Resource Representation in COMPASS*

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*Research support in part by code MD & MT

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Outline

- Introduction
- Statement of the Problem
- Representation of Resource Requirements
- Representation of Resource Availability
- Algorithm for Activity Placement
- Conclusion

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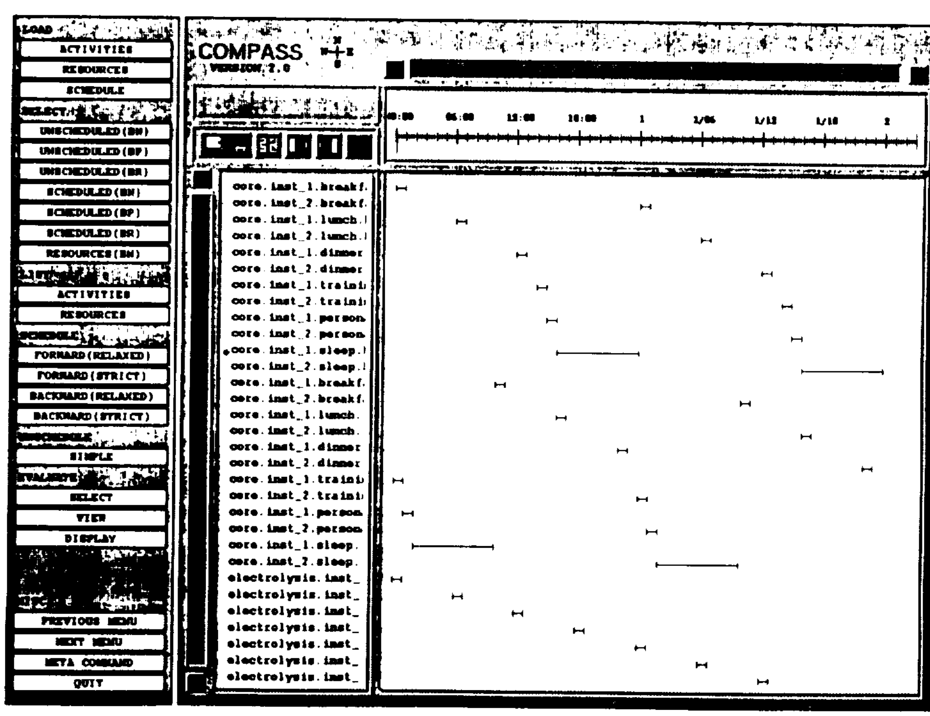
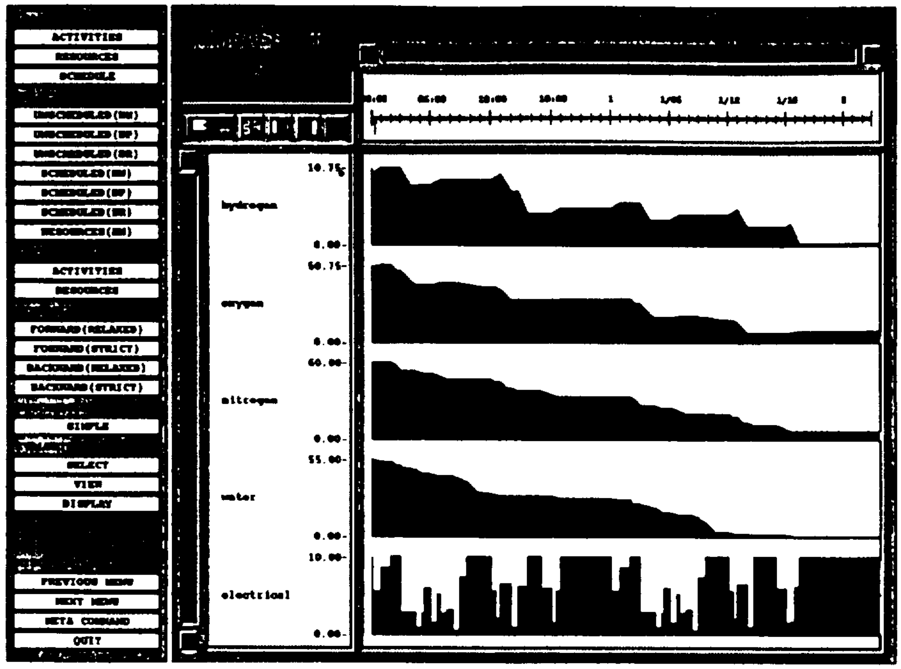
Introduction

COMPASS is an incremental, interactive, non-chronological scheduler written in Ada with an X-Windows user interface.





