESSAGE - The warning message.
    --
    ------------------------------------------------------------------------
    procedure WARNING(MESSAGE: in STRING) is separate;

  end ERROR_HDL_SUB;
```

III.4 Separate Procedure ERROR_HDL_SUB.PROCESS_ERROR

```
--------------------------------------------------------------------
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--      Inference Corporation, be used or disclosed
--      for other than evaluation purposes.
--
--------------------------------------------------------------------
with TEXT_IO;
use  TEXT_IO;
separate (ERROR_HDL_SUB)
procedure PROCESS_ERROR(ERROR: in ERROR_TYPE) is
  ERR: constant STRING := ";;; ERROR: ";
begin
  case ERROR is
    when CONSTRAINT_ERR
      => PUT_LINE(ERR & "Constraint error");
    when NUMERIC_ERR
      => PUT_LINE(ERR & "Numeric error");
    when PROGRAM_ERR
      => PUT_LINE(ERR & "Program error");
    when STORAGE_ERR
      => PUT_LINE(ERR & "Storage error");
    when TASKING_ERR
      => PUT_LINE(ERR & "Tasking error");
    when TIME_ERR
      => PUT_LINE(ERR & "Time error");
    when INTERNAL_ERR
      => PUT_LINE(ERR & "Internal ART error: " &
         CHARACTER_STRING.SUBSTRING_OF(CUR_USER.ERROR_BUFFER));
         CHARACTER_STRING.CLEAR(CUR_USER.ERROR_BUFFER);
    when RETRACT_ERR
      => PUT_LINE(ERR & "Retract error: " &
         CHARACTER_STRING.SUBSTRING_OF(CUR_USER.ERROR_BUFFER));
```

```
            CHARACTER_STRING.CLEAR(CUR_USER.ERROR_BUFFER);
        when INTERPRETER_ERR
          => PUT_LINE(ERR & "Interpreter error: " &
            CHARACTER_STRING.SUBSTRING_OF(CUR_USER.ERROR_BUFFER));
            CHARACTER_STRING.CLEAR(CUR_USER.ERROR_BUFFER);
        when USER_ERR
          => PUT_LINE(ERR & "User error: " &
            CHARACTER_STRING.SUBSTRING_OF(CUR_USER.ERROR_BUFFER));
            CHARACTER_STRING.CLEAR(CUR_USER.ERROR_BUFFER);
        when USER_DEFINED_ERR
          => PUT_LINE(ERR & "User defined error");
      end case;
    end PROCESS_ERROR;
```

III.5 Separate Procedure ERROR_HDL_SUB.WARNING

```
-----------------------------------------------------------------------
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--      they will not, without the permission of
--      Inference Corporation, be used or disclosed
--      for other than evaluation purposes.
--
-----------------------------------------------------------------------
with TEXT_IO;
use  TEXT_IO;
separate (ERROR_HDL_SUB)
procedure WARNING(MESSAGE: in STRING) is
begin
  PUT_LINE(";;; WARNING: " & MESSAGE);
end WARNING;
```

III.6 Specification of USER_INTERFACE Package

```
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-------------------------------------------------------------------------
-- Author: J. T. Badura
--
-- Package: USER_INTERFACE_SUB
--
-- Function: This package contains subprograms that controls the user
--           interface.
--
-- State Variables: None
--
-- State Variable Initialization: None
--
-- Change Log:
--
-------------------------------------------------------------------------
with STRUCT_DCL;
use STRUCT_DCL;
package USER_INTERFACE_SUB is
  ------------------------------------------------------------------------
  -- Function: This procedure invokes the interactive ART/Ada command loop.
  --           This procedure will display the initial banner and repeatly
  --           print the ART/Ada prompt for a ART command.
  --           The command loop should handle watch/unwatch, reset, run,
  --           agenda, facts.
  ------------------------------------------------------------------------
  procedure COMMAND_LOOP;

   ------------------------------------------------
   -- FACTS: Prints out a list of the current facts
   -- to the screen, in sorted order and with a
   -- sum of the total current facts.
   ------------------------------------------------
   procedure FACTS;

  ------------------------------------------------
  -- AGENDA: Prints out the agenda of the rules
  --         that are ready to fire.
  ------------------------------------------------
```

```
    procedure AGENDA;

    ------------------------------------------------------------------
    -- Timed_run: Calls a timing function to determine the amount of
    --            time a run has taken.
    ------------------------------------------------------------------
    procedure TIMED_RUN(RUN_LIMIT: INTEGER_TYPE);

end USER_INTERFACE_SUB;
```

IV. Benchmark Programs

This appendix includes the following ART-IM programs used to benchmark the ART/Ada prototype:

- Monkey and Banana
- N-Queens (6 Queens)

IV.1 Monkey and Banana

```
;;; -*- Mode: ART; Base: 10.; Package: ART-USER -*-

;;;=======================================================
;;;   Monkees and Bannanas Sample Problem
;;;
;;;     This is an extended version of a
;;;     rather common AI planning problem.
;;;     The point is for the monkee to find
;;;     and eat some bannanas.
;;;
;;;     To execute, merely load, reset and run.
;;;=======================================================

;;;*************************
;;;* chest unlocking rules *
;;;*************************

(defrule unlock-chest-to-hold-object ""
  (goal-is-to active holds ?obj)
  (object ?chest ? ? ? ?obj ?)
  (not (goal-is-to active unlock ?chest))
  =>
  (assert (goal-is-to active unlock ?chest)))

(defrule unlock-chest-to-move-object ""
  (goal-is-to active move ?obj ?)
  (object ?chest ? ? ? ?obj ?)
  (not (goal-is-to active unlock ?chest))
  =>
  (assert (goal-is-to active unlock ?chest)))

(defrule hold-chest-to-put-on-floor ""
  (goal-is-to active unlock ?chest)
  (object ?chest ? light ~floor ? ?)
  (not (goal-is-to active holds ?chest))
  =>
  (assert (goal-is-to active holds ?chest)))

(defrule put-chest-on-floor ""
  (goal-is-to active unlock ?chest)
  ?f1 <- (monkey ?place ?on ?chest)
  ?f2 <- (object ?chest held light held ?contains ?key)
  =>
;  (printout t "Monkey throws " ?chest " off " ?on " onto floor." t)
  (retract ?f1 ?f2)
  (assert (monkey ?place ?on blank))
  (assert (object ?chest ?place light floor ?contains ?key)))

(defrule get-key-to-unlock ""
  (goal-is-to active unlock ?obj)
  (object ?obj ?place ? floor ? ?key)
  (monkey ? ? ~?key)
  (not (goal-is-to active holds ?key))
  =>
  (assert (goal-is-to active holds ?key)))

(defrule move-to-chest-with-key ""
  (goal-is-to active unlock ?chest)
  (monkey ?mplace ? ?key)
  (object ?chest ?cplace&~?mplace ? floor ? ?key)
  (not (goal-is-to active walk-to ?cplace))
  =>
  (assert (goal-is-to active walk-to ?cplace)))
```

```
(defrule unlock-chest-with-key ""
  ?f1 <- (goal-is-to active unlock ?chest-obj)
  ?f2 <- (object ?chest-obj ?place ?weight ?on ?obj-in ?key)
  (monkey ?place ?on ?key)
  =>
;  (printout t "Monkey opens chest with " ?key " revealing " ?obj-in t)
  (retract ?f1 ?f2)
  (assert (object ?chest-obj ?place ?weight ?on nil ?key))
  (assert (object ?obj-in ?place light ?chest-obj nil nil)))

;;;**********************
;;;* process hold object *
;;;**********************

(defrule use-ladder-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light ceiling ? ?)
  (not (goal-is-to active move ladder ?place))
  =>
  (assert (goal-is-to active move ladder ?place)))

(defrule climb-ladder-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light ceiling ? ?)
  (object ladder ?place ? floor ? ?)
  (not (goal-is-to active on ladder))
  =>
  (assert (goal-is-to active on ladder)))

(defrule grab-object-from-ladder ""
  ?f1 <- (goal-is-to active holds ?obj)
  ?f2 <- (object ?obj ?place light ceiling ?contains ?key)
  (object ladder ?place ? ? ? ?)
  ?f3 <- (monkey ?place ladder blank)
  =>
;  (printout t "Monkey grabs the " ?obj t)
  (retract ?f1 ?f2 ?f3)
  (assert (object ?obj held light held ?contains ?key))
  (assert (monkey ?place ladder ?obj)))

(defrule climb-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light ?on&~floor&~ceiling ? ?)
  (monkey ?place ~?on ?)
  (not (goal-is-to active on ?on))
  =>
  (assert (goal-is-to active on ?on)))

(defrule walk-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light ~ceiling ? ?)
  (monkey ~?place ? ?)
  (not (goal-is-to active walk-to ?place))
  =>
  (assert (goal-is-to active walk-to ?place)))

(defrule drop-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light floor ? ?)
  (monkey ?place ? ~blank)
  (not (goal-is-to active holds blank))
  =>
  (assert (goal-is-to active walk-to ?place)))
```

```
(defrule get-on-floor-to-hold ""
  (goal-is-to active holds ?obj)
  (object ?obj ?place light floor ? ?)
  (monkey ?place ~floor ?)
  (not (goal-is-to active on floor))
  =>
  (assert (goal-is-to active on floor)))

(defrule grab-object ""
  ?f1 <- (goal-is-to active holds ?obj)
  ?f2 <- (object ?obj ?place light ?on ?contains ?key)
  ?f3 <- (monkey ?place ?on blank)
  =>
  (printout t "Monkey grabs the " ?obj t)
  (retract ?f1 ?f2 ?f3)
  (assert (object ?obj held light held ?contains ?key))
  (assert (monkey ?place ?on ?obj)))

;;;*************************
;;;* move object to a place *
;;;*************************

(defrule hold-object-to-move ""
  (goal-is-to active move ?obj ?place)
  (object ?obj ~?place light ? ? ?)
  (monkey ? ? ~?obj)
  (not (goal-is-to active holds ?obj))
  =>
  (assert (goal-is-to active holds ?obj)))

(defrule move-object-to-place ""
  (goal-is-to active move ?obj ?place)
  (monkey ~?place ? ?obj)
  (not (goal-is-to active walk-to ?place))
  =>
  (assert (goal-is-to active walk-to ?place)))

(defrule drop-object-once-moved ""
  ?f1 <- (goal-is-to active move ?obj ?place)
  ?f2 <- (monkey ?place ?on ?obj)
  ?f3 <- (object ?obj ? light ? ?contains ?key)
  =>
  (printout t "Monkey drops the " ?obj " " t)
  (retract ?f1 ?f2 ?f3)
  (assert (monkey ?place ?on blank))
  (assert (object ?obj ?place light floor ?contains ?key)))

(defrule already-moved-object ""
  ?f1 <- (goal-is-to active move ?obj ?place)
  (object ?obj ?place ? ? ? ?)
  =>
  (retract ?f1))

;;;*************************
;;;* process walk-to place *
;;;*************************

(defrule already-at-place ""
  ?f1 <- (goal-is-to active walk-to ?place)
  (monkey ?place ? ?)
  =>
  (retract ?f1))

(defrule get-on-floor-to-walk ""
```

```
    (goal-is-to active walk-to ?place)
    (monkey ~?place ~floor ?)
    (not (goal-is-to active on floor))
    =>
    (assert (goal-is-to active on floor)))

(defrule walk-holding-nothing ""
  ?f1 <- (goal-is-to active walk-to ?place)
  ?f2 <- (monkey ~?place floor blank)
  =>
  (printout t "Monkey walks to " ?place t)
  (retract ?f1 ?f2)
  (assert (monkey ?place floor blank)))

(defrule walk-holding-object ""
  ?f1 <- (goal-is-to active walk-to ?place)
  ?f2 <- (monkey ~?place floor ?obj&~blank)
  =>
  (printout t "Monkey walks to " ?place " holding " ?obj t)
  (retract ?f1 ?f2)
  (assert (monkey ?place floor ?obj)))

(defrule drop-object ""
  ?f1 <- (goal-is-to active holds blank)
  ?f2 <- (monkey ?place ?on ?obj&~blank)
  ?f3 <- (object ?obj held light held ?inside ?key)
  =>
  (printout t "Monkey drops " ?obj t)
  (retract ?f1 ?f2 ?f3)
  (assert (object ?obj ?place light ?on ?inside ?key))
  (assert (monkey ?place ?on blank)))

;;;*************************
;;;* process get on object *
;;;*************************

(defrule jump-onto-floor ""
  ?f1 <- (goal-is-to active on floor)
  ?f2 <- (monkey ?at ?on&~floor ?obj)
  =>
  (printout t "Monkey jumps off " ?on " onto the floor." t)
  (retract ?f1 ?f2)
  (assert (monkey ?at floor ?obj)))

(defrule walk-to-place-to-climb ""
  (goal-is-to active on ?obj)
  (object ?obj ?place ? ? ? ?)
  (monkey ~?place ? ?)
  (not (goal-is-to active walk-to ?place))
  =>
  (assert (goal-is-to active walk-to ?place)))

(defrule drop-to-climb ""
  (goal-is-to active on ?obj)
  (object ?obj ?place ? ? ? ?)
  (monkey ?place ? ~blank)
  (not (goal-is-to active holds blank))
  =>
  (assert (goal-is-to active holds blank)))

(defrule climb-indirectly ""
  (goal-is-to active on ?obj)
  (object ?obj ?place ? ?on ? ?)
  (monkey ?place ~?on&~?obj blank)
```

```
  (not (goal-is-to active on ?on))
  =>
  (assert (goal-is-to active on ?on)))

(defrule climb-directly ""
  ?f1 <- (goal-is-to active on ?obj)
  (object ?obj ?place ? ?on ? ?)
  ?f2 <- (monkey ?place ?on blank)
  =>
  (printout t "Monkey climbs onto " ?obj t)
  (retract ?f1 ?f2)
  (assert (monkey ?place ?obj blank)))

(defrule already-on-object ""
  ?f1 <- (goal-is-to active on ?obj)
  (monkey ? ?obj ?)
  =>
  (retract ?f1))

;;;**********************
;;;* process eat object *
;;;**********************

(defrule hold-to-eat ""
  (goal-is-to active eat ?obj)
  (monkey ? ? ?obj)
  (not (goal-is-to active holds ?obj))
  =>
  (assert (goal-is-to active holds ?obj)))

(defrule satisfy-hunger ""
  ?f1 <- (goal-is-to active eat ?obj)
  ?f2 <- (monkey ?place ?on ?obj)
  ?f3 <- (object ?obj ? ? ? ? ?)
  =>
  (printout t "Monkey eats the " ?obj "." t)
  (retract ?f1 ?f2 ?f3)
  (assert (monkey ?place ?on blank)))

;;;*****************
;;;* initial-state *
;;;*****************

(defrule startup ""
  (start-fact)
  =>
  (assert (monkey t5-7 green-couch blank))
  (assert (object green-couch t5-7 heavy floor foo foo))
  (assert (object red-couch t2-2 heavy floor foo foo))
  (assert (object big-pillow t2-2 light red-couch foo foo))
  (assert (object red-chest t2-2 light big-pillow ladder red-key))
  (assert (object blue-chest t7-7 light ceiling bananas blue-key))
  (assert (object blue-couch t8-8 heavy floor foo foo))
  (assert (object green-chest t8-8 light ceiling blue-key red-key))
  (assert (object red-key t1-3 light floor foo foo))
  (assert (goal-is-to active eat bananas)))

(deffacts start-fact (start-fact))
```

IV.2 N-Queens

```
;An ART-IM version of NQUEENS.
;Rich Schroeppel  October 1988
;Copyright (C) 1988  Inference Corp.

;The problem is to place N queens on an NxN chessboard so that no queen
;attacks another.  (A queen attacks another if they are on the same row,
;column, or diagonal.)
;
;Example:   - Q - -
;           - - - Q
;           Q - - -
;           - - Q -
;
;To run the demo, load this file into ART.  Then reset and run it.
;
;    (load "xxx/nqueens.art")
;    (reset)
;    (run)
;
;When the program asks "How many rows on the board?", type 4 and then ENTER.
;To run the program again, just (reset) and (run).
;
;
;ART features illustrated in this program:
;Defglobal
;Defrule
;Salience
;A startup rule, with null left-hand-side
;Pattern tests with &:
;Sequence variables, Variable length facts
;Assert, Retract, Binding a fact variable with <-
;Procedural language:
;Bind, Arithmetic, Absolute value function, Comparisons with = and <
;Sequence functions and predicates:  Length$, Nth$, Member$
;Iteration and Conditionals:  For, Downto, If, Not
;Input-Output:  Read, Printout, character strings
;
;
;Board size             1    2    3    4    5    6    7    8    9
;Number of solutions    1    0    0    2    10   4    40   92   352
;(Solutions that are reflections or rotations of another solution are
;considered distinct.)
;
;Since there are as many queens as rows of the chessboard, each row must
;contain exactly one queen.  This program generates partial solutions in
;which the first K rows of the board are filled with K non-attacking queens.
;We begin with a blank board.  The partial solutions are extended one
;row/queen at a time.  When the newly added queen attacks a previous queen,
;the extended partial solution is discarded.  Any partial solution that
;has N rows filled in is a true solution, and is printed.
;A partial solution is represented as (SOLUTION c1 c2 ... ck).  C1 ... Ck
;are numbers between 1 and N.  Ci is the column of the queen in row i.


(defglobal ?count = 0)  ;Count of solutions
(defglobal ?print = NIL);This may be set to NIL to turn off printing.

(defrule ask-user-for-problem-size
  "Ask the user how big the chessboard is."
  =>
;     (printout t t "How many rows on the board?  ")
;     (bind ?n (read))
     (bind ?n 6)      ; 6 queens
     (assert (problem-size ?n) (solution))
```

```
      (bind ?count 0))

(defrule grow-solution
  "Extend a partial solution by adding another queen."
     (problem-size ?n)
     (solution $?x)
  => (if (< (length$ ?x) ?n) then
       (for ?i from 1 to ?n do
         (if (not (member$ ?i ?x)) then (assert (solution $?x ?i))))))
;The (not (member$ ?i ?x)) condition checks that no previous queen
;occupies column ?i.

