Resource Limited Inferance in SNePS

a project for cs642 fall, 1981

by Gerard Donlon

1. Introduction

I have implemented resource limited inferance in SNePS. With my additions to SNePS, a user can specify "how hard" the system can work on one inferance. When the specified amount of work has been done, the inferance stops and returns only those answers that were found. There may or may not be more answers to find when the system reaches a resource limit. If there are more answers and the user restarts the inferance with more resources, the new answers will be found.

Reaching a resource limit is transparent to the user. That is, answers are returned in exactly the same way when inferance has been exhausted as when a resource bound is encountered.

2. Overview of the System

SNIPS is implemented useing MULTI, a multiprocessing package for LISP. Inferance is done by starting a set of processes that will produce the required results. Each process is a non-interuptable function that may create or initiate any number of processes. Answers produced by processes are retained so that future inferances may use these answers without re-doing the inferance. This will create a graph of processes.

Some of these processes control the order of execution of other processes or group processes into sets of related processes. These processes are called monitors.

The resource that will be limited is network matches. That choise was made because the number of matches done is easy to

count and is the slowest operation in the inferance system.

Monitors are the obvious place to control the amount of resources a set of processes may use. To implement this, I added two registers to each process. Register RMAX: is the maximum number of resources a process may consume. Register RSOURCE: contains a list of monitors that will contribute resources to the process and the number of resources the monitor is willing to contribute. When a process is ready to exicute, it first checks to see if it is possable to finish useing RMAX: or less resources. If it is possable, The process then checks to make sure its sources really have the resources to contribute. This two step process of resource allocation allows a monitor to initally give all of its resources to each process it initiates. When these processes exicute, some may use resources. When they do, they decrement the monitors total. If a process tries to exicute when the monitors total is too small, the process suspends itself.

If two or more processes with differant sources initiate a process, that processes RMAX: will be the sum of the maximum allowed by each initiateing process. And that processes RSOURCE: will be the union of the sources of the initiating processes. That way, processes that produce answers that are important to several processes will recieve larger resource counts.

The two step allocation procedure forces the scheduler to determine which processes will get the resources. And, since the process will not use more than RMAX: resources units, the monitor can also limit the number of resources available to any

process. By not forcing the monitor to allocate its resources staticly, the monitor can maintain a pool of resources that can be allocated to any process below the monitor that needs them. It also prevents wasteing resources since any process that does not use resources will not take them, even if the monitor allows it.

A special case of resource allocation allows an infinite number of resources. This is the default when the user does not specify a limit.

Limiting resources has an interesting effect on the non-derivable monitor. That monitor tries to deduce some consequent or its negation. If it can not, it reports that its argument is not derivable in the current network. If the monitor stops with no answer and some process below it was suspended because of a resource bound, the consequent may be derivable in the network but not in the resource bound given. So, instead of being non-derivable, the consequent is "not obvious". Since this may not be what the user wants, there is a special resource limit for non-derivable monitors. By default, every non-derivable monitor is allowed an infinite number of resource units. If anyone wants to, they can change that limit to be anything, including the standard allocation procedure, by changing the variable I-//-MTRLIMITS . The passing of resource limits is done by the functions NEW and INITIATE. The default for NEW is no resources passed. The default for INITIATE is the RMAX: and RSOURCE: of the initiateing process. When useing all of the defaults, the system behaves exactly as it did before adding resource limits.

3. Applications

Resource limited inferance may be used to set up a context in which all further inferance will be preformed. [Martins] shows how this can solve the symbol mapping problem and reduces the problems caused by fan out in full forward or backward inferance. The technique has been called bi-directional inferance.

A second application, mentioned earlier, is changing the nonderivable operator into a "not obvious" operator. With a resource limit of 1 placed on the nonderivable monitor, ∀(x)BIRD(x)⇒ΔFLIES(x) means that if x is a bird and it is not asserted in the network that x does not fly, then assume x flies. By changing the resource limit on the nonderivable monitor, you change the interpertation of "obvious".