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Introduction

Incremental

beginning with an empty schedule, activities are added to the schedule one at a time, taking into consideration the placement of the activities already on the timeline and the resources that have been reserved for them.

Interactive

the order that activities are added to the timeline and their location on the timeline are controlled by selection and placement commands invoked by the user.

Non-Chronological

the order that activities are added to the timeline and their location are independent

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Introduction

COMPASS is the successor of Wedge (1986), a scheduler of similar capability written in Lisp on a Symbolics machine.

COMPASS contains portable, generic packages that were useful and necessary in the conversion of a major Lisp program to Ada

- Lookahead I/O
- Stream Oriented I/O
- Symbol Data Types
- Generic List Package

COMPASS can be useful to anyone planning the conversion of software that relies heavily upon lists and symbol data types.

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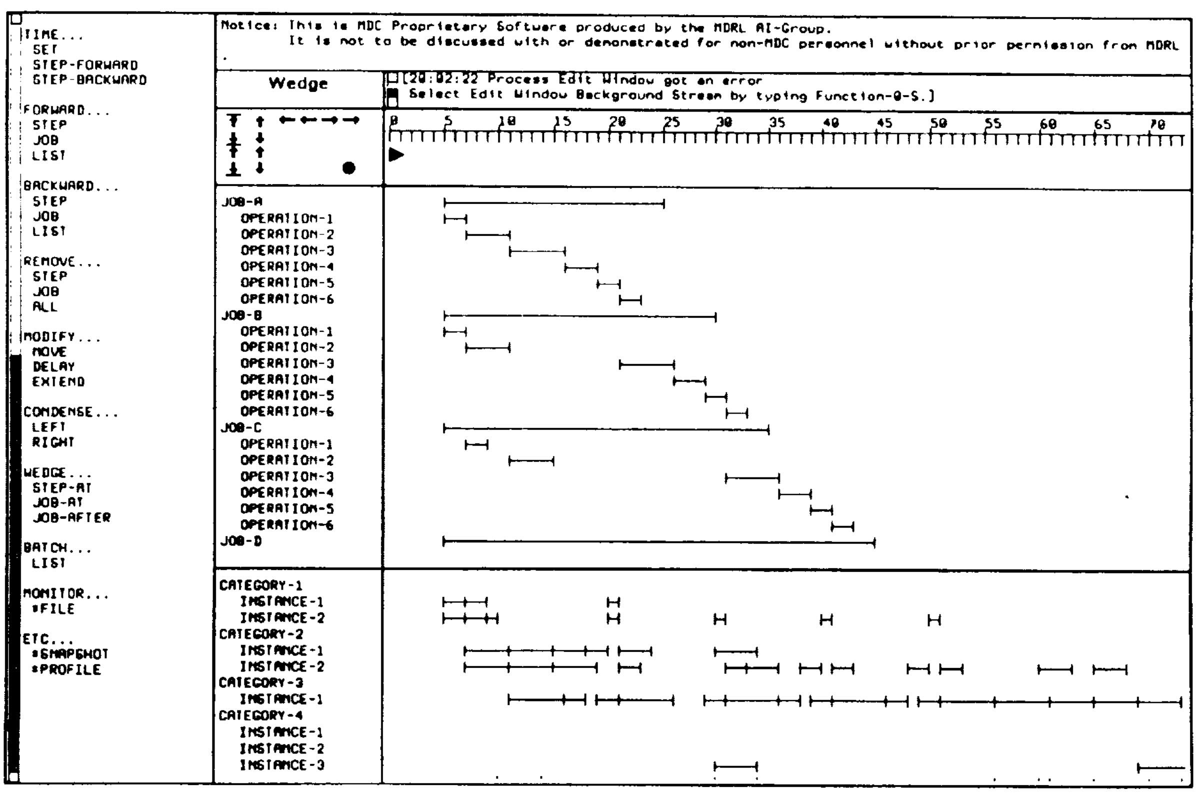

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Statement of the Problem

An activity can be performed only if all of its required resources are available in sufficient quantity for a sufficient duration of time.

