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PROJECT SCHEDULING TOOL

by

John Evans

September 1997

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   Prototyping System (CAPS) does near-optimal scheduling using an algorithm that runs in Order $N^2$ space
   and time. The problem addressed by this thesis is to improve the performance of the algorithm and make it more
   useful for scheduling software developers. The thesis accomplished three things: (1) Modified the algorithm to
   run in order $N$ time and space, preserving its near-optimal behavior; (2) implemented a calendaring package
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PROJECT SCHEDULING TOOL

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ABSTRACT

 Optimally scheduling a team of developers on a large software project is an NP-complete problem. The scheduling algorithm employed by the Evolutionary Control System (ECS) portion of the Computer-Aided Prototyping System (CAPS) does near-optimal scheduling using an algorithm that runs in Order $N^2$ space and time. The problem addressed by this thesis is to improve the performance of the algorithm and make it more useful for scheduling software developers. The thesis accomplished three things: (1) Modified the algorithm to run in order $N$ time and space, preserving its near-optimal behavior; (2) implemented a calendaring package that computes federal holidays for any year after 1970 and schedules tasks only on non-holiday workdays; and (3) incorporated a more realistic capability model to better match programming tasks with each developer's abilities.
DISCLAIMER

The computer programs in the Appendices are supplied on an “as is” basis, with no warranties of any kind. The author bears no responsibility for any consequences of using these programs.
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I. BACKGROUND

Much research into the formalization and automation of software development is underway. The need for such tools is obvious. It is fundamentally driven by Moore's Law, which states that the power of computer systems will double every 18 months—a maxim which has held for the past twenty years, and is expected to continue for at least the next ten. As computer systems grow inexorably faster and more powerful, new software to take advantage of this increased power is needed. The new software, however, is larger, and more complicated, and now requires larger teams of developers to produce in a timely manner. Software tools to manage the complexity of developing these larger programs are needed.

One such tool is the Evolutionary Control System (ECS) being developed at the Naval Postgraduate School (NPS). The basis of the ECS is Salah Badr’s Phd. Thesis, A Model and Algorithms for a Software Evolution Control System[Ref. 1], which itself was based on work by Luqi[Ref. 4] of NPS.

Salah’s thesis delved into a broad array of issues related to managing large projects and their concomitant complexity. One aspect of his thesis, which is the subject of this report, was the development and implementation of an on-line scheduling algorithm that did three specific tasks:

1. Supported teamwork by concurrently assigning ready steps to available designers.
2. Supported incremental replanning as additional information became available.
3. Minimized wasted design effort due to reorganization of the schedule by efficiently scheduling workers to assigned sub-tasks.

Over time, however, certain limitations have become evident. The implementation of the scheduling algorithm was found to be $O(N^2)$ in space. This led to a rapid exhaustion of memory resources on relatively small problem sets. Also, the model of time used to schedule the developers was not realistic. It assumed that the
developers were available always, and did not take into account weekends, holidays, or other commitments on a developer's time. Also, the capabilities of the developers was split into just three broad categories: low, medium, and high. This too proved unrealistic, as certain developers bring their own strengths and weaknesses to the task at hand. It would be nice to take note, for instance, of a special ability such as database expertise, and assign a programmer with this capability to a task that require this knowledge. The changes made to Salah Badr's codes do exactly this.
II. THE SCHEDULER

The problem of optimally scheduling tasks for both the preemptive and nonpreemptive cases is NP-complete [Ref. 6]. Scheduling nonpreemptive tasks with arbitrary ready times is also NP-complete in both multiprocessor and uniprocessor systems [Ref. 3]. For dynamic systems with more than one task, and mutual exclusion constraints between tasks, Mok and Dertouzos [Ref. 5] showed that an optimal scheduling algorithm does not exist.

Shiah, et al. [Ref. 2] came up with an heuristic scheduling algorithm that ran in order $kN$ time. Salah Badr extended the algorithm to consider arbitrary precedence constraints between pairs of tasks. His scheduler forms the basis of the current ECS scheduling algorithm.

The scheduling algorithm, as implemented by Badr, was recursive. It consumed order $N^2$ memory for a set of $N$ tasks. It attempted to improve performance by limiting backtracking, but was still at least order $N^2$ in time. It was based on an algorithm described in the paper by Stankovic, et al. [Ref. 3] The requirement for order $N^2$ space limited the size of the problem domain. This thesis describes the algorithm and the steps taken to make the algorithm run using only order $N$ space. It is based on the "myopic" algorithm [Ref. 2] and a radical restructuring of the data structures in the Ada code.

A. THE SCHEDULING MODEL

The task set in the ECS scheduling problem is a variable set of evolution steps $S = \{S_1, S_2, \ldots, S_N\}$, where $N$ varies with time. This set of tasks needs to be scheduled to a set of $M$ designers $D = \{D_1, D_2, \ldots, D_M\}$. The designers are of $L$ different expertise levels.

Tasks as used in the ECS are independent, nonperiodic and non-preemptive. They can be characterized by the following:
1. Task arrival Time $T_A$;
2. Task deadline $T_D$;
3. Task worst-case computation time $T_C$;
4. Task expertise level $T_E$;
5. Task priority $T_P$

Each task also has associated with it a precedence constraint given in the form of a directed acyclic graph $G = \{S, E\}$ such that $(S_i, S_j) \in E$ implies that $S_j$ cannot start until $S_i$ has completed.

The priority, $T_P$, is a small positive integer that is assigned to each task to reflect the criticality of its deadline. The priorities of different tasks should be compatible with the precedence constraints between the steps, i.e. no lower priority step can precede a higher priority step:

$$\text{if } (S_2, S_1) \in E \Rightarrow T_P(2) \geq T_P(1)$$

$$\text{if } (S_2, S_1) \in E \land T_P(1) \geq T_P(3) \Rightarrow T_P(2) \geq T_P(3)$$

**B. THE SCHEDULING ALGORITHM**

The goal of the scheduling algorithm is to determine if there exists a schedule for executing the tasks that satisfies the timing, precedence, and resource constraints, and to calculate such a schedule if it exists. A schedule that meets these constraints is termed *feasible*. It is not guaranteed to be optimal.

Scheduling a set of tasks to find a full feasible schedule is actually a search problem. The search space is a tree. The scheduling algorithm starts at the root of the tree, and using a predetermined heuristic, selects a candidate task to schedule. If the remaining tasks can be added to the schedule, in the order given by the heuristic, without violating the constraints, then the partial schedule is termed *strongly-feasible*, and the task is added to the search tree as a vertex node, and the process is repeated, recursively, till a full, feasible schedule is found. If instead, after the candidate task is
selected, and any one of the remaining tasks added to the schedule violates the constraints, the candidate task is rejected, and the next eligible, candidate task (ordered by the ranking function \( H(T) \)) is selected. The search process continues until all the tasks are scheduled, or no feasible schedule is found.

Instead of using all of the remaining tasks to determine if a partial schedule is strongly-feasible, Stankovic, et al.[Ref. 2], limited the candidate tasks to check to some number \( k \). So, instead of checking \( N, N - 1, \ldots, 1 \) remaining tasks, or \( N(N - 1)/2 \) total tasks, they limited the search to \( k \) or at most \( kN \) tasks to check. (This is where the term “myopic” comes in. Instead of looking at all the remaining tasks, we “near-sightedly” examine the next \( k \) tasks.)

The set of tasks ready to be scheduled are ordered by the heuristic \( H(T) \). The candidate heuristics are

1. Minimum deadline first (Min.D): \( H(T) = T_D \);
2. Minimum processing time first (Min.P): \( H(T) = T_P \);
3. Minimum earliest start time first (Min.S): \( H(T) = T_{est} \);
4. Minimum laxity first (Min.L): \( H(T) = T_D - (T_{est} + T_P) \);
5. Min.D + Min.P: \( H(T) = T_D + W \times T_P \);
6. Min.D + Min.S: \( H(T) = T_D + W \times T_{est} \);

According to Shia et al.[Ref. 3], The Min.D + Min.S heuristic is superior in all cases. It is supposedly used in Salah Badr’s dissertation, but since his simulation studies apparently used tasks with an earliest start time of 0 it defaults to Min.D. Min.D is used in the new implementation of the scheduling algorithm.

C. ANALYSIS

The scheduler as implemented by Salah Badr in Ada was Order N-squared in space. The heart of the code was a call on a search function performing a recursive search in tree-like fashion of potential schedules. In order to make the routine
Figure 1. Plot of scheduler run-time vs. number of tasks to schedule

$O(N)$ in space it was necessary to pull many of the large data structures out of the recursive routine, make them global, and manage changes with other global data structures. This necessarily complicated the code to a degree, but the result was an $O(N)$ algorithm in space.

Once the space problem was corrected, it became evident that the routine was also $O(N^2)$ in time. But this was easily rectified by using the “myopic” algorithm. Figure 1 shows the speed-up in processing speed vs. number of tasks to be scheduled for different versions of the code. The original data came with the original code. After the $N^2$ space problem was resolved, and before the myopic version of the code was added (first cut) we see that the code still runs in order $N^2$ time. The final cut shows the run-time for the final version of the code.

The original data collected goes upto only 4600 tasks because the storage required was $O(N^2)$ in the number of tasks to be scheduled. A number larger than 4600 tasks would cause the program to raise a storage-error exception.
D. SIMULATION

To test the new scheduler routine, a routine to generate tasks that always have a feasible schedule was written. (Actually Badr had a routine to generate tasks, but it generated lists of tasks that were “easy” to schedule—that is the algorithm never failed to find a schedule.) This routine varies the number of tasks, the number of programmers to use, and the “laxity” of the schedule generated. (Laxity is defined to be $T_D - (T_{est} + T_P)$.) It also uses the Ada '95 random number generators to generate uniform distributions of random variables. The graph in Figure 2 shows the performance of the algorithm when 500 tasks per test case were generated, and the laxity was varied between zero and 0.7. As you can see, the algorithm failed miserably when there was zero laxity, and got progressively better as this constraint was “relaxed.”
III. CALENDAR

The scheduling algorithm as originally implemented treated time continuously. Mapping this "continuous" time to calendar working time is a tedious task, especially as the number of tasks to schedule increases. Also, real dates give a better idea of the time-frames involved.

The algorithm to translate a "continous" time to calendar time works as follows: Consider the output of the scheduler in Table I for a simple set of 10 tasks.

The first column is the task id, the second column is the expertise level required for the task (more on expertise levels, later), and the third column is the developer assigned to the task. (In this case we have three developers: L1, M1, H1.) The second to last column is the start time and the last column is the end time in units of hours.

After translating the start times and end times to calendar times we get the output in Table II For this data set the start date was set to July 3rd, 1997. The translator also assumed that the work day is eight hours. At NRAD the the work weeks are 5/4, i.e., 9 hours a day on Monday thru Thursday and 8 hours on Friday, with every other Friday off. Using -nrad as an input switch to the program, we get the new output shown in Table III.

The dates in Table III start on the seventh of July because July 4th is a federal

<table>
<thead>
<tr>
<th></th>
<th>EXPERTISE</th>
<th>TASK</th>
<th>START TIME</th>
<th>END TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>HIGH</td>
<td>H1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>MEDIUM</td>
<td>M1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>LOW</td>
<td>L1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>HIGH</td>
<td>H1</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>MEDIUM</td>
<td>M1</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>LOW</td>
<td>L1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>MEDIUM</td>
<td>M1</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>LOW</td>
<td>L1</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>HIGH</td>
<td>H1</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>MEDIUM</td>
<td>M1</td>
<td>14</td>
<td>24</td>
</tr>
</tbody>
</table>

Table I. Raw output of Scheduler
3 HIGH H1 07/03/1997+00 07/03/1997+03
2 MEDIUM M1 07/03/1997+00 07/03/1997+04
1 LOW L1 07/03/1997+00 07/03/1997+06
4 HIGH H1 07/03/1997+03 07/07/1997+05
5 MEDIUM M1 07/03/1997+04 07/07/1997+04
6 LOW L1 07/03/1997+06 07/07/1997+02
8 MEDIUM M1 07/07/1997+04 07/07/1997+06
7 LOW L1 07/07/1997+02 07/07/1997+07
9 HIGH H1 07/07/1997+05 07/08/1997+03
10 MEDIUM M1 07/07/1997+06 07/08/1997+08

Table II. Standard Work Day

3 HIGH H1 07/07/1997+00 07/07/1997+03
2 MEDIUM M1 07/07/1997+00 07/07/1997+04
1 LOW L1 07/07/1997+00 07/07/1997+06
4 HIGH H1 07/07/1997+03 07/08/1997+05
5 MEDIUM M1 07/07/1997+04 07/08/1997+04
6 LOW L1 07/07/1997+06 07/08/1997+02
8 MEDIUM M1 07/08/1997+04 07/08/1997+06
7 LOW L1 07/08/1997+02 07/08/1997+07
9 HIGH H1 07/08/1997+05 07/09/1997+03
10 MEDIUM M1 07/08/1997+06 07/09/1997+08

Table III. NRaD Schedule

holiday, and an NRaD off-Friday, this moves the off-Friday to the 3rd, so the first work-day is actually the seventh. It appears complicated, but the Ada implementation handles it quite easily. The format of MM/DD/YYYY+HR is used because daily schedules are idiosyncratic. The notation “+HR” means start or finish at that many hours into the workday. It should be easy to map this time format to any person’s particular schedule, but in the interest of time was not done here.

The calendar package will also compute non-federal holidays such as Easter, election-day, and other useful dates. The present version runs in order $N^2$ time. It should be easy to convert to order $N$, but due to time constraints, this was not done during the course of this thesis. The calendar package was originally added to the
scheduler, but it didn't make sense to take an order $N^2$ algorithm, turn it into an order $N$ one, then turn it back to an order $N^2$ one with the addition of the calendar package. Besides, the scheduler is used to come up with feasible schedules. Once one is obtained, it can then be easily mapped to calendar dates. This separation of tasks also preserves the modularity of the codes. The conversion routine to convert from "continuous-time" to calendar dates (contocal) is in one of the appendices, as part of the scheduler package.
IV. EXPERTISE LEVELS

Every programmer brings certain competencies to the tasks at hand. Some are experts in Ada, others in Java, etc. So, the scheduler has been modified to handle this.

In the Shiah, et al. paper [Ref. 3] on scheduling multiple tasks, resources are represented by a vector data structure as follows:

\[ EAT = (EAT_1, EAT_2, \ldots, EAT_r) \]

(EAT stands for earliest available time.) If a task is ready to be scheduled, and it requires resource \( N \), the earliest it can be scheduled is at time \( EAT_N \). If there are multiple instances of a resource then the resources are represented as a matrix, and the earliest time a task can be scheduled is the earliest time any one of the multiple instances of that resource is available. In Salah Badr’s thesis, he represented developers as the resources, and since he classified them as \((low, medium, high)\) he could have multiple instances of developers. So the data structure to represent the available resources (developers) was a matrix.

In this latest revision of the code, each developer is unique, there are no multiple instances of a developer, so resources (developers) are represented as a vector. Each developer, though, has a capability attribute, which is a map of skills to \((low, medium, high)\). For example, one of the inputs to the new scheduler program is a file of developers, as shown in Table IV.

Each developer has an implicit attribute which is their name. Also, if a capability is not given, it is assumed to be \( low \). For example developer “Scott McNealy”

<table>
<thead>
<tr>
<th>Developer</th>
<th>Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill Gates</td>
<td>{ActiveX : High, Java : Low}</td>
</tr>
<tr>
<td>Scott McNealy</td>
<td>{Java : High, Unix : Medium}</td>
</tr>
<tr>
<td>Bill Joy</td>
<td>{Java : High, Unix : High}</td>
</tr>
</tbody>
</table>

Table IV. Sample developer file
Bill Gates: {ActiveX: High, Java: Low, Unix: Low, Bill Gates: High, Scott McNealy: Low, Bill Joy: Low}
Scott McNealy: {ActiveX: Low, Java: High, Unix: Medium, Bill Gates: Low, Scott McNealy: High, Bill Joy: Low}
Bill Joy: {ActiveX: Low, Java: High, Unix: High, Bill Gates: Low, Scott McNealy: Low, Bill Joy: High}

**Table V. Sample developer file with implicit capabilities**

...
V. CONCLUSIONS

A. SUMMARY OF DESIGN AND IMPLEMENTATION

The scheduler as implemented can now handle large problems in a reasonable time, i.e., ten thousand or more tasks. The scheduled tasks can now be mapped to a realistic calendar, and the tasks are now associated with problem-solving skills.

B. FUTURE WORK

The calendar implementation needs to be optimized. It currently runs in order $N^2$ time, but could easily be modified to run in order $N$ time. At present the calendar model does not consider individual variations in schedules. If a developer were to take a day off, the model cannot handle that, as it is only aware of work days and holidays for the general work-force. To allow individual schedules into the model a group planning program of some kind would be needed. A kludge to get around this in the present implementaton, is to create pseudo-tasks lasting the period of time off, and requiring only that particular developer perform it. This causes some inaccuracies because the current scheduler in non-preemptive, but in real life time off could be scheduled in the middle of a task. This weakens the algorithm because it can fail to find feasible schedules in which tasks are interrupted by time off.

Another enhancement that would be useful is the identification of critical paths. All schedules have critical paths, that is a sequence of tasks with the least laxity. It would be nice to enhance the scheduler to identify these critical paths. The project manager could then can focus his attention on those tasks in the critical path, as these would be the jobs that puts his schedule most at risk.
Schedule Tools

[Ada '95—Version 1.0]
September 18, 1997

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1. Introduction. Here is the Ada code for utilites used in Salah Badr’s scheduler program. His program was written by him May 25, 1993. It was translated by myself, John Evans of NRaD, into Donald Knuth’s WEB format for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

It is available on-line via the world-wide-web at URL:

http://white.nosc.mil/~evansjr/literate/

2. WEB is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called “Literate Programming.” For Further information get the book Literate Programming, by Donald Knuth, published by the Center for the Study of Language and Information, Stanford University, 1992. Another good source of information is the Usenet group comp.programming.literate. It has information on tools and answers to Frequently Asked Questions (FAQs).

3. Who should use the WEB paradigm for programming? Well, not everybody. Here are a few paragraphs from Donald Knuth’s book that explains it best.

4. Retrospect and Prospects. Enthusiastic reports about new computer languages, by the authors of those languages, are commonplace. Hence I’m well aware of the fact that my own experiences cannot be extrapolated too far. I also realize that, whenever I have encountered a problem with WEB, I’ve simply changed the system; other users of WEB cannot operate under the same ground rules.