A third application is resource-slicing through a deduction. It is similar to time-slicing but you limit the number of resources used, not time used. For instance, if we have $\mathbb{M}_1^1$(a b c d) and c is easy to prove and a,b and d are not easy to prove, then by setting up a resource slicing monitor, we can prove ~a,~b,~d and c in four times the minimum number of resources required. A random order can take some fraction of the maximum.

4. Status

Resource limited inferance has been added to SNePS and it is working. A user can specify a resource bound on any ADD, DEDUCE or RESUME by including the symbol < followed by an integer or

INF. INF is the default.

The nonderivable monitor limits can be set by setting the variable I-//-MTRLIMITS to any function. When evaled, the value returned should be a list whose first element will be RMAX: and whose second element will be RSOURCE:. By default, I-//-MTRLIMITS is ''(INF NIL) which allows infinite resources without charging any monitor.

I have started implementing resource-slicing in the verify andor process. This work is not compleate.

5. Future Work

1. Finish resource-slicing in VANDOR and similar processes.

2. Write a guide to the number of resources needed by an inferance. This should be investigated. It seems that to do L levels of inferance, you need $(\text{FAN-OUT-OF-RULES})^{L}$ resource units but I have not shown that.

3. The scheduler could be changed to run process with the largest resource count first. That would change the guide to the number of resources needed since that formula depends on a first in first out scheduler.

4. heuristics could be added to resource-slicing monitors to guide them to the easiest answer.

5. You could concider measuring some resource other than network matches.

6. APPENDIX 1

An example of a run with resource limited inferance.