A schedule must arrange activities so that the combined resource requirements at any point in time do not exceed the resource availability.

Statement of the Problem

Implementation of interactive and automated scheduling systems requires

an external (textual) representation for resource requirements,
an internal representation for resource requirements,

an external (textual) representation for resource availability,
an internal representation for resource availability,

an algorithm for placing activities on the timeline so that the combined resource requirements at any point in time do not exceed the resource availability.

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Statement of the Problem

NASA requires access to advanced scheduling technology.

Basic scheduling data structures and algorithms should be publicly available "textbook" knowledge.

- This enables traditional "time and space" analysis of proposed methods.
- This enables objective comparison of methods, unobscured by differences in implementation languages and hardware.
- This enables the creation of new scheduling applications without the costly process of re-discovery and re-invention.

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Representation of Resource Requirements

Resource requirements can be classified by the properties of the function that defines the quantity required at each point in time.

- Location of the origin
- Shape and continuity
- Sign
- Extent

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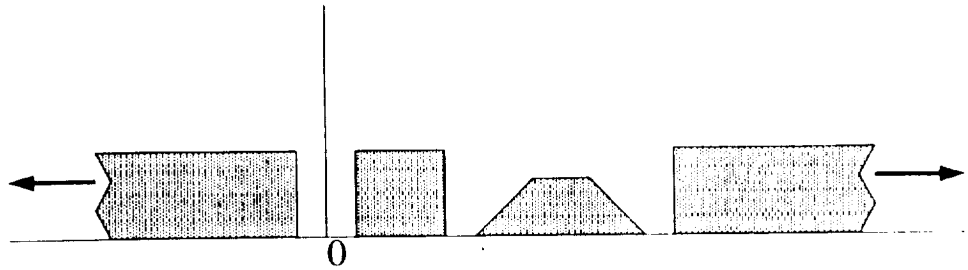
Representation of Resource Requirements

COMPASS represents resource requirements by piecewise linear functions.



The origin is relative to the beginning of the activity.

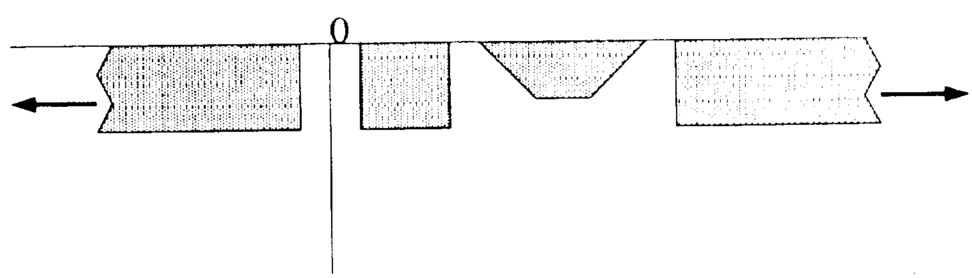
Positive quantities represent the amount required by an activity.

Positive segments with finite extent represent assignment.

Positive segments with infinite extent represent consumption.

Representation of Resource Requirements

COMPASS represents resource requirements by piecewise linear functions.



The origin is relative to the beginning of the activity.

Negative quantities represent the amount provided by an activity.

Negative segments with finite extent represent ___________ .

Negative segments with infinite extent represent production.

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Representation of Resource Requirements

This representation is suitable for a wide variety of resources including:

- electrical, thermal, communications, etc.
- water, oxygen, hydrogen, nitrogen, etc.
- crew members
- screwdrivers, hammers, pliers, etc.
- replaceable parts, packaged food, disposable clothing,etc.
- storage capacity
- mass and volume

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Representation of Resource Requirements

COMPASS provides a dotted notation for resource names which enables "wildcard" resource requirements.