5. However, I believe that I have stumbled on a way of programming that produces better programs that are more portable and more easily understood and maintained than ever before; furthermore, the system seems to work with large programs as well as with small ones. I’m pleased that my work on typography, which began as an application of computers to another field, has come full circle and become an application of typography to the heart of computer science; I like to think of WEB as a neat “spinoff” of my research on TeX. However, all of my experiences with this system have been highly colored by my own tastes, and only time will tell if a large number of other people will find WEB to be equally attractive and useful.
6. I made a conscious decision not to design a language that would be suitable for everybody. My goal was to provide a tool for system programmers, not for high school students or for hobbyists. I don’t have anything against high school students and hobbyists, but I don’t believe every computer language should attempt to offer all things to all people. A user of WEB needs to be good enough at computer science that he or she is comfortable dealing with several languates simultaneously. Since WEB combines T\TeX and Pascal with a few rules of its own, WEB programs can contain WEB syntax errors. T\TeX syntax errors, Pascal syntax errors, and algorithmic errors; in practice, all four types of errors occur, and a bit of sophistication is needed to sort out which is which. Computer specialists tend to be better at such things than other people. I have found that WEB programs can be debugged rapidly in spite of the profusion of languages, but I’m sure that many other intelligent people will find such a task difficult.

7. In other words, WEB seems to be specifically for the peculiar breed of people who are called computer scientists. And I’m pretty sure that there are also a lot of computer scientists who will not enjoy using WEB; some of us are glad that traditional programming languages have comparatively primitive capabilities for inserted comments, because such difficulties provide a good excuse for not documenting programs well. Thus, WEB may be only for the subset of computer scientists who like to write and to explain what they are doing. My hope is that the ability to make explanations more natural will cause more programmers to discover the joys of literate programming, because I believe it’s quite a pleasure to combine verbal and mathematical skills; but perhaps I’m hoping for too much. The fact that at least one paper has been written that is a syntactically correct ALGOL 68 program encourages me to persist in my hopes for the future. Perhaps we will even one day find Pulitzer prizes awarded to computer programs.

8. Donald Knuth goes on to write about his hopes for the future of WEB programming. In an interview with Donald Knuth by Amazon Books on the release of a new edition of Volume 1 of *The Art of Computer Programming* (July 1, 1997) he was asked:

**Amazon.com:** What do you see as the most interesting advance in programming since you published the first edition?

**Donald Knuth:** It’s what I call literate programming, a technique for writing, documenting, and maintaining programs using a high-level language combined with a written language like English. This is discussed in my book *Literate Programming*.

9. In the same book, *Literate Programming*, there is a chapter called *How to read a WEB*. But it is actually quite straightforward.
10. Very briefly, each "Module" within angle brackets (< >) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. This provides a type of PDL (program descriptor language) for your program and greatly aids modularity and readability. It is also a highly effective method of top-down programming. The first module here is expanded further down, and contains most of the structure in standard Ada packages.

(Package boiler-plate 12)

12. Here, finally, is the boilerplate. The Ada WEB tool atangle reads this and knows to write out two separate files, the specification and the body. (The Ada WEB tool aweave will write out just one documentation file.)

\[
\text{Package boiler-plate 12} \equiv \\
\text{output to file schedtools.ads} \\
\text{with Text.IO;} \\
\text{use Text.IO;} \\
\text{with generic.set.pkg;} \\
\text{with generic.map.pkg;} \\
\text{with Generic.List;} \\
\text{with SchedPrims;} \\
\text{use SchedPrims;} \\
\text{with capability;} \\
\text{use capability;} \\
\text{with ustrings;} \\
\text{use ustrings;} \\
\text{package schedtools is} \\
\text{\quad Instantiate generics 16} \\
\text{\quad Specification of types and variables visible from schedtools 23} \\
\text{\quad Specification of procedures visible from schedtools 26} \\
\text{end schedtools;} \\
\text{output to file schedtools.adb} \\
\text{with test.io.pkg;} \\
\text{use test.io.pkg;} \\
\text{with Ustrings; Use Ustrings; with Ada.calendar;} \\
\text{use Ada.calendar;} \\
\text{with calyr;} \\
\text{use calyr;} \\
\text{with capability;} \\
\text{use capability;} \\
\text{package body schedtools is} \\
\text{\quad Variables local to schedtools 41} \\
\text{\quad Procedures and Tasks in schedtools 42} \\
\text{end schedtools;} \\
\]

This code is used in section 10.
13. The scheduling tools in this package rely on some other packages. Here is how they relate to each other.

\[\text{Generic List Pkg} \rightarrow \text{SchedPrims Pkg} \rightarrow \text{SchedTools Pkg} \rightarrow \text{Scheduler}\]

Library Dependence Structure.

14. The schedules are kept in in linked-lists. Salah Badr's original code had separate routines for each linked list. In this version of the algorithm, I created a generic list type, and make multiple instantiations of it for different record types. Details of the differing records, comparisons, and display routines can be found in the schedprims package.

15. Since the main purpose of rewriting the code was to eliminate the order $N^2$ space requirement, I use linked lists to keep track of additions and deletions to the lists as the search space is traversed. What follows are all the instantiations of new linked-lists.

16. Here I instantiate a list type to manipulate StepRecord types.

\[
\text{Instantiate generics 16 } \equiv \\
\text{package InputList1 is new Generic_list(ElementType } \Rightarrow \text{StepRecord,} \\
\text{DisplayElement } \Rightarrow \text{DisplayStepRecord,}\"<\" \Rightarrow \text{CompareID);}
\text{use InputList1;}
\text{subtype InputList is InputList1.List;}
\]

See also sections 17, 18, 19, 20, 21, and 22.

This code is used in section 12.

17. Here I instantiate a list type to manipulate StepRecord types, but to restore deletions, in case the recursive procedure BranchAndBound needs to back out changes.

\[
\text{Instantiate generics 16 } + \equiv \\
\text{package DeletedInputList1 is new Generic_list(ElementType } \Rightarrow \text{StepRecord,} \\
\text{DisplayElement } \Rightarrow \text{DisplayStepRecord,}\"<\" \Rightarrow \text{CompareRecursionLevel);}
\text{use DeletedInputList1;}
\text{subtype DeletedInputList is DeletedInputList1.List;}
\]
18. Here I instantiate a list type to manipulate StepRecord types for the ReadyQueue, which requires that the records be sorted in Deadline first order.

\[\text{Instantiate generics 16} \vdash \equiv\]
\[
\text{package ReadyList1 is new Generic_list(}
\text{ElementType }\Rightarrow\text{ StepRecord},
\text{DisplayElement }\Rightarrow\text{ DisplayStepRecord},"<"\Rightarrow\text{ CompareDeadline},"="\Rightarrow\text{ IsEqual});
\]

use ReadyList1;

subtype ReadyList is ReadyList1.List;

19. Here I instantiate a list type to manipulate StepRecord types for deletions to the ReadyQueue, which requires that the records be sorted in RecursionLevel first order.

\[\text{Instantiate generics 16} \vdash \equiv\]
\[
\text{package DeletedReadyList1 is new Generic_list(}
\text{ElementType }\Rightarrow\text{ StepRecord},
\text{DisplayElement }\Rightarrow\text{ DisplayStepRecord},"<"\Rightarrow\text{ CompareRecursionLevel});
\]

use DeletedReadyList1;

subtype DeletedReadyList is DeletedReadyList1.List;

20. Here I instantiate a list type to manipulate StepRecord types for additions to the ReadyQueue, which requires that the records be sorted in RecursionLevel first order.

\[\text{Instantiate generics 16} \vdash \equiv\]
\[
\text{package AddedReadyList1 is new Generic_list(}
\text{ElementType }\Rightarrow\text{ StepRecord},
\text{DisplayElement }\Rightarrow\text{ DisplayStepRecord},"<"\Rightarrow\text{ CompareRecursionLevel});
\]

use AddedReadyList1;

subtype AddedReadyList is AddedReadyList1.List;

21. Here I instantiate a list type to manipulate StepRecord types for the ReadyQueue, which requires that the records be sorted in Deadline first order.

\[\text{Instantiate generics 16} \vdash \equiv\]
\[
\text{package ScheduleList1 is new Generic_list(}
\text{ElementType }\Rightarrow\text{ ScheduleRecord},
\text{DisplayElement }\Rightarrow\text{ DisplayScheduleRecord},"<"\Rightarrow\text{ CompareStartTime});
\]

use ScheduleList1;

subtype ScheduleList is ScheduleList1.List;

22. Here I instantiate a list type to manipulate StepRecord types for the ReadyQueue, which requires that the records be sorted in Deadline first order.

\[\text{Instantiate generics 16} \vdash \equiv\]
\[
\text{package CalendarList1 is new Generic_list(}
\text{ElementType }\Rightarrow\text{ CalendarRecord},
\text{DisplayElement }\Rightarrow\text{ DisplayCalendarRecord},"<"\Rightarrow\text{ CompareStartTime});
\]

use CalendarList1;

subtype CalendarList is CalendarList1.List;
23. Made global and visible.
\[ \text{(Specification of types and variables visible from } \text{schedtools 23)} \equiv \]
\[ \text{max_recursion : natural } \leftarrow 0; \]
\[ \text{recursion_level : natural } \leftarrow 0; \]
See also sections 24, 25, 33, and 59.
This code is used in section 12.

24. When the laxity of the input schedule is “tight,” it may be impossible to find a
schedule. (Finding a schedule is, after all, an NP-Complete problem.) In this case the
routine will give up after some amount of effort. In this implementation, I give up if the
number of “backtracks” is \text{FeasFactor} times the total of number of tasks to be scheduled.
If this number is exceeded then the exception \text{NoFeasibleScheduleFound} is thrown.
\[ \text{(Specification of types and variables visible from } \text{schedtools 23)} \equiv \]
\[ \text{NoFeasibleScheduleFound : Exception; FeasFactor : natural } \leftarrow 10; \]

25. Made global and visible.
\[ \text{(Specification of types and variables visible from } \text{schedtools 23)} \equiv \]
\[ \text{StepList : InputList; ReadyQueue : ReadyList; DeletedReadyQueue : DeletedReadyList; DeletedInputQueue : DeletedInputList; AddedReadyQueue : AddedReadyList; Schedule : ScheduleList; Calendar : CalendarList; FinalSchedule : ScheduleList;} \]

26. Print all the records in the Step list.
\[ \text{(Specification of procedures visible from } \text{schedtools 26)} \equiv \]
\[ \text{procedure PrintAllStepRecords (L : in InputList);} \]
See also sections 27, 28, 29, 30, 31, 32, 34, 35, 36, 37, 38, and 39.
This code is used in section 12.

27. Print all the records in the Step list.
\[ \text{(Specification of procedures visible from } \text{schedtools 26)} \equiv \]
\[ \text{procedure PrintAllStepRecords (L : in ReadyList);} \]

28. Print all the records in the Schedule list.
\[ \text{(Specification of procedures visible from } \text{schedtools 26)} \equiv \]
\[ \text{procedure PrintAllScheduleRecords (L : in ScheduleList);} \]
29. Print all the records in the Schedule list.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{PrintAllCalendarRecords} (\, L : \text{in out ScheduleList} \,);
   \]

30. Print all the records in the Schedule list.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{SaveAllScheduleRecords} (\, L : \text{in out ScheduleList} \,);
   \]

31. Creating new step from a file and linking it to the step list.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{CreateNewStepList} (\, L : \text{in out InputList} \,);
   \]

32.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{Procedure } \text{CreateDeadlineFirstSchedule} (\, \text{mr : in out natural; num_developers : natural} \,);
   \]

33. \[\langle \text{Specification of types and variables visible from } \text{schedtools 23} \rangle \equiv \]
   \[
   \text{type DesignerMatrix is array (POSITIVE range } < \text{) of natural};
   \]

34. Creating a new schedule record
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{CreateScheduleRecord} (\, \text{Rec : in out ScheduleRecord; S_ID : in}
   \]
   \[
   \text{natural; TIME1 : in natural; TIME2 : in natural; S_LEVEL : in}
   \]
   \[
   \text{cap.map.map; Developer : in ustring};
   \]

35.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{LevelMinimum} (\, \text{MATRIX : in DesignerMatrix; LEVEL : in}
   \]
   \[
   \text{cap.map.map; J : in out natural};
   \]

36. Checking the in_degree of the successors of the assigned step. This works with
    deadline heuristic
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{CheckInDegree} (\, \text{Rec : in StepRecord; Queue : in out ReadyList; InList : in}
   \]
   \[
   \text{out InputList; finish_t : in natural};
   \]

37.
   \[\langle \text{Specification of procedures visible from } \text{schedtools 26} \rangle \equiv \]
   \[
   \text{procedure } \text{StronglyFeasible} (\, \text{Queue : in out ReadyList; MATRIX : in}
   \]
   \[
   \text{DesignerMatrix; FEASIBLE : in out boolean});
   \]
§38  APPENDIX A

38. Assign a step to a designer according to its deadline and its expertise level

(Specification of procedures visible from schedtools 26) +≡
   procedure AssignStep(Current : StepRecord; MATRIX : in out DesignerMatrix;
                          Sch : in out ScheduleList; Finish : in out natural; FEAS : out boolean);

39.

(Specification of procedures visible from schedtools 26) +≡
   procedure BranchAndBound(S_List : in out InputList; R_Queue : in out ReadyList;
                            F_Sched : in out ScheduleList; MATRIX : in DesignerMatrix; Found : in out BOOLEAN);
40. Schedule Tools Body.

41. Global variable used to identify different tasks.

\[
\begin{align*}
\text{Variables local to schedtools 41} & \equiv \\
\text{StepID} & : \text{natural} \leftarrow 1; \\
\text{data\_file}, \text{data2\_file} & : \text{file\_type}; \\
\text{FOUND} & : \text{boolean} \leftarrow \text{FALSE}; \\
\text{FEASIBLE} & : \text{boolean} \leftarrow \text{TRUE}; \\
\text{debug} & : \text{boolean} \leftarrow \text{false}; \\
\text{debug2} & : \text{boolean} \leftarrow \text{false}; \\
\text{Start\_Time} & : \text{Time}; \\
\text{dailyhours} & : \text{Work\_Hours} \leftarrow (\text{Convert\_Hours\_To\_Duration}(8), \text{Convert\_Hours\_To\_Duration}(8), \\
& \quad \quad \quad \text{Convert\_Hours\_To\_Duration}(8), \text{Convert\_Hours\_To\_Duration}(8), \\
& \quad \quad \quad \text{Convert\_Hours\_To\_Duration}(8)); \\
\text{NRaD} & : \text{boolean} \leftarrow \text{false};
\end{align*}
\]

See also sections 55 and 56.

This code is used in section 12.

42. Print all the records in the STEP list.

\[
\begin{align*}
\text{Procedures and Tasks in schedtools 42} & \equiv \\
\text{procedure PrintAllStepRecords}(L : \text{in InputList}) \text{ is} \\
\text{begin} & \quad \text{Step\_Record\_Heading; Display}(L); \\
\text{end PrintAllStepRecords;}
\end{align*}
\]

See also sections 43, 44, 45, 47, 49, 52, 53, 57, 58, 62, 66, 70, and 71.

This code is used in section 12.

43. Print all the records in the STEP list.

\[
\begin{align*}
\text{Procedures and Tasks in schedtools 42} & \equiv \\
\text{procedure PrintAllStepRecords}(L : \text{in ReadyList}) \text{ is} \\
\text{begin} & \quad \text{Step\_Record\_Heading; Display}(L); \\
\text{end PrintAllStepRecords;}
\end{align*}
\]

44. Print all the records in the STEP list.

\[
\begin{align*}
\text{Procedures and Tasks in schedtools 42} & \equiv \\
\text{procedure PrintAllScheduleRecords}(L : \text{in ScheduleList}) \text{ is} \\
\text{begin} & \quad \text{Schedule\_Record\_Heading; Display}(L); \\
\text{end PrintAllScheduleRecords;}
\end{align*}
\]
45. Print all the records in the STEP list.

\( \text{Procedures and Tasks in schedtools 42} \) \( \equiv \)

\[
\text{procedure SaveAllScheduleRecords}(L : \text{in out ScheduleList}) \text{ is}
\]

\[
\begin{align*}
\text{input} & : \text{Ustring;} \\
\text{size} & : \text{natural;} \\
\text{cur} & : \text{ScheduleRecord}; \\
\text{begin} & \\
\text{(Get output file name 46)} & \\
\text{put.line("Opening your output file."); create(data2_file, out_file, S(input));} \\
\text{size} & \leftarrow \text{ListSize}(L); \text{rewind}(L); \\
\text{for } i \in 1 \ldots \text{size loop} & \\
\text{if } i = 1 \text{ then} & \\
\text{getCurrent}(L, \text{cur}); & \\
\text{else} & \\
\text{getNext}(L, \text{cur}); & \\
\text{end if}; & \\
\text{SaveScheduleRecord(cur, data2_file);} & \\
\text{end loop;} & \\
\text{end SaveAllScheduleRecords;} & \\
\end{align*}
\]

46.

\( \text{(Get output file name 46)} \equiv \)

\[
\text{put.line("Please Enter Output FileName:"); get.line(input);}
\]

This code is used in section 45.

47. Print all the records in the STEP list.

\( \text{Procedures and Tasks in schedtools 42} \) \( \equiv \)

\[
\text{procedure PrintAllCalendarRecords}(L : \text{in out ScheduleList}) \text{ is}
\]

\[
\begin{align*}
\text{size} & : \text{natural;} \\
\text{cur} & : \text{ScheduleRecord;} \\
\text{cal} & : \text{CalendarRecord;} \\
\text{dur} & : \text{Duration}; \\
\text{begin} & \\
\text{CalendarRecordHeading;} & \\
\text{(Convert ScheduleList to CalendarList 48)Display(Calendar);} & \\
\text{end PrintAllCalendarRecords;} & \\
\end{align*}
\]
(Convert ScheduleList to CalendarList 48) \equiv
\begin{align*}
&\text{MakeEmpty(Calendar)}; \; \text{size} \leftarrow \text{ListSize}(L); \; \text{Rewind}(L); \\
&\text{for } i \in 1 \ldots \text{size} \text{ loop} \\
&\quad \text{if } i = 1 \text{ then} \\
&\qquad \text{GetCurrent}(L, \text{cur}); \\
&\quad \text{else} \\
&\qquad \text{GetNext}(L, \text{cur}); \\
&\quad \text{end if}; \\
&\quad \text{dur} \leftarrow \text{ConvertHoursToDuration}(\text{cur}.\text{StartTime}); \\
&\quad \text{cal.}\text{StartTime} \leftarrow \text{DurationToCalendarTime} (\text{StartTime}, \text{dailyhours}, \text{dur}, \text{NRaD}); \\
&\quad \text{dur} \leftarrow \text{ConvertHoursToDuration}(\text{cur}.\text{FinishTime}); \\
&\quad \text{cal.}\text{FinishTime} \leftarrow \text{DurationToCalendarTime} (\text{StartTime}, \text{dailyhours}, \text{dur}, \text{NRaD}); \\
&\quad \text{cal.}\text{StepId} \leftarrow \text{cur.}\text{StepId}; \; \text{cal.}\text{Designer} \leftarrow \text{cur.}\text{Designer}; \\
&\quad \text{cap.map.assign} (\text{cal.}\text{StepLevel}, \text{cur.}\text{StepLevel}); \; \text{InsertInOrder} (\text{Calendar}, \text{cal}); \\
&\text{end loop;}
\end{align*}

This code is used in section 47.