The rules assert that all elephants are grey. All subs are grey. And, anything that is grey is a sub. By adding a resource bound, I prevent the last rule from being used.

```
ALISP  VERSION 3.3    22 DECEMBER 1981    4:09 PM

$ ? (LOAD '(SNEPS CSDTEMP))
SNEPS                                UDM4.0.1

********* SYSTEM NOT TESTED YET. **********************
PATH BASED INFERANCE HAS BEEN ADDED TO SNEPS.

(SNEPS INITIALIZED FOR BATCH OPERATION     COMPILED 81 10 28)
$ ? (LENGTH (INPUT (SNEPSRC CSDLIB)(SNEPSREAD SNEPSREAD1 NUMB?))))))

3
$ ? (LENGTH (INPUT (TEMP CSDXGFD))))))
6
$ ? (LENGTH (INPUT (AINF CSDXGFD))))))))
131
$ ? (EV-TRACE)
T
$ ? (SNEPS)
SNEPS
$* (DEFINE MEM MEM- CLASS CLASS- COLOROF COLOROF- IS IS-)
(MEM MEM-)
(CLASS CLASS-)
(COLOROF COLOROF-)
(IS IS-)
(DEFINED)
11 MSECS

$* (BUILD AVB $X
$*        ANT (BUILD MEM *X CLASS ELEPHANT)
$*        CQ  (BUILD COLOROF *X IS GREY))
(M3)
33 MSECS

$* (BUILD AVB $X
$*        ANT (BUILD MEM *X CLASS SUBS)
$*        CQ  (BUILD COLOROF *X IS GREY))
(M6)
32 MSECS

$* (BUILD AVB $X
$*              ANT (BUILD COLOROF *X IS GREY)
$*              CQ  (BUILD MEM *X CLASS SUBS))
(M9)
```

```
32 MSECS

$* (ADD MEM CLYDE CLASS ELEPHANT < 1)

          *****   "ENTERING"   PROCESS :  P61   *****
          NAME: RES-MTR
          CLINK: NIL
          QUEUE (P60)
          EVENTS NIL
          RMAX:1
          RSOURCE: NIL

          *****   "LEAVING"   PROCESS :  P61   *****
          NAME: RES-MTR-R
          CLINK: NIL
          QUEUE (P60)
          EVENTS NIL
          RMAX:1
          RSOURCE: ((P61 1))

          *****   "ENTERING"   PROCESS :  P60   *****
          NAME: F-INFER
          CLINK: NIL
          NODE : M10
          RMAX:1
          RSOURCE: ((P61 1))


          *****   "LEAVING"   PROCESS :  P60   *****
          NAME: F-INFER
          CLINK: NIL
          NODE: M10
          RMAX:0
          RSOURCE: ((P61 0))

          *****   "ENTERING"   PROCESS :  P61   *****
          NAME: RES-MTR-R
          CLINK: NIL
          QUEUE (P60)
          EVENTS NIL
          RMAX:0
          RSOURCE: ((P61 1))

          *****   "LEAVING"   PROCESS :  P61   *****
          NAME: RES-MTR-R
          CLINK: NIL
          QUEUE (P60)
          EVENTS NIL
          RMAX:0
          RSOURCE: ((P61 1))

          *****   "ENTERING"   PROCESS :  P66   *****
          NAME: GO-UP
          CLINK: P62
          CQ: M3
          BNDG: ((V1,CLYDE))
          RMAX:0
```

```
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P66   *****
NAME GO-UP
CLINK: P62
CQ: M3
BNDG: ((V1,CLYDE))
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P61   *****
NAME  RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "ENTERING"   PROCESS :  P68   *****
NAME: USE
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCES: :  P68   *****
NAME: USE
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "LEAVING"   PROCESS :  P61   *****
```

```
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "ENTERING"   PROCESS :  P69   *****
NAME: CHENT
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
ANT: (M1)
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P69   *****
NAME: CHENT-R
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
ANT: (M1)
BNDG: ((V1,CLYDE))
MSG: ((M1 (M10 ((V1,CLYDE)))))
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P69   *****
NAME: CHENT-R
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
ANT: (M1)
BNDG: ((V1,CLYDE))
MSG: ((M1 (M10 ((V1,CLYDE)))))
RMAX:0
RSOURCE: NIL

 SINCE
(M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL (CLYDE)))))

 WE INFER
(M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE)))))

*****   "LEAVING"   PROCESS :  P69   *****
NAME: CHENT-R
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
ANT: (M1)
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:0
RSOURCE: NIL
```

```
*****   "ENTERING"   PROCESS :  P67   *****
NAME: ANS-CATCH
CLINK: P62
BOSSES: (P62)
DATA: NIL
MSG: (((M2 ((V1,CLYDE)))))
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P67   *****
NAME: ANS-CATCH
CLINK: P62
BOSSES: (P62)
DATA: ((M2 ((V1,CLYDE))))
MSG: NIL
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P62   *****
NAME: IMPLY
CLINK: NIL
BOSSES: NIL
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: (((M2 ((V1,CLYDE)))))
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P62   *****