Given four crew members named: crew.so.bob
crew.so.carol
crew.ss.ted
crew.ss.alice

request	crew.ss.ted	crew.so	crew
instances	crew.ss.ted	crew.so.bob crew.so.carol	crew.so.bob crew.so.carol crew.ss.ted crew.ss.alice

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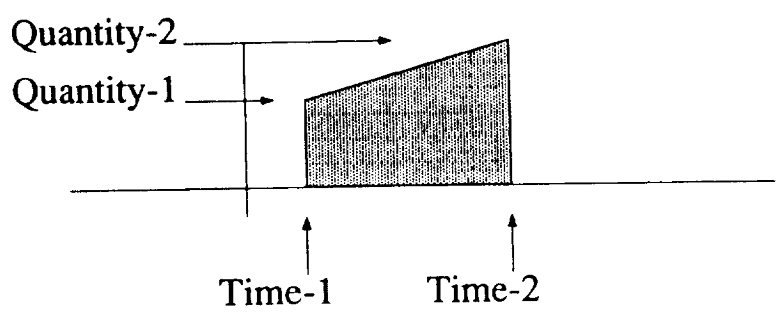
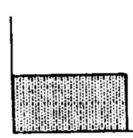
Representation of Resource Requirements

Piecewise linear functions are represented as an ordered list of segment descriptors:

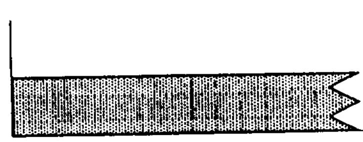


(Quantity-1 Quantity-2) / [Time-1 Time-2]

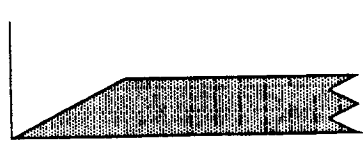
Representation of Resource Requirements



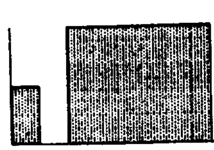
(1.0)/[0 1:00] ;



(1.0)/[0 +inf] ;



(0.0 1.0)/[0 1:00] (1.0)/[1:00 +inf] ;



(1.0)/[0 0:15] (2.0)/[0:30 1:45] ;

Representation of Resource Requirements

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Notation for time:

1	1 day
1/2	1 day, 2 hours
1/2:03	1 day, 2 hours, 3 minutes
1/2:03:04	1 day, 2 hours, 3 minutes, 4 seconds
2:03	2 hours, 3 minutes
2:03:04	2 hours, 3 minutes, 4 seconds
12/31/1990	December 31, 1990
12/31/1990 @ 2	December 31, 1990 at 2:00
12/31/1990 @ 2:03	December 31, 1990 at 2:03
12/31/1990 @ 2:03:04	December 31, 1990 at 2:03:04

(32 bit internal representation: +/- 65 years at resolution of 1 second)

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Representation of Resource Requirements

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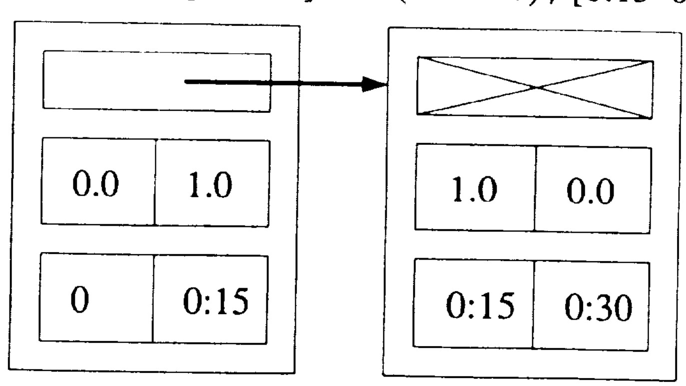
Piecewise linear functions are represented by linked lists of <ramp>/<interval> pairs created using the generic list package.

(0.0 1.0) / [0 0:15]   (1.0 0.0) / [0:15 0:30] ;



Total memory required is proportional to the amount of detail, not to the span of time!

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Representation of Resource Requirements

Given Ada's ability to create dynamically sized arrays, it is feasible to represent lists as both linked lists and arrays!

However, this is safe only if the compiler correctly implements unchecked deallocation!

(0.0 1.0) / [0 0:15] (1.0 0.0) / [0:15 0:30] ;

0.0	1.0
0	0:15

1.0	0.0
0:15	0:30

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Representation of Resource Availability

COMPASS represents resource availability by piecewise linear functions.