(defrule prune-diagonal-attacks
  "This rule kills off solutions in which a newly added queen attacks a
   previous queen along a diagonal."
  (declare (salience 20))  ;High salience to kill bad solutions immediately.
     ?fact <- (solution $?x ?c)
  => (bind ?xlen (length$ ?x))
     (for ?i from ?xlen downto 1 do
       (if (= (- (+ ?xlen 1) ?i) (abs (- ?c (nth$ ?x ?i)))) then
         (retract ?fact))))

(defrule print-solution
  "This rule detects solutions and prints a chessboard showing the position
   of the queens."
     (problem-size ?n)
     (solution $?x&:(= (length$ ?x) ?n))
  => (bind ?count (+ ?count 1))
     (if ?print then
       (printout t t "Solution " ?count ":" t)
       (for ?row from 1 to ?n do
         (bind ?qrc (nth$ ?x ?row))
         (for ?column from 1 to ?n do
           (if (= ?qrc ?column) then (printout t " Q") else (printout t " -")))
         (printout t t))))

(defrule print-total
  "This rule prints the total number of solutions."
  (declare (salience -20))  ;Wait for solutions to be generated.
  => (printout t t "Total solutions: " ?count t))
```

V. Test Programs

This appendix includes the following ART-IM programs used to validate the ART/Ada prototype:

- Sweeptop: Contains about 30 rules that test the rule RHS.
- Sweep2: Contains about 270 rules that test the pattern/join network.

V.1 Sweeptop

```
;;; This file contains a multitude of simple "top-level" command
;;; tests of ART/C.  It is intended to be self-diagnostic; at least,
;;; it should either die horribly or complain if any part of ART/C
;;; is broken.  BDC

;; If dribble isn't working, or if its behavior has changed
;; substantially, large parts of this program will blow up.

;;; ***************************************************************************
(defrule if-test ""
  =>
  (printout t "IF tests..." t)
  (if t then t else (printout t ">>>>> IF error 1." t))
  (if nil then (printout t ">>>>> IF error 2." t)
       else t)
)

;;; ***************************************************************************
(defrule bind-test-1 ""
  =>
  (printout t "BIND tests..." t)
  (bind ?d1 foo)
  (if (not (equal ?d1 foo))
    then (printout t ">>>>> BIND error 1." t))
)

(defrule bind-test-2 ""
  =>
  (bind ?d1 "foo")
  (if (not (equal ?d1 "foo"))
    then (printout t ">>>>> BIND error 2." t))
)

(defrule bind-test-3 ""
  =>
  (bind ?d1 12)
  (if (not (equal ?d1 12))
    then (printout t ">>>>> BIND error 3." t))
)

(defrule bind-test-4 ""
  =>
  (bind ?d1 12.45)
  (if (not (equal ?d1 12.45))
    then (printout t ">>>>> BIND error 4." t))
)

;;; ***************************************************************************
;;; Need a scratch defglobal for later use:
(defglobal ?scratch = "foo")

(defglobal ?b = "foo")                          ;string
(defglobal ?c = 55)                             ;integer
(defglobal ?d = 55.55)                          ;float
(defglobal ?e = foo)                            ;symbol

(defrule defglobal-test-1 ""
  =>
  (printout t "DEFGLOBAL tests..." t)
  (if (not (equal ?b "foo"))
    then (printout t ">>>>> DEFGLOBAL error 1" t))
)

(defrule defglobal-test-2 ""
```

```
  =>
  (if (not (equal ?c 55))
    then (printout t ">>>>> DEFGLOBAL error 2" t))
)

(defrule defglobal-test-3 ""
  =>
  (if (not (equal ?d 55.55))
    then (printout t ">>>>> DEFGLOBAL error 3" t))
)

(defrule defglobal-test-4 ""
  =>
  (if (not (equal ?e foo))
    then (printout t ">>>>> DEFGLOBAL error 4" t))
)

;;; ******************************************************************

(defrule print-test ""
=>
(printout t "Tests of PRINT *****" t)
(print foo )                                    ;symbol
(print 12 )                                     ;integer
(print 12.456 )                         ;float
(print "foo bar" )                              ;string
(print (equal 1 1) )                            ;T
(print (equal 1 2) )                            ;NIL

(printout t t "Tests of PRIN1 ***** " t)
(prin1 12.456 )                         ;float
(printout t t)                                  ;to separate tests
(prin1 foo )                                    ;symbol
(prin1 12 )                                     ;integer
(prin1 "foo bar" )                              ;string
(prin1 (equal 1 1))                             ;T
(prin1 (equal 1 2))                             ;NIL

(printout t t "tests of PRINC ***** " t)
(printout t t)                                  ;to separate tests
(princ 12.456 )                         ;float
(printout t t)
(princ foo )                                    ;symbol
(princ 12 )                                     ;integer
(princ "foo bar" )                              ;string
(princ (equal 1 1) )                            ;T
(princ (equal 1 2) )                            ;NIL

(printout t t "tests of PRINTOUT *****" t)
(printout t t)                                  ;to separate tests
(printout t  12.456)                            ;float
(printout t t)                                  ;to separate tests
(printout t  foo)                               ;symbol
(printout t  12 t)                              ;integer
(printout t  "foo bar" t)                       ;string
(printout t  (equal 1 1) t)                     ;T
(printout t  (equal 1 2))                       ;NIL

;; complex formatting commands
(printout t t)                                  ;to separate tests
(printout t "tests of  TERPRI *****" t)
(printout t t "foo")                            ;to separate tests
(terpri)
(printout t "bar" t)
```

```
)

;;; ************************************************************************
(defrule eq-and-test ""
  =>
(printout t "EQ and ")
(if (not (eq foo foo))
    then (printout t ">>>>> EQ error 1." t))            ;symbols

(if (not (eq "foo" "foo"))
    then (printout t ">>>>> EQ error 2." t))            ;strings

(if (not (eq 12 12))
    then (printout t ">>>>> EQ error 3." t))            ;integers

(if (not (eq 12.45 12.450))
    then (printout t ">>>>> EQ error 4." t))            ;floats

;;; sequences and facts will have to be tested through rules.
;;; Not top-level.

;;; There are all kinds of things that could be unequal.
;;; I'll test a few of them...

(if (eq foo foot)
    then (printout t ">>>>> EQ error 6." t))            ;symbols

(if (eq foo "foo")
    then (printout t ">>>>> EQ error 7." t))            ;symbol and similar string

(if (eq "foo" "Foo")
    then (printout t ">>>>> EQ error 8." t))            ;strings with capitalization differences

(if (eq 12 12.0)
    then (printout t ">>>>> EQ error 9." t))            ;integers and = floats

;; EQUAL uses EQ for most tests, but it might be good to
;; exercise it anyway.
(printout t "EQUAL tests..." t)

(if (not (equal foo foo))
    then (printout t ">>>>> EQUAL error 1." t)) ;symbols

(if (not (equal "foo" "foo"))
    then (printout t ">>>>> EQUAL error 2." t)) ;strings

(if (not (equal 12 12))
    then (printout t ">>>>> EQUAL error 3." t)) ;integers

(if (not (equal 12.45 12.450))
    then (printout t ">>>>> EQUAL error 4." t)) ;floats

(if (equal foo foot)
    then (printout t ">>>>> EQUAL error 6." t)) ;symbols

(if (equal foo "foo")
    then (printout t ">>>>> EQUAL error 7." t)) ;symbol and similar string

(if (equal "foo" "Foo")
    then (printout t ">>>>> EQUAL error 8." t)) ;strings with capitalization differences

(if (equal 12 12.0)
    then (printout t ">>>>> EQUAL error 9." t)) ;integers and = floats
```

```
)

;;; ***************************************************************************
(defrule gentemp-test ""
=>
(printout t "GENTEMP tests..." t)
;; How do you test something that is defined as returning something
;; different every time you call it???

(if (or (not (symbolp (gentemp)))
        (equal (gentemp) (gentemp)))
    then (printout t ">>>>> GENTEMP error 1." t))
)
;;; ***************************************************************************
(defrule symbolp-test ""
=>
(printout t "SYMBOLP tests..." t)

(if (not (symbolp foo))                          ;symbol
    then (printout t ">>>>> SYMBOLP error 1." t))

(if (symbolp 12)                                 ;integer
    then (printout t ">>>>> SYMBOLP error 2." t))

(if (symbolp 12.4)                               ;float
    then (printout t ">>>>> SYMBOLP error 3." t))

(if (symbolp "foo")                              ;string
    then (printout t ">>>>> SYMBOLP error 4." t))

(if (not (symbolp (eq 1 1)))                     ;T
    then (printout t ">>>>> SYMBOLP error 6." t))

(if (not (symbolp (eq 1 2)))                     ;NIL
    then (printout t ">>>>> SYMBOLP error 7." t))
)

;;; ***************************************************************************
(defrule stringp-test ""
=>
(printout t "STRINGP tests..." t)

(if (stringp foo)                                ;symbol
    then (printout t ">>>>> STRINGP error 1." t))

(if (stringp 12)                                 ;integer
    then (printout t ">>>>> STRINGP error 2." t))

(if (stringp 12.4)                               ;float
    then (printout t ">>>>> STRINGP error 3." t))

(if (not (stringp "foo"))                        ;string
    then (printout t ">>>>> STRINGP error 4." t))

(if (stringp (eq 1 1))                           ;T
    then (printout t ">>>>> STRINGP error 6." t))

(if (stringp (eq 1 2))                           ;NIL
    then (printout t ">>>>> STRINGP error 7." t))
)

;;; ***************************************************************************
(defrule numberp-test ""
=>
```

```
(printout t "NUMBERP tests..." t)
(if (numberp foo)                              ;symbol
    then (printout t ">>>>> NUMBERP error 1." t))

(if (not (numberp 12))                         ;integer
    then (printout t ">>>>> NUMBERP error 2." t))

(if (not (numberp 12.4))                       ;float
    then (printout t ">>>>> NUMBERP error 3." t))

(if (numberp "foo")                            ;string
    then (printout t ">>>>> NUMBERP error 4." t))

(if (numberp (eq 1 1))                         ;T
    then (printout t ">>>>> NUMBERP error 6." t))

(if (numberp (eq 1 2))                         ;NIL
    then (printout t ">>>>> NUMBERP error 7." t))
)

;;; ***************************************************************************
(defrule not-test ""
=>
(printout t "NOT tests..." t)

(if (not foo)                                  ;symbol
    then (printout t ">>>>> NOT error 1." t))

(if (not 12)                                   ;integer
    then (printout t ">>>>> NOT error 2." t))

(if (not 12.4)                                 ;float
    then (printout t ">>>>> NOT error 3." t))

(if (not "foo")                                ;string
    then (printout t ">>>>> NOT error 4." t))

(if (not (eq 1 1))                             ;T
    then (printout t ">>>>> NOT error 6." t))

(if (not (not (eq 1 2)))                       ;NIL
    then (printout t ">>>>> NOT error 7." t))
)

;;; ***************************************************************************
(defrule and-or-test ""
=>
(printout t "AND and OR tests..." t)

(if (and t t nil)
    then (printout t "AND error 1."))

(if (not (and t t t))
    then (printout t "AND error 2."))

(if (not (or nil t nil))
    then (printout t "OR error 1."))

(if (or nil nil nil)
    then (printout t "OR error 2."))
)

;;; ***************************************************************************
(defrule string-append-test ""
```

```
=>
(printout t "STRING-APPEND tests..." t)

(if (not (equal (string-append "a" "b" "c") "abc"))
    then (printout t ">>>>> STRING-APPEND error 1." t))
)
;;; ******************************************************************
(defrule ceiling-test ""
=>
(printout t "CEILING tests..." t)

(if (not (equal (ceiling -1000000000.1) -1000000000))
    then (printout t ">>>>> CEILING error 1." t))

(if (not (equal (ceiling 1000000000.1) 1000000001))
    then (printout t ">>>>> CEILING error 2." t))

(if (not (equal (ceiling 0) 0))
    then (printout t ">>>>> CEILING error 3." t))

(if (not (equal (ceiling -1) -1))
    then (printout t ">>>>> CEILING error 4." t))

(if (not (equal (ceiling 1) 1))
    then (printout t ">>>>> CEILING error 5." t))

(if (not (equal (ceiling -1.1) -1))
    then (printout t ">>>>> CEILING error 6." t))

(if (not (equal (ceiling 1.1) 2))
    then (printout t ">>>>> CEILING error 7." t))
)

;;; ******************************************************************
(defrule truncate-test ""
=>
(printout t "TRUNCATE tests..." t)

(if (not (equal (truncate -1000000000.1) -1000000000))
    then (printout t ">>>>> TRUNCATE error 1." t))

(if (not (equal (truncate 1000000000.1) 1000000000))
    then (printout t ">>>>> TRUNCATE error 2." t))

(if (not (equal (truncate 0) 0))
    then (printout t ">>>>> TRUNCATE error 3." t))

(if (not (equal (truncate -1) -1))
    then (printout t ">>>>> TRUNCATE error 4." t))

(if (not (equal (truncate 1) 1))
    then (printout t ">>>>> TRUNCATE error 5." t))

(if (not (equal (truncate -1.1) -1))
    then (printout t ">>>>> TRUNCATE error 6." t))

(if (not (equal (truncate 1.1) 1))
    then (printout t ">>>>> TRUNCATE error 7." t))
)

;;; ******************************************************************
(defrule evenp-test ""
=>
(printout t "EVENP tests..." t)
```

```
(if (not (evenp 2))
    then (printout t ">>>>> EVENP error 1." t))

(if (not (evenp -2))
    then (printout t ">>>>> EVENP error 2." t))

(if (evenp 1)
    then (printout t ">>>>> EVENP error 3." t))

(if (evenp -1)
    then (printout t ">>>>> EVENP error 4." t))
)

;;; ******************************************************************
(defrule oddp-test ""
=>
(printout t "ODDP tests..." t)

(if (oddp 2)
    then (printout t ">>>>> ODDP error 1." t))

(if (oddp -2)
    then (printout t ">>>>> ODDP error 2." t))

(if (not (oddp 1))
    then (printout t ">>>>> ODDP error 3." t))

(if (not (oddp -1))
    then (printout t ">>>>> ODDP error 4." t))
)

;;; ******************************************************************
(defrule rem-test ""
=>
(printout t "REM tests..." t)
;; tests from Steele p. 217

(if (not (= (rem 13 4) 1))
    then (printout t ">>>>> REM error 1." t))

(if (not (= (rem -13 4) -1))
    then (printout t ">>>>> REM error 2." t))

(if (not (= (rem 13 -4) 1))
    then (printout t ">>>>> REM error 3." t))

(if (not (= (rem -13 -4) -1))
    then (printout t ">>>>> REM error 4." t))

;(if (not (= (rem 13.4 1) 0.4))                    ;ours is defined for ints only
;    then (printout t ">>>>> REM error 5." t))
;
;(if (not (= (rem -13.4 1) -0.4))
;    then (printout t ">>>>> REM error 6." t))
)

;;; ******************************************************************

(defrule mod-test ""
=>
(printout t "MOD tests..." t)
;; tests from Steele, p. 217

(if (not (= (mod 13 4) 1))
```

```
    then (printout t ">>>>> MOD error 1." t))

(if (not (= (mod -13 4) 3))
    then (printout t ">>>>> MOD error 2." t))

(if (not (= (mod 13 -4) -3))
    then (printout t ">>>>> MOD error 3." t))

(if (not (= (mod -13 -4) -1))
    then (printout t ">>>>> MOD error 4." t))

;(if (not (= (mod 13.4 1) 0.4))                    ;ours is defined for ints only
;    then (printout t ">>>>> MOD error 5." t))
;
;(if (not (= (mod -13.4 1) 0.6))
;    then (printout t ">>>>> MOD error 6." t))
)

;;; ************************************************************************
(defrule math-test ""
=>
(printout t "MATH tests..." t)

;; Testing of library math functions is abbreviated to a single test
;; for each, mainly to prove that the function is present and is properly
;; linked with ART/C.  There seems no point in trying to carefully
;; explore for singularities and precision when the functions are
;; beyond our reach, and will not have the same behavior from one site
;; to another. BDC

(if (not (= (max 3 2 1.5) 3))
    then (printout t ">>>>> MATH error 3." t))

(if (not (= (min 3 2 1.5) 1.500000))
    then (printout t ">>>>> MATH error 4." t))

(if (not (= (mod 5 3) 2))
    then (printout t ">>>>> MATH error 5." t))

(if (not (= (+ 1 1.5) 2.5))
    then (printout t ">>>>> MATH error 6." t))

(if (not (= (- 1 0.5) 0.5))
    then (printout t ">>>>> MATH error 7." t))

(if (not (= (* 1 1.5) 1.5))
    then (printout t ">>>>> MATH error 8." t))

(if (not (= (/ 1 2.0) 0.5))
    then (printout t ">>>>> MATH error 9." t))

(if (not (= 1 1))
    then (printout t ">>>>> MATH error 20." t))

;(if (not (/= 1 2))
;    then (printout t ">>>>> MATH error 21." t))    ;broken in 392 on VAX

(if (not (> 2 1))
    then (printout t ">>>>> MATH error 22." t))

(if (not (< 1 2))
    then (printout t ">>>>> MATH error 23." t))

(if (not (>= 2 1))
```

```
    then (printout t ">>>>> MATH error 24." t))

(if (not (<= 1 2))
    then (printout t ">>>>> MATH error 25." t))

(if (not (= (abs -1) 1))
    then (printout t ">>>>> MATH error 27." t))
)

;;; ************************************************************************
(defglobal ?m = 5)                              ;iterative counter
(defglobal ?n = 0)                              ;accumulator

(defrule while-test ""
=>
(printout t "WHILE tests..." t)

(while (> ?m 0) do
       (bind ?n (+ ?n 1))
       (bind ?m (- ?m 1)))

(if (not (= ?n 5))
    then (printout t ">>>>> WHILE error 1." t))
)
;;; ************************************************************************
;(defrule progn-test ""
;=>
;(printout t "PROGN tests..." t)

;(if (not
;      (equal nil
;            (progn (bind ?m 10)
;                   (bind ?n 20)
;                   (= 1 2))))
;    then (printout t ">>>>> PROGN error 1." t))

;(if (not (= ?m 10))
;    then (printout t ">>>>> PROGN error 2." t))
;
;(if (not (= ?n 20))
;    then (printout t ">>>>> PROGN error 3." t))
;)

;;; ************************************************************************
(deffacts init
   (fact one two three four five))

(defrule length-test-1
   "Bind a sequence to ?x"
   (fact $?x)
  =>
  (printout t "LENGTH$ tests..." t)
  (if (not (= (length$ ?x) 5))
        then (printout t ">>>>> LENGTH$ error 1." t))
)

;;; ************************************************************************
(defrule nth-test-1
   "Bind a sequence to ?o"
   (fact $?o)
  =>
  (printout t "NTH$ tests..." t)

  (if (not (equal (nth$ ?o 3) three))
```

```
        then (printout t ">>>>> NTH$ error 1." t))
)
;;; ******************************************************************
(defrule position-test-1
   "Bind a sequence to ?o"
   (fact $?o)
  =>
  (printout t "POSITION$ tests..." t)
  (if (not (= (POSITION$ four ?o) 4))
        then (printout t ">>>>> POSITION$ error 1." t))
)
;;; ******************************************************************
(defrule member-test-1
   "Bind a sequence to ?o"
   (fact $?o)
  =>
  (printout t "MEMBER$ tests..." t)

  (if (member$ six ?o)
    then (printout t ">>>>> MEMBER$ error 1." t))

  (if (not (member$ five ?o))
    then (printout t ">>>>> MEMBER$ error 2." t))
)
```

V.2 Sweep2

```
;;; -*- Mode: ART; Base: 10.; Package: ART-USER -*-
;;; 10-20-88 AMK added sequences tests.