NAME: IMPLY
CLINK: NIL
BOSSES: ((P70,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P70   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: NIL
MSG: (((M2 ((V1,CLYDE)))))
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P70   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: ((M2 ((V1,CLYDE))))
MSG: NIL
RMAX:0
RSOURCE: NIL
```

```
*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

*****   "ENTERING"   PROCESS :  P63   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P63   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P71   *****
NAME: F-INFER
CLINK: NIL
NODE: M11
RMAX:0
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P71   *****
NAME: F-INFER
CLINK: NIL
NODE: M11
RMAX:0
RSOURCE: NIL

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:0
RSOURCE: ((P61 1))

SUSPENDING  P61
```

```
            *****   "LEAVING"   PROCESS :  P61   *****
            NAME: RES-MTR-R
            CLINK: NIL
            QUEUE (P60)
            EVENTS NIL
            RMAX:0
            RSOURCE: ((P61 1))


(M10 M11)
1687 MSECS

$* (DEDUCE COLOROF CLYDE IS GREY)

            *****   "ENTERING"   PROCESS :  P74   *****
            NAME: I-MTR
            CLINK: NIL
            QUEUE (P73)
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P74 INF))

            *****   "LEAVING"   PROCESS :  P74   *****
            NAME: I-MTR-R
            CLINK: NIL
            QUEUE NIL
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P74 INF))

            *****   "ENTERING"   PROCESS :  P73   *****
            NAME: INFER
            CLINK: P75
            CQ: T72
            BNDG: NIL
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P74 INF))

 WE KNOW
(T72 (IS (GREY)) (COLOROF (CLYDE)))

            *****   "LEAVING"   PROCESS :  P73   *****
            NAME: INFER
            CLINK: P75
            CQ: T72
            BNDG: NIL
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P74 INF))

            *****   "ENTERING"   PROCESS :  P75   *****
            NAME: TOPMOST-TOPINF
            CLINK: NIL
            CQ: T72
            DATA: NIL
            MSG: ((T72 (M11 NIL)))
```

```
            N-ANS: 0
            P-ANS: 0
            TOT: NIL
            N-POS: NIL
            N-NEG: NIL
            #SUSPS# NIL
            BOSSES: NIL
            MTR: P74
            RMAX:INF
            RSOURCE: ((P74 INF) (P74 INF))

            *****   "LEAVING"   PROCESS :  P75   *****
            NAME: TOPMOST-TOPINF
            CLINK: NIL
            CQ: T72
            DATA: ((M11 NIL))
            MSG: NIL
            N-ANS: 0
            P-ANS: 1
            TOT: NIL
            N-POS: NIL
            N-NEG: NIL
            #SUSPS# NIL
            BOSSES: NIL
            MTR: P74
            RMAX:INF
            RSOURCE: ((P74 INF) (P74 INF))

            *****   "ENTERING"   PROCESS :  P74   *****
            NAME: I-MTR-R
            CLINK: NIL
            QUEUE NIL
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P74 INF))

            *****   "LEAVING"   PROCESS :  P74   *****
            NAME: I-MTR
            CLINK: NIL
            QUEUE NIL
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P74 INF))


(M11)
401 MSECS

$* (DESCRIBE *NODES)
(M11 (IS (GREY)) (COLOROF (CLYDE)))
(CLYDE)
(M10 (CLASS (ELEPHANT)) (MEM (CLYDE)))
(M9 (CQ (M8 (CLASS (SUBS)) (MEM (V3 (:VAR (T))))))
    (ANT (M7 (IS (GREY)) (COLOROF (V3 (:VAR (T))))))
    (AVB (V3 (:VAR (T)))))
(M8 (CLASS (SUBS)) (MEM (V3 (:VAR (T)))))
(M7 (IS (GREY)) (COLOROF (V3 (:VAR (T)))))
```

```
 (V3 (:VAR (T)))
 (M6 (CQ (M5 (IS (GREY)) (COLOROF (V2 (:VAR (T))))))
     (ANT (M4 (CLASS (SUBS)) (MEM (V2 (:VAR (T))))))
     (AVB (V2 (:VAR (T)))))
 (M5 (IS (GREY)) (COLOROF (V2 (:VAR (T)))))
 (SUBS)
 (M4 (CLASS (SUBS)) (MEM (V2 (:VAR (T)))))
 (V2 (:VAR (T)))
 (M3 (CQ (M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE))))))
     (ANT (M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL
(CLYDE))))))
     (AVB (V1 (:VAR (T)) (:VAL (CLYDE)))))
 (GREY)
 (M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE)))))
 (ELEPHANT)
 (M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL (CLYDE)))))
 (V1 (:VAR (T)) (:VAL (CLYDE)))
 (X (:VAL (V3 (:VAR (T)))))
 (DUMPED)
 320 MSECS

 $* (LISP)
 END SNEPS
 $ ? (EXIT)
 END ALISP RUN
```