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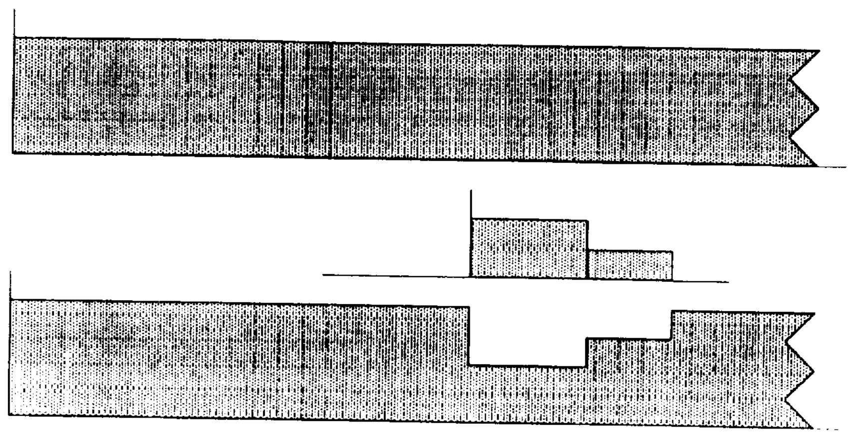
Algorithm for Activity Placement

To schedule an activity

- locate a time where its resource requirement can be satisfied
- schedule the activity to occur at that time
- translate its resource requirement to that time
- subtract its resource requirement from the resource availability



Algorithm for Activity Placement

Subtraction of the resource requirement from the resource availability ensures that the resource requirement will be satisfied even after other activities are added to the timeline.

Subsequently, another activity can be scheduled to occur at the same time only if its resource requirement can be satisfied by the remainder.

The reversibility of this method for resource reservation enables us to "unschedule" an activity by adding its resource requirement back into the resource availability!

Algorithm for Activity Placement

To locate where a resource requirement can be satisfied

- locate where each segment of the requirement can be satisfied
- normalize the results and combine by interval intersection

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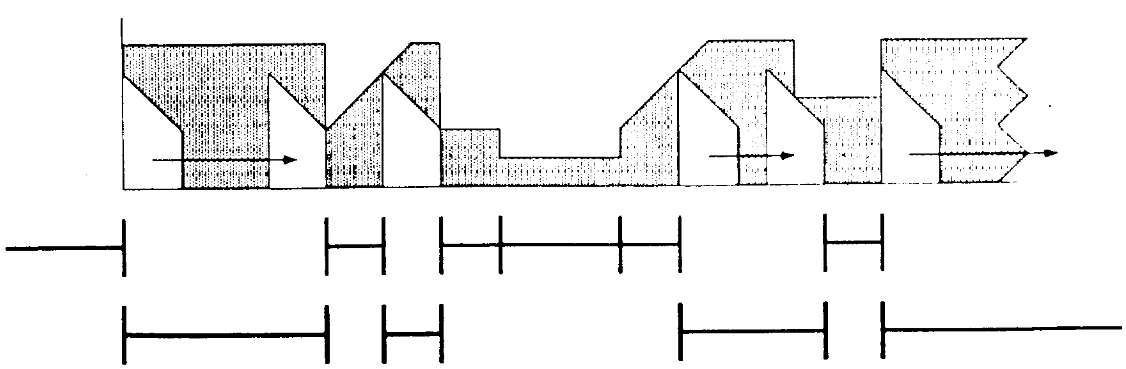
Algorithm for Activity Placement

To locate where a segment of a requirement can be satisfied

- Begin by assuming that all of time is satisfactory
- Consider each segment of the resource availability
  - If there is a subsegment which is not satisfactory
  - then exclude it from the answer.