(deffacts initial-1 "Facts to match the rules in SUITE-RULE1 ART"
  (test-case sd1-1 test-case)
  (test-case sd1-2 "a red flag")
  (test-case sd1-3 1)
  (test-case sd1-4 100 321)
  (test-case sd1-5)
  (test-case sd1-6 green)
  (test-case sd1-7 "green")
  (test-case sd1-8 green green)
  (test-case sd1-9)
  (test-case sd1-10 green)
  (test-case sd1-11 "green")
  (test-case sd1-12 green green)
  (sd1-13 sd1-13)
  (sd1-14 sd1-14 green)
  (sd1-15 sd1-15 "green")
  (sd1-16 sd1-16 green green)
  (sd1-17 sd1-17)
  (sd1-18 sd1-18 green)
  (sd1-19 sd1-19 "green")
  (sd1-20 sd1-20 green green)
  (sd1-21 sd1-21 blue red green)
  (sd1-22 sd1-22 red)
  (sd1-23 red sd1-23)
  (sd1-24 sd1-24)
  (sd1-25 sd1-25 data sd1-25)
  (sd1-26 blue fun blue)
  (sd1-27 blue fun get)
  (sd1-28 blue blue blue)
  (sd1-29 blue fun "blue")
  (sd1-30 red blue green)
  (sd1-30 purple blue green)
  (sd1-31 red blue green)
  (sd1-31 purple blue brown)
  (sd1-32 red)
  (sd1-33 green)
  (sd1-34 red)
  (sd1-35 blue)
  (sd1-36 green)

  (sd1-37 red)
  (sd1-38 blue)
  (sd1-39 green)

  (sd1-40 red)
  (sd1-41 blue)
  (sd1-42 get)
  (sd1-43 green)

  (sd1-44 red)
  (sd1-45 green)

  (sd1-46 red)
  (sd1-47 blue)
  (sd1-48 green)

  (sd1-49 a red)
  (sd1-49 b red)
  (sd1-50 a red)
```

```
(sdl-50 b green)
(sdl-51 a blue)
(sdl-51 b blue)
(sdl-52 a red)
(sdl-52 b red)
(sdl-53 a red)
(sdl-53 b blue)
(sdl-54 a green)
(sdl-54 b green)

(sdl-55 2)
(sdl-56 red)
(sdl-57 2)
(sdl-58 2)
(sdl-59 "red")

(sdl-60 2)
(sdl-61 "red")
(sdl-62 2)
(sdl-63 "red")

(sdl-64 4)
(sdl-64 9)

(sdl-65 data 6)
(sdl-65 value 9)

(sdl-66 1 4.00 7.00)
(sdl-66 2 5.00 9.00)

(sdl-67 data1 3)
(sdl-67 data2 5)

(sdl-68 data1 9)
(sdl-68 data2 5)

(sdl-69 data1 4)
(sdl-69 data2 4)

(sdl-70 data1 red)
(sdl-70 data2 5)

(sdl-71 data1 "4")
(sdl-71 data2 4)

(sdl-72 data1 red)
(sdl-72 data2 5)

(sdl-73 data1 red)
(sdl-73 data2 5)

(sdl-74)
(sdl-75)
(sdl-76)
(sdl-77)
(sdl-78)
(sdl-78 1 5)
(sdl-78 2 8)
(sdl-79 a b c d e f g)
(sdl-80 a b c d e f g)
(sdl-81 a b c d e f g)

(sdl-108 10)
(sdl-109 3)
```

```
)

(deffacts initial-1-sequences "Facts to match the rules in SUITE-RULE1.ART"
  (test-case (sdl-1 test-case))
  (test-case (sdl-2 "a red flag"))
  (test-case (sdl-3 1))
  (test-case (sdl-4 (100 321)))
  (test-case (sdl-5))
  (test-case (sdl-6 green))
  (test-case sdl-7 ("green"))
  (test-case (sdl-8 green green))
  (test-case sdl-9())
  (test-case sdl-10 (green))
  (test-case sdl-11 ("green"))
  (test-case (sdl-12 green green))
  (sdl-13 (sdl-13))
  (sdl-14 (sdl-14 (green)))
  (sdl-15 (sdl-15 ("green")))
  (sdl-16 (sdl-16 (green green)))
  (sdl-17 (sdl-17))
  (sdl-18 (sdl-18 green))
  (sdl-19 (sdl-19 "green"))
  (sdl-20 (sdl-20 green (green)))
  (sdl-21 (sdl-21 blue red green))
  (sdl-22 (sdl-22 red))
  (sdl-23 (red sdl-23))
  (sdl-24 (sdl-24))
  (sdl-25 (sdl-25 data sdl-25))
  (sdl-26 (blue fun blue))
  (sdl-27 (blue fun get))
  (sdl-28 (blue blue blue))
  (sdl-29 (blue fun ("blue")))
  (sdl-30 (red (blue green)))
  (sdl-30 (purple (blue green)))
  (sdl-31 (red blue green))
  (sdl-31 (purple blue brown))
  (sdl-32 (red))
  (sdl-33 (green))
  (sdl-34 (red))
  (sdl-35 (blue))
  (sdl-36 (green))

  (sdl-37 (red))
  (sdl-38 (blue))
  (sdl-39 (green))

  (sdl-40 (red))
  (sdl-41 (blue))
  (sdl-42 (get))
  (sdl-43 (green))

  (sdl-44 (red))
  (sdl-45 (green))

  (sdl-46 (red))
  (sdl-47 (blue))
  (sdl-48 (green))

  (sdl-49 (a (red)))
  (sdl-49 (b (red)))
  (sdl-50 (a (red)))
  (sdl-50 (b (green)))
  (sdl-51 (a (blue)))
  (sdl-51 (b (blue)))
```

```
(sdl-52 (a (red)))
(sdl-52 (b (red)))
(sdl-53 (a (red)))
(sdl-53 (b (blue)))
(sdl-54 (a (green)))
(sdl-54 (b (green)))

(sdl-55 (2))
(sdl-56 (red))
(sdl-57 (2))
(sdl-58 (2))
(sdl-59 ("red"))

(sdl-60 (2))
(sdl-61 ("red"))
(sdl-62 (2))
(sdl-63 ("red"))

(sdl-64-seq (4))
(sdl-64-seq (9))

(sdl-65 (data 6))
(sdl-65 (value 9))

(sdl-66 (1 4.00 7.00))
(sdl-66 (2 5.00 9.00))

(sdl-67 (data1 (3)))
(sdl-67 (data2 (5)))

(sdl-68 (data1 (9)))
(sdl-68 (data2 (5)))

(sdl-69 (data1 (4)))
(sdl-69 (data2 (4)))

(sdl-70 (data1 red))
(sdl-70 (data2 5))

(sdl-71 (data1 "4"))
(sdl-71 (data2 4))

(sdl-72 (data1 red))
(sdl-72 (data2 5))

(sdl-73 (data1 red))
(sdl-73 (data2 5))

(sdl-74 ())
(sdl-75 ())
(sdl-76 ())
(sdl-77 ())
(sdl-78 () )
(sdl-78 (1 5))
(sdl-78 (2 8))
(sdl-79 (a b c d e f g))
(sdl-80 (a b c d e f g))
(sdl-81 (a b c d e f g))

(sdl-108 (10))
(sdl-109 (3))
)
```

```
(deffacts initial-2 ""
  (sdl-115 to be foo bar to be)
  (sdl-116 a e i o u)
  (sdl-117 fluff mug bump bleet lolita)

  ;; go hiking or skiing

  (non-working sdl-118)
  (weather sdl-118 major-blizzard)

  (non-working sdl-119)
  (drive sdl-119 two-wheel)

  (non-working sdl-120)
  (weather sdl-120 major-blizzard)
  (drive sdl-120 two-wheel)
  (working sdl-120 weekend)

  ;; wild card

  (sdl-121 one one)
  (sdl-122 one one one)
  (sdl-123 6 5 4 5)
  (sdl-124 a r t h u r)
  (sdl-125 a rose is a rose)
  (sdl-126 to be or not to be)
  (sdl-127 frank)
  (sdl-128 1 2)
  (sdl-129 love in bloom)
  (sdl-130 a rose is a rose)

  ;; str_cat
  (sdl-131 "foo")
  (sdl-133 first second)
  (sdl-134 republicans fox jones nixon williams harvey)
  (sdl-134 quakers pallas sanchez stone nixon fregge)
  (sdl-135 yellow)
  (sdl-135 green)
  (sdl-136 yellow)
  (sdl-136 green)
  (sdl-137 yellow)
  (sdl-138 green)
  (sdl-139 -12 12)
  (sdl-140 1 1)
  (sdl-140 1 2)
  (sdl-141 1 1)
  (sdl-141 1 2)
  (sdl-142 cold hot)
  (sdl-143 green yellow red blue white)
  (sdl-144 brother-of walter daniel)
  (sdl-144 child-of walter david)
  (sdl-144 sex-of david male)
  (sdl-144 child-of walter jane)
  (sdl-144 sex-of jane female)
  (sdl-145-list red white blue)
  (sdl-145 red)
  (sdl-145 white)
  (sdl-145 blue)
  (sdl-146-seats 8 9 11 14 3)
  (sdl-146-names tom carol fred alex)
  (sdl-147 donors start fred)
  (sdl-147 donors fred john)
  (sdl-147 donors john mike)
  (sdl-147 donors mike finish)
```

```
(sdl-147 donation fred 7.0)
(sdl-147 donation john 10.0)
(sdl-147 donation mike 0.5)
(sdl-147-sum donors start 0)
(sdl-148 donor-list fred john mike)
(sdl-148 donation fred 7.0)
(sdl-148 donation john 10.0)
(sdl-148 donation mike 0.5)
(sdl-148-sum donors start 0)
(sdl-149 inventory shirt-11 7.00)
(sdl-149 inventory pants-9 10.00)
(sdl-149 inventory belt-14 2.50)
(sdl-149 current-sum 0)
(sdl-150 inventory shirt-11 7.00)
(sdl-150 inventory pants-9 10.00)
(sdl-150 inventory belt-14 2.50)
(sdl-150 current-count 0)
(sdl-151 quarter 10)
(sdl-151 dime 8)
(sdl-151 nickel 6)
(sdl-151 penny 4)
(sdl-152 quarter 10)
(sdl-152 dime 8)
(sdl-152 nickel 6)
(sdl-152 penny 4)
(sdl-153 yes)
(sdl-153 no)
(sdl-153 unknown)
(sdl-153 1)
(sdl-154 foo)
(sdl-154 1)
(sdl-154 2)
(sdl-154 3)
(sdl-155 foo)
(sdl-155 1)
(sdl-155 2)
(sdl-155 3)
(sdl-156 "string")
(sdl-157 "string")
(sdl-158 "string")
(sdl-159 yes)
(sdl-159 no)
(sdl-159 unknown)
(sdl-159 1)
(sdl-160 yes)
(sdl-160 no)
(sdl-160 unknown)
(sdl-160 1)
(sdl-161 foo)
(sdl-161 1)
(sdl-161 2)
(sdl-161 3)
(sdl-162 foo)
(sdl-162 1)
(sdl-162 2)
(sdl-162 3)

(sdl-163 "overflow")
(sdl-164 input "overflow")
(sdl-164 list "yes" "no" "unknown" "overflow" "inference")
(sdl-165 12345.89)

(patient-name paul)
(patient-name brad)
```

```
(sdl-166 paul yes)
(sdl-166 paul 1.5)
(sdl-166 1.5 paul)
(sdl-166 yes paul)
(sdl-166 I think paul said yes)
(sdl-166 paul did say 1.5)
(sdl-166 1.5 says paul)
(sdl-166 yes says paul)
(SDL-167   YES FOR PAUL AND BRAD)
(SDL-167   YES FOR PAUL BRAD AND BILL)
(SDL-167   YES PAUL BRAD)
(SDL-167   PAUL YES BRAD)
(SDL-167   PAUL BRAD YES)
(SDL-167   PAUL BRAD 1.5)
(sdl-167   1.5 BRAD PAUL MARK)
(sdl-167 BRAD AND PAUL SAY YES)
(sdl-167 BRAD SAYS YES AND SO DOES PAUL)
(sdl-168 YES FOR PAUL AND NO FOR BRAD AND MARK)
(SDL-168    NO says BRAD and YES says PAUL)
(SDL-168    NO for BRAD YES for PAUL)
(SDL-168    THE ANSWER FOR BRAD AND MARK IS NO and PAUL IS YES)
(SDL-168    BRAD MARK ARE NO AND PAUL IS YES TOO)
(SDL-168    THE ANSWER FOR BRAD AND MARK IS NO and PAUL IS 1.5)
(SDL-168    BRAD is unknown AND PAUL IS 1.5)
(SDL-169    NO says BRAD but not PAUL)
(SDL-169    NO for BRAD but not for PAUL)
(SDL-169    THE ANSWER FOR BRAD AND MARK IS NO but not PAUL)
(SDL-169    BRAD MARK ARE NO but not PAUL)
(sdl-170 paul complains of vertigo and faintness)
(sdl-170 brad has a headache)
(age paul 30)
(age brad 18)
(sdl-172 major-complaint paul drowsiness)
(sdl-172 recent-head-injury paul no)
(sdl-172 confusion-mild paul yes)
(sdl-172 major-complaint brad confusion)
(sdl-172 major-complaint brad vertigo)
(sdl-173 case1 450 550 3)
(sdl-173 case2 440 560 2)
(sdl-173 case3 440 440 1)
(sdl-174 case1 dummy dummy dummy 450 dummy 550 dummy 3)
(sdl-174 case2 foo foo foo 440 foo 560 foo 2)
(sdl-174 case3 bar bar bar 440 bar 440 bar 1)
(sdl-175 pallet 5)
(sdl-175 pallet 4)
(sdl-175 options 1000 3000 4000 5024)
(sdl-175 case 3024)
(sdl-175 case 5000)
(sdl-175 case 5024)
(sdl-175 case 4000)
(sdl-176 options 1000 3000 5000)
(sdl-176 case 5000)
(sdl-177 options 1000 3000 4000)
(sdl-177 case 5000)
(sdl-178 1)
(sdl-179 options 1000 3000 5000)
(sdl-179 case 5000)
(sdl-180 options 1000 3000 4000)
(sdl-180 case 5000)
(sdl-181 5000)
(sdl-181 6000)
(sdl-182 "est" "pst")
(sdl-182 "pst" "pst")
(sdl-182 "est" "est")
```

```
  (sdl-182 "pst" "est")
  (sdl-183 2)
  (sdl-184 2)
  (sdl-185 "string")
  (sdl-186 "string")
  (sdl-186 "foo")
  (sdl-187 "string" "foo")
  (sdl-187 "foo" "foo")
  (sdl-188 "foobar")
  (sdl-189 2)
  (sdl-190 1)
  (sdl-190 foo)
  (sdl-191 1)
  (sdl-191 0.1)
  (sdl-191 "foo")
  (sdl-191 bar)
  (sdl-191 2)
  (sdl-191 12345.6789)
  (sdl-191 "fee")
  (sdl-191 blee)
  (sdl-192 40)
  (sdl-192 50)
  (sdl-192 60)
  (sdl-192 70)
  (sdl-192 80)
  (sdl-192 90)
  (sdl-192 100)
)

(deffacts initial-2-sequences ""
  (sdl-115 ((to be) (foo bar) (to be)))
  (sdl-116 (a e i o u))
  (sdl-117 (fluff mug bump bleet lolita))
  ;; go hiking or skiing
  (non-working (sdl-118))
  (weather (sdl-118 major-blizzard))
  (non-working (sdl-119))
  (drive (sdl-119 two-wheel))
  (non-working (sdl-120))
  (weather (sdl-120 major-blizzard))
  (drive (sdl-120 two-wheel))
  (working (sdl-120 weekend))
  ;; wild card
  (sdl-121 (one one))
  (sdl-122 (one one one))
  (sdl-123 (6 5 4 5))
  (sdl-124 (a r t h u r))
  (sdl-125 (a rose is a rose))
  (sdl-126 (to be or not to be))
  (sdl-127 (frank))
  (sdl-128 (1 2))
  (sdl-129 (love in bloom))
  (sdl-130 (a rose is a rose))
  ;; str_cat
  (sdl-131 ("foo"))
  (sdl-133 (first second))
  (sdl-134 (republicans fox jones nixon williams harvey))
  (sdl-134 (quakers pallas sanchez stone nixon fregge))
  (sdl-135 (yellow))
  (sdl-135 (green))
  (sdl-136 (yellow))
  (sdl-136 (green))
  (sdl-137 (yellow))
```