(Procedures and Tasks in schedtools 42) +≡

```
procedure CreateNewStepList (L : in out InputList) is
  sr : StepRecord;
  input : Ustring;
  do_alternate : boolean ← false;
  (Variables local to CreateNewStepList 51)
begin
  MakeEmpty(L);
  StepId ← 1;
  put_line("Please ENTER INPUT FILE NAME");
  get_line(input);
  put_line("Opening your data file");
  open(data_file, in_file, S(input));
  while ¬end_of_file(data_file) loop
    sr.StepId ← StepID;
    if do_alternate then
      D_time ← get_date(data_file);
    else
      nat_io.get(data_file, sr.Deadline);
    end if;
    nat_io.get(data_file, sr.Priority);
    nat_io.get(data_file, sr.EstimatedDuration);
    if do_alternate then
      Earlytime ← get_date(data_file);
    else
      nat_io.get(data_file, sr.EarliestStartTime);
    end if;
    getf_set(data_file, sr.Predecessors);
    getf_set(data_file, sr.Successors);
    declare
      yrcap : cap_map.map;
    begin
      get_capability(data_file, yrcap); cap_map.assign(sr.ExpLevel, yrcap);
    end;
    sr.InDegree ← nat_set.size(sr.Predecessors);
    if do_alternate then
      (Convert calendar times to absolute times 50)
    else
      Start Time ← Time_Of (1997,7,3,0.0);
    end if;
    AddToEnd(L, sr); StepID ← StepID + 1;
  end loop;
```
CLOSE(data_file);
end CreateNewStepList;

50.
\(\text{Convert calendar times to absolute times 50} \equiv\)
\(\text{if } \text{StepID} = 1 \text{ then}\)
\(\text{StartTime } \leftarrow \text{ Earlytime};\)
\(\text{end if;}\)
\(\text{dur } \leftarrow \text{ CalendarTimeToDuration} (\text{StartTime, dailyhours, Deadtime, NRaD});\)
\(\text{sr.\ Deadline } \leftarrow \text{ ConvertDurationToHours} (\text{dur});\)
\(\text{dur } \leftarrow \text{ CalendarTimeToDuration} (\text{StartTime, dailyhours, EarlyTime, NRaD});\)
\(\text{sr.\ EarliestStartTime } \leftarrow \text{ ConvertDurationToHours} (\text{dur});\)

This code is used in section 49.

51.
\(\text{Variables local to CreateNewStepList 51} \equiv\)
\(\text{dur : Duration};\)
\(\text{EarlyTime, DeadTime : Time};\)

This code is used in section 49.

52.
\(\text{Procedures and Tasks in schedtools 42} \equiv\)
\text{procedure ReInitializeMatrix (MATRIIX : in out DesignerMatrix) is}\begin{align*}
&\text{begin} \\
&\text{for } i \in 1 \ldots \text{matrix.length loop} \\
&\text{matrix}(i) \leftarrow 0; \\
&\text{end loop;} \\
&\text{end ReInitializeMatrix;}
\end{align*}
§53. Creating new step.

(Procedures and Tasks in schedtools 42) +

Procedure CreateDeadlineFirstSchedule (mr : in out natural; num_developers : natural)
  is
  Current : StepRecord;
  Feasible : boolean ← True;
  eat : designermatrix (1 .. num_developers);
begin
  Kntr ← ListSize (StepList);  (Initialize the lists for intensive list-processing 54)
  Rewind (StepList); GetCurrent (StepList, Current);
  for i ∈ 1 .. Kntr loop
    if Current.InDegree = 0 then
      DeleteCurrent (StepList); InsertInOrder (ReadyQueue, Current);
      if i < Kntr then
        GetCurrent (StepList, Current);
      end if;
    else
      if i < Kntr then
        GetNext (StepList, Current);
      end if;
    end if;
  end loop;
  Feasible ← True; Found ← False; ReInitializeMatrix (EAT);
  StronglyFeasible (ReadyQueue, EAT, Feasible);
  if Feasible then
    put_line ("Calling lBranchAndBound lRoutine.");
    BranchAndBound (StepList, ReadyQueue, Schedule, EAT, FOUND);
    put_line ("Returned from lBranchAndBound lRoutine.");
  end if;
  if ~FOUND then
    put_line ("SORRY, THERE IS NO FEASIBLE SCHEDULE");
  end if;
  mr ← max_recursion;
end CreateDeadlineFirstSchedule;

54. If this is not the first time this routine is called then it behooves us to clean up the old lists from previous processing. If this is the first time, no harm done.

(Initialize the lists for intensive list-processing 54) ≡

MakeEmpty (ReadyQueue); MakeEmpty (Schedule); MakeEmpty (DeletedReadyQueue);
MakeEmpty (DeletedInputQueue); MakeEmpty (AddedReadyQueue);

This code is used in section 53.
55. \(\text{Variables local to \text{schedtools 41}}\) \(\equiv\)
   \(\text{kntr : integer} \leftarrow 0;\)

56. \(\text{Variables local to \text{schedtools 41}}\) \(\equiv\)
   \(\text{counter : natural} \leftarrow 0; \quad \text{\{Used for tracking backtracking\}}\)

57. Creating a new schedule record
\(\text{Procedures and Tasks in \text{schedtools 42}}\) \(\equiv\)
   \text{procedure CreateScheduleRecord(Rec : out ScheduleRecord; S.ID : in natural; TIME1 : in natural; TIME2 : in natural; S.LEVEL : in cap.map.map; Developer : in ustring) is}
   \begin{align*}
   &\text{Rec.StepID} \leftarrow \text{S.ID}; \quad \text{Rec.StartTime} \leftarrow \text{TIME1}; \quad \text{Rec.FinishTime} \leftarrow \text{TIME2}; \\
   &\text{Rec.Designer} \leftarrow \text{Developer}; \quad \text{cap.map.assign(Rec.StepLevel, S.LEVEL)};
   \end{align*}
   \text{end CreateScheduleRecord;}

58. \(\text{Procedures and Tasks in \text{schedtools 42}}\) \(\equiv\)
   \text{procedure LevelMinimum(MATRIX : in DesignerMatrix; LEVEL : in cap.map.map; J : in out natural) is}
   \begin{align*}
   &\text{min : natural;} \\
   &\text{n : natural;} \\
   \text{begin}
   &j \leftarrow 0; \quad \text{min} \leftarrow \text{natural'.last}; \quad n \leftarrow 1; \\
   &\text{if is.qualified(level, n) then} \\
   &\quad j \leftarrow 1; \quad \text{min} \leftarrow \text{matriz}(1); \\
   &\text{end if;} \\
   &\text{for } m \in 2 \ldots \text{matriz'.length loop} \\
   &\quad \text{if matriz(m) < min then} \\
   &\quad\quad \text{if is.qualified(level, m) then} \\
   &\quad\quad\quad \text{min} \leftarrow \text{matriz(m)}; \quad j \leftarrow m; \\
   &\quad\text{end if;} \\
   &\quad\text{end if;} \\
   &\text{end loop;} \\
   &\text{if } j = 0 \text{ then} \\
   &\quad \text{raise noqualifieddevelopers;} \\
   &\text{end if;} \\
   &\text{end levelminimum;}
   \end{align*}
§59  APPENDIX A  SCHEDULE TOOLS BODY

59.

\( \langle \text{Specification of types and variables visible from schedtools 23} \rangle +\equiv \\
\text{noqualifieddevelopers : exception;} \)
60. Check In Degree. Checking the \textit{in-degree} of the successors of the assigned step. This works with deadline heuristic.

61. Presently changes the start-time of any successors. Will need to modify when I convert the updates from a recursive local variable to a global one. Also deletes a scheduled task from the \textit{INPUT\_LIST}. Then it updates the queue of "ready" tasks.
62. This procedure loops through the entire \textit{InputList} finding the successors of \textit{Rec}. Once found it updates the \textit{EarliestStartTime}. Also, if the \textit{InDegree} reaches zero this means it no longer is waiting on a predecessor to be scheduled, it is “ready” to be scheduled—that is, moved from the \textit{InputList} to the \textit{ReadyQueue}.

Note: It appears that the \textit{Predecessor} field of the \textit{StepRecord} is ignored. Only the successor field is used.

\begin{verbatim}
(Procedures and Tasks in schedtools 42) +==
procedure CheckInDegree(Rec : in StepRecord; Queue : in out ReadyList; InList : in
out InputList; finish_t : in natural) is
    Current : StepRecord;
    t : nat.set.set ← Rec.Successors;
    k, kntr : natural;
    FOUND : boolean ← FALSE;
    deleted : boolean ← false;
begin
    if nat.set.size(t) ≠ 0 then
        Rewind(InList); kntr ← ListSize(InList); GetCurrent(InList, Current);
        for i ∈ 1 .. kntr loop
            k ← Current.StepId;
            if nat.set.member(k, t) then
                if Current.EarliestStartTime < finish_t then
                    Current.EarliestStartTime ← finish_t;
                end if;
                Current.InDegree ← Current.InDegree − 1;
                if Current.InDegree = 0 then
                    (Move record from input list to ready list 64)
                else
                    UpdateCurrent(InList, Current);
                end if;
            end if;
        end loop;
    end if;
end CheckInDegree;
\end{verbatim}
CHECK IN DEGREE

63.
\[ \langle \text{Get next record 63} \rangle \equiv \]
\[ \quad \text{if } i < kntr \text{ then} \]
\[ \quad \quad \text{if deleted then} \]
\[ \quad \quad \quad \text{GetCurrent(InList, Current); deleted } \leftarrow \text{false}; \]
\[ \quad \quad \text{else} \]
\[ \quad \quad \quad \text{GetNext(InList, Current);} \]
\[ \quad \quad \text{end if;} \]
\[ \quad \text{end if;} \]
This code is used in section 62.

64.
\[ \langle \text{Move record from input list to ready list 64} \rangle \equiv \]
\[ \quad \text{DeleteCurrent(InList); Current.recursionlevel } \leftarrow \text{recursion.level;} \]
\[ \quad \text{InsertInOrder(Queue, Current); InsertInOrder(AddedReadyQueue, Current);} \]
\[ \quad \text{Current.InDegree } \leftarrow \text{Current.Indegree } + 1; \]
\[ \quad \text{InsertInOrder(DeletedInputQueue, Current); deleted } \leftarrow \text{true;} \]
\[ \quad \text{if debug then} \]
\[ \quad \quad \text{put.line("Moving Record to DeletedInputQueue.")}; \quad \text{Display(DeletedInputQueue);} \]
\[ \quad \text{end if;} \]
This code is used in section 62.
65. **StrongFeasible.** Checking the feasibility of the schedule with each step in the ready queue.
66. Definition: A partial feasible schedule is said to be strongly-feasible if all the schedules obtained by extending the current schedule with any one of the remaining tasks are also feasible. Thus, if a partial feasible schedule is found not to be strongly-feasible because, say, task $T$ misses its deadline when the current schedule is extended by $T$, then it is appropriate to stop the search since none of the future extensions involving task $T$ will meet its deadline. In this case, a set of tasks can not be scheduled given the current partial schedule. (In the terminology of branch-and-bound techniques, the search path represented by the current partial schedule is bound since it will not lead to a feasible complete schedule.)

(Procedures and Tasks in schedtools 42) +

procedure StronglyFeasible(Queue : in out ReadyList; MATRIX : in
   DesignerMatrix; feasible : in out boolean) is
   temp : natural;
   $J : \text{natural} \leftarrow 1$;
   $L : \text{natural} \leftarrow 1$;
   min : natural $\leftarrow 0$;
   kntr : natural $\leftarrow 0$;
   myonum : natural $\leftarrow 0$;
   Current : StepRecord;
   Myopic_Num : constant natural $\leftarrow 7$;
begin
if debug then
   put.Line("StronglyFeasible\texttt{Start}\texttt{"});
end if;
feasible $\leftarrow$ True; kntr $\leftarrow$ ListSize(Queue); (Compute myopic number 67)
Rewind(Queue);
for $i \in 1 .. \text{myonum}$ loop
   if $\neg$feasible then
      exit;
   end if;
   if $i = 1$ then
      GetCurrent(Queue, Current);
   else
      GetNext(Queue, Current);
   end if;
LevelMinimum(MATRIX, Current.ExpLevel, $J$); min $\leftarrow$ MATRIX($J$); (Debug code set 1 68)
if $min \geq \text{Current.EarliestStartTime}$ then
   temp $\leftarrow$ min;
else
   temp $\leftarrow$ Current.EarliestStartTime;
end if;
$\text{temp} \leftarrow$ temp + Current.EstimatedDuration; (Debug code set 2 69)
if temp > Current.Deadline then
    feasible ← False;
end if;
end loop;
end StronglyFeasible;

67. Without this tidbit of code, the algorithm goes from order n to order \( n^2 \).

Compute myopic number 67
if kntr > Myopic.Num then
    myonum ← Myopic.Num;
else
    myonum ← kntr;
end if;

This code is used in section 66.

68.
Debug code set 1 68
if debug then
    put("StronglyFeasible>Id=\_\_\_"); nat.io.put(Current.StepId,1);
    put("Umin=\_\_\_"); nat.io.put(min,2); put("UCurrent.EarliestStartTime=\_\_\_");
    nat.io.put(Current.EarliestStartTime,2); put.line("\_\_\_\_");
end if;

This code is used in section 66.

69.
Debug code set 2 69
if debug then
    put("\_\_\_"); nat.io.put(i,2); put("temp=\_\_\_");
    nat.io.put(temp,2); put("Deadline=\_\_\_");
    nat.io.put(Current.Deadline,2); put.line("\_\_\_");
end if;

This code is used in section 66.
ASSIGNSTEP

70. AssignStep. Assign a step to a designer according to its deadline and its expertise level: BRANCH AND BOUND CASE

\textit{(Procedures and Tasks in schedtools 42)} \begin{align*}
\text{procedure AssignStep}(Current : \text{in} \ StepRecord; MATRIX : \text{in out} \\
\text{DesignerMatrix; Sch : in out ScheduleList; Finish : in out natural; FEAS : out} \\
\text{boolean}) \text{ is} \\
J : \text{natural;} \\
MIN : \text{natural;} \\
temp : \text{natural} \gets 0; \\
temp1 : \text{StepRecord} \gets Current; \\
Dummy : \text{ScheduleRecord;} \\
\text{begin} \\
\text{LevelMinimum}(MATRIX, Current.\text{ExpLevel}, J); MIN \gets MATRIX(J); \\
\text{if } MIN \leq Current.\text{EarliestStartTime} \text{ then} \\
\quad \text{temp} \gets Current.\text{EarliestStartTime}; \text{finish} \gets \text{temp} + Current.\text{EstimatedDuration}; \\
\quad \text{if } \text{finish} > Current.Deadline \text{ then} \\
\quad \quad \text{FEAS} \gets \text{FALSE}; \\
\quad \text{else} \\
\quad \quad \text{FEAS} \gets \text{TRUE}; \text{MATRIX}(J) \gets \text{finish}; \text{CreateScheduleRecord}(Dummy, \\
\quad \quad \quad \text{temp1.}\text{StepID}, \text{temp, finish, temp1.}\text{ExpLevel, get_developer_name}(j)); \\
\quad \text{addToEnd}(\text{Sch, Dummy}); \\
\text{end if;} \\
\text{else} \\
\quad \text{temp} \gets \text{MIN}; \text{finish} \gets \text{temp} + Current.\text{EstimatedDuration}; \\
\quad \text{if } \text{finish} > Current.Deadline \text{ then} \\
\quad \quad \text{FEAS} \gets \text{FALSE}; \\
\quad \text{else} \\
\quad \quad \text{FEAS} \gets \text{TRUE}; \text{MATRIX}(J) \gets \text{finish}; \text{CreateScheduleRecord}(Dummy, \\
\quad \quad \quad \text{temp1.}\text{StepID}, \text{temp, finish, temp1.}\text{ExpLevel, get_developer_name}(j)); \\
\quad \text{addToEnd}(\text{Sch, Dummy}); \\
\text{end if;} \\
\text{end if;} \\
\text{end AssignStep;} \\
\end{align*}
71. Branch And Bound.

(Procedures and Tasks in schedtools 42) +

procedure BranchAndBound(S_List : in out InputList; R_Queue : in out ReadyList;
F_Sched : in out ScheduleList; MATRIX : in DesignerMatrix; Found : in out
BOOLEAN) is
(Variables local to BranchAndBound 73)

begin
(Update some recursion stuff 72)
if IsEmpty(R_Queue) then
if do_verbose then
  ScheduleRecordHeading; PrintAllScheduleRecords(F_Sched); new_line;
end if;
pf("Backtracking:="); text_io_pkg.put(counter); new_line;
@{Copy(F_Sched,FinalSchedule); @}Found := True;
if debug then
  pf("Found&valid_schedule.");
end if;
elsif ~found then
  OrigSize := ListSize(R_Queue);
  for i IN 1 .. OrigSize loop
    (Update backtrack counter 74)
    (Copy linked lists and the designer matrix onto the stack 80)
    (Get appropriate R_Queue record 76)
    if debug then
      pf("BranchAndBound>&Current="); DisplayStepRecord(Current);
      pf("BranchAndBound>&ListSize(R_Queue)=");
      nat_io.put(ListSize(R_Queue)); pf(".");
    end if;
    AssignStep(Current, MAT, F_Sched, FinishTime, Feasible);
    CheckInDegree(Current, R_Queue, S_List, FinishTime);
    (Delete appropriate R_Queue record 78)
    if debug then
      pf("After assigning step, but before testing for Feasibility: ");
      PrintAllStepRecords(R_Queue); PrintAllScheduleRecords(F_Sched);
    end if;
    StronglyFeasible(R_Queue, MAT, Feasible1);
    if Feasible1 then
      BranchAndBound(S_List, R_Queue, F_Sched, MAT, Found);
      (Update recursion stuff again 79)
    end if;
    (Free up local linked lists 83)
    if Found then
      exit;
    end if;
  end loop;
end if;
end BranchAndBound;
BRANCH AND BOUND

end if;
end loop;
if recursion_level ≤ 1 then
  if debug then
    put_line("BranchAndBound Finished unwinding the stack.");
  end if;
end if;
end if;
end BranchAndBound;

72.
⟨Update some recursion stuff 72⟩ ≡
  if (diag_sched ∨ diag_step ∨ diag_ready_queue) then
    do_verbose ← true;
  end if;
  recursion_level ← recursion_level + 1;
  if recursion_level > max_recursion then
    max_recursion ← recursion_level;
  end if;
This code is used in section 71.