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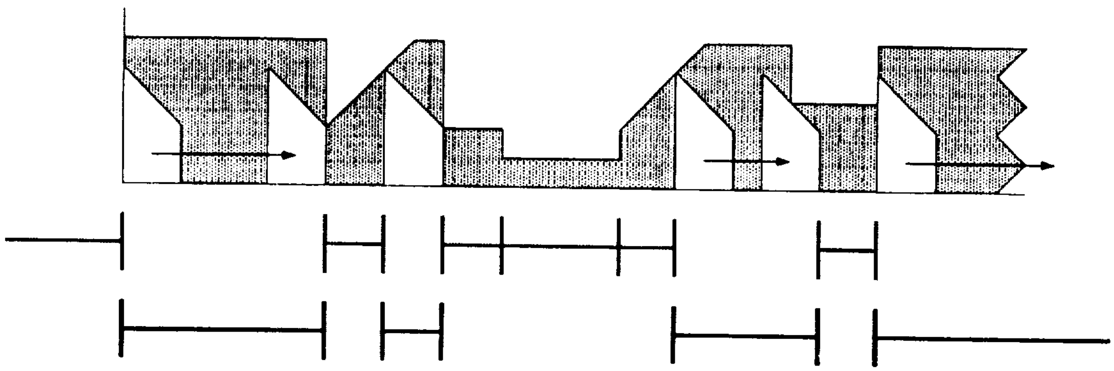
Work in Process

This same algorithm for computing feasible intervals of time can be used for pattern matching against other numeric data, like latitude, longitude, light and dark, which can be reasonably approximated by piecewise linear functions. (Special notation needs to be introduced in order to represent conjunction and disjunction.)



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Work in Process

Few resources can be accurately modeled as quantity available over time.

Rather than building more complex, domain specific models into COMPASS, we are building a distributed system of schedulers and resource managers that communicate with each other through a stylized protocol of requests and reservations.

Interprocess communication is greatly facilitated by the stream oriented I/O facilities already part of COMPASS.

Development of the basic capabilities is being performed jointly with the COOPES project. Specific resource models are being developed under the MDC IR&D program.

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Full Activity Representation

```
Activity
Name                          Crystal.Step_2
Priority                      10
Value                         5000
Penalty                       1000
Predecesor_List               (Crystal.Step_1)
Successor_list                ()
Non_ConCurrent_Activity_List  ()
Temporal_Constraint_List      [Start of * <= Finish of Crystal.Step_1 + 0:15] ;
Duration                      1:15
Earliest_Start                3/00:00
Latest_Finish                 3/12:00
Preferred_Interval_list       [3/04:00 3/05:30] [3/07:00 3/08:30] ;
Required_Resources            Crew         (1.0)/[0 1:15] ;
                              Electricity  (5.5)/[0 0:15] ( 9.0)/[0:15 1:15] ;
                              Thermal      (5.5)/[0 0:15] (14.0)/[0:15 1:15] ; ;
Required_Conditions           MicroGravity     T/[0:15 1:00] ; ;
Activity_End
```


Conclusion

The COMPASS code library is a cost-effective platform for the development of new artificial intelligence applications that must be delivered in Ada and X-Windows.

It implements symbols, strongly typed lists, and stream oriented low-level i/o libraries which are based upon very simple requirements and pragmatic compromises.

The implementation has been tested in the context of a large complex, computationally intensive application.

The implementation is being refined on the basis of design reviews, code audits, time and space benchmarks, and the wisdom of hindsight.

Conclusion

The COMPASS code library is a cost-effective platform for the developement of new scheduling applications.

The code library contains generic, portable, modular, and adaptable scheduling technology.

It can be effectively used off-the-shelf for compatibile scheduling applications or it can be used as a parts library for the development of custom scheduling systems

It has proved useful as a neutral benchmark for comparing the time, space, and qualitative performance of existing schedulers.

It has proved useful for assessing the feasibility of building scheduling systems, and other symbolic applications in Ada.