```
(sdl-138 (green))
(sdl-139 (-12 (12)))
(sdl-140 (1 1))
(sdl-140 (1 2))
(sdl-141 (1 1))
(sdl-141 (1 2))
(sdl-142 (cold hot))
(sdl-143 (green yellow red blue white))
(sdl-144 (brother-of walter daniel))
(sdl-144 (child-of walter david))
(sdl-144 (sex-of david male))
(sdl-144 (child-of walter jane))
(sdl-144 (sex-of jane female))
(sdl-145-list (red white blue))
(sdl-145 (red))
(sdl-145 (white))
(sdl-145 (blue))
(sdl-146-seats (8 9 11 14 3))
(sdl-146-names (tom carol fred alex))
(sdl-147 (donors start fred))
(sdl-147 (donors fred john))
(sdl-147 (donors john mike))
(sdl-147 (donors mike finish))
(sdl-147 (donation fred 7.0))
(sdl-147 (donation john 10.0))
(sdl-147 (donation mike 0.5))
(sdl-147-sum (donors start 0))
(sdl-148 (donor-list fred john mike))
(sdl-148 (donation fred 7.0))
(sdl-148 (donation john 10.0))
(sdl-148 (donation mike 0.5))
(sdl-148-sum (donors start 0))
(sdl-149 (inventory shirt-11 7.00))
(sdl-149 (inventory pants-9 10.00))
(sdl-149 (inventory belt-14 2.50))
(sdl-149 (current-sum 0))
(sdl-150 (inventory shirt-11 7.00))
(sdl-150 (inventory pants-9 10.00))
(sdl-150 (inventory belt-14 2.50))
(sdl-150 (current-count 0))
(sdl-151 (quarter 10))
(sdl-151 (dime 8))
(sdl-151 (nickel 6))
(sdl-151 (penny 4))
(sdl-152 (quarter 10))
(sdl-152 (dime 8))
(sdl-152 (nickel 6))
(sdl-152 (penny 4))
(sdl-153 (yes))
(sdl-153 (no))
(sdl-153 (unknown))
(sdl-153 (1))
(sdl-154 (foo))
(sdl-154 (1))
(sdl-154 (2))
(sdl-154 (3))
(sdl-155 (foo))
(sdl-155 (1))
(sdl-155 (2))
(sdl-155 (3))
(sdl-156 ("string"))
(sdl-157 ("string"))
(sdl-158 ("string"))
(sdl-159 (yes))
```

```
(sdl-159 (no))
(sdl-159 (unknown))
(sdl-159 (1))
(sdl-160 (yes))
(sdl-160 (no))
(sdl-160 (unknown))
(sdl-160 (1))
(sdl-161 (foo))
(sdl-161 (1))
(sdl-161 (2))
(sdl-161 (3))
(sdl-162 (foo))
(sdl-162 (1))
(sdl-162 (2))
(sdl-162 (3))

(sdl-163 ("overflow"))
(sdl-164 (input "overflow"))
(sdl-164 (list "yes" "no" "unknown" "overflow" "inference"))
(sdl-165 (12345.89))
(patient-name (paul))
(patient-name (brad))
(sdl-166 (paul yes))
(sdl-166 (paul 1.5))
(sdl-166 (1.5 paul))
(sdl-166 (yes paul))
(sdl-166 (I think paul said yes))
(sdl-166 (paul did say 1.5))
(sdl-166 (1.5 says paul))
(sdl-166 (yes says paul))
(SDL-167   (YES FOR PAUL AND BRAD))
(SDL-167   (YES FOR PAUL BRAD AND BILL))
(SDL-167   (YES PAUL BRAD))
(SDL-167   (PAUL YES BRAD))
(SDL-167   (PAUL BRAD YES))
(SDL-167   (PAUL BRAD 1.5))
(sdl-167   (1.5 BRAD PAUL MARK))
(sdl-167 (BRAD AND PAUL SAY YES))
(sdl-167 (BRAD SAYS YES AND SO DOES PAUL))
(sdl-168 (YES FOR PAUL AND NO FOR BRAD AND MARK))
(SDL-168    (NO says BRAD and YES says PAUL))
(SDL-168    (NO for BRAD YES for PAUL))
(SDL-168    (THE ANSWER FOR BRAD AND MARK IS NO and PAUL IS YES))
(SDL-168    (BRAD MARK ARE NO AND PAUL IS YES TOO))
(SDL-168    (THE ANSWER FOR BRAD AND MARK IS NO and PAUL IS 1.5))
(SDL-168    (BRAD is unknown AND PAUL IS 1.5))
(SDL-169    (NO says BRAD but not PAUL))
(SDL-169    (NO for BRAD but not for PAUL))
(SDL-169    (THE ANSWER FOR BRAD AND MARK IS NO but not PAUL))
(SDL-169    (BRAD MARK ARE NO but not PAUL))
(sdl-170 (paul complains of vertigo and faintness))
(sdl-170 (brad has a headache))
(seq-age paul (30))
(seq-age brad (18))
(sdl-172 (major-complaint paul drowsiness))
(sdl-172 (recent-head-injury paul no))
(sdl-172 (confusion-mild paul yes))
(sdl-172 (major-complaint brad confusion))
(sdl-172 (major-complaint brad vertigo))
(sdl-173 (case1 450 550 3))
(sdl-173 (case2 440 560 2))
(sdl-173 (case3 440 440 1))
(sdl-174 (case1 dummy dummy dummy 450 dummy 550 dummy 3))
(sdl-174 (case2 foo foo foo 440 foo 560 foo 2))
```

```
    (sdl-174 (case3 bar bar bar 440 bar 440 bar 1))
    (sdl-175 (pallet 5))
    (sdl-175 (pallet 4))
    (sdl-175 (options 1000 3000 4000 5024))
    (sdl-175 (case 3024))
    (sdl-175 (case 5000))
    (sdl-175 (case 5024))
    (sdl-175 (case 4000))
    (sdl-176 (options 1000 3000 5000))
    (sdl-176 (case 5000))
    (sdl-177 (options 1000 3000 4000))
    (sdl-177 (case 5000))
    (sdl-178 (1))
    (sdl-179 (options 1000 3000 5000))
    (sdl-179 (case 5000))
    (sdl-180 (options 1000 3000 4000))
    (sdl-180 (case 5000))
    (sdl-181 (5000))
    (sdl-181 (6000))
    (sdl-182 ("est" "pst"))
    (sdl-182 ("pst" "pst"))
    (sdl-182 ("est" "est"))
    (sdl-182 ("pst" "est"))
    (sdl-183 (2))
    (sdl-184 (2))
    (sdl-185 ("string"))
    (sdl-186 ("string"))
    (sdl-186 ("foo"))
    (sdl-187 ("string" "foo"))
    (sdl-187 ("foo" "foo"))
    (sdl-188 ("foobar"))
    (sdl-189 (2))
    (sdl-190 (1))
    (sdl-190 (foo))
    (sdl-191 (1))
    (sdl-191 (0.1))
    (sdl-191 ("foo"))
    (sdl-191 (bar))
    (sdl-191 (2))
    (sdl-191 (12345.6789))
    (sdl-191 ("fee"))
    (sdl-191 (blee))
    (sdl-192-seq (40))
    (sdl-192-seq (50))
    (sdl-192-seq (60))
    (sdl-192-seq (70))
    (sdl-192-seq (80))
    (sdl-192-seq (90))
    (sdl-192-seq (100))
)

(defrule print-fail
   (declare (salience -100))
   (fail ?test-case)
=>
   (printout t t "^^^^^^ Runtime Error   " ?test-case))

(defrule sdl-rule-1 "Match a literal symbol "
  (or (not (test-case sdl-1 TEST-CASE))
      (not (test-case (sdl-1 TEST-CASE))))
=>
  (assert (fail sdl-1)))

(defrule sdl-rule-2 "Match a literal string"
```

```
  (or (not (test-case sdl-2 "a red flag"))
      (not (test-case (sdl-2 "a red flag"))))
=>
  (assert (fail sdl-2)))

(defrule sdl-rule-3 "Match an integer"
  (or (not (test-case sdl-3 1))
      (not (test-case (sdl-3 1))))
=>
  (assert (fail sdl-3)))

(defrule sdl-rule-4 "Don't match a float that is almost equal"
  (or (test-case sdl-4 100.3)
      (test-case (sdl-4 (100.3))))
=>
  (assert (fail sdl-4)))

(defrule sdl-rule-5 "Don't let ? match nothing"
  (or (test-case sdl-5 ?)
      (test-case (sdl-5 ?)))
=>
  (assert (fail sdl-5)))

(defrule sdl-rule-6 "? must match a symbol"
  (or (not (test-case sdl-6 ?))
      (not (test-case (sdl-6 ?))))
=>
  (assert (fail sdl-6)))

(defrule sdl-rule-7 "? must match a string"
  (or (not (test-case sdl-7 ?))
      (not (test-case sdl-7 (?))))
=>
  (assert (fail sdl-7)))

(defrule sdl-rule-8 "? must not match TWO symbols"
  (or (test-case sdl-8 ?)
      (test-case (sdl-8 ?)))
=>
  (assert (fail sdl-8)))

(defrule sdl-rule-9 "$? must match nothing"
  (or (not (test-case sdl-9 $?))
      (not (test-case sdl-9 ($?))))
=>
  (assert (fail sdl-9)))

(defrule sdl-rule-10 "$? must match a single symbol"
  (or (not (test-case sdl-10 $?))
      (not (test-case sdl-10 ($?))))
=>
  (assert (fail sdl-10)))

(defrule sdl-rule-11 "$? must match a single string"
  (or (not (test-case sdl-11 $?))
      (not (test-case sdl-11 ($?))))
=>
  (assert (fail sdl-11)))

(defrule sdl-rule-12 "$? must match two symbols"
  (or (not (test-case sdl-12 $?))
      (not (test-case (sdl-12 $?))))
=>
  (assert (fail sdl-12)))
```

```
(defrule sdl-rule-13 "? matches symbol, $? matches nothing"
  (or (not (sdl-13 ? $?))
      (not (sdl-13 (?) $?)))
=>
  (assert (fail sdl-13)))

(defrule sdl-rule-14 "? and $? each match a single symbol"
  (or (not (sdl-14 ? $?))
      (not (sdl-14 (? ($?)))))
=>
  (assert (fail sdl-14)))

(defrule sdl-rule-15 "? matches symbol; $? matches string"
  (or (not (sdl-15 ? $?))
      (not (sdl-15 (? ($?)))))
=>
  (assert (fail sdl-15)))

(defrule sdl-rule-16 "? matches one symbol; $? matches two symbols"
  (or (not (sdl-16 ? $?))
      (not (sdl-16 (? ($?)))))
=>
  (assert (fail sdl-16)))

(defrule sdl-rule-17 "$? matches nothing; ? matches symbol"
  (or (not (sdl-17 $? ?))
      (not (sdl-17 $? (?))))
=>
  (assert (fail sdl-17)))

(defrule sdl-rule-18 "$? matches symbol; ? matches symbol"
  (or (not (sdl-18 $? ?))
      (not (sdl-18 ($? ?))))
=>
  (assert (fail sdl-18)))

(defrule sdl-rule-19 "$? matches symbol; ? matches string"
  (or (not (sdl-19 $? ?))
      (not (sdl-19 ($? ?))))
=>
  (assert (fail sdl-19)))

(defrule sdl-rule-20 "$? matches two symbols; ? matches one symbol"
  (or (not (sdl-20 $? ?))
      (not (sdl-20 ($? (?)))))
=>
  (assert (fail sdl-20)))

(defrule sdl-rule-21 ""
  (or (not (sdl-21 $?                          ;matches nothing
               sdl-21
               $?))
      (not (sdl-21 ($?
               sdl-21
               $?))))
=>
  (assert (fail sdl-21)))

(defrule sdl-rule-22 ""
  (or (not (sdl-22 $?                          ;matches nothing
               sdl-22
               $?))
      (not (sdl-22 ($?
               sdl-22
```

```
                $?))))
=>
  (assert (fail sd1-22)))

(defrule sd1-rule-23 ""
  (or (not (sd1-23 $?                          ;matches red
                sd1-23
                $?))
      (not (sd1-23 ($?
                sd1-23
                $?))))
=>
  (assert (fail sd1-23)))

(defrule sd1-rule-24 ""
  (or (not (sd1-24 $?                          ;matches nothing
                sd1-24
                $?))
      (not (sd1-24 ($?
                sd1-24
                $?))))
=>
  (assert (fail sd1-24)))

(defrule sd1-rule-25 ""
  (or (not (sd1-25 $?                          ;matches sd1-25 data
                sd1-25
                $?))
      (not (sd1-25 ($?
                sd1-25
                $?))))
=>
  (assert (fail sd1-25)))

(defrule sd1-rule-26 ""
  (or (not (sd1-26 ?x                          ;matches blue
                fun
                ?x))
      (not (sd1-26 (?x
                fun
                ?x))))
=>
  (assert (fail sd1-26)))

(defrule sd1-rule-27 ""
  (or (sd1-27 ?x                                     ;matches blue
          fun
          ?x)
      (sd1-27 (?x                                    ;matches blue
          fun
          ?x)))
=>
  (assert (fail sd1-27)))

(defrule sd1-rule-28 ""
  (or (sd1-28 ?x                                     ;matches blue
          fun                                  ;does not match blue
          ?x)
      (sd1-28 (?x                                    ;matches blue
          fun                                  ;does not match blue
          ?x)))                                ;matches blue
=>
  (assert (fail sd1-28)))
```

```
(defrule sdl-rule-29 ""
  (or (sdl-29 ?x                                    ;matches blue
          fun
          ?x)
      (sdl-29 (?x                                   ;matches blue
          fun
          (?x))))                                   ;matches "blue"
=>
  (assert (fail sdl-29)))

(defrule sdl-rule-30 ""
  (sdl-30 red $?x)
  (sdl-30 (red ($?x)))          ;matches blue green
  (sdl-30 purple $?x)                               ;matches blue green
  (sdl-30 (purple ($?x)))                           ;matches blue green
=>
  (assert (success sdl-30))
  (assert (success (sdl-30))))

(defrule sdl-rule-30-2 ""
  (declare (salience -1))                           ;bdc added 02/04/88
  (or (not (success sdl-30))
      (not (success (sdl-30))))
=>
  (assert (fail sdl-30)))

(defrule sdl-rule-31 ""
  (sdl-31 red $?x)
  (sdl-31 (red $?x))                                ;matches blue green
  (sdl-31 purple $?x)
  (sdl-31 (purple $?x))                             ;matches blue brown (no match)
=>
  (assert (fail sdl-31)))

(defrule sdl-rule-32 ""
  (sdl-32 ~red)
  (sdl-32 (~red))                                   ;matches red (no match)
=>
  (assert (fail sdl-32)))

(defrule sdl-rule-33 ""
  (or (not (sdl-33 ~red))                           ;matches gree
      (not (sdl-33 (~red))))                        ;matches green
=>
  (assert (fail sdl-33)))

(defrule sdl-rule-34 ""
  (or (not (sdl-34 red|blue))
      (not (sdl-34 (red|blue))))                    ;matches red
=>
  (assert (fail sdl-34)))


(defrule sdl-rule-35 ""
  (or (not (sdl-35 red|blue))                       ;matches blue
      (not (sdl-35 (red|blue))))
=>
  (assert (fail sdl-35)))

(defrule sdl-rule-36 ""
  (sdl-36 red|blue)
  (sdl-36 (red|blue))                               ;matches green (no match)
=>
  (assert (fail sdl-36)))
```

```
(defrule sdl-rule-37 ""
  (sdl-37 ~red&~blue)
  (sdl-37 (~red&~blue))                    ;matches red (no match)
=>
  (assert (fail sdl-37)))

(defrule sdl-rule-38 ""
  (sdl-38 ~red&~blue)                      ;matches blue (no match)
  (sdl-38 (~red&~blue))
=>
  (assert (fail sdl-38)))

(defrule sdl-rule-39 ""
  (or (not (sdl-39 ~red&~blue))            ;matches green
      (not (sdl-39 (~red&~blue))))
=>
  (assert (fail sdl-39)))

(defrule sdl-rule-40 ""
  (sdl-40 ~red&blue|get)                   ;matches red (no match)
  (sdl-40 (~red&blue|get))
=>
  (assert (fail sdl-40)))


(defrule sdl-rule-41 ""
  (or (not (sdl-41 ~red&blue|get))
      (not (sdl-41 (~red&blue|get))))              ;matches blue
=>
  (assert (fail sdl-41)))

(defrule sdl-rule-42 ""
  (or (not (sdl-42 ~red&blue|get))
      (not (sdl-42 (~red&blue|get))))              ;matches get
=>
  (assert (fail sdl-42)))

(defrule sdl-rule-43 ""
  (sdl-43 ~red&blue|get)                   ;matches green (no match)
  (sdl-43 (~red&blue|get))
=>
  (assert (fail sdl-43)))

(defrule sdl-rule-44 ""
  (sdl-44 ?x&~red)                         ;matches red (no match)
  (sdl-44 (?x&~red))
=>
  (assert (fail sdl-44)))

(defrule sdl-rule-45 ""
  (or (not (sdl-45 ?x&~red))               ;matches green
      (not (sdl-45 (?x&~red))))
=>
  (assert (fail sdl-45)))

(defrule sdl-rule-46 ""
  (or (not (sdl-46 ?x&red|blue))                ;matches red
      (not (sdl-46 (?x&red|blue))))
=>
  (assert (fail sdl-46)))

(defrule sdl-rule-47 ""
  (or (not (sdl-47 ?x&red|blue))                ;matches blue
      (not (sdl-47 (?x&red|blue))))
```

```
 =>
   (assert (fail sdl-47)))

 (defrule sdl-rule-48 ""
   (sdl-48 ?x&red|blue)                          ;matches green (no match)
   (sdl-48 (?x&red|blue))
 =>
   (assert (fail sdl-48)))

 (defrule sdl-rule-49 ""
   (sdl-49 a ?x)                                 ;matches red
   (sdl-49 (a (?x)))
   (sdl-49 b ?x&~red)                            ;matches red (no match)
   (sdl-49 (b (?x&~red)))
 =>
   (assert (fail sdl-49)))

 (defrule sdl-rule-50 ""
   (sdl-50 a ?x)                                 ;matches red
   (sdl-50 (a (?x)))
   (sdl-50 b ?x&~red)                            ;matches green (no match)
   (sdl-50 (b (?x&~red)))
 =>
   (assert (fail sdl-50)))

 (defrule sdl-rule-51 ""
   (sdl-51 a ?x)                                 ;matches blue
   (sdl-51 (a (?x)))
   (sdl-51 b ?x&~red)                            ;matches blue
   (sdl-51 (b (?x&~red)))
 =>
   (assert (success sdl-51))
   (assert (success (sdl-51))))