73.
⟨Variables local to BranchAndBound 73⟩ ≡
  do_verbose : boolean ← false;
  OrigSize : natural;
See also sections 75, 77, 82, 85, 88, and 90.
This code is used in section 71.

74.
⟨Update backtrack counter 74⟩ ≡
  if i ≠ 1 then
    counter ← counter + 1;
  end if;
  TotSize ← ListSize(R_Queue) + ListSize(S_List) + ListSize(F_Sched);
  if counter > (FeasFactor * TotSize) then
    raise NoFeasibleScheduleFound;
  end if;
This code is used in section 71.

75.
⟨Variables local to BranchAndBound 73⟩ +≡
  TotSize : natural;
(Get appropriate R.Queue record 76) ≡
    appropriate ← i − (OrigSize − ListSize(R.Queue));
    if debug then
        put("BranchAndBound>Getting_number_"); nat.io.put(Appropriate, 1);
        put("Record_in_ReadyQueue."); put("(i="); nat.io.put(i, 1);
        put("Origsize="); nat.io.put(Origsize, 1); put.line(".");
    end if;
    GetNth(R.Queue, appropriate, Current);
This code is used in section 71.

(Variables local to BranchAndBound 73) ≡
    appropriate : natural;

(Delete appropriate R.Queue record 78) ≡
    if debug then
        put.line("Deleting_R.Queue_record.");
    end if;
    GetNth(R.Queue, appropriate, Current); DeleteCurrent(R.Queue);
    Current.RecursionLevel ← Recursion_Level;
    InsertInOrder(DeletedReadyQueue, Current);
    if debug then
        put.line("Finished_deleting_R.Queue_record.");
    end if;
This code is used in section 71.

(Update recursion stuff again 79) ≡
    recursion_level ← recursion_level − 1;
This code is used in section 71.

80. As far as I can see the step list is never modified, so why is it copied? Aha! It is modified in procedure check_in_degree.

(Copy linked lists and the designer matrix onto the stack 80) ≡
    (Do diagnostics 81)
    @1Copy(S.List, InList); Copy(R.Queue, Queue); Copy(F.Sched, Sched);
    @2MAT ← MATRIX;
This code is used in section 71.
81. 

(Do diagnostics 81) ≡

    if do_verbose then
        put_line("======================================");
        put("Recursion::level::is::"); nat_io.put(recursion_level); put_line(".");
    end if;
    if diag_step then
        PrintAllStepRecords(S_List);
    end if;
    if diag_ready_queue then
        PrintAllStepRecords(R_QUEUE);
    end if;
    if diag_sched then
        PrintAllScheduleRecords(F_sched);
    end if;

This code is used in section 80.

82. 

(Variables local to BranchAndBound 73) ≡

    diag_step : boolean ← false;
    diag_ready_queue : boolean ← false;
    diag_sched : boolean ← false;

83. 

(Free up local linked lists 83) ≡

    @{MakeEmpty(InList); MakeEmpty(Queue); MakeEmpty(Sched);
    @} (Restore R_Queue 84)
    (Restore S_List 86)
    (Restore F_Sched 89)

This code is used in section 71.
(Restore \texttt{R.Queue} 84) \equiv
    \text{if } \neg \text{Found then}
    \text{if debug then}
        \text{println}\left("\text{Restoring}_i\text{R.Queue}.\"ight);
    \text{end if;}
    \text{Dsize } \leftarrow \text{ListSize(AddedReadyQueue)};
    \text{if Dsize } \neq 0 \text{ then}
        \text{GetNth(AddedReadyQueue, Dsize, Current);}
        \text{while Current.recursionlevel } = \text{recursion.level loop}
            \text{DeleteCurrent(AddedReadyQueue);}\n            \text{DeleteMatching(R.Queue, Current, Success);}\n            \text{if debug then}
                \text{println}\left("\text{Deleting}_i\text{record}_j\"ight);
                \text{println}\left("\text{From}_i\text{ReadyQueue}.\"ight);
                \text{DisplayStepRecord(Current);}\n            \text{end if;}
            \text{if } \neg \text{Success then}
                \text{println}\left("\text{Did}_i\text{not}_j\text{find}_i\text{matching}_i\text{record!}\"ight);
            \text{end if;}
            \text{Dsize } \leftarrow \text{ListSize(AddedReadyQueue)};
            \text{if Dsize } = 0 \text{ then}
                \text{exit;}\n            \text{else}
                \text{GetNth(AddedReadyQueue, Dsize, Current);}\n            \text{end if;}
        \text{end loop;}
    \text{end if;}
    \text{Dsize } \leftarrow \text{ListSize(DeletedReadyQueue)};
    \text{GetNth(DeletedReadyQueue, Dsize, Current);}\n    \text{DeleteCurrent(DeletedReadyQueue);}\n    \text{InsertInOrder(R.Queue, Current);}\quad\langle\text{Reset InDegree 87}\rangle
    \text{if debug then}
        \text{println}\left("\text{Finished}_i\text{restoring}_i\text{R.Queue}.\"ight);
    \text{end if;}
\text{end if;}

This code is used in section 83.

85.

\langle\text{Variables local to BranchAndBound 73}\rangle \equiv
\begin{align*}
\text{Success} : \text{boolean;}
\end{align*}
(Restore $S\_List$ 86) ≡

if ¬Found then
    $Dsize ← ListSize(DeletedInputQueue)$;
    if $Dsize ≠ 0$ then
        GetNth($DeletedInputQueue$, $Dsize$, Current);
        while Current.recursionlevel = recursion_level loop
            DeleteCurrent($DeletedInputQueue$); InsertInOrder($S\_List$, Current);
            (Reset InDegree 87)
            $Dsize ← ListSize(DeletedInputQueue)$;
            if $Dsize ≠ 0$ then
                GetNth($DeletedInputQueue$, $Dsize$, Current);
            else
                exit;
                end if;
            end loop;
        end if;
    end if;
end if;

This code is used in section 83.
87. \( \text{Reset InDegree 87} \equiv \)
   \( \text{if debug then} \)
   \( \text{put("Resetting InDegree for successors of ": n'" \})}; \text{DisplayStepRecord (Current);} \)
   \( \text{end if;} \)
   \( \text{Dsize } \leftarrow \text{ListSize (S.List); } t \leftarrow \text{Current.Successors;} \text{Rewind (S.List);} \)
   \( \text{for } i \in 1 \ldots \text{Dsize loop} \)
   \( \text{if } i = 1 \text{ then} \)
   \( \text{GetCurrent (S.List, Current);} \)
   \( \text{else} \)
   \( \text{GetNext (S.List, Current);} \)
   \( \text{end if;} \)
   \( k \leftarrow \text{Current.StepId;} \)
   \( \text{if debug then} \)
   \( \text{put("StepId} _ {\text{u}} = \text{u"}; \text{put(k); put("Now checking for membership.");} \)
   \( \text{end if;} \)
   \( \text{if } \text{nat.set.member}(k,t) \text{ then} \)
   \( \text{if debug then} \)
   \( \text{put.line("(Member)";} \text{DisplayStepRecord (Current);} \)
   \( \text{end if;} \)
   \( \text{Current.InDegree } \leftarrow \text{Current.InDegree } + 1; \text{UpdateCurrent (S.List, Current);} \)
   \( \text{if debug then} \)
   \( \text{DisplayStepRecord (Current);} \)
   \( \text{end if;} \)
   \( \text{else} \)
   \( \text{if debug then} \)
   \( \text{put.line("(Not Member)");} \)
   \( \text{end if;} \)
   \( \text{end if;} \)
   \( \text{end loop;} \)
\( \text{This code is used in sections 84 and 86.} \)

88. \( \text{Variables local to BranchAndBound 73} \equiv \)
   \( t : \text{nat.set.set;} \)
   \( k : \text{natural;} \)
BRANCH AND BOUND

89.
\( \langle \text{Restore } F\_\text{Sched } 89 \rangle \equiv \)
\begin{verbatim}
if \( \neg \text{Found} \) then
  if \( \text{debug} \) then
    put.line("Restoring}_{F\_\text{Sched}.");
  end if;
  \( Dsize \leftarrow \text{ListSize}(F\_\text{Sched}); \)
  \( \text{GetNth}(F\_\text{Sched}, Dsize, DCurrent); \)
  \( \text{DeleteCurrent}(F\_\text{Sched}); \)
  if \( \text{debug} \) then
    put.line("Finished}_{restoring}_{F\_\text{Sched}.");
  end if;
end if;
end if;
\end{verbatim}
This code is used in section 83.

90.
\( \langle \text{Variables local to } \text{BranchAndBound } 73 \rangle + \equiv \)
\begin{verbatim}
  \( \text{InList} : \text{InputList}; \)
  \( DCurrent : \text{ScheduleRecord}; \)
  \( Q\} \text{Queue} : \text{ReadyList}; \)
  \( Sched : \text{ScheduleList}; \)
  \( Dsize : \text{natural}; \)
  \( Current : \text{StepRecord}; \)
  \( MAT : \text{DesignerMatrix}(1..\text{matrix'}length); \)
  \( \text{Feasible} : \text{BOOLEAN} \leftarrow \text{TRUE}; \)
  \( \text{Feasible1} : \text{BOOLEAN} \leftarrow \text{TRUE}; \)
  \( \text{FinishTime} : \text{natural} \leftarrow 0; \)
\end{verbatim}
§91. **System-dependent changes.** This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

§92. I enclose the RCS Keywords here as well, since that is how I keep track of versions.

```plaintext
$RCSfile: schedtools.aweb,v
$Revision: 1.5
$Date: 1997/08/24 22:27:29
$Author: evansjr
$Locker: evansjr
$State: Exp
```
93. Index. Here is a cross-reference table for the schedtools package. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

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Schedule Primitives

[Ada '95—Version 1.0]
(Printed September 6, 1997)
§ APPENDIX B

INTRODUCTION

1. Introduction. Here is the Ada code for utilites used in Salah Badr's scheduler program. His program was written by him May 25, 1993. It was translated by John Evans of NRaD into Donald Knuth's WEB format for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

   It is available on-line via the world-wide-web at URL:

   http://white.nosc.mil/~evansjr/literate/

2. WEB is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called "Literate Programming." For further information see the paper Literate Programming, by Donald Knuth in The Computer Journal, Vol 27, No. 2, 1984; or the book Weaving a Program: Literate Programming in WEB by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group comp.programming.literate. It has information on new tools and Frequently Asked Questions (FAQs).

3. Since the original AWEB package was written for Ada '83, it does not properly format new Ada '95 keywords protected and private. We remedy using the web format commands below.

   format protected ≡ procedure
   format private ≡ procedure

4. As a way of explanation, each "Module" withing angle brackets (< >) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. This provides a type of PDL (program descriptor language) for your program and greatly aids modularity and readability. It is also a highly effective method of top-down programming. The first module here is expanded further down, and contains most of the structure in standard Ada packages.

   (Package boiler-plate 5)
5. Schedule Primitives.

\( \langle \text{Package boiler-plate 5} \rangle \equiv \)
output to file \texttt{schedprims.ads}
\begin{verbatim}
with \texttt{generic_set.pkg};
with \texttt{generic_map.pkg};
with \texttt{test.io};
use \texttt{test.io};
with \texttt{test_io_pkg};
use \texttt{test_io_pkg};
with \texttt{Ada.Calendar};
use \texttt{Ada.calendar};
with \texttt{capability};
use \texttt{capability};
with \texttt{ustrings};
use \texttt{ustrings};
package \texttt{schedprims} is
  \langle \text{Instantiate generics 9} \rangle
  \langle \text{Specification of types and variables visible from \texttt{schedprims 6}} \rangle
  \langle \text{Specification of procedures visible from \texttt{schedprims 11}} \rangle
end \texttt{schedprims};
\end{verbatim}

output to file \texttt{schedprims.adb}
\begin{verbatim}
with \texttt{test_io.pkg};
with \texttt{calyr};
use \texttt{calyr};
package body \texttt{schedprims} is
  \langle \text{Variables local to \texttt{schedprims 25}} \rangle
  \langle \text{Procedures and Tasks in \texttt{schedprims 26}} \rangle
end \texttt{schedprims};
\end{verbatim}

This code is used in section 4.
6. I make this a tagged record so that I can extend it in other packages that inherit this one.

\[ \text{Specify of types and variables visible from \textit{schedprims} 6) } \equiv \]
\[
\text{type StepRecord is tagged record StepID : natural; Deadline : natural } \leftarrow 0; \\
\quad Priority : \text{natural}; EstimatedDuration : \text{natural } \leftarrow 0; \\
\quad EarliestStartTime : \text{natural } \leftarrow 0; ExpLevel : \text{cap_map.map; Successors : nat_set.set; Predecessors : nat_set.set; InDegree : natural } \leftarrow 0; \\
\quad RecursionLevel : \text{natural } \leftarrow 0;\]
\]
end record;
See also sections 7 and 8.
This code is used in section 5.

7.

\[ \text{Specify of types and variables visible from \textit{schedprims} 6) } + \equiv \]
\[
\text{type ScheduleRecord is record} \\
\quad \text{StepID : natural; StartTime : natural; FinishTime : natural; Designer : ustring; StepLevel : cap_map.map; RecursionLevel : natural } \leftarrow 0;\]
\]
end record;

8.

\[ \text{Specify of types and variables visible from \textit{schedprims} 6) } + \equiv \]
\[
\text{type CalendarRecord is record} \\
\quad \text{StepID : natural; StartTime : Time; FinishTime : Time; Designer : ustring; StepLevel : cap_map.map; }\]
\]
end record;
SCHEDULE PRIMITIVES

9. Here is the specification for generics.

\[
\text{Instantiate generics 9) } \equiv \\
\text{package nat_set is new generic_set.pkg(natural,5);} \\
\text{\quad \{Instantiate instances of the generic map package.\}} \\
\text{package nat_map is new generic_map.pkg(key } \Rightarrow \text{ natural, result } \Rightarrow \text{ natural);} \\
\text{package set_map is new generic_map.pkg(key } \Rightarrow \text{ natural, result } \Rightarrow \text{ nat_set.set);} \\
\text{package exp_map is new generic_map.pkg(key } \Rightarrow \text{ natural, result } \Rightarrow \text{ ExpertiseLevel);} \\
\]

See also section 10.

This code is used in section 5.

10. Here is the specification for generics.

\[
\text{\{Instantiate generics 9) } +\equiv \\
\text{package nat_io is new integer_io(natural);} \\
\text{procedure put_set is new nat_set.generic_put;} \\
\text{procedure get_set is new nat_set.generic_input;} \\
\text{procedure getf_set is new nat_set.generic_file_input;} \\
\text{package enu_io is new text_io.ENUMERATION.IO(ExpertiseLevel);} \\
\]

11. This function is used to compare the ID of StepRecords

\[
\text{\{Specification of procedures visible from schedprims 11\) } \equiv \\
\text{function CompareID(L1, L2 : StepRecord)return Boolean;} \\
\]

See also sections 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23.

This code is used in section 5.

12. This function is used to compare the ID of StepRecords

\[
\text{\{Specification of procedures visible from schedprims 11\) } +\equiv \\
\text{function IsEqual(L1, L2 : StepRecord)return Boolean;} \\
\]

13. This function is used to compare the Deadline of StepRecords

\[
\text{\{Specification of procedures visible from schedprims 11\) } +\equiv \\
\text{function CompareDeadLine(L1, L2 : StepRecord)return Boolean;} \\
\]

14. This function is used to compare the Recursion of StepRecords

\[
\text{\{Specification of procedures visible from schedprims 11\) } +\equiv \\
\text{function CompareRecursionLevel(L1, L2 : StepRecord)return Boolean;} \\
\]

15. This function is used to compare the StartTime of StepRecords

\[
\text{\{Specification of procedures visible from schedprims 11\) } +\equiv \\
\text{function CompareStartTime(L1, L2 : ScheduleRecord)return Boolean;} \\
\]

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16. This function is used to compare the Start Time of Step Records
   \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
   function CompareStartTime(\text{L1, L2 : CalendarRecord}) return Boolean;

17. Printing a step heading line before printing any records.
   \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
   procedure StepRecordHeading;

18. Display a record given its LOCATION in the list.
   \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
   procedure DisplayStepRecord(\text{rec : in StepRecord});

19. Printing a schedule heading line before printing any record.
   \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
   procedure ScheduleRecordHeading;

20. Printing a schedule heading line before printing any record.
    \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
    procedure CalendarRecordHeading;

21. Display a record given its LOCATION in the list.
    \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
    procedure DisplayScheduleRecord(\text{Current : in ScheduleRecord});

22. \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
    procedure SaveScheduleRecord(\text{Current : in ScheduleRecord; fd : file_type});

23. Display a record given its LOCATION in the list.
    \( \langle \text{Specification of procedures visible from } \text{schedprims 11} \rangle + \equiv \)
    procedure DisplayCalendarRecord(\text{Current : in CalendarRecord});

25.

\langle Variables local to schedprims 25 \rangle \equiv

debug : boolean \leftarrow false;

debug2 : boolean \leftarrow false;

This code is used in section 5.

26.

\langle Procedures and Tasks in schedprims 26 \rangle \equiv

function CompareID(L1, L2 : StepRecord) return Boolean is

begin

if L1.StepId < L2.StepId then

return True;

else

return False;

end if;

end CompareID;

See also sections 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, and 38.

This code is used in section 5.