Appendix B—List of Attendees

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SNC Conference on Resource Allocation - List of Attendees				
Name	Organization	Street Address	City, State, Zip Code	Telephone
David W. Harris	NASA HQ, Code OX		Washington, DC 20546	202/454-2030
Ed Lowe	NASA HQ, Code OX		Washington, DC 20546	202/454-2058
Rhoda S. Hornstein	NASA HQ, Code OX		Washington, DC 20546	202/454-2030
Angie Kelly	NASA GSFC, Code 423		Greenbelt, MD 20771	301/286-7726
Bill Macoughtry	NASA GSFC, Code 501		Greenbelt, MD 20771	301/286-7155
Dolly Perkins	NASA GSFC, Code 510		Greenbelt, MD 20771	301/286-6228
Les Wentz	NASA GSFC, Code 510.1		Greenbelt, MD 20771	301/286-5563
Arthur Hughes	NASA GSFC, Code 510.1		Greenbelt, MD 20771	301/286-7311
Beth Antonopulos	NASA GSFC, Code 511.2		Greenbelt, MD 20771	301/286-3251
Wayne Gustafson	NASA GSFC, Code 513		Greenbelt, MD 20771	301/286-3173
Patricia Lightfoot	NASA GSFC, Code 514		Greenbelt, MD 20771	301/286-7378
Tom Barlett	NASA GSFC, Code 514		Greenbelt, MD 20771	301/286-5579
Carolyn Dent	NASA GSFC, Code 514		Greenbelt, MD 20771	301/286-3030
Pepper Hartley	NASA GSFC, Code 522		Greenbelt, MD 20771	301/286-6887
Karen Moe	NASA GSFC, Code 522		Greenbelt, MD 20771	301/286-5998
Sylvia Sheppard	NASA GSFC, Code 522.1		Greenbelt, MD 20771	301/286-5049
Mike Tong	NASA GSFC, Code 522.1		Greenbelt, MD 20771	301/286-3176
Eric Richmond	NASA GSFC, Code 522.1		Greenbelt, MD 20771	301/286-2617
Larry Hull	NASA GSFC, Code 522.2		Greenbelt, MD 20771	301/286-3009
Nancy Goodman	NASA GSFC, Code 522.2		Greenbelt, MD 20771	301/286-6635

SNC Conference on Resource Allocation - List of Attendees

Name	Organization	Street Address	City, State, Zip Code	Telephone
Bill Watson	NASA GSFC, Code 530		Greenbelt, MD 20771	301/286-2920
Phil Liebrecht	NASA GSFC, Code 530		Greenbelt, MD 20771	301/286-7028
Tony Maione	NASA GSFC, Code 530		Greenbelt, MD 20771	301/286-5943
Candace Carlisle	NASA GSFC, Code 530		Greenbelt, MD 20771	301/286-9469
Virg True	NASA GSFC, Code 530	NGT P.O. Drawer GSFC	Las Cruces, NM 88004	505/523-1497
Ray Davis	NASA GSFC, Code 530.3		Greenbelt, MD 20771	301/286-3264
James Rash	NASA GSFC, Code 531.1		Greenbelt, MD 20771	301/286-3595
Keiji Tasaki	NASA GSFC, Code 532		Greenbelt, MD 20771	301/286-8871
Al Goodson	NASA GSFC, Code 532		Greenbelt, MD 20771	301/286-7364
Mark Stokrp	NASA GSFC, Code 534		Greenbelt, MD 20771	301/286-8422
B.J. Hayden	NASA GSFC, Code 534		Greenbelt, MD 20771	301/286-3702
Ray Granata	NASA GSFC, Code 534		Greenbelt, MD 20771	301/286-7037
Greg Blaney	NASA GSFC, Code 534.1		Greenbelt, MD 20771	301/286-1818
Vern Hall	NASA GSFC, Code 534.1		Greenbelt, MD 20771	301/286-7920
Allen Levine	NASA GSFC, Code 534.2		Greenbelt, MD 20771	301/286-9436
Gene Young	NASA GSFC, Code 534.2		Greenbelt, MD 20771	301/286-6591
Lynne Cooper	NASA JPL, MS 301-490	4800 Oak Grove Drive	Pasadena, CA 91109	818/354-3252
David Werntz	NASA JPL, MS 601-237	4800 Oak Grove Drive	Pasadena, CA 91109	818/354-1270
Norman Reilly	NASA JPL, MS 601-237	4800 Oak Grove Drive	Pasadena, CA 91109	818/354-1239
Robert Aller	Aller Associates	7714 Glenmore Spring Way	Bethesda, MD 20817	301/469-8796