 (defrule sdl-rule-51-1 "check on sdl-rule-51"
   (declare (salience -1))                       ;added by BDC 02/04
   (or (not (success sdl-51))
       (not (success (sdl-51))))
 =>
   (assert (fail sdl-51)))



 (defrule sdl-rule-52 ""
   (sdl-52 a ?x)                                 ;matches red
   (sdl-52 (a (?x)))
   (sdl-52 b ?x&red|blue)                        ;matched red
   (sdl-52 (b (?x&red|blue)))
 =>
   (assert (success sdl-52))
   (assert (success (sdl-52))))

 (defrule sdl-rule-52-1 ""
   (declare (salience -1))                       ;added by BDC 02/04
   (or (not (success sdl-52))
       (not (success (sdl-52))))
 =>
   (assert (fail sdl-52)))

 (defrule sdl-rule-53 ""
   (sdl-53 a (?x))                                     ;matches red
   (sdl-53 (a ?x))
   (sdl-53 b ?x&red|blue)                        ;matches blue (no match)
   (sdl-53 (b (?x&red|blue)))
```

```
=>
  (assert (fail sdl-53)))

(defrule sdl-rule-54 ""
  (sdl-54 a ?x)                                  ;matches green
  (sdl-54 (a (?x)))
  (sdl-53 b ?x&red|blue)
  (sdl-54 (b (?x&red|blue)))                     ;matches green (no match)
=>
  (assert (fail sdl-54)))

(defrule sdl-rule-55 ""
  (or (not (sdl-55 ?x&:(numberp ?x)))            ;matches 2
      (not (sdl-55 (?x&:(numberp ?x)))))
=>
  (assert (fail sdl-55)))

(defrule sdl-rule-56 ""
  (or (sdl-56 ?x&:(numberp ?x))                  ;matches red (no match)
      (sdl-56 (?x&:(numberp ?x))))
=>
  (assert (fail sdl-56)))

(defrule sdl-rule-57 ""
  (or (sdl-57 ?x&:(numberp ?x)&:(oddp ?x))              ;matches 2 (no match)
      (sdl-57 (?x&:(numberp ?x)&:(oddp ?x))))
=>
  (assert (fail sdl-57)))

(defrule sdl-rule-58 ""
  (or (sdl-58 ?x&:(stringp ?x))                  ;matches 2 (no match)
      (sdl-58 (?x&:(stringp ?x))))
=>
  (assert (fail sdl-58)))

(defrule sdl-rule-59 ""
  (or (not (sdl-59 ?x&:(stringp ?x)))            ;matches "red"
      (not (sdl-59 (?x&:(stringp ?x)))))
=>
  (assert (fail sdl-59)))

(defrule sdl-rule-60 ""
  (or (not (sdl-60 =(+ 1 1)))                    ;matches 2
      (not (sdl-60 (=(+ 1 1)))))
=>
  (assert (fail sdl-60)))

(defrule sdl-rule-61 ""
  (or (sdl-61 =(+ 1 1))
      (sdl-61 (=(+ 1 1))))                              ;matches "red" (no match)
=>
  (assert (fail sdl-61)))

(defrule sdl-rule-62 ""
  (or (sdl-62 =(string-append "re" "d"))                ;matches 2 (no match)
      (sdl-62 (=(string-append "re" "d"))))
=>
  (assert (fail sdl-62)))

(defrule sdl-rule-63 ""
  (or (not (sdl-63 =(string-append "re" "d")))  ;matches "red"
      (not (sdl-63 (=(string-append "re" "d")))))
=>
  (assert (fail sdl-63)))
```

```
(defrule sdl-rule-64 ""
  (sdl-64 ?y)
  (sdl-64 ?x&:(= 5 ?y)|:(- 12 ?y))
=>
  (assert (success sdl-64)))

(defrule sdl-rule-64-seq ""
  (sdl-64-seq (?y))
  (sdl-64-seq (?x&:(= 5 ?y)|:(- 12 ?y)))
=>
  (assert (success sdl-64-seq)))

(defrule sdl-rule-64-2 ""
  (declare (salience -1))
  (or (not (success sdl-64))
      (not (success sdl-64-seq)))
=>
  (assert (fail sdl-64)))


(defrule sdl-rule-65 ""
  (sdl-65 data ?x)
  (sdl-65 (data ?x))
  (sdl-65 value ?y)
  (sdl-65 (value ?y))
  (test (>= (- ?y ?x) 3))
=>
  (assert (success sdl-65))
  (assert (success (sdl-65))))

(defrule sdl-rule-65-2 ""
  (declare (salience -1))
  (or (not (success sdl-65))
      (not (success (sdl-65))))
=>
  (assert (fail sdl-65)))

(defrule sdl-rule-66 ""
  (sdl-66 ?a ?x1 ?y1)
  (sdl-66 (?a ?x1 ?y1))
  (sdl-66 ?b&~?a ?x2 ?y2)
  (sdl-66 (?b&~?a ?x2 ?y2))
  (test (< 0 (/ (- ?y2 ?y1)
                (- ?x2 ?x1))))
=>
  (assert (success sdl-66))
  (assert (success (sdl-66))))

(defrule sdl-rule-66-2 ""
  (declare (salience -1))
  (or (not (success sdl-66))
      (not (success (sdl-66))))
=>
      (assert (fail sdl-66)))

(defrule sdl-rule-67 ""
  (sdl-67 data1 ?y)
  (sdl-67 (data1 (?y)))
  (sdl-67 data2 ?x&:(> ?x ?y))
  (sdl-67 (data2 (?x&:(> ?x ?y))))
=>
  (assert (success sdl-67))
  (assert (success (sdl-67))))
```

```
;  4    4    9    9
;  4    9    4    9
;  nil  t    nil  nil

;        4    4    9    9
;        4    9    4    9
;  nil   t    nil  nil

;added by BDC 02/04

;matches 6

;matches 9

;succeeds

;added by BDC 02/04

;1 4.0 7.0    or    2 5.0 9.0

;1 4.0 7.0    or    2 5.0 9.0

;succeeds

;added by BDC 02/04

;matches 3

;matches 5
```

```
(defrule sdl-rule-67-2 ""
  (declare (salience -1))                          ;added by BDC 02/04
  (or (not (success sdl-67))
      (not (success (sdl-67))))
=>
  (assert (fail sdl-67)))

(defrule sdl-rule-68 ""
  (sdl-68 data1 ?y)                                ;matches 9
  (sdl-68 (data1 (?y)))
  (sdl-68 data2 ?x&:(> ?x ?y))                     ;matches 5 (no match)
  (sdl-68 (data2 (?x&:(> ?x ?y))))
=>
  (assert (fail sdl-68)))

(defrule sdl-rule-69 ""
  (sdl-69 data1 ?y)                                ;matches 4
  (sdl-69 (data1 (?y)))
  (sdl-69 data2 ?x&:(= ?y ?x))                     ;matches 4
  (sdl-69 (data2 (?x&:(= ?y ?x))))
=>
  (assert (success sdl-69))
  (assert (success (sdl-69))))

(defrule sdl-rule-69-2 ""
  (declare (salience -1))                          ;added by BDC 02/04
  (or (not (success sdl-69))
      (not (success (sdl-69))))
=>
  (assert (fail sdl-69)))

(defrule sdl-rule-70 ""
  (sdl-70 data1 ?y&:(numberp ?y))                  ;matches red (no match)
  (sdl-70 (data1 ?y&:(numberp ?y)))
  (sdl-70 data2 ?x&:(numberp ?x) & :(= ?x ?y))     ;matches 5
  (sdl-70 (data2 ?x&:(numberp ?x) & :(= ?x ?y)))
=>
  (assert (fail sdl-70)))

(defrule sdl-rule-71 ""
  (sdl-71 data1 ?y&:(numberp ?y))                  ;matches "4" (no match)
  (sdl-71 (data1 ?y&:(numberp ?y)))
  (sdl-71 data2 ?x&:(numberp ?x)&:(= ?y ?x))       ;matches 5
  (sdl-71 (data2 ?x&:(numberp ?x)&:(= ?y ?x)))
=>
  (assert (fail sdl-71)))

(defrule sdl-rule-72 ""
  (sdl-72 data1 ?y&:(numberp ?y))                  ;matches red (no match)
  (sdl-72 data2 ?x&:(numberp ?x)&:(= ?x ?y))       ;matches 5
  (sdl-72 (data1 ?y&:(numberp ?y)))                ;matches red (no match)
  (sdl-72 (data2 ?x&:(numberp ?x)&:(= ?x ?y)))
=>
  (assert (fail sdl-72)))

(defrule sdl-rule-73 ""
   (sdl-73 data1 ?y)                    ;matches red
   (sdl-73 data2 ?x&:(eq ?x ?y))        ;matches 5 (no match)
   (sdl-73 (data1 ?y))                  ;matches red
   (sdl-73 (data2 ?x&:(eq ?x ?y)))
=>
  (assert (fail sdl-73)))

(defrule sdl-rule-74 ""
```

```
  (sdl-74)                                    ;matches sdl-74
  (sdl-74 ())
=>
  (assert (fail sdl-74))
  (assert (fail (sdl-74))))                   ;asserts fail fact

(defrule sdl-rule-74-2 ""
  ?temp1 <- (fail sdl-74)                     ;matches fail fact
  ?temp2 <- (fail (sdl-74))                   ;matches fail fact
=>
  (retract ?temp1 ?temp2))                            ;retracts fail fact

(defrule sdl-rule-75 ""
  (sdl-75)                                    ;matches sdl-75
  (sdl-75 ())
=>
  (assert (sdl-75 1 =(gentemp)))              ;asserts temp facts
  (assert (sdl-75 2 =(gentemp)))
  (assert (sdl-75 (1 =(gentemp))))
  (assert (sdl-75 (2 =(gentemp)))))

(defrule sdl-rule-75-2 ""
  ?temp1 <- (sdl-75 1 ?)
  ?temp2 <- (sdl-75 (1 ?))                    ;matches temp facts
  ?temp3 <- (sdl-75 2 ?)
  ?temp4 <- (sdl-75 (2 ?))
=>
  (retract ?temp1 ?temp2 ?temp3 ?temp4))                      ;retracts temp facts

(defrule sdl-rule-75-3 ""
  (declare (salience -10))
  (or (sdl-75 ? ?)                                    ;matches (sdl-75) (no match)
      (sdl-75 (? ?)))
=>
  (assert (fail sdl-75)))

;;(defrule sdl-rule-76 ""
;;  (sdl-76)                                    ;matches (sdl-76)
;;=>
;;  (assert ("sdl-76 temp")))                   ;asserts temp fact

;; Was (string_assert "sdl-76 temp")


;;(defrule sdl-rule-76-2 ""
;;  (declare (salience -1))                     ;added by BDC 02/04
;;  (not ("sdl-76 temp"))                               ;matches temp fact
;;=>
;;  (assert (fail sdl-76)))

;;(defrule sdl-rule-77 ""
;;  (sdl-77)                                    ;matches (sdl-77)
;;=>
;;  (assert ("sdl-77 \"temp\"")))                       ;asserts temp fact

;; Was (string_assert "sdl-77 \"temp\"")

;;(defrule sdl-rule-77-2 ""
;;  (declare (salience -1))                     ;added by BDC 02/04
;;  (not ("sdl-77 \"temp\""))                   ;matches temp fact
;;=>
;;  (assert (fail sdl-77)))

(defrule sdl-rule-78 ""
```

```
  (sd1-78)                                  ;matches (sd1-78)
  (sd1-78 ())
  (sd1-78 1 ?x)                             ;matches 5
  (sd1-78 (1 ?x))
  (sd1-78 2 ?y)                             ;matches 8
  (sd1-78 (2 ?y))
=>
  (bind ?a (+ ?x ?y))                       ;binds ?a to 13
  (assert (sd1-78 3 ?a)))                   ;asserts (sd1-78 3 13)

(defrule sd1-rule-78-2 ""
  (declare (salience -1))                   ;added by BDC 02/04
  (not (sd1-78 3 13))                       ;matches temp fact from above
=>
  (assert (fail sd1-78)))

(defrule sd1-rule-79 ""
  (sd1-79 $?data)                           ;matches a b c d e f g
  (sd1-79 ($?data))
=>
  (assert (sd1-79 length =(length$ ?data)))     ;asserts 7
  (assert (sd1-79 (length =(length$ ?data)))))


(defrule sd1-rule-79-2 ""
  (or (not (sd1-79 length 7))               ;matches 7 fact from above
      (not (sd1-79 (length 7))))
=>
  (assert (fail sd1-79)))

(defrule sd1-rule-80 ""
  (sd1-80 $?data)                           ;matches a b c d e f g
  (sd1-80 ($?data))
=>
  (assert (sd1-80 second =(nth$ ?data 2)))      ;asserts b
  (assert (sd1-80 (second =(nth$ ?data 2)))))


(defrule sd1-rule-80-2 ""
  (or (not (sd1-80 second b))               ;matches b fact from above
      (not (sd1-80 (second b))))
=>
  (assert (fail sd1-80)))

(defrule sd1-rule-81 ""
  (sd1-81 $?data1)                          ;matches a b c d e f g
  (sd1-81 ($?data2))
=>
  (bind ?a1 (position$ b ?data1))                   ;binds ?a to 2
  (bind ?a2 (position$ b ?data2))                   ;binds ?a to 2
  (assert (temp sd1-81 position ?a1))       ;asserts 2
  (assert (temp sd1-81 (position ?a2))))

(defrule sd1-rule-81-2 ""
  (or (not (temp sd1-81 position 2))                ;matches 2 fact from above
      (not (temp sd1-81 (position 2))))
=>
  (assert (fail sd1-81)))

(defrule sd1-rule-108 ""
  (sd1-108 ?x)                              ;matches 10
  (sd1-108 (?x))                                    ;matches 10
=>
  (if (= ?x 10)
```

```
        then
        (assert (success sdl-108))
        else
        (assert (fail sdl-108))))

(defrule sdl-rule-109 ""
  (sdl-109 ?y)                                  ;matches 3
  (sdl-109 (?y))                                        ;matches 3
=>
  (bind ?x ?y)
  (while (> ?x 0) do
         (assert (sdl-109 while ?x)
                 (sdl-109 (while ?x)))
         (bind ?x (- ?x 1))))

(defrule sdl-rule-109-2 ""
  (sdl-109 while 3)                             ;three facts from previous rule
  (sdl-109 while 2)
  (sdl-109 (while 1))
  (sdl-109 (while 3))                           ;three facts from previous rule
  (sdl-109 (while 2))
  (sdl-109 (while 1))
=>
  (assert (success sdl-109)))

(defrule sdl-rule-109-3 ""
  (declare (salience -1))
  (not (success sdl-109))                       ;added by BDC 02/05/88
=>
  (assert (fail sdl-109)))

(defrule sdl-rule-115 ""
  (sdl-115 $?x foo bar $?x)                     ;(sdl-115 to be foo bar to be)
  (sdl-115 (($?x) (foo bar) ($?x)))                     ;(sdl-115 to be foo bar to be)
 =>
  (assert (success sdl-115)))

(defrule sdl-rule-115-1 ""
  (declare (salience -10))
  (not (success sdl-115))                       ;previous rule
 =>
  (assert (fail sdl-115)))

(defrule sdl-rule-116 ""
  (or (not (sdl-116 $?vowels u))                        ;(sdl-116 a e i o u)
      (not (sdl-116 ($?vowels u))))
=>
  (assert (fail sdl-116)))

(defrule sdl-rule-117 ""
  (sdl-117 $?a $?b)                             ;(sdl-117 fluff mug bump bleet lolita)
  (sdl-117 ($?a $?b))                           ;(sdl-117 fluff mug bump bleet lolita)
=>
  (assert (sdl-117-a $?a))                      ;should be six pairs of facts
  (assert (sdl-117-b $?b))
  (assert (sdl-117-a ($?a)))                    ;should be six pairs of facts
  (assert (sdl-117-b ($?b))))

(defrule sdl-rule-117-1 ""
  (sdl-117-a)
  (sdl-117-a fluff)
  (sdl-117-a fluff mug)
  (sdl-117-a fluff mug bump)
  (sdl-117-a fluff mug bump bleet)
```

```
  (sdl-117-a fluff mug bump bleet lolita)       ;six pairs
  (sdl-117-b fluff mug bump bleet lolita)
  (sdl-117-b mug bump bleet lolita)
  (sdl-117-b bump bleet lolita)
  (sdl-117-b bleet lolita)
  (sdl-117-b lolita)
  (sdl-117-b)
  (sdl-117-a ())
  (sdl-117-a (fluff))
  (sdl-117-a (fluff mug))
  (sdl-117-a (fluff mug bump))
  (sdl-117-a (fluff mug bump bleet))
  (sdl-117-a (fluff mug bump bleet lolita))     ;another six pairs
  (sdl-117-b (fluff mug bump bleet lolita))
  (sdl-117-b (mug bump bleet lolita))
  (sdl-117-b (bump bleet lolita))
  (sdl-117-b (bleet lolita))
  (sdl-117-b (lolita))
  (sdl-117-b ())
=>
  (assert (success sdl-117)))

(defrule sdl-rule-117-2 ""
  (declare (salience -10))
  (not (success sdl-117))                       ;from previous rule
=>
  (assert (fail sdl-117)))

(defrule sdl-rule-ski-1 ""
  (non-working ?date)                           ;(non-working sdl-118) (non-working sdl-119)
  (non-working (?date))                         ;(non-working sdl-118) (non-working sdl-119)
  (and (not (weather ?date hot-and-humid))      ;no match
       (not (weather ?date major-blizzard))     ;(weather sdl-118 major-blizzard), no match 119
       (not (traffic ?date massive))
       (not (weather (?date hot-and-humid)))    ;no match
       (not (weather (?date major-blizzard)))   ;(weather sdl-118 major-blizzard), no match 119
       (not (traffic (?date massive))))         ;no match
=>
  (assert (go-hiking ?date))                    ;no 118; yes 119
  (assert (go-hiking (?date))))                 ;no 118; yes 119


(defrule sdl-rule-ski-2 ""
  (non-working ?date)                           ;(non-working sdl-119)
  (non-working (?date))                         ;(non-working sdl-119)
  (or (not (weather ?date major-blizzard))      ;no match for 119, yes for 118
      (not (drive ?date two-wheel))             ;(drive sdl-119 two-wheel), no for 118
      (not (working ?date weekend))
      (not (weather (?date major-blizzard)))    ;no match for 119, yes for 118
      (not (drive (?date two-wheel)))           ;(drive sdl-119 two-wheel), no for 118
      (not (working (?date weekend))))          ;no match
=>
  (assert (go-skiing ?date))                    ;119 yes, 118 yes
  (assert (go-skiing (?date))))                 ;119 yes, 118 yes