27. StepId's are suppose to be unique.

\langle Procedures and Tasks in schedprims 26 \rangle +\equiv

function IsEqual(L1, L2 : StepRecord) return Boolean is

begin

if debug2 then

put("L1.StepId\_u="); nat.io.put(L1.StepId,1); put("\_u");

put("L2.StepId\_u="); nat.io.put(L2.StepId,1); put_line("\_u");

end if;

if L1.StepId = L2.StepId then

return True;

else

return False;

end if;

end IsEqual;
28. (Procedures and Tasks in schedprims 26) +≡

function CompareDeadline(L1, L2 : StepRecord) return Boolean is
    answer : boolean;
    A, B : natural;
begin
    A ← L1.Deadline; B ← L2.Deadline;
    if debug then
        put("L1.Deadline_elements="); nat.io.put(A); put.line(".");
        put("L2.Deadline_elements="); nat.io.put(B); put.line(".");
    end if;
    if A < B then
        answer ← True;
    else
        answer ← false;
    end if;
    if debug then
        put("CompareDeadline_elements");
        if answer then
            nat.io.put(A); put("is LESS then"); nat.io.put(B); put.line(".");
        else
            nat.io.put(A); put("is NOT LESS then"); nat.io.put(B); put.line(".");
        end if;
    end if;
    return answer;
end CompareDeadline;
29. (Procedures and Tasks in schedprims 26) +≡

function CompareRecursionLevel(L1, L2 : StepRecord) return Boolean is
  answer : boolean;
  A, B : natural;
begin
  A ← L1.RecursionLevel; B ← L2.RecursionLevel;
  if A < B then
    answer ← True;
  else
    answer ← false;
  end if;
if debug then
  put("CompareRecursionLevel>\_\_\_\_");
  if answer then
    nat.io.put(A); put("\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_"); nat.io.put(B); put.line("\_\_\_\_");
  else
    nat.io.put(A); put("\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_"); nat.io.put(B); put.line("\_\_\_\_");
  end if;
end if;
return answer;
end CompareRecursionLevel;

30. (Procedures and Tasks in schedprims 26) +≡

function CompareStartTime(L1, L2 : ScheduleRecord) return Boolean is
begin
  if L1.StartTime < L2.StartTime then
    return True;
  else
    return False;
  end if;
end CompareStartTime;
Appendix B: Schedule Primitives Body

31. (Procedures and Tasks in schedprims 26) +≡
function CompareStartTime(L1, L2 : CalendarRecord) return Boolean is
begin
  if L1.StartTime < L2.StartTime then
    return True;
  else
    return False;
  end if;
end CompareStartTime;

32. Printing a step record heading line before printing any records.
(Procedures and Tasks in schedprims 26) +≡
procedure StepRecordHeading is
begin
  text_io.put("STEP_ID,DEADLINE,PRIORITY,PREDECESSORS,SUCCESSOR,E_LEVEL,IN_DEGREE");
  text_io.put("_Recursion"); text_io.new_line;
  text_io.put("-----------u-----------u-----------u-----------u-----------u-----------");
  text_io.put("_u------"); text_io.new_line;
end StepRecordHeading;

33. Display a record given its LOCATION in the list.
(Procedures and Tasks in schedprims 26) +≡
procedure DisplayStepRecord(rec : in StepRecord) is
begin
  text_io.set_col(4); test_io.pkg.put(rec.StepId); text_io.set_col(12);
  test_io.pkg.put(rec.Deadline); text_io.set_col(23); test_io.pkg.put(rec.Priority);
  text_io.set_col(31); put.set(rec.Predecessors); text_io.set_col(41);
  put.set(rec.Successors); text_io.set_col(49); print_capabilities(rec.ExpLevel);
  text_io.set_col(61); test_io.pkg.put(rec.InDegree); text_io.set_col(72);
  test_io.pkg.put(rec.RecursionLevel); text_io.new_line;
end DisplayStepRecord;

34. Printing a schedule heading line before printing any record.
(Procedures and Tasks in schedprims 26) +≡
procedure ScheduleRecordHeading is
begin
  text_io.put("ID,START_TIME,FINISH_TIME,S_LEVEL,LEVEL,DEVELOPER");
  text_io.new_line;
  text_io.put("-----------u-----------u-----------");
  text_io.new_line;
end ScheduleRecordHeading;
SCHEDULE PRIMITIVES BODY

35. Printing a schedule heading line before printing any record.

    procedure CalendarRecordHeading is
       begin
          text_io.put("ID,START_TIME,FINISH_TIME,LEVEL,DEVELOPER");
          text_io.new_line;
          text_io.put("----------,----------,----------,----------");
          text_io.new_line;
       end CalendarRecordHeading;

36. Display a record given its LOCATION in the list.

    procedure DisplayScheduleRecord (Current : in ScheduleRecord) is
       begin
          text_io.set_col(1); nat_io.put(Current.StepID,1); text_io.set_col(10);
          nat_io.put(Current.StartTime,1); text_io.set_col(20);
          nat_io.put(Current.FinishTime,1); text_io.set_col(35);
          print_capabilities(Current.StepLevel); text_io.put("_");
          text_io.put(S(Current.Designer)); text_io.new_line;
       end DisplayScheduleRecord;

37. Display a record given its LOCATION in the list.

    procedure SaveScheduleRecord (Current : in ScheduleRecord; fd : file_type) is
       begin
          text_io.set_col(fd,1); put(fd, Current.StepID,1); text_io.set_col(fd,10);
          put(fd, Current.StartTime,1); text_io.set_col(fd,20);
          put(fd, Current.FinishTime,1); text_io.set_col(fd,35);
          print_capabilities(fd, Current.StepLevel); put(fd,"_"); put(fd, Current.Designer);
          text_io.new_line(fd);
       end SaveScheduleRecord;
38. Display a record given its LOCATION in the list.

(Procedures and Tasks in schedprims 26) +

procedure DisplayCalendarRecord (Current : in CalendarRecord) is

begin
  text_io.set_col(2); text_io.pkg.put(Current.StepID); text_io.set_col(10);
  calyr.print_date(Current.StartTime); text_io.set_col(25);
  calyr.print_date(Current.FinishTime); text_io.set_col(40);
  print_capabilities(Current.StepLevel); text_io.put("WS");
  text_io.put(S(Current.Designer)); text_io.new_line;
end DisplayCalendarRecord;
39. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

40. RCS Keywords.

$RCSfile: schedprims.aweb,v$
$Revision: 1.4$
$Date: 1997/08/22 23:14:45$
$Author: evansjr$
$Id: schedprims.aweb,v 1.4 1997/08/22 23:14:45 evansjr Exp evansjr$
$Locker: evansjr$
$State: Exp$
41. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

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NAMES OF THE SECTIONS

(Instantiate generics 9, 10) Used in section 5.
(Package boiler-plate 5) Used in section 4.
(Procedures and Tasks in schedprims 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38)
Used in section 5.
(Specification of procedures visible from schedprims 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23) Used in section 5.
(Specification of types and variables visible from schedprims 6, 7, 8) Used in section 5.
(Variables local to schedprims 25) Used in section 5.

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September 18, 1997

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1. **Introduction.** Here is the Ada code for Salah Badr's scheduler program. It was written by him May 25, 1993. Here it has been translated to Donald Knuth's WEB format for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

   It is available on-line via the world-wide-web at URL:

   http://white.nosc.mil/~evansjr/literate/

2. **WEB** is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called "Literate Programming." For further information see the paper *Literate Programming*, by Donald Knuth in *The Computer Journal*, Vol 27, No. 2, 1984; or the book *Weaving a Program: Literate Programming in WEB* by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group *comp.programming.literate*. It has information on new tools and Frequently Asked Questions (FAQs).

3. The program consists of several packages that are declared right now; each of these packages and either the specification and the body of the packages are sent to a separate file. The main program itself is declared later. (Since the original AWEB package was written for Ada '83, it does not properly format new Ada '95 keywords `protected` and `private`. We remedy using the web format commands below.

   format `protected` ≡ `procedure`

   format `private` ≡ `procedure`

4. As a way of explanation, each "Module" within angle brackets (`< >`) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. This provides a type of PDL (program descriptor language) for your program and greatly aids modularity and readability. It is also a highly effective method of top-down programming.
5. Main driver. This is the main routine that starts everything.
6. (Note: The following format is used by all the packages. We write the top-level code, in macro-level descriptions, and it gets expanded into code further down. This way you can write small, easily understood modules. It also lets you declare and describe variables and types where you need them.)

    output to file main.adb

    pragma suppress(all_checks);
    with SchedTools;
    with scheduler;
    use scheduler;
    with text_io;
    use text_io;
    with capability;
    use capability;
    with ustrings;
    use ustrings;

    procedure main is
    begin
        loop
            begin
                SCHEDULER_MENU; get(SELECTOR); skip_line;
                case SELECTOR is
                when 1 =>
                    (Create new step list 10)
                when 2 =>
                    (Read in developer list 12)
                when 3 =>
                    (Schedule steps according to their deadlines 14)
                when 4 =>
                    (Print all steps in the ready queue 15)
                when 5 =>
                    (Print all step records 19)
                when 6 =>
                    (Print final schedule 16)
                when 7 =>
                    (Save final schedule 17)
                when 8 =>
                    (Print calendar schedule 18)
                when 9 =>
                    (Exit the program to the system 20)
                when others =>
                    (Exception handling for selector case 21)
                end case;
            exception
            exception
when storage_error ⇒
  put_line("You have a storage error.");
  put("Your level of recursion is ", recursion_level);
  put_line(".");
when Data_Error ⇒
  put_line("Value entered is not in proper range. Please try again.");
  New_line; Skip_Line;
when SchedTools.NoFeasibleScheduleFound ⇒
  put_line("Unable to find feasible schedule. Need to increase laxity.");
  New_line;
when NoDevelopers ⇒
  put_line("No developers to schedule tasks with. Please try again.");
  New_line;
end;
end loop;
end main;

7. As a way of explanation, each "Module" withing angle brackets (< >) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. This provides a type of PDL (program descriptor language) for your program and greatly aids modularity and readability. It is also a highly effective method of top-down programming. The first module here is expanded further down, and contains most of the structure in standard Ada packages.

(Package boiler-plate 22)

8.

(Instantiate generic packages 8) $\equiv$

package nat_io is new integer_io(natural);
  use nat_io;
This code is used in section 6.

9.

(Variables local to main 9) $\equiv$

type selector_type is new natural range 1..9;
  selector : selector_type := 1;
package sel_io is new integer_io(selector_type);
  use sel_io;
See also sections 11 and 13.
This code is used in section 6.
10. This routine has been modified to read in a file and build up the linked list of "steps."

( Create new step list 10 ) ≡
  if  num_developers > 0 then
    MakeNewStepList(num_developers);
  else
    raise NoDevelopers;
  end if;

This code is used in section 6.

11.

( Variables local to main 9 ) +≡
  NoDevelopers : exception;

12.

( Read in developer list 12 ) ≡
  put_line( "Please enter developer file name: " );
  get_line( infile );
  get_developers( S(infile) );
  num_developers ← get_num_developers;

This code is used in section 6.

13.

( Variables local to main 9 ) +≡
  infile : ustring;
  num_developers : natural ← 0;

14.

( Schedule steps according to their deadlines 14 ) ≡
  Put_line("Scheduling steps according to their deadlines.");
  MakeDeadlineFirstSchedule( max_recursion, num_developers);

This code is used in section 6.

15.

( Print all steps in the ready queue 15 ) ≡
  PrintReadyQueue;

This code is used in section 6.

16.

( Print final schedule 16 ) ≡
  PrintFinalSchedule;

This code is used in section 6.
17.  
( Save final schedule 17 ) ≡
   SaveFinalSchedule;
This code is used in section 6.

18.  
( Print calendar schedule 18 ) ≡
   PrintCalendarSchedule;
This code is used in section 6.

19.  
( Print all step records 19 ) ≡
   new line; PrintStepList;
This code is used in section 6.

20.  
( Exit the program to the system 20 ) ≡
   put("Maximum recursion level is \_\_\_\_"); nat_i.o.put(max_recursion); put_line("...");
   put("Current recursion level is \_\_\_\_"); nat_i.o.put(recursion_level); put_line("...");
   put("thank you... Bye... Bye"); new_line; exit;
This code is used in section 6.

21.  
( Exception handling for selector case 21 ) ≡
   put("BAD\_\_\_\_CHOICE... PLEASE\_\_\_\_TRY\_\_\_\_AGAIN"); new_line;
This code is used in section 6.
22. Scheduler specification.

(Package boiler-plate 22) \equiv

output to file scheduler.ads

with generic_set.pkg;
with generic_map.pkg;
with generic_list;
with schedprims;
use schedprims;
with schedtools;
use schedtools;
with TEXT.IO;
use TEXT.IO;
with test_io.pkg;
use test_io.pkg;

package scheduler is

(Specification of types and variables visible from scheduler 23)
(Specification of procedures visible from scheduler 24)

end scheduler;

output to file scheduler.adb

with unchecked_deallocation;

package body scheduler is

(Procedures and Tasks in scheduler 33)

end scheduler;

This code is used in section 7.

23. Here are variables global to the recursion.

(Specification of types and variables visible from scheduler 23) \equiv

recursion_level : natural \leftarrow 0;
max_recursion : natural \leftarrow 0;

This code is used in section 22.


(Specification of procedures visible from scheduler 24) \equiv

Procedure MakeNewStepList(num_developers : natural);

See also sections 25, 26, 27, 28, 29, 30, and 31.

This code is used in section 22.


(Specification of procedures visible from scheduler 24) \equiv

Procedure MakeDeadlineFirstSchedule(max_recursion : in out natural;
num_developers : natural);
26. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{SCHEDULER\_MENU};

27. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{PrintReadyQueue};

28. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{PrintFinalSchedule};

29. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{SaveFinalSchedule};

30. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{PrintCalendarSchedule};

31. \( \text{Specification of procedures visible from } \text{scheduler } 24 \) \( + \equiv \) 
procedure \textit{PrintStepList};
32. Scheduler Body.

33. Creating new step.

(Procedures and Tasks in scheduler 33) ≡

Procedure MakeNewStepList(num_developers : natural) is
begin
    CreateNewStepList(StepList);
end MakeNewStepList;

See also sections 34, 35, 36, 37, 38, 39, and 40.
This code is used in section 22.

34.

(Procedures and Tasks in scheduler 33) ≡

Procedure MakeDeadlineFirstSchedule(max_recursion : in out natural;
                                    num_developers : natural) is
begin
    put_line("Start of CreateDeadlineFirstSchedule.");
    CreateDeadlineFirstSchedule(max_recursion, num_developers);
    put_line("End of CreateDeadlineFirstSchedule.");
end MakeDeadlineFirstSchedule;
35. DISPLAY THE MAIN MENU.

\[\text{Procedures and Tasks in scheduler 33} \equiv\]

\begin{verbatim}
procedure SCHEDULER_MENU is
begin
  new_line; set_col(25); put("MAIN\u_MENU"); new_line; set_col(25);
  put("---------"); new_line(2);
  set_col(5); put("[1]\u_\text{Read}_{\text{in}}\u_\text{step}_{\text{list}}");
  new_line;
  set_col(5); put("[2]\u_\text{Read}_{\text{in}}\u_\text{developer}_{\text{list}}");
  new_line;
  set_col(5); put("[3]\u_\text{schedule}_{\text{steps}}\u_{\text{using}}\u_{\text{BranchAndBound}}");
  new_line;
  set_col(5); put("[4]\u_\text{Print}_{\text{ready}_{\text{queue}}}");
  new_line;
  set_col(5); put("[5]\u_\text{Print}_{\text{step}_{\text{list}}}");
  new_line;
  set_col(5); put("[6]\u_\text{Print}_{\text{final}_{\text{schedule}}}");
  new_line;
  set_col(5); put("[7]\u_\text{Save}_{\text{final}_{\text{schedule}}}");
  new_line;
  set_col(5); put("[8]\u_\text{Print}_{\text{Calendar}_{\text{schedule}}}");
  new_line;
  set_col(5); put("[9]\u_\text{Quit}"); new_line(3); set_col(5);
  put("Enter\_the\_number\_of\_your\_choice:\u\u\u");
end SCHEDULER_MENU;
\end{verbatim}

36.

\[\text{Procedures and Tasks in scheduler 33} \equiv\]

\begin{verbatim}
procedure PrintFinalSchedule is
begin
  PrintAllScheduleRecords(Schedule);
end PrintFinalSchedule;
\end{verbatim}

37.

\[\text{Procedures and Tasks in scheduler 33} \equiv\]

\begin{verbatim}
procedure SaveFinalSchedule is
begin
  SaveAllScheduleRecords(Schedule);
end SaveFinalSchedule;
\end{verbatim}
38. (Procedures and Tasks in scheduler 33) \( \equiv \)
   procedure PrintCalendarSchedule is
   begin
     PrintAllCalendarRecords (Schedule);
   end PrintCalendarSchedule;

39. (Procedures and Tasks in scheduler 33) \( \equiv \)
   procedure PrintReadyQueue is
   begin
     PrintAllStepRecords (ReadyQueue);
   end PrintReadyQueue;

40. (Procedures and Tasks in scheduler 33) \( \equiv \)
   procedure PrintStepList is
   begin
     PrintAllStepRecords (StepList);
   end PrintStepList;
41. Continuous Time to Calendar Time Translator. The purpose of this routine is to take the output of the scheduler and translate the continuous time fields ($\text{StartTime}$ and $\text{FinishTime}$) to calendar dates.

\begin{verbatim}
output to file contocal.ado
pragma suppress(all_checks);
with text_io;
use text_io;
with getopt;
use getopt;
with Ustrings;
use Ustrings;
with Ada.Calendar;
use Ada.Calendar;
with calyr;
use calyr;
with capability;
use capability;
procedure ConToCal is
  (Variables local to ConToCal 45)
package boolio is new enumeration_io(boolean);
use boolio;
begin
  (Get parameters to ConToCal 43)
  (Open files 51)
  (Iterate through input file 53) end ConToCal;
\end{verbatim}

42. The command syntax is as follows:

\texttt{contocal [-nrad < boolean>] [-start < startdate>] infile outfile}

43. The -nrad option is by default false, but when set to \textit{true} will create a schedule that respects NRaD off-fridays. An example invocation could be:

\texttt{contocal -nrad true -start 07/03/97-00 infile outfile}

If no start is given then the default is the same as the example.

\begin{verbatim}
(Get parameters to ConToCal 43) ≡
  (Get nrad 44)
  (Get start date 46)
  (Get input file 48)
  (Get output file 50)
\end{verbatim}

This code is used in section 41.
(Get nrad 44) ≡
  if option_present(U("-nrad")) then
    get_option(U("-nrad"), param); get(S(param), nrad, Last);
  else
    nrad ← false;
  end if;
This code is used in section 43.

(Variables local to ConToCal 45) ≡
  param : Ustring;
  Last : positive;
  nrad : boolean;
See also sections 47, 49, 52, 55, 56, and 58.
This code is used in section 41.

(Get start date 46) ≡
  if option_present(U("-start")) then
    get_option(U("-start"), param); StartDate ← get_date(param);
  else
    StartDate ← Time_Of(1997, 7, 3, 0.0);
  end if;
This code is used in section 43.