7. APPENDIX 2

This run has the same data as the previous run, but gives an infinite number of resources to the add. Notice that it asserts that Clyde is a sub.

```
ALISP  VERSION 3.3     22 DECEMBER 1981    9:54 PM

$ ? (LOAD '(SNEPS CSDTEMP))
SNEPS                                  UDM4.0.1

********* SYSTEM NOT TESTED YET. **********************
PATH BASED INFERANCE HAS BEEN ADDED TO SNEPS.

(SNEPS INITIALIZED FOR BATCH OPERATION      COMPILED 81 10 28)
$ ? (LENGTH (INPUT (SNEPSRC CSDLIB)(SNEPSREAD SNEPSREAD1 NUMB?))))))

3
$ ? (LENGTH (INPUT (TEMP CSDXGFD))))))
6
$ ? (LENGTH (INPUT (AINF CSDXGFD))))))))
131
$ ? (EV-TRACE)
T
$ ? (SNEPS)
SNEPS
$* (DEFINE MEM MEM- CLASS CLASS- COLOROF COLOROF- IS IS-)
(MEM MEM-)
(CLASS CLASS-)
(COLOROF COLOROF-)
(IS IS-)
(DEFINED)
11 MSECS

$* (BUILD AVB $X
$*        ANT (BUILD MEM *X CLASS ELEPHANT)
$*        CQ  (BUILD COLOROF *X IS GREY))
(M3)
34 MSECS

$* (BUILD AVB $X
$*        ANT (BUILD MEM *X CLASS SUBS)
$*        CQ  (BUILD COLOROF *X IS GREY))
(M6)
35 MSECS

$* (BUILD AVB $X
$*              ANT (BUILD COLOROF *X IS GREY)
$*              CQ  (BUILD MEM *X CLASS SUBS))
(M9)
35 MSECS

$* (ADD MEM CLYDE CLASS ELEPHANT < INF)

           *****   "ENTERING"   PROCESS :  P61   *****
```

```
NAME: RES-MTR
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: NIL

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P60   *****
NAME: F-INFER
CLINK: NIL
NODE: M10
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P60   *****
NAME: F-INFER
CLINK: NIL
NODE: M10
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P66   *****
NAME: GO-UP
CLINK: P62
CQ: M3
BNDG: ((V1,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P66   *****
NAME: GO-UP
CLINK: P62
CQ: M3
```

```
BNDG: ((V1,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P68   *****
NAME: USE
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P68   *****
NAME: USE
CLINK: P67
BOSSES: ((P67,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))
```

```
            *****   "ENTERING"   PROCESS :  P69   *****
            NAME: CHENT
            CLINK: P67
            BOSSES: ((P67,M2))
            CQ: (M2)
            ANT: (M1)
            BNDG: ((V1,CLYDE))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "LEAVING"   PROCESS :  P69   *****
            NAME: CHENT-R
            CLINK: P67
            BOSSES: ((P67,M2))
            CQ: (M2)
            ANT: (M1)
            BNDG: ((V1,CLYDE))
            MSG: ((M1 (M10 ((V1,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P69   *****
            NAME: CHENT-R
            CLINK: P67
            BOSSES: ((P67,M2))
            CQ: (M2)
            ANT: (M1)
            BNDG: ((V1,CLYDE))
            MSG: ((M1 (M10 ((V1,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

 SINCE
(M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL (CLYDE)))))

 WE INFER
(M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE)))))

            *****   "LEAVING"   PROCESS :  P69   *****
            NAME: CHENT-R
            CLINK: P67
            BOSSES: ((P67,M2))
            CQ: (M2)
            ANT: (M1)
            BNDG: ((V1,CLYDE))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P67   *****
            NAME: ANS-CATCH
            CLINK: P62
            BOSSES: (P62)
            DATA: NIL
            MSG: (((M2 ((V1,CLYDE)))))
```

```
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P67   *****
NAME: ANS-CATCH
CLINK: P62
BOSSES: (P62)