(defrule sdl-rule-118 ""
  (or
    (go-hiking sdl-118)
    (not (go-skiing sdl-118))
    (go-hiking (sdl-118))
    (not (go-skiing (sdl-118))))                        ;from above rules
=>
  (assert (fail sdl-118)))
```

```
(defrule sdl-rule-119 ""
  (or
    (not (go-hiking sdl-119))                ;from above rules
    (not (go-skiing sdl-119))
    (not (go-hiking (sdl-119)))              ;from above rules
    (not (go-skiing (sdl-119))))
=>
  (assert (fail sdl-119)))

(defrule sdl-rule-120 ""
  (or
    (go-hiking sdl-120)
    (go-skiing sdl-120)
    (go-hiking (sdl-120))
    (go-skiing (sdl-120)))
=>
  (assert (fail sdl-120)))

(defrule sdl-rule-121 ""
  (sdl-121 $? ?x $? ?x $?)                   ;(sdl-121 one one)
  (sdl-121 ($? ?x $? ?x $?))                 ;(sdl-121 one one)
=>
  (assert (match sdl-121 ?x)))

(defrule sdl-rule-121-2 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
  (not (match sdl-121 one))
=>
  (assert (fail sdl-121)))

(defrule sdl-rule-122 ""
  (sdl-122 $? ?x $? ?x $?)                   ;(sdl-122 one one one)
  (sdl-122 ($? ?x $? ?x $?))                 ;(sdl-122 one one one)
=>
  (assert (match sdl-122 ?x)))

(defrule sdl-rule-122-2 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
   (not (match sdl-122 one))
=>
  (assert (fail sdl-122)))

(defrule sdl-rule-123 ""
  (sdl-123 $? ?x $? ?x $?)                   ;(sdl-123 6 5 4 5)
  (sdl-123 ($? ?x $? ?x $?))                 ;(sdl-123 6 5 4 5)
=>
  (assert (match sdl-123 ?x)))

(defrule sdl-rule-123-2 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
  (not (match sdl-123 5))
=>
  (assert (fail sdl-123)))

(defrule sdl-rule-124 ""
  (sdl-124 $? ?x $? ?x $?)                   ;(sdl-124 a r t h u r)
  (sdl-124 ($? ?x $? ?x $?))                 ;(sdl-124 a r t h u r)
=>
  (assert (match sdl-124 ?x)))

(defrule sdl-rule-124-2 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
  (not (match sdl-124 r))
=>
```

```
  (assert (fail sdl-124)))

(defrule sdl-rule-125 ""
  (sdl-125 $? ?x $? ?x $?)                ;(sdl-125 a rose is a rose)
  (sdl-125 ($? ?x $? ?x $?))              ;(sdl-125 a rose is a rose)
=>
  (assert (match sdl-125 ?x)))            ;should get two asserted facts

(defrule sdl-rule-125-2 ""
  (declare (salience -1))                 ;added by BDC 02/05/88
  (or (not (match sdl-125 a))
      (not (match sdl-125 rose)))
=>
  (assert (fail sdl-125)))


(defrule sdl-rule-126 ""
  (or (not (sdl-126 $?x or not $?x))      ;(sdl-126 to be or not to be)
      (not (sdl-126 ($?x or not $?x))))
=>
  (assert (fail sdl-126)))

(defrule sdl-rule-127-master ""
  (sdl-127 ? $?x)                         ;(sdl-127 frank)
  (sdl-127 (? $?x))                       ;(sdl-127 frank)
=>
  (assert (sdl-127-result $?x))
  (assert (sdl-127-result ($?x))))

(defrule sdl-rule-127 ""
  (or (not (sdl-127-result))              ;should be no fact of this type
      (not (sdl-127-result ())))
=>
  (assert (fail sdl-127)))

(defrule sdl-rule-128-master ""
  (sdl-128 ? $?x)                         ;(sdl-128 1 2)
  (sdl-128 (? $?x))                       ;(sdl-128 1 2)
=>
  (assert (sdl-128-result $?x))
  (assert (sdl-128-result ($?x))))

(defrule sdl-rule-128 ""
  (declare (salience -1))                 ;added by BDC 02/05/88
  (or (not (sdl-128-result 2))
      (not (sdl-128-result (2))))
=>
  (assert (fail sdl-128)))

(defrule sdl-rule-129-master ""
  (sdl-129 ? $?x)                         ;(sdl-129 love in bloom)
  (sdl-129 (? $?x))                       ;(sdl-129 love in bloom)
=>
  (assert (sdl-129-result $?x))
  (assert (sdl-129-result ($?x))))

(defrule sdl-rule-129 ""
  (declare (salience -1))                 ;added by BDC 02/05/88
  (or (not (sdl-129-result in bloom))     ;from previous rule
      (not (sdl-129-result (in bloom))))
=>
  (assert (fail sdl-129)))

(defrule sdl-rule-130-master ""
```

```
  (sdl-130 ? $?x)                          ;(sdl-130 a rose is a rose)
  (sdl-130 (? $?x))                        ;(sdl-130 a rose is a rose)
=>
  (assert (sdl-130-result $?x))
  (assert (sdl-130-result ($?x))))

(defrule sdl-rule-130 ""
  (declare (salience -1))                  ;added by BDC 02/05/88
  (or (not (sdl-130-result rose is a rose))        ;from previous rule
      (not (sdl-130-result (rose is a rose))))
=>
  (assert (fail sdl-130)))

(defrule sdl-rule-131 ""
  (sdl-131 ?a)                             ;"foo
  (sdl-131 (?a))                                   ;"foo"
=>
  (bind ?b (string-append ?a "-bar"))
  (assert (sdl-131-result ?b))
  (assert (sdl-131-result (?b))))

(defrule sdl-rule-131-1 ""
  (declare (salience -1))                  ;added by BDC 02/05/88
  (or (not (sdl-131-result "foo-bar"))
      (not (sdl-131-result ("foo-bar"))))
=>
  (assert (fail sdl-131))
  (assert (fail (sdl-131))))

(defrule sdl-133-rule ""
  (sdl-133 ?first ? $?x)                   ;(sdl-133 first second)  $?x binds to nothing
  (sdl-133 (?first ? $?x))                 ;(sdl-133 first second)  $?x binds to nothing
=>
  (bind ?y (string-append ?first "-RESULT"))
  (assert (sdl-133-result ?y $?x))
  (assert (sdl-133-result (?y $?x))))

(defrule sdl-133-rule-1 ""
  (declare (salience -1))                  ;added by BDC 02/05/88
  (or (not (sdl-133-result "FIRST-RESULT"))        ;from previous rule
      (not (sdl-133-result ("FIRST-RESULT"))))
=>
  (assert (fail sdl-133)))

(defrule sdl-134-rule ""
  (sdl-134 republicans $? ?x $?)       ;(sdl-134 republicans fox jones nixon williams harvey)
  (sdl-134 quakers $? ?x $?)
  (sdl-134 (republicans $? ?x $?))     ;(sdl-134 republicans fox jones nixon williams harvey)
  (sdl-134 (quakers $? ?x $?))         ;(sdl-134 quakers pallas sanchez stone nixon fregge)
=>
  (assert (sdl-134-result ?x))         ;?x is nixon
  (assert (sdl-134-result (?x))))      ;?x is nixon

(defrule sdl-134-rule-1 ""
  (declare (salience -1))                  ;added by BDC 02/05/88
  (or (not (sdl-134-result nixon))                 ;from previous rule
      (not (sdl-134-result (nixon))))
=>
  (assert (fail sdl-134)))

(defrule sdl-135-rule ""
  ;;(sdl-135 yellow) (sdl-135 green)
  (sdl-135 ?a &~red & ~blue & ~green & ~violet & ~orange & ~black)
  ;;(sdl-135 yellow) (sdl-135 green)
```

```
  (sdl-135 (?a &~red & ~blue & ~green & ~violet & ~orange & ~black))
=>
  (assert (sdl-135-result ?a))                    ;yellow
  (assert (sdl-135-result (?a))))                         ;yellow

(defrule sdl-135-rule-1 ""
  (sdl-135-result yellow)                         ;from previous rule
  (sdl-135-result (yellow))                       ;from previous rule
  (not (sdl-135-result green))                    ;should be no such fact
  (not (sdl-135-result (green)))
=>
  (assert (success sdl-135)))

(defrule sdl-135-rule-2 ""
  (declare (salience -10))
  (not (success sdl-135))                         ;previous rule
=>
  (assert (fail sdl-135)))

(defrule sdl-136-rule ""
  (sdl-136 ?a &red | blue | green | violet | orange | black)    ;yellow and green
  (sdl-136 (?a &red | blue | green | violet | orange | black))  ;yellow and green
=>
  (assert (sdl-136-result ?a))                    ;one green asserted
  (assert (sdl-136-result (?a))))                         ;one green asserted

(defrule sdl-136-rule-1 ""
  (not (sdl-136-result yellow))                   ;should not exist
  (not (sdl-136-result (yellow)))
  (sdl-136-result green)                          ;should exist
  (sdl-136-result (green))                        ;should exist
=>
  (assert (success sdl-136)))

(defrule sdl-136-rule-2 ""
  (declare (salience -10))
  (not (success sdl-136))                         ;from previous rule
=>
  (assert (fail sdl-136)))

(defrule sdl-137-rule ""
  (sdl-137 red|blue|green|violet|orange|black)
  (sdl-137 (red|blue|green|violet|orange|black))
=>
  (assert (fail sdl-137)))

(defrule sdl-138-rule ""
  (or (not (sdl-138 red | blue | green | violet | orange | black))      ;yellow and green
      (not (sdl-138 (red | blue | green | violet | orange | black))))
=>
  (assert (fail sdl-138)))

(defrule sdl-139-rule ""
  (or (not (sdl-139 ?x =(abs ?x)))                        ;-12 12
      (not (sdl-139 (?x (=(abs ?x))))))
=>
  (assert (fail sdl-139)))

(defrule sdl-140-rule ""
  (sdl-140 ?x1 ?y1)                               ;1 1   also   1 2
  (sdl-140 ?x2 & ~?x1 ?y2 & ~?y1)
  (sdl-140 (?x1 ?y1))                             ;1 1   also   1 2
  (sdl-140 (?x2 & ~?x1 ?y2 & ~?y1))
=>
```

```
    (assert (fail sdl-140)))

  (defrule sdl-141-rule **
    (sdl-141 ?x1 ?y1)                          ;1 1   also   1 2
    (sdl-141 ?x2 ?y2)
    (sdl-141 (?x1 ?y1))                        ;1 1   also   1 2
    (sdl-141 (?x2 ?y2))
    (test (or (not (= ?x1 ?x2))
              (not (= ?y1 ?y2))))
  =>
    (assert (success sdl-141)))

  (defrule sdl-141-rule-1 **
    (declare (salience -10))
    (not (success sdl-141))
  =>
    (assert (fail sdl-141)))

  (defrule sdl-142-rule **
    (sdl-142 ?first ?second)                   ;cold hot
    (sdl-142 (?first ?second))                 ;cold hot
  =>
    (assert (sdl-142 ?second ?first))          ;hot cold
    (assert (sdl-142 (?second ?first))))       ;hot cold

  (defrule sdl-142-rule-1 **
    (declare (salience -1))                    ;added by BDC 02/05/88
    (or (not (sdl-142 hot cold))               ;from above rule
        (not (sdl-142 (hot cold))))
  =>
    (assert (fail sdl-142)))

  (defrule sdl-143-rule **
    (sdl-143 $?x red $?y)                      ;green yellow red blue white
    (sdl-143 ($?x red $?y))                           ;green yellow red blue white
  =>
    (assert (sdl-143 red $?x $?y))
    (assert (sdl-143 (red $?x $?y))))

  (defrule sdl-143-rule-1 **
    (declare (salience -1))                    ;added by BDC 02/05/88
    (or (not (sdl-143 red green yellow blue white))       ;from above rule
        (not (sdl-143 (red green yellow blue white))))
  =>
    (assert (fail sdl-143)))

  (defrule sdl-144-rule **
    (sdl-144 brother-of ?father ?uncle)        ;walter daniel
    (sdl-144 child-of ?father ?child)          ;walter jane
    (sdl-144 sex-of ?child female)             ;jane female
    (sdl-144 (brother-of ?father ?uncle))      ;walter daniel
    (sdl-144 (child-of ?father ?child))        ;walter jane
    (sdl-144 (sex-of ?child female))           ;jane female
  =>
    (assert (sdl-144 niece-of ?uncle ?child))  ;daniel jane
    (assert (sdl-144 uncle-of ?child ?uncle))
    (assert (sdl-144 (niece-of ?uncle ?child)))   ;daniel jane
    (assert (sdl-144 (uncle-of ?child ?uncle))))  ;jane daniel

  (defrule sdl-144-rule-2 **
    (sdl-144 brother-of ?father ?uncle)        ;walter daniel
    (sdl-144 child-of ?father ?child)          ;walter david
    (sdl-144 sex-of ?child male)
    (sdl-144 (brother-of ?father ?uncle))      ;walter daniel
```

```
  (sdl-144 (child-of ?father ?child))          ;walter david
  (sdl-144 (sex-of ?child male))                       ;david male
=>
  (assert (sdl-144 nephew-of ?uncle ?child))   ;walter david
  (assert (sdl-144 uncle-of ?child ?uncle))
  (assert (sdl-144 (nephew-of ?uncle ?child)))  ;walter david
  (assert (sdl-144 (uncle-of ?child ?uncle))))  ;david walter

(defrule sdl-144-rule-3 ""
  (sdl-144 niece-of daniel jane)               ;all from above rules
  (sdl-144 uncle-of jane daniel)
  (sdl-144 nephew-of daniel david)
  (sdl-144 uncle-of david daniel)
  (sdl-144 (niece-of daniel jane))             ;all from above rules
  (sdl-144 (uncle-of jane daniel))
  (sdl-144 (nephew-of daniel david))
  (sdl-144 (uncle-of david daniel))
=>
  (assert (success sdl-144)))                  ;if all here assert success

(defrule sdl-144-rule-4 ""
  (declare (salience -10))
  (not (success sdl-144))
=>
  (assert (fail sdl-144)))

(defrule sdl-rule-145 ""
  (sdl-145-list $?colors)                      ;red white blue
  (sdl-145-list ($?colors))                    ;red white blue
=>
  (bind ?i 1)
  (bind ?length (length$ ?colors))             ;3
  (while (<= ?i ?length) do
         (assert (sdl-145-control =(nth$ ?colors ?i))
                 (sdl-145-control (=(nth$ ?colors ?i))))
         (bind ?i (+ ?i 1))))

(defrule sdl-rule-145-1 ""
  (sdl-145-control ?color)                     ;red or white or blue
  (sdl-145-control (?color))                   ;red or white or blue
  (or (not (sdl-145 ?color))                   ;if no matching generated fact
      (not (sdl-145 (?color))))
=>
  (assert (fail sdl-145)))

(defrule sdl-rule-146 ""
  (sdl-146-seats $?seats)                      ;8 9 11 14 3
  (sdl-146-names $?names)
  (sdl-146-seats ($?seats))                    ;8 9 11 14 3
  (sdl-146-names ($?names))                    ;tom carol fred alex
=>
  (bind ?i 1)
  (bind ?length (min (length$ ?seats)
                     (length$ ?names)))
  (while (<= ?i ?length) do
         (assert (sdl-146-assignment
                   =(nth$ ?seats ?i)
                   =(nth$ ?names ?i))
                 (sdl-146-assignment
                  (=(nth$ ?seats ?i)
                  =(nth$ ?names ?i))))
         (bind ?i (+ ?i 1))))

  (defrule sdl-rule-146-1 ""
```

```
    (sdl-146-assignment 8 tom)
    (sdl-146-assignment 9 carol)
    (sdl-146-assignment 11 fred)
    (sdl-146-assignment 14 alex)
    (sdl-146-assignment (8 tom))
    (sdl-146-assignment (9 carol))
    (sdl-146-assignment (11 fred))
    (sdl-146-assignment (14 alex))
  =>
    (assert (success sdl-146)))

  (defrule sdl-146-rule-2 ""
    (declare (salience -10))
    (not (success sdl-146))
  =>
    (assert (fail sdl-146)))

  (defrule sdl-147 ""
  ?state-fact-1 <- (sdl-147-sum ?list ?donor ?sum-so-far)
    (sdl-147 ?list ?donor ?next-donor & ~finish)
    (sdl-147 donation ?next-donor ?contribution)
  ?state-fact-2 <- (sdl-147-sum (?list ?donor ?sum-so-far))
    (sdl-147 (?list ?donor ?next-donor & ~finish))
    (sdl-147 (donation ?next-donor ?contribution))
  =>
    (retract ?state-fact-1 ?state-fact-2)
    (assert (sdl-147-sum ?list ?next-donor
                         =(+ ?sum-so-far ?contribution)))
    (assert (sdl-147-sum (?list ?next-donor
                         =(+ ?sum-so-far ?contribution)))))

  (defrule sdl-147-2 ""
    ?state-fact-1 <- (sdl-147-sum ?list ?donor ?sum)
    (sdl-147 ?list ?donor finish)
    ?state-fact-2 <- (sdl-147-sum (?list ?donor ?sum))
    (sdl-147 (?list ?donor finish))
  =>
    (retract ?state-fact-1 ?state-fact-2)
    (assert (sdl-147-final ?list ?sum))
    (assert (sdl-147-final (?list ?sum))))

  (defrule sdl-147-3 ""
    (or (not (sdl-147-final donors 17.5))
        (not (sdl-147-final (donors 17.5))))
  =>
    (assert (fail sdl-147)))

  (defrule sdl-rule-148 ""
    (sdl-148 donor-list $?donors)
    (sdl-148 (donor-list $?donors))
  =>
    (bind ?length (length$ ?donors))
    (assert (sdl-148 donors start =(nth$ ?donors 1)))
    (assert (sdl-148 (donors start =(nth$ ?donors 1))))
    (assert (sdl-148 donors =(nth$ ?donors ?length) finish))
    (assert (sdl-148 (donors =(nth$ ?donors ?length) finish)))
    (bind ?i 1)
    (while (< ?i ?length) do
           (assert (sdl-148 donors =(nth$ ?donors ?i) =(nth$ ?donors (+ ?i 1)))
                   (sdl-148 (donors =(nth$ ?donors ?i) =(nth$ ?donors (+ ?i 1)))))
           (bind ?i (+ ?i 1))))