SNC Conference on Resource Allocation - List of Attendees

Name	Organization	Street Address	City, State, Zip Code	Telephone
Cathy Bazel	Bendix BFEC/534	10210 Greenbelt Rd. #450	Seabrook, MD 20706	301/794-3221
Wen Yen	Bendix BFEC/514	10210 Greenbelt Rd.	Seabrook, MD 20706	301/794-3134
Brenda Page	Bendix BFEC	10210 Greenbelt Rd. #500	Seabrook, MD 20706	301/794-3170
Andy Kispert	Bendix BFEC	10210 Greenbelt Rd.	Seabrook, MD 20706	301/794-3128
Dave Miller	COMSO, Inc.	7701 Greenbelt Rd.	Seabrook, MD 20706	301/622-0060
Fred Messing	CSC	4600 Powder Mill Rd.	Beltsville, MD 20705	301/572-8234
Surender Reddy	CSC/520	4600 Powder Mill Rd.	Beltsville, MD 20705	301/572-8311
Todd Welden	CSC/520	4600 Powder Mill Rd.	Beltsville, MD 20705	301/572-8457
Brian Dealy	CSC/520	4600 Powder Mill Rd.	Beltsville, MD 20705	301/572-8267
Toni Robinson	CTA Inc.	6116 Executive Blvd. #800	Rockville, MD 20852	301/816-1342
Betty Murphy	CTA Inc.	6116 Executive Blvd. #800	Rockville, MD 20852	301/816-1262
John A. Gingrich	GE	P.O. Box 8048	Philadelphia, PA 19101	215/354-2439
Arthur S. Paul	Howard University	2300 6th Street, N.W.	Washington, DC 20059	202/806-6661
J. W. Browning	Hughes	16800 E. Centretech Pkwy.	Aurora, CO 80011	303/344-6010
A. Sandor Hasznos	Hughes	16800 E. Centretech Pkwy.	Aurora, CO 80011	303/344-6272
John Willoughby	Information Sciences, Inc.	304 Inverness Way, #265	Englewood, CO 80112	303/790-0510
Masoud Toufanian	LinCom Corp.	P.O. Box 70002	Chevy Chase, MD 20813	301/577-9275
Pete Pataro	Lockheed LMSC/440.8	NASA/GSFC Code 440.8	Greenbelt, MD 20771	301/286-2604

SNC Conference on Resource Allocation - List of Attendees

Name	Organization	Street Address	City, State, Zip Code	Telephone
Stuart Weinstein	Loral AeroSys	7375 Executive Place, #100	Seabrook, MD 20706	301/805-0456
David Zoch	Loral AeroSys	7375 Executive Place, #100	Seabrook, MD 20706	301/805-0457
Amy Geoffrey	Martin Marietta, MS XL4372	P.O. Box 1260	Denver, CO 80201-1260	303/977-8186
Dan Britt	Martin Marietta, MS XL4370	P.O. Box 1260	Denver, CO 80201-1260	303/977-4491
Barry Fox	McDonnell Douglas SSC	16055 Space Center Blvd.	Houston, TX 77062	713/283-4194
Dirk Storm	MITRE/Code OX	600 Maryland Ave., S.W.	Washington, DC 20024	202/453-9787
James Logan	MITRE Corp.	1259 Lake Plaza Dr.	Colorado Springs, CO 80906	719/576-2602
Mary Pulvermacher	MITRE Corp.	1259 Lake Plaza Dr.	Colorado Springs, CO 80906	719/527-2241
Jim Boyle	RMS	NASA/GSFC Code 530	Greenbelt, MD 20771	301/249-3250
Cliff Kurtzman	Space Industries Internat'l	711 W. Bay Area Blvd. #320	Webster, TX 77598-4001	713/338-2676
Lisa Karr	Stanford Telecom	1761 Business Center Dr.	Reston, VA 22090	703/438-8038
Doug McNulty	Stanford Telecom	1761 Business Center Dr.	Reston, VA 22090	703/438-8066
Ken Johnson	Stanford Telecom	1761 Business Center Dr.	Reston, VA 22090	703/438-8099
Nadine Happell	Stanford Telecom	1761 Business Center Dr.	Reston, VA 22090	703/438-8028
Jeff Wike	TRW	One Space Park, MS R2-2062	Redondo Beach, CA 90278	213/813-4266
Tom Sparn	University of Colorado	Campus Box 392	Boulder, CO 80309	303/492-2799
Dan Gablehouse	University of Colorado	Campus Box 392	Boulder, CO 80309	303/492-2744

Appendix C—Submitted Papers