DATA: ((M2 ((V1,CLYDE))))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P62   *****
NAME: IMPLY
CLINK: NIL
BOSSES: NIL
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: (((M2 ((V1,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P62   *****
NAME: IMPLY
CLINK: NIL
BOSSES: ((P70,M2))
CQ: (M2)
RULE: M3
BNDG: ((V1,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P70   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: NIL
MSG: (((M2 ((V1,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P70   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: ((M2 ((V1,CLYDE))))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
```

```
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P63   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P63   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P71   *****
NAME: F-INFER
CLINK: NIL
NODE: M11
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P71   *****
NAME: F-INFER
CLINK: NIL
NODE: M11
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))
```

```
*****   "ENTERING"   PROCESS :  P76   *****
NAME: GO-UP
CLINK: P72
CQ: M9
BNDG: ((V3,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P76   *****
NAME: GO-UP
CLINK: P72
CQ: M9
BNDG: ((V3,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P78   *****
NAME: USE
CLINK: P77
BOSSES: ((P77,M8))
CQ: (M8)
RULE: M9
BNDG: ((V3,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P78   *****
NAME: USE
CLINK: P77
BOSSES: ((P77,M8))
CQ: (M8)
RULE: M9
BNDG: ((V3,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
```

```
            QUEUE (P60)
            EVENTS NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "LEAVING"   PROCESS :  P61   *****
            NAME: RES-MTR-R
            CLINK: NIL
            QUEUE (P60)
            EVENTS NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P79   *****
            NAME: CHENT
            CLINK: P77
            BOSSES: ((P77,M8))
            CQ: (M8)
            ANT: (M7)
            BNDG: ((V3,CLYDE))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "LEAVING"   PROCESS :  P79   *****
            NAME: CHENT-R
            CLINK: P77
            BOSSES: ((P77,M8))
            CQ: (M8)
            ANT: (M7)
            BNDG: ((V3,CLYDE))
            MSG: ((M7 (M11 ((V3,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P79   *****
            NAME: CHENT-R
            CLINK: P77
            BOSSES: ((P77,M8))
            CQ: (M8)
            ANT: (M7)
            BNDG: ((V3,CLYDE))
            MSG: ((M7 (M11 ((V3,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

 SINCE
(M7 (IS (GREY)) (COLOROF (V3 (:VAR (T)) (:VAL (CLYDE)))))

 WE INFER
(M8 (CLASS (SUBS)) (MEM (V3 (:VAR (T)) (:VAL (CLYDE)))))

            *****   "LEAVING"   PROCESS :  P79   *****
            NAME: CHENT-R
            CLINK: P77
            BOSSES: ((P77,M8))
            CQ: (M8)
```

```
ANT: (M7)
BNDG: ((V3,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P77   *****
NAME: ANS-CATCH
CLINK: P72
BOSSES: (P72)
DATA: NIL
MSG: (((M8 ((V3,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P77   *****
NAME: ANS-CATCH
CLINK: P72
BOSSES: (P72)
DATA: ((M8 ((V3,CLYDE))))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P72   *****
NAME: IMPLY
CLINK: NIL
BOSSES: NIL
CQ: (M8)
RULE: M9
BNDG: ((V3,CLYDE))
MSG: (((M8 ((V3,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P72   *****
NAME: IMPLY
CLINK: NIL
BOSSES: ((P80,M8))
CQ: (M8)
RULE: M9
BNDG: ((V3,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P80   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: NIL