  (defrule sdl-148-1 ""
    ?state-fact-1 <- (sdl-148-sum ?list ?donor ?sum-so-far)
```

```
  (sdl-148 ?list ?donor ?next-donor & ~finish)
  (sdl-148 donation ?next-donor ?contribution)
  ?state-fact-2 <- (sdl-148-sum (?list ?donor ?sum-so-far))
  (sdl-148 (?list ?donor ?next-donor & ~finish))
  (sdl-148 (donation ?next-donor ?contribution))
=>
  (retract ?state-fact-1 ?state-fact-2)
  (assert (sdl-148-sum ?list ?next-donor
                       =(+ ?sum-so-far ?contribution)))
  (assert (sdl-148-sum (?list ?next-donor
                       =(+ ?sum-so-far ?contribution)))))

(defrule sdl-148-2 ""
  ?state-fact-1 <- (sdl-148-sum ?list ?donor ?sum)
  (sdl-148 ?list ?donor finish)
  ?state-fact-2 <- (sdl-148-sum (?list ?donor ?sum))
  (sdl-148 (?list ?donor finish))
=>
  (retract ?state-fact-1 ?state-fact-2)
  (assert (sdl-148-final ?list ?sum))
  (assert (sdl-148-final (?list ?sum))))

(defrule sdl-148-3 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
  (or (not (sdl-148-final donors 17.5))
      (not (sdl-148-final (donors 17.5))))
=>
  (assert (fail sdl-148)))

(defrule sdl-149 ""
  (declare (salience 1000))
  (sdl-149 inventory ?name ?amount)
  (sdl-149 (inventory ?name ?amount))
=>
  (assert (sdl-149 add-to-sum ?name ?amount))
  (assert (sdl-149 (add-to-sum ?name ?amount))))

(defrule sdl-149-1 ""
  (declare (salience 1000))
  ?x <- (sdl-149 add-to-sum ?name ?amount)
  ?y <- (sdl-149 current-sum ?sum)
  ?z <- (sdl-149 (add-to-sum ?name ?amount))
  ?w <- (sdl-149 (current-sum ?sum))
=>
  (retract ?x ?y)
  (assert (sdl-149 current-sum =(+ ?sum ?amount)))
  (assert (sdl-149 (current-sum =(+ ?sum ?amount)))))

(defrule sdl-149-2 ""
  (declare (salience -1))                    ;added by BDC 02/05/88
  (or (not (sdl-149 current-sum 19.5))
      (not (sdl-149 (current-sum 19.5))))
=>
  (assert (fail sdl-149)))

(defrule sdl-150 ""
  (declare (salience 1000))
  (sdl-150 inventory ?name ?amount)
  (sdl-150 (inventory ?name ?amount))
=>
  (assert (sdl-150 count-item ?name ?amount))
  (assert (sdl-150 (count-item ?name ?amount))))

(defrule sdl-150-1 ""
```

```
    (declare (salience 1000))
    ?x <- (sdl-150 count-item ?name ?amount)
    ?y <- (sdl-150 current-count ?count)
    ?z <- (sdl-150 (count-item ?name ?amount))
    ?w <- (sdl-150 (current-count ?count))
  =>
    (retract ?x ?y ?z ?w)
    (assert (sdl-150 current-count =(+ ?count 1)))
    (assert (sdl-150 counted ?name ?amount))
    (assert (sdl-150 (current-count =(+ ?count 1))))
    (assert (sdl-150 (counted ?name ?amount)))
    )

  (defrule sdl-150-2 **
    (declare (salience 1000))
    ?x <- (sdl-150 counted ?name ?amount)
    ?z <- (sdl-150 (counted ?name ?amount))
    (or (not (sdl-150 inventory ?name ?amount))
        (not (sdl-150 (inventory ?name ?amount))))
    ?y <- (sdl-150 current-count ?count)
    ?w <- (sdl-150 (current-count ?count))
  =>
    (retract ?x ?y ?w ?z)
    (assert (sdl-150 current-count =(- ?count 1)))
    (assert (sdl-150 (current-count =(- ?count 1))))
    )

  (defrule sdl-150-3 **
    (declare (salience -1))                    ;added by BDC 02/05/88
    (or (not (sdl-150 current-count 3))
        (not (sdl-150 (current-count 3))))
  =>
    (assert (fail sdl-150)))

  (defrule sdl-151
    (sdl-151 quarter ?w)                       ;10
    (sdl-151 dime ?x)                          ;8
    (sdl-151 nickel ?y)                        ;6
    (sdl-151 penny ?z)                         ;4
    (sdl-151 (quarter ?w))                             ;10
    (sdl-151 (dime ?x))                        ;8
    (sdl-151 (nickel ?y))                      ;6
    (sdl-151 (penny ?z))
    (test (> ?w ?x ?y ?z))                             ;4
  =>
    (assert (success sdl-151)))

  (defrule sdl-151-1 **
    (declare (salience -10))
    (not (success sdl-151))
  =>
    (assert (fail sdl-151)))

  (defrule sdl-152 **
    (sdl-152 quarter ?w)
    (sdl-152 dime ?x)
    (sdl-152 nickel ?y)
    (sdl-152 penny ?z)
    (sdl-152 (quarter ?w))
    (sdl-152 (dime ?x))
    (test (> ?w ?x))
    (sdl-152 (nickel ?y))
    (test (> ?x ?y))
    (sdl-152 (penny ?z))
```

```
  (test (> ?y ?z))
=>
  (assert (success sdl-152)))

(defrule sdl-152-1 ""
  (declare (salience -10))
  (not (success sdl-152))
=>
  (assert (fail sdl-152)))

(defrule sdl-153 ""
  (sdl-153 ?answer & yes | no | unknown | :(numberp ?answer))    ;yes, no, unknown, 1
  (sdl-153 (?answer & yes | no | unknown | :(numberp ?answer))) ;yes, no, unknown, 1
=>
  (assert (sdl-153 matched ?answer))
  (assert (sdl-153 (matched ?answer))))

(defrule sdl-153-1 ""
  (sdl-153 matched yes)
  (sdl-153 matched no)
  (sdl-153 matched unknown)
  (sdl-153 matched 1)
  (sdl-153 (matched yes))
  (sdl-153 (matched no))
  (sdl-153 (matched unknown))
  (sdl-153 (matched 1))
=>
  (assert (success sdl-153)))

(defrule sdl-153-2 ""
  (declare (salience -10))
  (not (success sdl-153))
=>
  (assert (fail sdl-153)))

(defrule sdl-154 ""
  (sdl-154 ?time1 & :(numberp ?time1))
  (sdl-154 ?time2 & :(numberp ?time2) & :(> ?time2 ?time1) )
  (sdl-154 (?time1 & :(numberp ?time1)))
  (sdl-154 (?time2 & :(numberp ?time2) & :(> ?time2 ?time1) ))
=>
  (assert (sdl-154-matched ?time1 ?time2))
  (assert (sdl-154-matched (?time1 ?time2))))

(defrule sdl-154-1 ""
  (sdl-154-matched 1 2)
  (sdl-154-matched 2 3)
  (sdl-154-matched 1 3)
  (sdl-154-matched (1 2))
  (sdl-154-matched (2 3))
  (sdl-154-matched (1 3))
=>
  (assert (success sdl-154)))

(defrule sdl-154-2 ""
  (declare (salience -10))
  (not (success sdl-154))
=>
  (assert (fail sdl-154)))

(defrule sdl-155 ""
  (sdl-155 ?time1 & :(numberp ?time1))
  (sdl-155 ?time2 & :(numberp ?time2))
  (sdl-155 (?time1 & :(numberp ?time1)))
```

```
  (sdl-155 (?time2 & :(numberp ?time2)))
  (test (> ?time2 ?time1))
=>
  (assert (sdl-155 matched ?time1 ?time2))
  (assert (sdl-155 (matched ?time1 ?time2))))

(defrule sdl-155-1 ""
  (sdl-155 matched 1 2)
  (sdl-155 matched 2 3)
  (sdl-155 matched 1 3)
  (sdl-155 (matched 1 2))
  (sdl-155 (matched 2 3))
  (sdl-155 (matched 1 3))
=>
  (assert (success sdl-155)))

(defrule sdl-155-2 ""
  (declare (salience -10))
  (not (success sdl-155))
=>
  (assert (fail sdl-155)))

(defrule sdl-156 ""
  (or (not (sdl-156 ?x & yes | no | :(numberp ?x) | :(stringp ?x)))
      (not (sdl-156 (?x & yes | no | :(numberp ?x) | :(stringp ?x)))))
=>
  (assert (fail sdl-156)))
vvvv
(defrule sdl-157 ""
  (or (not (sdl-157 ?x & :(stringp ?x) | yes | no | :(numberp ?x)))
      (not (sdl-157 (?x & :(stringp ?x) | yes | no | :(numberp ?x)))))
=>
  (assert (fail sdl-157)))

(defrule sdl-158 ""
  (or (not (sdl-158 ?x & :(stringp ?x)))
      (not (sdl-158 (?x & :(stringp ?x)))))
=>
  (assert (fail sdl-158)))

(defrule sdl-159 ""
  (sdl-159 ?answer & yes | no | unknown | :(numberp ?answer))
  (sdl-159 (?answer & yes | no | unknown | :(numberp ?answer)))
=>
  (assert (sdl-159 matched ?answer))
  (assert (sdl-159 (matched ?answer))))

(defrule sdl-159-1 ""
  (sdl-159 matched yes)
  (sdl-159 matched no)
  (sdl-159 matched unknown)
  (sdl-159 matched 1)
  (sdl-159 (matched yes))
  (sdl-159 (matched no))
  (sdl-159 (matched unknown))
  (sdl-159 (matched 1))
=>
  (assert (success sdl-159)))

(defrule sdl-159-2 ""
  (declare (salience -10))
  (not (success sdl-159))
=>
  (assert (fail sdl-159)))
```

```
(defrule sdl-160 ""
  (sdl-160 ?answer &:(numberp ?answer) | yes | no | unknown)
  (sdl-160 (?answer &:(numberp ?answer) | yes | no | unknown))
=>
  (assert (sdl-160 matched ?answer))
  (assert (sdl-160 (matched ?answer))))

(defrule sdl-160-1 ""
  (sdl-160 matched yes)
  (sdl-160 matched no)
  (sdl-160 matched unknown)
  (sdl-160 matched 1)
  (sdl-160 (matched yes))
  (sdl-160 (matched no))
  (sdl-160 (matched unknown))
  (sdl-160 (matched 1))
=>
  (assert (success sdl-160)))

(defrule sdl-160-2 ""
  (declare (salience -10))
  (not (success sdl-160))
=>
  (assert (fail sdl-160)))

(defrule sdl-161 ""
  (sdl-161 ?time1&:(numberp ?time1))
  (sdl-161 (?time1&:(numberp ?time1)))
  (sdl-161 ?time2&:(numberp ?time2)&:(> ?time2 ?time1))
  (sdl-161 (?time2&:(numberp ?time2)&:(> ?time2 ?time1)))
=>
  (assert (sdl-161 matched ?time1 ?time2)))

(defrule sdl-161-1 ""
  (sdl-161 matched 1 2)
  (sdl-161 matched 2 3)
  (sdl-161 matched 1 3)
=>
  (assert (success sdl-161)))

(defrule sdl-161-2 ""
  (declare (salience -10))
  (not (success sdl-161))
=>
  (assert (fail sdl-161)))

(defrule sdl-162 ""
  (sdl-162 ?time1&:(numberp ?time1))
  (sdl-162 (?time1&:(numberp ?time1)))
  (sdl-162 ?time2&:(numberp ?time2))
  (sdl-162 (?time2&:(numberp ?time2)))
  (test (> ?time2 ?time1))
=>
  (assert (sdl-162 matched ?time1 ?time2)))

(defrule sdl-162-1 ""
  (sdl-162 matched 1 2)
  (sdl-162 matched 2 3)
  (sdl-162 matched 1 3)
=>
  (assert (success sdl-162)))

(defrule sdl-162-2 ""
  (declare (salience -10))
```

```
  (not (success sdl-162))
=>
  (assert (fail sdl-162)))

(defrule sdl-163 ""
  (or (not (sdl-163 ?input & "yes" | "no" | "unknown" | "overflow" | "inference"))
      (not (sdl-163 (?input & "yes" | "no" | "unknown" | "overflow" | "inference"))))
=>
  (assert (fail sdl-163)))

(defrule sdl-164 ""
  (sdl-164 input ?input)                        ;"overflow"
  (sdl-164 list $?list)
  (sdl-164 (input ?input))                      ;"overflow"
  (sdl-164 (list $?list))                       ;"yes" "no" "unknown" "overflow" "inference"
=>
  (if (position$ ?input ?list)
      then
      (assert (success sdl-164))
      else
      (assert (fail sdl-164))))

(defrule sdl-165 ""
  (or (not (sdl-165 12345.89))                  ;matches literal fact
      (not (sdl-165 (12345.89))))
=>
  (assert (fail sdl-165)))

(defrule sdl-166 ""
  (patient-name ?patient-1)                     ;paul brad
  (patient-name (?patient-1))                   ;paul brad
  (sdl-166 $? ?patient-1 $?
              ?answer &
              yes |
              no |
              unknown |
              :(numberp ?answer) $?)
      (sdl-166  $? ?answer &
                yes |
                no |
                unknown |
                :(numberp ?answer) $?
                ?patient-1 $?)
      (sdl-166 ($? ?patient-1 $?
               ?answer &
               yes |
               no |
               unknown |
               :(numberp ?answer) $?))
      (sdl-166  ($? ?answer &
                yes |
                no |
                unknown |
                :(numberp ?answer) $?
                ?patient-1 $?))
=>
  (assert (sdl-166-matched ?patient-1 ?answer))
  (assert (sdl-166-matched (?patient-1 ?answer))))

(defrule sdl-166-1 ""
  (sdl-166-matched paul 1.5)
  (sdl-166-matched paul yes)
  (sdl-166-matched (paul 1.5))
  (sdl-166-matched (paul yes))
```

```
=>
  (assert (success sdl-166)))

(defrule sdl-166-2 ""
  (declare (salience -10))
  (not (success sdl-166))
=>
  (assert (fail sdl-166)))

(defrule sdl-167 ""
  (patient-name ?patient-1)
  (patient-name (?patient-1))
  (patient-name ?patient-2 & ~?patient-1)
  (patient-name (?patient-2 & ~?patient-1))
  (or (sdl-167 $?w ?patient-1
               $?x ?patient-2
               $?y ?answer &
               yes |
               no |
               unknown |
               :(numberp ?answer)
               $?z)
    (sdl-167 $?w ?patient-1
               $?x ?answer &
               yes |
               no |
               unknown |
               :(numberp ?answer)
               $?y ?patient-2
               $?z)
    (sdl-167 ($?w ?patient-1
               $?x ?patient-2
               $?y ?answer &
               yes |
               no |
               unknown |
               :(numberp ?answer)
               $?z))
    (sdl-167 ($?w ?patient-1
               $?x ?answer &
               yes |
               no |
               unknown |
               :(numberp ?answer)
               $?y ?patient-2
               $?z)))
=>
  (assert (sdl-167-matched ?patient-1 ?answer))
  (assert (sdl-167-matched ?patient-2 ?answer))
  (assert (sdl-167-matched (?patient-1 ?answer)))
  (assert (sdl-167-matched (?patient-2 ?answer))))

(defrule sdl-167-1 ""
  (sdl-167-matched paul 1.5)
  (sdl-167-matched paul yes)
  (sdl-167-matched brad 1.5)
  (sdl-167-matched brad yes)
  (sdl-167-matched (paul 1.5))
  (sdl-167-matched (paul yes))
  (sdl-167-matched (brad 1.5))
  (sdl-167-matched (brad yes))
=>
  (assert (success sdl-167)))
```

```
(defrule sdl-167-2 ""
  (declare (salience -10))
  (not (success sdl-167))
=>
  (assert (fail sdl-167)))

(defrule sdl-168 ""
  (patient-name ?patient-1)
  (patient-name ?patient-2 & ~?patient-1)
  (patient-name (?patient-1))
  (patient-name (?patient-2 & ~?patient-1))
  (or (sdl-168 $?v
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown
               $?w
               ?patient-1
               $?x

               ;; split the fact BEFORE the second answer
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?y
               ?patient-2
               $?z)
      (sdl-168 $?v
               ?patient-1
               $?w
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown

               ;; split the fact AFTER the first answer
               $?x
               ?patient-2
               $?y
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?z)
      (sdl-168 ($?v
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown
               $?w
               ?patient-1
               $?x

               ;; split the fact BEFORE the second answer
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?y
               ?patient-2
               $?z))
      (sdl-168 ($?v
               ?patient-1
               $?w
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown

               ;; split the fact AFTER the first answer
               $?x
               ?patient-2
               $?y
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?z)))
=>
  (assert (sdl-168-matched ?patient-1 ?answer-1))
  (assert (sdl-168-matched ?patient-2 ?answer-2))
  (assert (sdl-168-matched (?patient-1 ?answer-1)))
  (assert (sdl-168-matched (?patient-2 ?answer-2))))

(defrule sdl-168-1 ""
  (sdl-168-matched paul yes)
  (sdl-168-matched paul 1.5)
```

```
  (sdl-168-matched brad NO)
  (sdl-168-matched brad unknown)
  (sdl-168-matched (paul yes))
  (sdl-168-matched (paul 1.5))
  (sdl-168-matched (brad NO))
  (sdl-168-matched (brad unknown))
=>
  (assert (success sdl-168)))

(defrule sdl-168-2 ""
  (declare (salience -10))
  (not (success sdl-168))
=>
  (assert (fail sdl-168)))