(Variables local to ConToCal 45) +≡
  StartDate : Time;

(Get input file 48) ≡
  if name_present(1) then
    get_name(infile, 1);
  else
    raise nofilename;
  end if;
This code is used in section 43.
49.

\{ Variables local to ConToCal 45 \} \equiv

  nofilename : exception;
  infile, outfile : Ustring;

50.

\{ Get output file 50 \} \equiv

  if name_present(2) then
    get.name(outfile, 2);
  else
    raise nofilename;
  end if;

This code is used in section 43.

51.

\{ Open files 51 \} \equiv

  open(data_file, in_file, S(infile)); create(data2_file, out_file, S(outfile));

This code is used in section 41.

52.

\{ Variables local to ConToCal 45 \} \equiv

  data_file, data2_file : file_type;

53.

\{ Iterate through input file 53 \} \equiv

  while \neg End_Of_File(data_file) loop
    \{ Read in record 54 \}
    \{ Do time translations 57 \}
    \{ Write out new record 59 \}
  end loop;

This code is used in section 41.
54. A typical input file would look like the following:

<table>
<thead>
<tr>
<th></th>
<th>3</th>
<th>HIGH</th>
<th>H1</th>
<th>0</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>MEDIUM</td>
<td>M1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>LOW</td>
<td>L1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>HIGH</td>
<td>H1</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>MEDIUM</td>
<td>M1</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>LOW</td>
<td>L1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>MEDIUM</td>
<td>M1</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>LOW</td>
<td>L1</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>HIGH</td>
<td>H1</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>MEDIUM</td>
<td>M1</td>
<td>14</td>
<td>24</td>
</tr>
</tbody>
</table>

The second to last column is the start time and the last column is the end time.

\[
\text{(Read in record 54) } \equiv \n\]

\[
\text{kntr } \leftarrow \text{kntr } + 1; \text{ put("Reading in record"); put(kntr); put_line("."); get(data_file, stepid); get(data_file, Start); get(data_file, Finish); get_capability(data_file, ExpLevel); get_line(data_file, Developer);}
\]

This code is used in section 53.

55.

\[
\text{(Variables local to ConToCal 45) } \equiv \n\]

\[
\text{type ExpertiseLevel is (low, medium, high);} \n\]

\[
\text{stepid : natural;}
\]

\[
\text{ExpLevel : cap_map.map;}
\]

\[
\text{Developer : ustring;}
\]

\[
\text{start, finish : natural;}
\]

\[
\text{kntr : natural } \leftarrow 0;
\]

56.

\[
\text{(Variables local to ConToCal 45) } \equiv \n\]

\[
\text{package exp/io is new enumeration/io(ExpertiseLevel);} \n\]

\[
\text{use exp/io;}
\]

\[
\text{package nat/io is new integer/io(natural);} \n\]

\[
\text{use nat/io;}
\]

57.

\[
\text{(Do time translations 57) } \equiv \n\]

\[
\text{dur } \leftarrow \text{ConvertHoursToDuration(Start);} \n\]

\[
\text{StartTime } \leftarrow \text{DurationToCalendarTime(StartDate, dailyhours, dur, NRaD);} \n\]

\[
\text{dur } \leftarrow \text{ConvertHoursToDuration(Finish);} \n\]

\[
\text{FinishTime } \leftarrow \text{DurationToCalendarTime(StartDate, dailyhours, dur, NRaD);} \n\]

This code is used in section 53.
58.

(Variables local to ConToCal 45) ≡

dur : Duration;

StartTime, FinishTime : Time;

dailyhours : WorkHours ← (ConvertHoursToDuration(8), ConvertHoursToDuration(8),

ConvertHoursToDuration(8), ConvertHoursToDuration(8),

ConvertHoursToDuration(8));

59.

(Write out new record 59) ≡

set_col(data2_file, 1); put(data2_file, stepid, 1); set_col(data2_file, 10);

print_date(data2_file, StartTime); set_col(data2_file, 25);

print_date(data2_file, FinishTime); set_col(data2_file, 40);

print_capabilities(data2_file, ExpLevel); put(data2_file, "\n");

put(data2_file, Developer); new_line(data2_file);

This code is used in section 53.
§60  APPENDIX C  SYSTEM-DEPENDENT CHANGES

60. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

61. RCS Keywords.

    $RCSfile: main.aweb,v$
    $Revision: 1.5$
    $Date: 1997/08/22 23:14:45$
    $Author: evansjr$
    $Id: main.aweb,v 1.5 1997/08/22 23:14:45 evansjr Exp evansjr$
    $Locker: evansjr$
    $State: Exp$
INDEX

62. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity’s body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like “ASCII code” are indexed here too.

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Generic List processing routines

[Ada '95—Version 1.0]
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1. **Introduction.** The scheduler designed and implemented by Salah Badr uses lists extensively. However, it has specific routines for each list used by the scheduler. This is redundant, as well as error prone. In my design to eliminate some large data structures that are slightly modified and duplicated in a very recursive and space consuming manner, I have decided to use additional linked lists to keep track of additions and deletions at each level of recursion. By keeping track of just the “changes” this will turn an N squared space problem into one that is linear. (This is shown to be true, later.)

2. So since linked lists are used extensively, it pays to have a single generic routine. The implementation is thus hidden from the user. This allows “information-hiding,” and increased modularity,

3. This code is written using Donald Knuth’s **WEB** paradigm for literate programming. To compile and link the code in its present format you will need the Ada version of the **WEB** tool.

   It is available on-line via the world-wide-web at URL:

   http://white.nosc.mil/~evansjr/literate/

4. **WEB** is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called “Literate Programming.” For further information see the paper *Literate Programming*, by Donald Knuth in *The Computer Journal*, Vol 27, No. 2, 1984; or the book *Weaving a Program: Literate Programming in WEB* by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group *comp.programming.literate*. It has information on new tools and Frequently Asked Questions (FAQs).

5. The program consists of several packages that are declared right now; each of these packages and either the specification and the body of the packages are sent to a separate file. The main program itself is declared later. (Since the original AWEB package was written for Ada ‘83, it does not properly format new Ada ’95 keywords **protected** and **private**. We remedy using the web format commands below.

   format **protected** \equiv **procedure**
   format **private** \equiv **procedure**

6. As a way of explanation, each “Module” withing angle brackets (< >) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. It is top-down in appearance, and in actual fact.

7. All the modules follow the same, top-down format. I will group all the boiler-plate into one module, for the compiler, but you will see it with the packages, as they are described.

   (Package boiler-plate 8)
8. List Specification. This specification is a modification of the one presented in the book *Ada 95 Problem Solving and Program Design*, by Michael Feldman and Elliot B. Koffman. The implementation was left as an exercise for the student.

\[
\text{(Package boiler-plate 8) } \equiv \\
\text{output to file generic_list.ads} \\
\text{with TEXT.IO;} \\
\text{use TEXT.IO;} \\
\text{generic} \\
\text{type ElementType is private ; } \{ \text{Any nonlimited type will do} \} \\
\text{with procedure DisplayElement(Item : IN ElementType);} \\
\text{with function }"<"(L1, L2 : ElementType) return Boolean ; \\
\text{with function }"="(L1, L2 : ElementType) return Boolean is <>; \\
\text{package generic_list is} \\
\text{(Specification of types and variables visible from generic_list 9)} \{ \text{Specification of procedures visible from generic_list 12} \} \text{ private} \\
\text{(Specification of private types and variables in generic_list 10)} \\
\text{end generic_list;} \\
\text{output to file generic_list.adb} \\
\text{(Packages needed by generic_list body 32)} \\
\text{package body generic_list is} \\
\text{(Variables local to generic_list 30)} \\
\text{(Procedures and Tasks in generic_list 33)} \\
\text{end generic_list;} \\
\text{This code is used in section 7.}
\]

9.

\[
\text{(Specification of types and variables visible from generic_list 9) } \equiv \\
\text{type list is limited private ;} \\
\text{ListEmpty : exception;} \\
\text{This code is used in section 8.}
\]

10.

\[
\text{(Specification of private types and variables in generic_list 10) } \equiv \\
\text{type ListNode; type ListPtr is access ListNode;} \\
\text{type ListNode is record} \\
\text{Element : ElementType; } \\
\text{Next : ListPtr; } \\
\text{end record;} \\
\text{See also section 11.} \\
\text{This code is used in section 8.}
\]

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LIST SPECIFICATION

11. Added Size field to original code.

(Specification of private types and variables in generic_list 10) +≡

type List is

  record
    Size : Natural;
    Head : ListPtr;
    Tail : ListPtr;
    Current : ListPtr;
    Previous : ListPtr;
  end record;

12.

(Specification of procedures visible from generic_list 12) +≡

  function ListSize(L : in List)return natural;

See also sections 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28.
This code is used in section 8.

13. Returns True if L is empty, False otherwise.

(Specification of procedures visible from generic_list 12) +≡

  function IsEmpty(L : IN List)RETURN Boolean;

14.

Pre: Element is defined; L may be empty.
Post: Element is inserted at the beginning of L.

(Specification of procedures visible from generic_list 12) +≡

  procedure AddToFront(L : in out List; Element : in ElementType);

15.

Pre: L is defined; L may be empty.
Post: returns a complete copy of the list L.
Raises: ListEmpty if the list is empty before the retrieval.

(Specification of procedures visible from generic_list 12) +≡

  function RetrieveFront(L : in List)return ElementType;

16.

Pre: L is defined; L may be empty.
Post: The first node of L is removed.
 Raises: ListEmpty if the list is empty before the removal.

(Specification of procedures visible from generic_list 12) +≡

  procedure RemoveFront(L : in out List);
17.  Pre: L is defined.
    Post: L is empty.
    \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure MakeEmpty}(L : \text{in out List});
    \end{align*}
    \]

18.  Pre: \textit{Element} is defined; L may be empty.
    Post: \textit{Element} is appended to the end of L.
    \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure AddToEnd}(L : \text{in out List}; E : \text{in ElementType});
    \end{align*}
    \]

19.  Pre: Source may be empty.
    Post: Returns a complete copy of Source in Target.
    \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure Copy}(S : \text{in List}; T : \text{out List});
    \end{align*}
    \]

20.  Pre: L may be empty.
    Post: displays the contents of L's Element fields, in the
    order in which they appear in L.
    \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure Display}(L : \text{IN List});
    \end{align*}
    \]

21.  \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure InsertInOrder}(L : \text{in out List}; E : \text{ElementType});
    \end{align*}
    \]

22.  \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure GetNext}(L : \text{in out List}; E : \text{out ElementType});
    \end{align*}
    \]

23.  \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure DeleteCurrent}(L : \text{in out List});
    \end{align*}
    \]

24.  \[
    \langle \text{Specification of procedures visible from generic.list 12} \rangle \equiv
    \begin{align*}
    \text{procedure DeleteMatching}(L : \text{in out List}; E : \text{in ElementType}; \text{success} : \text{out boolean});
    \end{align*}
    \]

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25. 
(Specification of procedures visible from generic_list 12) +≡ 
procedure GetCurrent(\textit{L} : in \textit{List}; \textit{Element} : out \textit{ElementType});

26. 
(Specification of procedures visible from generic_list 12) +≡ 
procedure UpdateCurrent(\textit{L} : in \textit{List}; \textit{Element} : in \textit{ElementType});

27. 
(Specification of procedures visible from generic_list 12) +≡ 
procedure GetNth(\textit{L} : in out \textit{List}; \textit{N} : in \text{natural}; \textit{Element} : out \textit{ElementType});

28. 
(Specification of procedures visible from generic_list 12) +≡ 
procedure Rewind(\textit{L} : in out \textit{List});
29. List Body.

30.
\[ \text{Variables local to } \text{generic.list 30} \equiv \]
\[ \text{debug : boolean } \leftarrow \text{false}; \]
See also section 31.
This code is used in section 8.

31.
\[ \text{Variables local to } \text{generic.list 30} + \equiv \]
\[ \text{procedure Dispose is new unchecked.deallocation (Object } \Rightarrow \text{ListNode,} \]
\[ \text{Name } \Rightarrow \text{ListPtr);} \]
\[ \text{package nat.io is new integer.io(natural);} \]

32.
\[ \text{Packages needed by } \text{generic.list body 32} \equiv \]
\[ \text{with unchecked.deallocation;} \]
\[ \text{with Ustrings;} \]
\[ \text{use Ustrings;} \]
This code is used in section 8.

33.
\[ \text{Procedures and Tasks in } \text{generic.list 33} \equiv \]
\[ \text{function ListSize(L : in List) return Natural is} \]
\[ \text{begin} \]
\[ \text{return L.Size;} \]
\[ \text{end ListSize;} \]
See also sections 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, and 49.
This code is used in section 8.

34. Returns True if L is empty, False otherwise.
\[ \text{Procedures and Tasks in } \text{generic.list 33} + \equiv \]
\[ \text{functionIsEmpty(L : IN List) RETURN Boolean is} \]
\[ \text{begin} \]
\[ \text{if ListSize(L) = 0 then} \]
\[ \text{return True;} \]
\[ \text{else} \]
\[ \text{return False;} \]
\[ \text{end if;} \]
\[ \text{end IsEmpty;} \]
35.
Pre: $Element$ is defined; $L$ may be empty.
Post: $Element$ is inserted at the beginning of $L$.

(Procedures and Tasks in $generic\_list$ 33) +⇒
procedure AddToFront($L$ : in out List; $Element$ : in ElementType) is
  $Temp$ : ListPtr;
begin
  $Temp ← new ListNode$; $Temp$.all.Element ← $Element$; $Temp$.all.Next ← $L$.Head;
  $L$.Head ← $Temp$; $L$.Size ← $L$.Size + 1;
  if $L$.Size = 1 then
    $L$.Tail ← $L$.Head;
  end if;
end AddToFront;

36.
Pre: $L$ is defined; $L$ may be empty.
Post: returns a complete copy of the list $L$.
Raises: $ListEmpty$ if the list is empty before the retrieval.

(Procedures and Tasks in $generic\_list$ 33) +⇒
function RetrieveFront($L$ : in List) return ElementType is
  $Temp$ : ListPtr;
begin
  if $L$.Head = null then
    raise $ListEmpty$;
  else  { $L$.Head points to a node; remove it }
    $Temp ← L$.Head; return $Temp$.Element;
  end if;
end RetrieveFront;
37. Pre: \( L \) is defined; \( L \) may be empty.
Post: The first node of \( L \) is removed.
Raises: \( ListEmpty \) if the list is empty before the removal.

\[
\text{procedure } \text{RemoveFront}(L : \text{in out List}) \text{ is}
\begin{align*}
&\text{Temp : ListPtr;} \\
&\text{begin}
&\quad \text{if } L.\text{Head} = \text{null then}
&\quad\quad \text{raise ListEmpty;} \\
&\quad \text{else } \{ L.\text{Head} \text{ points to a node; remove it } \}
&\quad\quad \text{Temp} \leftarrow L.\text{Head}; L.\text{Head} \leftarrow L.\text{Head}.\text{all.Next}; \{ \text{jump around first node} \}
&\quad\quad \text{Dispose}(X \Rightarrow \text{Temp}); L.\text{Size} \leftarrow L.\text{Size} - 1;
&\quad \text{end if}
&\text{end RemoveFront;}
\end{align*}
\]

38. \( \text{procedure } \text{MakeEmpty}(L : \text{IN OUT List}) \text{ is} \)
\[
\begin{align*}
&\text{ptr : ListPtr;} \\
&\text{begin}
&\quad \text{While } L.\text{Head} \neq \text{null loop}
&\quad\quad \text{RemoveFront}(L); \\
&\quad \text{end loop;}
&\quad L.\text{Size} \leftarrow 0; L.\text{Tail} \leftarrow \text{null;}
&\text{end MakeEmpty;}
\end{align*}
\]
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39.
Pre: Element is defined; L may be empty.
Post: Element is appended to the end of L.