MSG: (((M8 ((V3,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P80   *****
NAME: ANS-CATCH
```

```
CLINK: NIL
BOSSES: NIL
DATA: ((M8 ((V3,CLYDE))))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P73   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P73   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P81   *****
NAME: F-INFER
CLINK: NIL
NODE: M12
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P81   *****
NAME: F-INFER
CLINK: NIL
NODE: M12
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
```

```
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P86   *****
NAME: GO-UP
CLINK: P82
CQ: M6
BNDG: ((V2,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P86   *****
NAME: GO-UP
CLINK: P82
CQ: M6
BNDG: ((V2,CLYDE))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P88   *****
NAME: USE
CLINK: P87
BOSSES: ((P87,M5))
CQ: (M5)
RULE: M6
BNDG: ((V2,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P88   *****
NAME: USE
```

```
CLINK: P87
BOSSES: ((P87,M5))
CQ: (M5)
RULE: M6
BNDG: ((V2,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P89   *****
NAME: CHENT
CLINK: P87
BOSSES: ((P87,M5))
CQ: (M5)
ANT: (M4)
BNDG: ((V2,CLYDE))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P89   *****
NAME: CHENT-R
CLINK: P87
BOSSES: ((P87,M5))
CQ: (M5)
ANT: (M4)
BNDG: ((V2,CLYDE))
MSG: ((M4 (M12 ((V2,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P89   *****
NAME: CHENT-R
CLINK: P87
BOSSES: ((P87,M5))
CQ: (M5)
ANT: (M4)
BNDG: ((V2,CLYDE))
MSG: ((M4 (M12 ((V2,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))
```

```
 SINCE
(M4 (CLASS (SUBS)) (MEM (V2 (:VAR (T)) (:VAL (CLYDE)))))

 WE INFER
(M5 (IS (GREY)) (COLOROF (V2 (:VAR (T)) (:VAL (CLYDE)))))

            *****   "LEAVING"   PROCESS :  P89   *****
            NAME: CHENT-R
            CLINK: P87
            BOSSES: ((P87,M5))
            CQ: (M5)
            ANT: (M4)
            BNDG: ((V2,CLYDE))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P87   *****
            NAME: ANS-CATCH
            CLINK: P82
            BOSSES: (P82)
            DATA: NIL
            MSG: (((M5 ((V2,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "LEAVING"   PROCESS :  P87   *****
            NAME: ANS-CATCH
            CLINK: P82
            BOSSES: (P82)
            DATA: ((M5 ((V2,CLYDE))))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "ENTERING"   PROCESS :  P82   *****
            NAME: IMPLY
            CLINK: NIL
            BOSSES: NIL
            CQ: (M5)
            RULE: M6
            BNDG: ((V2,CLYDE))
            MSG: (((M5 ((V2,CLYDE)))))
            RMAX:INF
            RSOURCE: ((P61 INF))

            *****   "LEAVING"   PROCESS :  P82   *****
            NAME: IMPLY
            CLINK: NIL
            BOSSES: ((P90,M5))
            CQ: (M5)
            RULE: M6
            BNDG: ((V2,CLYDE))
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P61 INF))
```

```
*****   "ENTERING"   PROCESS :  P90   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: NIL
MSG: (((M5 ((V2,CLYDE)))))
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P90   *****
NAME: ANS-CATCH
CLINK: NIL
BOSSES: NIL
DATA: ((M5 ((V2,CLYDE))))
MSG: NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P83   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "LEAVING"   PROCESS :  P83   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P61 INF))

*****   "ENTERING"   PROCESS :  P61   *****
NAME: RES-MTR-R