(defrule sdl-169-0 ""
  (declare (salience 100))
  ?a <- (sdl-169 $?before ?answer & yes
                 | no
                 $?middle not $?after)
  ?b <- (sdl-169 ($?before ?answer & yes
                 | no
                 $?middle not $?after))
=>
  (retract ?a ?b)
  (if
     (equal ?answer yes)
      then (assert (sdl-169 $?before ?answer $?middle no $?after)
                   (assert (sdl-169 ($?before ?answer $?middle no $?after))))
      else (assert (sdl-169 $?before ?answer $?middle yes $?after)
                   (assert (sdl-169 ($?before ?answer $?middle yes $?after))))))

(defrule sdl-169 ""
  (patient-name ?patient-1)
  (patient-name ?patient-2 & ~?patient-1)
  (patient-name (?patient-1))
  (patient-name (?patient-2 & ~?patient-1))
  (or (sdl-169 $?v
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown
               $?w
               ?patient-1
               $?x

               ;; split the fact BEFORE the second answer
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?y
               ?patient-2
               $?z)
      (sdl-169 $?v
               ?patient-1
               $?w
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown

               ;; split the fact AFTER the first answer
               $?x
               ?patient-2
               $?y
               ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
               $?z)
      (sdl-169 ($?v
               ?answer-1 & yes | no | :(numberp ?answer-1) | unknown
               $?w
               ?patient-1
               $?x
```

```
                ;; split the fact BEFORE the second answer
                ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
                $?y
                ?patient-2
                $?z))
        (sdl-169 ($?v
                ?patient-1
                $?w
                ?answer-1 & yes | no | :(numberp ?answer-1) | unknown

                ;; split the fact AFTER the first answer
                $?x
                ?patient-2
                $?y
                ?answer-2 & yes | no | :(numberp ?answer-2) | unknown
                $?z)))
 =>
   (assert (sdl-169-matched ?patient-1 ?answer-1))
   (assert (sdl-169-matched ?patient-2 ?answer-2))
   (assert (sdl-169-matched (?patient-1 ?answer-1)))
   (assert (sdl-169-matched (?patient-2 ?answer-2))))

(defrule sdl-169-1 ""
  (sdl-169-matched paul yes)
  (sdl-169-matched brad NO)
  (sdl-169-matched (paul yes))
  (sdl-169-matched (brad NO))
=>
  (assert (success sdl-169)))

(defrule sdl-169-2 ""
  (declare (salience -10))
  (not (success sdl-169))
=>
  (assert (fail sdl-169)))

(defrule sdl-170 ""
  (patient-name ?patient)
  (patient-name (?patient))
  (sdl-170 ?patient COMPLAINS | HAS $?
                      ?complaint & blackout |
                      faintness |
                      fatigue |
                      headache |
                      vertigo |
                      anxiety |
                      confusion |
                      depression |
                      drowsiness |
                      nervousness |
                      numbness |
                      paralysis |
                      tension |
                      tingling |
                      weakness $?)
  (sdl-170 (?patient COMPLAINS | HAS $?
                      ?complaint & blackout |
                      faintness |
                      fatigue |
                      headache |
                      vertigo |
                      anxiety |
                      confusion |
                      depression |
```

```
                        drowsiness |
                        nervousness |
                        numbness |
                        paralysis |
                        tension |
                        tingling |
                        weakness $?))
    =>
      (assert (sdl-170-complaint ?patient ?complaint))
      (assert (sdl-170-complaint (?patient ?complaint))))

    (defrule sdl-170-1 ""
      (sdl-170-complaint paul vertigo)
      (sdl-170-complaint paul faintness)
      (sdl-170-complaint brad headache)
      (sdl-170-complaint (paul vertigo))
      (sdl-170-complaint (paul faintness))
      (sdl-170-complaint (brad headache))
    =>
      (assert (success sdl-170)))

    (defrule sdl-170-2 ""
      (declare (salience -10))
      (not (success sdl-170))
    =>
      (assert (fail sdl-170)))

    (defrule sdl-171 ""
      (patient-name ?patient)
      (age ?patient ?age & ~unknown
           & :(>= ?age 21))
      (patient-name (?patient))
      (seq-age ?patient (?age & ~unknown
                          & :(>= ?age 21)))
    =>
      (assert (sdl-171 ?patient yes))
      (assert (sdl-171 (?patient yes))))

    (defrule sdl-171-2 ""
      (patient-name ?patient)
      (age ?patient ?age & ~unknown
           & :(< ?age 21))
      (patient-name (?patient))
      (seq-age ?patient (?age & ~unknown
                  & :(< ?age 21)))
    =>
      (assert (sdl-171 ?patient no))
      (assert (sdl-171 (?patient no))))

    (defrule sdl-171-3 ""
      (sdl-171 paul yes)
      (sdl-171 brad no)
      (sdl-171 (paul yes))
      (sdl-171 (brad no))
    =>
      (assert (success sdl-171)))

    (defrule sdl-171-4 ""
      (declare (salience -10))
      (not (success sdl-171))
    =>
      (assert (fail sdl-171)))

    (defrule sdl-172-2 ""
```

```
  (patient-name ?patient)
  (patient-name (?patient))
  (sdl-172 major-complaint ?patient
           ?reason &
           drowsiness |                          ;one of these complaints
           confusion)
  (sdl-172 recent-head-injury ?patient no)       ;no recent head injury
  (sdl-172 confusion-mild ?patient yes)
  (sdl-172 (major-complaint ?patient
           ?reason &
           drowsiness |                          ;one of these complaints
           confusion))
  (sdl-172 (recent-head-injury ?patient no))     ;no recent head injury
  (sdl-172 (confusion-mild ?patient yes))                ;mild symptom
  (or (not (sdl-172 major-complaint ?patient
                ~confusion &
                ~drowsiness))
      (not (sdl-172 (major-complaint ?patient
                ~confusion &
                ~drowsiness))))                  ;no other complaints

=>
  (assert (sdl-172 recommendation ?patient waiting room))
  (assert (sdl-172 (recommendation ?patient waiting room))))

(defrule sdl-172-3 ""
  (sdl-172 recommendation paul waiting room)
  (sdl-172 (recommendation paul waiting room))
  (or (not (sdl-172 recommendation brad waiting room))
      (not (sdl-172 (recommendation brad waiting room))))
=>
  (assert (success sdl-172)))

(defrule sdl-172-4 ""
  (declare (salience -10))
  (not (success sdl-172))
=>
  (assert (fail sdl-172)))

(defrule sdl-173 ""
  (sdl-173 ?case1 ?a1 ?b1 ?c1)
  (sdl-173 (?case1 ?a1 ?b1 ?c1))
  (sdl-173 ?case2 & ~case1 & ~foo & ~bar
           ?a2 & :(not (symbolp ?a2)) & :(numberp ?a2) & :(< ?a2 ?a1)
           ?b2 & :(not (symbolp ?b2)) & :(numberp ?b2) & :(> ?b2 ?b1)
           ?c2 & :(not (symbolp ?c2)) & :(numberp ?c2) & :(< ?c2 ?c1))
  (sdl-173 (?case2 & ~case1 & ~foo & ~bar
           ?a2 & :(not (symbolp ?a2)) & :(numberp ?a2) & :(< ?a2 ?a1)
           ?b2 & :(not (symbolp ?b2)) & :(numberp ?b2) & :(> ?b2 ?b1)
           ?c2 & :(not (symbolp ?c2)) & :(numberp ?c2) & :(< ?c2 ?c1)))
=>
  (assert (sdl-173-matched ?case1 ?case2))
  (assert (sdl-173-matched (?case1 ?case2))))

(defrule sdl-173-3 ""
  (sdl-173-matched case1 case2)
  (sdl-173-matched (case1 case2))
  (or (not (sdl-173-matched ~case1 ~case2))
      (not (sdl-173-matched (~case1 ~case2))))
=>
  (assert (success sdl-173)))

(defrule sdl-173-4 ""
  (declare (salience -10))
```

```
   (not (success sdl-173))
=>
   (assert (fail sdl-173)))

(defrule sdl-174 ""
   (sdl-174 ?case1 ? ? ? ?a1 ? ?b1 ? ?c1)
   (sdl-174 (?case1 ? ? ? ?a1 ? ?b1 ? ?c1))
   (sdl-174 ?case2 & ~case1 & ~foo & ~bar ? ? ?
            ?a2 & :(not (symbolp ?a2)) & :(numberp ?a2) & :(< ?a2 ?a1) ?
            ?b2 & :(not (symbolp ?b2)) & :(numberp ?b2) & :(> ?b2 ?b1) ?
            ?c2 & :(not (symbolp ?c2)) & :(numberp ?c2) & :(< ?c2 ?c1))
   (sdl-174 (?case2 & ~case1 & ~foo & ~bar ? ? ?
            ?a2 & :(not (symbolp ?a2)) & :(numberp ?a2) & :(< ?a2 ?a1) ?
            ?b2 & :(not (symbolp ?b2)) & :(numberp ?b2) & :(> ?b2 ?b1) ?
            ?c2 & :(not (symbolp ?c2)) & :(numberp ?c2) & :(< ?c2 ?c1)))
=>
   (assert (sdl-174-matched ?case1 ?case2))
   (assert (sdl-174-matched (?case1 ?case2))))

(defrule sdl-174-3 ""
   (sdl-174-matched case1 case2)
   (sdl-174-matched (case1 case2))
   (or (not (sdl-174-matched ~case1 ~case2))
       (not (sdl-174-matched (~case1 ~case2))))
=>
   (assert (success sdl-174)))

(defrule sdl-174-4 ""
   (declare (salience -10))
   (not (success sdl-174))
=>
   (assert (fail sdl-174)))

(defrule sdl-175 ""
   (sdl-175 pallet ?pallet)
   (sdl-175 options $?options)
   (sdl-175 (pallet ?pallet))
   (sdl-175 (options $?options))
   (sdl-175 case ?ASB
            & :(= (/ (- ?ASB (mod ?asb 1000)) 1000) ?PALLET)
            & :(= 0 (POSITION$ ?asb ?OPTIONS)))  ; if not a member
   (sdl-175 (case ?ASB
            & :(= (/ (- ?ASB (mod ?asb 1000)) 1000) ?PALLET)
            & :(= 0 (POSITION$ ?asb ?OPTIONS))))  ; if not a member
=>
   (assert (sdl-175-matched ?asb))
   (assert (sdl-175-matched (?asb))))

(defrule sdl-175-3 ""
   (sdl-175-matched ~5000)
   (sdl-175-matched (~5000))
=>
   (assert (fail sdl-175)))

(defrule sdl-176 ""
   (sdl-176 options $?options)
   (sdl-176 (options $?options))
   (sdl-176 case ?asb
            & :(not (= (position$ ?asb ?options) 0)))
   (sdl-176 (case ?asb
            & :(not (= (position$ ?asb ?options) 0))))
=>
   (assert (sdl-176-matched ?asb))
   (assert (sdl-176-matched (?asb))))
```

```
(defrule sdl-176-3 ""
  (sdl-176-matched ~5000)
  (sdl-176-matched (~5000))
=>
  (assert (fail sdl-176)))

(defrule sdl-177 ""
  (sdl-177 options $?options)
  (sdl-177 (options $?options))
  (sdl-177 case ?ASB
           & :(= 0 (POSITION$ ?asb ?OPTIONS)))
  (sdl-177 (case ?ASB
           & :(= 0 (POSITION$ ?asb ?OPTIONS))))
=>
  (assert (sdl-177-matched ?asb))
  (assert (sdl-177-matched (?asb))))

(defrule sdl-177-3 ""
  (sdl-177-matched ~5000)
  (sdl-177-matched (~5000))
=>
  (assert (fail sdl-177)))

(defrule sdl-178 ""
  (or (not (sdl-178 ?a
           & :(not (symbolp ?a))))
      (not (sdl-178 (?a
           & :(not (symbolp ?a))))))
=>
  (assert (fail sdl-178)))

(defrule sdl-179 ""
  (sdl-179 options $?options)
  (sdl-179 case ?ASB)
  (sdl-179 (options $?options))
  (sdl-179 (case ?ASB))
  (test (not (= 0 (POSITION$ ?asb ?OPTIONS))))
=>
  (assert (sdl-179-matched ?asb))
  (assert (sdl-179-matched (?asb))))

(defrule sdl-179-3 ""
  (sdl-179-matched ~5000)
  (sdl-179-matched (~5000))
=>
  (assert (fail sdl-179)))

(defrule sdl-180 ""
  (sdl-180 options $?options)
  (sdl-180 case ?ASB)
  (sdl-180 (options $?options))
  (sdl-180 (case ?ASB))
  (test (= (POSITION$ ?asb ?OPTIONS) 0))
=>
  (assert (sdl-180-matched ?asb))
  (assert (sdl-180-matched (?asb))))

(defrule sdl-180-3 ""
  (sdl-180-matched ~5000)
  (sdl-180-matched (~5000))
=>
  (assert (fail sdl-180)))

(defrule sdl-181 ""
```

```
    (sdl-181 5000)
    (sdl-181 (5000))
    (or (not (sdl-181 ~5000))
        (not (sdl-181 (~5000))))
 =>
   (assert (fail sdl-181)))

(defrule sdl-182 ""
   (declare (salience 100))
   (sdl-182 ?est & ~"pst" ?pst & ~"est")
   (sdl-182 (?est & ~"pst" ?pst & ~"est"))
 =>
   (assert (sdl-182-matched ?est ?pst))
   (assert (sdl-182-matched (?est ?pst))))

(defrule sdl-182-1 ""
   (or
     (sdl-182-matched "pst" "pst")
     (sdl-182-matched "est" "est")
     (sdl-182-matched "pst" "est")
     (sdl-182-matched ("pst" "pst"))
     (sdl-182-matched ("est" "est"))
     (sdl-182-matched ("pst" "est"))
     (not (sdl-182-matched "est" "pst"))
     (not (sdl-182-matched ("est" "pst"))))
 =>
   (assert (fail sdl-182)))

(defrule sdl-183 ""
   (sdl-183 ~=(+ 1 1))
   (sdl-183 (~=(+ 1 1)))
 =>
   (assert (fail sdl-183)))

(defrule sdl-184 ""
   (sdl-184 ~2)
   (sdl-184 (~2))
 =>
   (assert (fail sdl-184)))

(defrule sdl-185 ""
   (sdl-185 ~"string")
   (sdl-185 (~"string"))
 =>
   (assert (fail sdl-185)))

(defrule sdl-186 ""
   (declare (salience 100))
   (sdl-186 ?string & ~"string")
   (sdl-186 (?string & ~"string"))
 =>
   (assert (sdl-186-matched ?string))
   (assert (sdl-186-matched (?string))))

(defrule sdl-186-1 ""
   (or
     (sdl-186-matched "string")
     (sdl-186-matched ("string"))
     (not (sdl-186-matched "foo"))
     (not (sdl-186-matched ("foo"))))
 =>
   (assert (fail sdl-186)))

(defrule sdl-187 ""
```

```
  (declare (salience 100))
  (sdl-187 ?string1 & ~"string" ?string2 & ~"string")
  (sdl-187 (?string1 & ~"string" ?string2 & ~"string"))
=>
  (assert (sdl-187-matched ?string1 ?string2))
  (assert (sdl-187-matched (?string1 ?string2))))

(defrule sdl-187-1 ""
  (or
    (sdl-187-matched "string" "foo")
    (sdl-187-matched ("string" "foo"))
    (not (sdl-187-matched "foo" "foo"))
    (not (sdl-187-matched ("foo" "foo"))))
=>
  (assert (fail sdl-187)))

(defrule sdl-188 ""
  (sdl-188 ~=(string-append "foo" "bar"))
  (sdl-188 (~=(string-append "foo" "bar")))
=>
  (assert (fail sdl-188)))

(defrule sdl-189 ""
  (sdl-189 ?a & ~=(+ 1 1))
  (sdl-189 (?a & ~=(+ 1 1)))
=>
  (assert (fail sdl-189)))

(defrule sdl-190 ""
  (sdl-190 ?a & :(not (numberp ?a)))
  (sdl-190 (?a & :(not (numberp ?a))))
=>
  (assert (sdl-190-matched ?a))
  (assert (sdl-190-matched (?a))))

(defrule sdl-190-1 ""
  (or
    (sdl-190-matched 1)
    (sdl-190-matched (1))
    (not (sdl-190-matched foo))
    (not (sdl-190-matched (foo))))
=>
  (assert (fail sdl-190)))

(defrule sdl-191 ""
  (sdl-191 ~1 & ~0.1 & ~"foo" & ~bar & ~2 & ~12345.6789 & ~"fee" & ~blee)
  (sdl-191 (~1 & ~0.1 & ~"foo" & ~bar & ~2 & ~12345.6789 & ~"fee" & ~blee))
=>
  (assert (fail sdl-191)))

(defrule sdl-192 ""
  (sdl-192 ?char-num & :(or (<= 97 ?char-num 102)
                            (<= 65 ?char-num 70)
                            (<= 48 ?char-num 57)))
  (sdl-192-seq (?char-num & :(or (<= 97 ?char-num 102)
                                 (<= 65 ?char-num 70)
                                 (<= 48 ?char-num 57))))
=>
  (assert (sdl-192-matched ?char-num))
  (assert (sdl-192-matched (?char-num))))

(defrule sdl-192-1 ""
  (or
    (sdl-192-matched 40)
```

```
      (not (sdl-192-matched 50))
      (sdl-192-matched 60)
      (not (sdl-192-matched 70))
      (sdl-192-matched 80)
      (sdl-192-matched 90)
      (not (sdl-192-matched 100))
      (sdl-192-matched (40))
      (not (sdl-192-matched (50)))
      (sdl-192-matched (60))
      (not (sdl-192-matched (70)))
      (sdl-192-matched (80))
      (sdl-192-matched (90))
      (not (sdl-192-matched (100))))
=>
   (assert (fail sdl-192)))

;;; ******************************************************************************
;;; BDC additions to the rule base follow...

(defrule bdc-200-1
   "Does HALT work?"
   (declare (salience -1000))
=>
   (printout t t "TEST IS OVER" t)
   (halt))

(defrule bdc-200-2
   (declare (salience -1001))
=>
   (assert (fail bdc-200)))

(deffacts bdc-201
  (bdc-201 a b c d e))

(deffacts bdc-201-sequences
  (bdc-201 (a b c d e)))

(defrule bdc-201-1 ""
  (bdc-201 $?data)
  (bdc-201 ($?data))                          ;matches a b c d e f g
=>
  (if (not (member$ b ?data))
      then (assert (fail bdc-201a)))
  (if (member$ z ?data)
      then (assert (fail bdc-201b))))
```