(Procedures and Tasks in generic_list 33) \equiv

procedure AddToEnd(L: IN OUT List; Element: IN ElementType) is
ptr : ListPtr;
begin
  if debug then
    put("AddToEnd\nAdding\to\end\of\list:\n"); DisplayElement(Element);
  end if;
  if L.Head = null then
    L.Tail \leftarrow new ListNode'(Element, null); L.Head \leftarrow L.Tail;
  else
    ptr \leftarrow new ListNode'(Element, null); L.Tail.all.next \leftarrow ptr; L.Tail \leftarrow ptr;
  end if;
  L.Size \leftarrow L.Size + 1;
end AddToEnd;

40.
Pre: Source may be empty.
Post: Returns a complete copy of Source in Target.

(Procedures and Tasks in generic_list 33) \equiv

procedure Copy(Source: in List; Target: out List) is
ptr : listptr;
begin
  ptr \leftarrow Source.head; MakeEmpty(Target);
  while ptr \neq null loop
    AddToEnd(Target, ptr.all.element); ptr \leftarrow ptr.all.next;
  end loop;
end Copy;
41.
Pre: $L$ may be empty.
Post: displays the contents of $L$'s Element fields, in the
order in which they appear in $L$.

$$
\text{Procedures and Tasks in } \textit{generic\_list 33} + \equiv \\
\text{procedure } \textit{Display}(L : \textit{IN List}) \text{ is} \\
\hspace{1em} \text{ptr : ListPtr;} \\
\hspace{1em} \text{begin} \\
\hspace{2em} \text{if } \textit{debug} \text{ then} \\
\hspace{3em} \text{put\_Line("Display"}); \\
\hspace{2em} \text{end if;} \\
\hspace{2em} \text{ptr } \leftarrow L.\text{Head}; \\
\hspace{2em} \text{while } \text{ptr} \neq \text{null} \text{ loop} \\
\hspace{3em} \text{Display\_Element(ptr.all.Element)}; \hspace{1em} \text{ptr } \leftarrow \text{ptr.all.Next}; \\
\hspace{2em} \text{end loop;} \\
\hspace{1em} \text{end Display;} \\
$$
(Procedures and Tasks in generic_list 33) ⊆

procedure InsertInOrder (L : in out List; Element : ElementType) is
  Current : ListPtr;
  Previous : ListPtr;
  Temp : ListPtr;
begin
  if debug then
    put("InsertInOrder>"); put_line("Your input list is:"); display(L);
    put("InsertInOrder>"); put_line("Your input element is:");
    display_element(Element);
  end if;
  if L.Head = null then
    AddToFront(L, Element);
  elsif Element < L.Head.all.Element then
    AddToFront(L, Element);
  elsif (L.Tail.all.Element < Element) ∨ (L.Size = 1) then
    AddToEnd(L, Element);
  else
    if L.size = 1 then
      put_line("InsertInOrder> Should not be here!"); raise ListEmpty;
    end if;
    Temp ← new ListNode'(Element, null); Previous ← L.Head;
    Current ← Previous.all.next;
    while Current.all.element < Element loop
      Previous ← Current; Current ← Current.all.next;
    end loop;
    Temp.all.next ← Current; Previous.all.next ← Temp; L.Size ← L.Size + 1;
  end if;
  if debug then
    put("InsertInOrder>"); put_line("Your input list is now:"); display(L);
  end if;
end InsertInOrder;
LIST BODY

43. Must be used with ListSize and Rewind or you will never know when you are at the end of the list.

\[ \text{Procedures and Tasks in } \text{generic_list 33} \] 
\[ \text{procedure GetNth}(L : \text{in out List}; N : \text{in natural}; \text{Element : out ElementType}) \text{ is} \]
\[ \text{begin} \]
\[ \text{if debug then} \]
\[ \quad \text{put("GetNth\_Getting\_"); nat\_io\_put}(N,1); \text{put("\_th\_record\_=>");} \]
\[ \text{end if;} \]
\[ \text{if } L.\text{Head} = \text{null then} \]
\[ \quad \text{raise ListEmpty;} \]
\[ \text{elsif } N > L.\text{Size} \text{ then} \]
\[ \quad \text{raise ListEmpty;} \]
\[ \text{elsif } N = 1 \text{ then} \]
\[ \quad L.\text{Current} \leftarrow L.\text{Head}; L.\text{Previous} \leftarrow L.\text{Tail}; \]
\[ \text{else} \]
\[ \quad \text{Rewind}(L); \]
\[ \quad \text{for } i \in 2 .. N \text{ loop} \]
\[ \quad \quad L.\text{Previous} \leftarrow L.\text{Current}; L.\text{Current} \leftarrow L.\text{Current}.\text{all}.\text{next}; \]
\[ \quad \text{end loop;} \]
\[ \text{end if;} \]
\[ \quad \text{Element} \leftarrow L.\text{Current}.\text{all}.\text{element}; \]
\[ \quad \text{if debug then} \]
\[ \quad \quad \text{DisplayElement}(\text{Element}); \]
\[ \quad \text{end if;} \]
\[ \text{end GetNth;} \]

44. Must be used with ListSize and Rewind or you will never know when you are at the end of the list.

\[ \text{Procedures and Tasks in } \text{generic_list 33} \]
\[ \text{procedure GetCurrent}(L : \text{in List}; \text{Element : out ElementType}) \text{ is} \]
\[ \text{begin} \]
\[ \text{if } L.\text{Head} = \text{null then} \]
\[ \quad \text{raise ListEmpty;} \]
\[ \text{end if;} \]
\[ \quad \text{Element} \leftarrow L.\text{Current}.\text{all}.\text{element}; \]
\[ \text{end GetCurrent;} \]
45. Must be used with ListSize and Rewind or you will never know when you are at the end of the list.

\[\text{(Procedures and Tasks in generic\_list 33)} \equiv \]
\[\text{procedure UpdateCurrent}(L : \text{in List}; \text{Element : in ElementType}) \text{ is} \]
\[\text{begin} \]
\[\text{if } L.\text{Head} = \text{null then} \]
\[\text{raise ListEmpty;} \]
\[\text{end if;} \]
\[L.\text{Current}.\text{all.element} \leftarrow \text{Element;} \]
\[\text{end UpdateCurrent;} \]

46.

\[\text{(Procedures and Tasks in generic\_list 33)} \equiv \]
\[\text{procedure DeleteCurrent}(L : \text{in out List}) \text{ is} \]
\[\text{Temp : ListPtr;} \]
\[\text{begin} \]
\[\text{if } L.\text{Head} = \text{null then} \]
\[\text{raise ListEmpty;} \]
\[\text{elsif } L.\text{Size} = 1 \text{ then} \]
\[\text{Temp} \leftarrow L.\text{Current}; \quad L.\text{Current} \leftarrow \text{null}; \quad L.\text{Previous} \leftarrow \text{null}; \quad L.\text{Head} \leftarrow \text{null}; \quad L.\text{Tail} \leftarrow \text{null}; \]
\[\text{else} \]
\[\text{Temp} \leftarrow L.\text{Current;} \]
\[\text{if } L.\text{Current} = L.\text{Tail} \text{ then} \]
\[L.\text{Previous}.\text{all.next} \leftarrow L.\text{Current}.\text{all.next}; \quad L.\text{Current} \leftarrow L.\text{Head}; \quad L.\text{Tail} \leftarrow L.\text{Previous}; \]
\[\text{elsif } L.\text{Current} = L.\text{Head} \text{ then} \]
\[L.\text{Current} \leftarrow L.\text{Current}.\text{all.Next}; \quad \{\text{jump around current node}\} \]
\[L.\text{Head} \leftarrow L.\text{Current}; \]
\[\text{else} \]
\[L.\text{Previous}.\text{all.next} \leftarrow L.\text{Current}.\text{all.next}; \quad L.\text{Current} \leftarrow L.\text{Current}.\text{all.Next}; \quad \{\text{jump around current node}\} \]
\[\text{end if;} \]
\[\text{end if;} \]
\[\text{if debug then} \]
\[\text{put("DeleteCurrent\_deleting=>")}; \quad \text{DisplayElement(Temp.all.Element);} \]
\[\text{end if;} \]
\[\text{Dispose(X \Rightarrow Temp)}; \quad L.\text{Size} \leftarrow L.\text{Size} - 1; \]
\[\text{end DeleteCurrent;} \]

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47.

\[
\begin{aligned}
&\text{procedures and tasks in } \text{generic\_list 33} \equiv \\
&\text{procedure } \text{DeleteMatching}(L : \text{in out } \text{List}; \text{Element} : \text{in } \text{ElementType}; \text{success} : \text{out boolean}) \text{ is} \\
&\quad \text{kntr : natural;} \\
&\quad \text{Current : ElementType}; \\
&\begin{aligned}
&\text{begin} \\
&\quad \text{success} \leftarrow \text{false}; \\
&\quad \text{if } L.\text{Head} = \text{null} \text{ then} \\
&\quad\quad \text{raise ListEmpty;} \\
&\quad \text{end if}; \\
&\quad \text{Rewind}(L); \text{kntr} \leftarrow L.\text{Size}; \\
&\quad \text{for } i \in 1 \ldots \text{kntr} \text{ loop} \\
&\quad\quad \text{GetNext}(L, \text{Current}); \\
&\quad\quad \text{if } \text{Current} = \text{Element} \text{ then} \\
&\quad\quad\quad \text{DeleteCurrent}(L); \text{success} \leftarrow \text{true}; \text{ exit;} \\
&\quad\quad \text{end if}; \\
&\quad \text{end loop}; \\
&\text{end DeleteMatching}; 
\end{aligned}
\end{aligned}
\]

48.

\[
\begin{aligned}
&\text{procedures and tasks in } \text{generic\_list 33} \equiv \\
&\text{procedure } \text{Rewind}(L : \text{in out } \text{List}) \text{ is} \\
&\text{begin} \\
&\quad L.\text{Current} \leftarrow L.\text{Head}; L.\text{Previous} \leftarrow L.\text{Tail}; \\
&\text{end Rewind;}
\end{aligned}
\]

49. Must be used with ListSize and Rewind or you will never know when you are at the end of the list.

\[
\begin{aligned}
&\text{procedures and tasks in } \text{generic\_list 33} \equiv \\
&\text{procedure } \text{GetNext}(L : \text{in out } \text{List}; \text{Element} : \text{out ElementType}) \text{ is} \\
&\begin{aligned}
&\text{begin} \\
&\quad \text{if } L.\text{Head} = \text{null} \text{ then} \\
&\quad\quad \text{raise ListEmpty;} \\
&\quad\text{elsif } L.\text{Current} = L.\text{Tail} \text{ then} \\
&\quad\quad\quad L.\text{Current} \leftarrow L.\text{Head}; L.\text{Previous} \leftarrow L.\text{Tail}; \\
&\quad\text{else} \\
&\quad\quad L.\text{Previous} \leftarrow L.\text{Current}; L.\text{Current} \leftarrow L.\text{Current}.\text{all.prev}; \\
&\quad\text{end if}; \\
&\quad \text{Element} \leftarrow L.\text{Current}.\text{all.element}; \\
&\text{end GetNext;}
\end{aligned}
\end{aligned}
\]
§50 Appendix D

SYSTEM-DEPENDENT CHANGES

50. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

51. RCS Keywords.

$ RCSfile: list.aweb,v 
$ Revision: 1.4 
$ Date: 1997/08/06 16:54:30 
$ Author: evansjr 
$ Id: list.aweb,v 1.4 1997/08/06 16:54:30 evansjr Exp evansjr 
$ Locker: evansjr 
$ State: Exp

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INDEX

52. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

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(2) Packages needed by generic_list body 32) Used in section 8.
(3) Procedures and Tasks in generic_list 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49) Used in section 8.
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APPENDIX E

Project Scheduling Tool

calyr

[Ada '95—Version 1.0]

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§ APPENDIX E

INTRODUCTION

1. Introduction. This package computes federal holidays, and off-fridays for NRaD. (We work five days one week, four the next—nine hours a day, except for Fridays.) The input is just the year. If you do not work the 5/4 weeks then there is a switch (\texttt{-nps \textit{true}}) that you can use to turn it off.

2. This is based on a C program \textit{calyr}, written by Bob Hall of Nrad in the eighties. Bob was a brilliant, and prolific programmer at NRaD who retired in the early nineties. One of his programs \textit{msg}, formed the basis of \textit{Eudora}, a popular mail tool for PC's and Macintoshes, and now owned by Qualcomm.

3. This program was written to work for dates after 1970. It should work till the year 2099. (A year 3000 problem!) To test it out compile the driver program and run it with the following command line:

$$\text{main } [-\text{year }\textit{<year>}] [-\text{nps }\textit{<boolean>}]$$

For example:

$$\text{main -year 1993 -nps false}$$

4. This code is written using Donald Knuth's \textit{WEB} paradigm for literate programming. To compile and link the code in its present format you will need the Ada version of the \textit{WEB} tool.

It is available on-line via the world-wide-web at URL:

$$\text{http://white.nosc.mil/~evansjr/literate/}$$

5. \textit{WEB} is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called "Literate Programming." For further information see the paper \textit{Literate Programming}, by Donald Knuth in \textit{The Computer Journal}, Vol 27, No. 2, 1984; or the book \textit{Weaving a Program: Literate Programming in WEB} by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group \textit{comp.programming.literate}. It has information on new tools and Frequently Asked Questions (FAQs).

6. The program consists of several packages that are declared right now; each of these packages and either the specification and the body of the packages are sent to a separate file. The main program itself is declared later. (Since the original AWEB package was written for Ada '83, it does not properly format new Ada '95 keywords \textit{protected} and \textit{private}. We remedy using the web format commands below.

\texttt{format protected \equiv procedure}

\texttt{format private \equiv procedure}
7. As a way of explanation, each "Module" with angle brackets (< >) is expanded somewhere further down in the document. Consider it a high-level PDL (Program Descriptor Language). The trailing number you see within the brackets is where you can find this expansion. It is top-down in appearance, and in actual fact.

8. All the modules follow the same, top-down format. I will group all the boiler-plate into one module, for the compiler, but you will see it with the packages, as they are described.

(Package boiler-plate 9)
§9 APPENDIX E


(Package boiler-plate 9) ≡

output to file calyr.ads

with Ustrings;
use Ustrings;
with TEXT.IO;
use TEXT.IO;
with Ada.Command.Line;
use Ada.Command.Line;
with Ada.Calendar;
use Ada.Calendar;

package calyr is

(Specification of types and variables visible from calyr 11)
(Specification of procedures visible from calyr 16)

end calyr;

output to file calyr.adb

(Packages needed by calyr body 10)

package body calyr is

(Types local to calyr 57)
(Variables local to calyr 33)
(Local Procedures 59)
(Procedures and Tasks in calyr 39)

end calyr;

This code is used in section 8.

10.

(Packages needed by calyr body 10) ≡

with text.io;
use text.io;

See also section 32.

This code is used in section 9.

11.

(Specification of types and variables visible from calyr 11) ≡

subtype Hour_Number is integer range 0 .. 23;
subtype Minute_Number is integer range 0 .. 59;
subtype Second_Number is integer range 0 .. 59;

See also sections 12, 13, 14, and 15.

This code is used in section 9.
12. \(\langle\text{Specification of types and variables visible from calyr 11} \rangle\) \(\equiv\)
\begin{align*}
\text{BadYear} & : \text{Exception}; \\
\text{BadDay} & : \text{Exception}; \\
\text{type fourarray} & \text{ is array (0 .. 3) of integer;} \\
\text{type threearray} & \text{ is array (0 .. 2) of integer;}
\end{align*}

13. \(\langle\text{Specification of types and variables visible from calyr 11} \rangle\) \(\equiv\)
\begin{align*}
\text{type month} & \text{ is (Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec);} \\
\text{type DayOfWeek} & \text{ is (Sun, Mon, Tue, Wed, Thu, Fri, Sat);} \\
\end{align*}

14. \(\langle\text{Specification of types and variables visible from calyr 11} \rangle\) \(\equiv\)
\begin{align*}
\text{subtype WeekDay} & \text{ is DayOfWeek range Mon .. Fri;}
\end{align*}

15. \(\langle\text{Specification of types and variables visible from calyr 11} \rangle\) \(\equiv\)
\begin{align*}
\text{Type WorkHours} & \text{ is array (WeekDay) of Duration;}
\end{align*}

16. \(\langle\text{Specification of procedures visible from calyr 16} \rangle\) \(\equiv\)
\begin{align*}
\text{procedure print_holidays (yr : in Year.Number; do_nps : in boolean);} \\
\text{See also sections 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, and 30.} \\
\text{This code is used in section 9.}
\end{align*}

17. Given a date (in Ada time format), \textit{hol.dy} returns any special info about it.

\begin{align*}
\text{status return values:} & \quad 0 & \text{not a special day} \\
& \quad 1 & \text{a non-work holiday} \\
& \quad 2 & \text{observation of a non-work holiday} \\
& \quad 3 & \text{other special day (not non-work)} \\
& \quad 4 & \text{an off-Friday or Thursday} \\
\text{di return values:} & \quad \text{di[0]} & \text{weekday of holiday (0 to 6)} \\
& \quad \text{di[1]} & \text{day identification index} \\
& \quad \text{di[2]} & \text{2: off-Friday; 1 : off-Thursday} \\
& & \text{0: not an offday}
\end{align*}

\(\langle\text{Specification of procedures visible from calyr 16} \rangle\) \(\equiv\)
\begin{align*}
\text{procedure hol.dy (yrdate : time; di : out threearray; status : out integer);} \\
\end{align*}
18. This function was taken from the book *Numerical Recipes*. It actually works on any year, not the artificial limit imposed by Ada type *Year_Number* (1901 .. 2099).

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *julian_day* (*Month* : *Month_Number*; *Day* : *Day_Number*; *Year* : Integer) return long_integer;

19. This procedure calculates the Month, Day, and Year when given the *Julian_day*.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

procedure *caldate* (*Julian* : Long_integer; *Month* : out Month_Number; *Day* : out Day_Number; *Year* : out Integer);

20. Computes whether this is an off-day or a work-day.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *IsWorkDay* (*YrDate* : Time; *NRaD* : boolean ← false; *debugit* : boolean ← false) return boolean;

21. Function aid computing new dates based on work hours.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *DurationToCalendarTime* (*StartDate* : Time; *dailyhours* : WorkHours; *hrs* : Duration; *NRaD* : boolean) return Time;

22. Inverse of above.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *CalendarTimeToDuration* (*StartDate* : Time; *dailyhours* : WorkHours; *EndDate* : Time; *NRaD* : boolean) return Duration;

23. 

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *SameDay* (*Time1*, *Time2* : Time) return boolean;

24. 

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *GetDayOfWeek* (*Today* : Time) return DayOfWeek;

25. Straightforward transformation.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *ConvertHoursToDuration* (*hrs* : natural) return Duration;

26. Inverse of previous.

(Specification of procedures visible from *calyr 16*) \(\equiv\)

function *ConvertDurationToHours* (*dur* : Duration) return natural;
27.

\( \langle \text{Specification of procedures visible from \textit{calyr} 16} \rangle \oplus \)

\begin{verbatim}
Procedure Split(Seconds : Day.Duration; Hour : out Hour.Number; Minute : out
Minute.Number; Second : out Second.Number);
\end{verbatim}

28.

\( \langle \text{Specification of procedures visible from \textit{calyr} 16} \rangle \oplus \)

\begin{verbatim}
procedure print_date(date : time);
procedure print_date(outfile : file.type; date : time);
\end{verbatim}

29.

\( \langle \text{Specification of procedures visible from \textit{calyr} 16} \rangle \oplus \)

\begin{verbatim}
function get_date(str : in Ustring) return Time;
function get_date(infile : file.type) return Time;
\end{verbatim}

30. Adds one day to the input parameter.

\( \langle \text{Specification of procedures visible from \textit{calyr} 16} \rangle \oplus \)

\begin{verbatim}
function IncrementDay(YrDate : Time) return Time;
\end{verbatim}

32. (Packages needed by calyr body 10) \equiv
   with Ada.Strings.Unbounded; Use Ada.Strings.Unbounded; with Ustrings;
   use Ustrings;

33. Number days in the month.
   (Variables local to calyr 33) \equiv
   \textit{ndm} \; : \; \textbf{array} (\textit{Month\_Number}) \; \textbf{of} \; \textit{natural} \; \leftarrow \; (31, 28, 31, 30, 31, 30, 31, 30, 31, 30, 31);
   See also sections 34, 35, 36, 37, 38, 46, 48, 49, 50, 58, and 65.
   This code is used in section 9.

34. Last day/previous month.
   (Variables local to calyr 33) \equiv
   \textit{idpm} \; : \; \textbf{array} (\textit{Month\_Number}) \; \textbf{of} \; \textit{natural} \; \leftarrow \; (0, 31, 59, 90, 120, 151, 181, 212, 243, 273, 304, 334);

35. List of holidays.
   (Variables local to calyr 33) \equiv
   \textit{NumHolidays} \; : \; \textbf{constant} \; \textit{natural} \; \leftarrow \; 20;
   \textit{holidays} \; : \; \textbf{constant} \; \textbf{array} (1..\textit{NumHolidays}) \; \textbf{of} \; \textit{Ustring} \; \leftarrow \; (U("New\_Year\_s\_Day"),
   U("MLK\_Day"), U("Presidents\_Day"), U("Memorial\_Day"),
   U("Independence\_Day"), U("Labor\_Day"), U("Columbus\_Day"),
   U("Veterans\_Day"), U("Thanksgiving\_Day"), U("Christmas\_Day"),
   U("Valentine\_s\_Day"), U("St\_Patrick\_s\_Day"), U("Good\_Friday"),
   U("Easter"), U("Mothers\_Day"), U("Armed\_Forces\_Day"), U("Flag\_Day"),
   U("Fathers\_Day"), U("Halloween"), U("Election\_Day"));
36. Index of Holidays.