CLINK: NIL
QUEUE (P60)
EVENTS NIL
RMAX:INF
```

```
            RSOURCE: ((P61 INF))

SUSPENDING  P61

            *****   "LEAVING"   PROCESS :  P61   *****
            NAME: RES-MTR-R
            CLINK: NIL
            QUEUE (P60)
            EVENTS NIL
            RMAX:INF
            RSOURCE: ((P61 INF))


(M10 M11 M12)
4474 MSECS

$* (DEDUCE COLOROF CLYDE IS GREY)

            *****   "ENTERING"   PROCESS :  P93   *****
            NAME: I-MTR
            CLINK: NIL
            QUEUE (P92)
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P93 INF))

            *****   "LEAVING"   PROCESS :  P93   *****
            NAME: I-MTR-R
            CLINK: NIL
            QUEUE NIL
            EXTRAS NIL
            RMAX:INF
            RSOURCE: ((P93 INF))

            *****   "ENTERING"   PROCESS :  P92   *****
            NAME: INFER
            CLINK: P94
            CQ: T91
            BNDG: NIL
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P93 INF))

 WE KNOW
(T91 (IS (GREY)) (COLOROF (CLYDE)))

            *****   "LEAVING"   PROCESS :  P92   *****
            NAME: INFER
            CLINK: P94
            CQ: T91
            BNDG: NIL
            MSG: NIL
            RMAX:INF
            RSOURCE: ((P93 INF))

            *****   "ENTERING"   PROCESS :  P94   *****
            NAME: TOPMOST-TOPINF
```

```
CLINK: NIL
CQ: T91
DATA: NIL
MSG: ((T91 (M11 NIL)))
N-ANS: 0
P-ANS: 0
TOT: NIL
N-POS: NIL
N-NEG: NIL
#SUSPS# NIL
BOSSES: NIL
MTR: P93
RMAX:INF
RSOURCE: ((P93 INF) (P93 INF))

*****   "LEAVING"   PROCESS :  P94   *****
NAME: TOPMOST-TOPINF
CLINK: NIL
CQ: T91
DATA: ((M11 NIL))
MSG: NIL
N-ANS: 0
P-ANS: 1
TOT: NIL
N-POS: NIL
N-NEG: NIL
#SUSPS# NIL
BOSSES: NIL
MTR: P93
RMAX:INF
RSOURCE: ((P93 INF) (P93 INF))

*****   "ENTERING"   PROCESS :  P93   *****
NAME: I-MTR-R
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P93 INF))

*****   "LEAVING"   PROCESS :  P93   *****
NAME: I-MTR
CLINK: NIL
QUEUE NIL
EXTRAS NIL
RMAX:INF
RSOURCE: ((P93 INF))


(M11)
411 MSECS

$* (DESCRIBE *NODES)
(M12 (CLASS (SUBS)) (MEM (CLYDE)))
(M11 (IS (GREY)) (COLOROF (CLYDE)))
(CLYDE)
(M10 (CLASS (ELEPHANT)) (MEM (CLYDE)))
```

```
(M9 (CQ (M8 (CLASS (SUBS)) (MEM (V3 (:VAR (T)) (:VAL (CLYDE))))))
    (ANT (M7 (IS (GREY)) (COLOROF (V3 (:VAR (T)) (:VAL (CLYDE))))))
    (AVB (V3 (:VAR (T)) (:VAL (CLYDE)))))
(M8 (CLASS (SUBS)) (MEM (V3 (:VAR (T)) (:VAL (CLYDE)))))
(M7 (IS (GREY)) (COLOROF (V3 (:VAR (T)) (:VAL (CLYDE)))))
(V3 (:VAR (T)) (:VAL (CLYDE)))
(M6 (CQ (M5 (IS (GREY)) (COLOROF (V2 (:VAR (T)) (:VAL (CLYDE))))))
    (ANT (M4 (CLASS (SUBS)) (MEM (V2 (:VAR (T)) (:VAL (CLYDE))))))
    (AVB (V2 (:VAR (T)) (:VAL (CLYDE)))))
(M5 (IS (GREY)) (COLOROF (V2 (:VAR (T)) (:VAL (CLYDE)))))
(SUBS)
(M4 (CLASS (SUBS)) (MEM (V2 (:VAR (T)) (:VAL (CLYDE)))))
(V2 (:VAR (T)) (:VAL (CLYDE)))
(M3 (CQ (M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE))))))
    (ANT (M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL
(CLYDE))))))
    (AVB (V1 (:VAR (T)) (:VAL (CLYDE)))))
(GREY)
(M2 (IS (GREY)) (COLOROF (V1 (:VAR (T)) (:VAL (CLYDE)))))
(ELEPHANT)
(M1 (CLASS (ELEPHANT)) (MEM (V1 (:VAR (T)) (:VAL (CLYDE)))))
(V1 (:VAR (T)) (:VAL (CLYDE)))
(X (:VAL (V3 (:VAR (T)) (:VAL (CLYDE)))))
(DUMPED)
386 MSECS

$* (LISP)
END SNEPS
$ ? (EXIT)
END ALISP RUN
```

References

1. Martins, J.; McKay, D. P.; and Shapiro, S. C. [1981] Bi-directional Inference. Technical Report No. 174, Department of Computer Science, SUNY at Buffalo, Amherst, NY, 32pp.