\{Variables local to calyr 33\} +≡

\texttt{JNYD : constant integer ← 1;}
\texttt{JMLK : constant integer ← 2;}
\texttt{JPRS : constant integer ← 3;}
\texttt{JMEM : constant integer ← 4;}
\texttt{JIND : constant integer ← 5;}
\texttt{JLAB : constant integer ← 6;}
\texttt{JCOL : constant integer ← 7;}
\texttt{JVET : constant integer ← 8;}
\texttt{JTHX : constant integer ← 9;}
\texttt{JCHR : constant integer ← 10;}
\texttt{JVAL : constant integer ← 11;}
\texttt{JSPT : constant integer ← 12;}
\texttt{JGFR : constant integer ← 13;}
\texttt{JEST : constant integer ← 14;}
\texttt{JMOT : constant integer ← 15;}
\texttt{JAFD : constant integer ← 16;}
\texttt{JFLG : constant integer ← 17;}
\texttt{JFAT : constant integer ← 18;}
\texttt{JHAL : constant integer ← 19;}
\texttt{JELC : constant integer ← 20;}

37. Index of something.

\{Variables local to calyr 33\} +≡

\texttt{INYD : constant integer ← 0; \{index for NEW YEAR'S DAY, etc.\}}
\texttt{IMLK : constant integer ← 1;}
\texttt{IPRS : constant integer ← 1;}
\texttt{IGFR : constant integer ← 1;}
\texttt{IEST : constant integer ← 2;}
\texttt{IMEM : constant integer ← 2;}
\texttt{ICOL : constant integer ← 0;}
\texttt{IVET : constant integer ← 1;}
\texttt{IHAL : constant integer ← 2;}
\texttt{IELEC : constant integer ← 0;}

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38.

(Variables local to calyr 33) \equiv
  \begin{align*}
  &\text{debug : boolean } \leftarrow \text{false;} \\
  &\text{debug2 : boolean } \leftarrow \text{false;} \\
  &\text{verbose : boolean } \leftarrow \text{true;} \\
  &\text{nps : boolean } \leftarrow \text{false;} \\
  &\text{already.leaped : boolean } \leftarrow \text{false;} \\
  \text{package int.io is new integer.io(integer);} \\
  &\text{use int.io;}
\end{align*}

39.

(Procedures and Tasks in calyr 39) \equiv
  \begin{align*}
  &\text{procedure hol.dy(yrdate : time; di : out threearray; status : out integer) is} \\
  &\text{\hspace{1em} (Types and Variables local to hol.dy 41)} \\
  &\text{\hspace{2em} begin} \\
  &\text{\hspace{3em} (Parse date 40)} \\
  &\text{\hspace{3em} (Check if leap year 42)} \\
  &\text{\hspace{3em} (Set year 43)} \\
  &\text{\hspace{3em} (Set month 63)} \\
  &\text{\hspace{3em} (Loop over holidays and Off-Fridays 67)} \\
  &\text{\hspace{2em} end hol.dy;}
\end{align*}

See also sections 81, 88, 93, 101, 109, 118, 129, 131, 132, 133, 134, 136, 137, 139, 141, and 143.

This code is used in section 9.

40.

(Parse date 40) \equiv
  \begin{align*}
  &\text{Split(yrdate, Year, Month, Day, Seconds); hmn } \leftarrow \text{Calyr.month'val(Month } \leftarrow \text{1);} \\
  &\text{status } \leftarrow \text{0;} \\
  &\text{di(0) } \leftarrow \text{0;} \\
  &\text{di(1) } \leftarrow \text{0;} \\
  &\text{di(2) } \leftarrow \text{0;}
\end{align*}

This code is used in section 39.

41.

(Types and Variables local to hol.dy 41) \equiv
  \begin{align*}
  &\text{Year : Year.Number;} \\
  &\text{Month : Month.Number;} \\
  &\text{Day : Day.Number;} \\
  &\text{Seconds : Day.Duration;} \\
  &\text{hmn : Calyr.Month;}
\end{align*}

See also sections 45, 64, 68, and 71.

This code is used in section 39.
42. Simple-minded check. Must later look up what to do at end of century.

\[
\begin{align*}
(\text{Check if leap year } 42) & \equiv \\
\text{if } ((\text{Year } \mod 4) = 0) \land (\neg \text{already leaped}) \text{ then} \\
\text{already leaped } & \leftarrow \text{true}; \ n_{\text{dm}}(\text{calyr}.\text{month}'\text{pos}(\text{Feb}) + 1) \leftarrow 29; \\
\text{for } j \in 3 \ldots 12 \text{ loop} \\
\text{ldpm}(j) & \leftarrow \text{ldpm}(j) + 1; \\
\text{end loop;} \\
\text{end if.}
\end{align*}
\]

This code is used in section 39.

43. The datatype \textit{hol} must be modified based on the year. The following code does just that.

\[
\begin{align*}
(\text{Set year } 43) & \equiv \\
(\text{Calculate weekday of Jan 1. } 44) & \equiv \\
(\text{Calculate beginning date of 1st pay period in year } 47) & \equiv \\
(\text{Update ML King Day } 51) & \equiv \\
(\text{Update President's Day } 52) & \equiv \\
(\text{Update Memorial Day } 53) & \equiv \\
(\text{Update Columbus Day } 54) & \equiv \\
(\text{Update Veteran's Day } 55) & \equiv \\
(\text{Compute Easter } 56) & \equiv \\
\end{align*}
\]

This code is used in section 39.

44.

\[
\begin{align*}
(\text{Calculate weekday of Jan 1. } 44) & \equiv \\
\text{ jul } & := \text{ Julian}.\text{day}(1,1,\text{Year}); \ fdy \leftarrow \text{ DayOfWeek}'\text{val}((\text{Jul} + 1) \mod 7); \\
\text{ jul } & := \text{ Julian}.\text{day}(\text{Month},\text{Day},\text{Year}); \ d_{(1)} \leftarrow \text{ integer}((\text{Jul} + 1) \mod 7);
\end{align*}
\]

This code is used in section 43.

45.

\[
\begin{align*}
(\text{Types and Variables local to } \text{hol}.\text{dy } 41) + & \equiv \\
\text{ jul : long.integer;}
\end{align*}
\]

46. Make global.

\[
\begin{align*}
(\text{Variables local to } \text{calyr } 33) + & \equiv \\
\text{ fdy : DayOfWeek;}
\end{align*}
\]
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47.  Funny C logic. Seems to work.

(Calculate beginning date of 1st pay period in year 47) \equiv
\begin{verbatim}
tYear \leftarrow Year - 1970; tmp \leftarrow (Year - 1) \text{rem} 4;
if tmp = 0 then
\hspace{1em} tmp \leftarrow 1;
else
\hspace{1em} tmp \leftarrow 0;
end if;
bpp \leftarrow (11 - tYear - tmp - (tYear/4)) \text{rem} 14;
if bpp < 1 then
\hspace{1em} bpp \leftarrow bpp + 14;
end if;
\end{verbatim}
This code is used in section 43.

48.  Make global.

(Variables local to calyr 33) \equiv
\begin{verbatim}
bpp : integer;
tYear : integer;
tmp : integer;
\end{verbatim}

49.

(Variables local to calyr 33) \equiv
\begin{verbatim}
type holtype is
record
\hspace{1em} dy : fourarray; \{ Day of week or date of holiday \}
\hspace{1em} wn : fourarray; \{ Week number \(-1-\) \text{skip} \}
\hspace{1em} fl : fourarray; \{ 1/0 -\text{ non-work/work holiday} \}
\hspace{1em} iz : fourarray; \{ Index of holiday name \}
end record;
\end{verbatim}
50. I know this is ugly, but it comes directly from C code.

\[ \text{hol} : \text{array (Month) of hol.type} \leftarrow (((1, \text{DayOfWeek,pos(MON)}, -1, 0), (0, 3, 0, 0), (1, 1, 0, 0), (JNYD, JMLK, 0, 0)), ((14, \text{DayOfWeek,pos(MON)}, -1, 0), (0, 3, 0, 0), (0, 1, 0, 0), (JVAL, JPRS, 0, 0)), ((17, 0, 0, -1), (0, -1, -1, 0), (0, 0, 0, 0), (JSPR, JGFR, JEST, 0)), ((0, 0, 0, -1), (-1, -1, -1, 0), (0, 0, 0, 0), (0, JGFR, JEST, 0)),

\]

\[ ((\text{DayOfWeek,pos(SUN)}, \text{DayOfWeek,pos(SAT)}, \text{DayOfWeek,pos(MON)}, -1), (2, 3, 5, 0), (0, 0, 1, 0), (JMOY, JAFD, JMEM, 0)), ((14, \text{DayOfWeek,pos(SUN)}, -1, 0), (0, 3, 0, 0), (0, 0, 0, 0), (JFLG, JFAT, 0, 0)), ((4, -1, 0, 0), (0, 0, 0, 0), (1, 0, 0, 0), (JIND, 0, 0, 0)), ((-1, 0, 0, 0), (0, 0, 0, 0), (0, 0, 0, 0)), ((\text{DayOfWeek,pos(MON)}, -1, 0, 0), (1, 0, 0, 0), (1, 0, 0, 0), (JLAB, 0, 0, 0)), ((\text{DayOfWeek,pos(MON)}, 31, -1), (2, -1, 0, 0), (1, 1, 0, 0), (JCOL, JVET, JHAL, 0)),

\]

\[ ((\text{DayOfWeek,pos(TUE)}, 11), \text{DayOfWeek,pos(THU)}, -1), (-1, 0, 4, 0), (0, 1, 1, 0), (JELC, JVET, JTHX, 0)), ((25, -1, 0, 0), (0, 0, 0, 0), (1, 0, 0, 0), (JCHR, 0, 0, 0)) \];

51. ML King Day became federal holiday in 1986.

\[ \text{if Year > 1985 then} \\
\text{hol(JAN).wn(IMLK) } \leftarrow 3; \\
\text{else} \\
\text{hol(JAN).wn(IMLK) } \leftarrow -1; \\
\text{end if;}
\]

This code is used in section 43.

52. President's day is third Monday (after 1971).

\[ \text{if Year < 1971 then} \\
\text{hol(Feb).dy(IPRS) } \leftarrow \text{DayOfWeek(pos(Mon)}; \text{hol(Feb).wn(IPRS) } \leftarrow 3; \\
\text{end if;}
\]

This code is used in section 43.

53. Memorial Day is last Monday in May.

\[ \text{hol(May).dy(IMEM) } \leftarrow \text{DayOfWeek(pos(Mon)}; \text{hol(May).wn(IMEM) } \leftarrow 5;
\]

This code is used in section 43.
54. Columbus Day is second Monday in October. Did not exist before 1971, I guess?
\[
\langle \text{Update Columbus Day } 54 \rangle \equiv \\
\text{hol}(Oct).\text{wn(ICAL)} \leftarrow 2; \\
\text{if Year} < 1971 \text{ then} \\
\hfill \text{hol}(Oct).\text{wn(ICAL)} \leftarrow -1; \\
\hfill \text{end if}; \\
\text{This code is used in section 43.}
\]

55.
\[
\langle \text{Update Veteran's Day } 55 \rangle \equiv \\
\text{hol}(Oct).\text{wn(IVET)} \leftarrow -1; \text{hol}(Nov).\text{wn(IVET)} \leftarrow 0; \\
\text{if Year} < 1978 \text{ then} \\
\hfill \text{hol}(Oct).\text{wn(IVET)} \leftarrow 4; \text{hol}(Nov).\text{wn(IVET)} \leftarrow -1; \\
\hfill \text{end if}; \\
\text{This code is used in section 43.}
\]

56. Calls the function Easter. Also computes Good Friday.
\[
\langle \text{Compute Easter } 56 \rangle \equiv \\
\text{edt} \leftarrow \text{easter(Year)}; \text{hol(edt.mn).dy(IEST)} \leftarrow \text{edt.dt}; \text{hol(edt.mn).wn(IEST)} \leftarrow 0; \\
\text{edt.dt} \leftarrow \text{edt.dt} - 2; \\
\text{if edt.dt} < 1 \text{ then} \\
\hfill \text{edt.dt} \leftarrow \text{edt.dt} + \text{ndm(3)}; \text{edt.mn} \leftarrow \text{Mar}; \\
\hfill \text{end if}; \\
\text{hol(edt.mn).dy(IGFR)} \leftarrow \text{edt.dt}; \text{hol(edt.mn).wn(IGFR)} \leftarrow 0; \\
\text{This code is used in section 43.}
\]

57.
\[
\langle \text{Types local to calyr } 57 \rangle \equiv \\
\text{type caldat is} \\
\text{record} \\
\quad \text{mn : Month;} \\
\quad \text{dt : integer;} \\
\text{end record;} \\
\text{This code is used in section 9.}
\]

58.
\[
\langle \text{Variables local to calyr } 33 \rangle \equiv \\
\text{edt : caldat;}
\]
59. Here is the function easter that returns the day and month Easter occurs for a given year.

( Local Procedures 59 ) \equiv
function easter(Year : in Year_Number) return caldat is
   ( Types and variables local to easter 60 )
begin
   fde \leftarrow ndm(1) + ndm(2); dt.dt \leftarrow pfm((Year - 1900) \mod 19);
   if dt.dt < 0 then
      dt.mn \leftarrow Mar; dt.dt \leftarrow -dt.dt;
   else
      dt.mn \leftarrow Apr; fde \leftarrow fde + ndm(3);
   end if;
   ( Compute weekday for Paschal Full Moon 62 )
   return dt;
end easter;
This code is used in section 9.

60. Here is the Paschal Full Moon table used to find Easter.

( Types and variables local to easter 60 ) \equiv
   pfm : constant array (0..18) of integer \leftarrow (14, 3, -23, 11, -31, 18, 8, -28, 16, 5, -25, 13, 2, -22, 10, -30, 17, 7, -27);
See also section 61.
This code is used in section 59.

61.

( Types and variables local to easter 60 ) \equiv
   fde : integer;
   dt : caldat;

62. Easter is the next Sunday following the Paschal Full Moon.

( Compute weekday for Paschal Full Moon 62 ) \equiv
   fde \leftarrow (dt.dt + fde - (8 - DayOfWeek'pos(fd.y))) \mod 7;
   if fde < 0 then
      fde \leftarrow (7 + fde) \mod 7;
   end if;
   dt.dt \leftarrow dt.dt + 7 - fde;
   if dt.dt > ndm(month'pos(dt.mn) + 1) then
      dt.dt \leftarrow dt.dt - ndm(month'pos(dt.mn) + 1); dt.mn \leftarrow month'succ(dt.mn);
   end if;
This code is used in section 59.
63. Used to determine off-fridays of month. Also, if November, figure out election day.

(Set month 63) ≡

declare
  ldm, ofr, ii, jj : integer;
begin
  ofr ← bpp - 2;
  if ofr ≤ 1 then
    ofr ← ofr + 14;
  end if;
  ldm ← ldpm(Month); ofr ← ofr + (ldm/14) * (14) - ldm;
  if ofr < 0 then
    ofr ← ofr + 14;
  elsif ((Month > 1) ∧ (ofr > 14)) then
    ofr ← ofr - 14;
  end if;
ofrdy(0) ← UNST; ofrdy(1) ← UNST; ofrdy(2) ← UNST; ofrdy(3) ← UNST;
if (Year > 1979) then
  jj ← 0;
loop
  if ((Year ≠ 1982) ∨ (Month ≠ 4) ∨ (ofr ≠ 2)) ∧ ((Year ≠ 1980) ∨ (Month ≠ 1)) then
    ofrdy(jj) ← ofr; jj ← jj + 1;
  end if;
ofr ← ofr + 14; exit when ofr > ndm(Month);
end loop;
end if;
fdm ← (ldm - (7 - DayOfWeek'pos(fdw))) rem 7;
if fdm < 0 then
  fdm ← (7 + fdm) rem 7;
end if;
(Figure out election day 66)
end;

This code is used in section 39.

64.

(Types and Variables local to holiday 41) ≡
  UNST : constant integer ← 64;
  jj : integer;
  ofrdy : fourarray;

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CALYR BODY

65. Make global.
\langle Variables local to calyr \ 33 \rangle \equiv
\begin{align*}
  \text{fdm} : \text{integer};
\end{align*}

66. \hspace{1em} \langle Figure\ out\ election\ day\ 66 \rangle \equiv
\begin{align*}
  \text{if} \ (hmn = \text{Nov}) \land ((\text{Year} \ \text{rem} 2) = 0) \ \text{then} \\
  & \quad \text{ii} \leftarrow \text{hol(Nov)}.dy(\text{IELC}) - \text{fdm} + 1; \\
  & \quad \text{if} \ \text{ii} < 1 \ \text{then} \\
  & \qquad \text{ii} \leftarrow \text{ii} + 7; \\
  & \text{end if;} \\
  & \text{if} \ \text{ii} < 2 \ \text{then} \\
  & \quad \text{hol(Nov)}.wn(\text{IELC}) \leftarrow 2; \\
  & \text{else} \\
  & \quad \text{hol(Nov)}.wn(\text{IELC}) \leftarrow 1; \\
  & \text{end if;} \\
  & \text{end if};
\end{align*}
This code is used in section 63.

67. Main part of hol.dy.
\langle Loop\ over\ holidays\ and\ Off-Fridays\ 67 \rangle \equiv
\begin{align*}
  \text{ii} \leftarrow 0; \ \text{jj} \leftarrow 0; \\
\end{align*}
loop

\langle Check\ for\ no\ more\ holidays\ 69 \rangle \\
\begin{align*}
  \text{if} \ (\text{hol}(\text{hmn}).\text{wn}(\text{ii}) \geq 0) \ \text{then} \\
  & \quad \text{ho} \leftarrow 0; \ \langle \text{Holiday\ with\ fixed\ week\ day\ or\ fixed\ date\ 70} \rangle \\
  & \quad \langle \text{Exhaust\ any\ earlier\ off-Fridays\ 72} \rangle \\
  & \quad \langle \text{Check\ if\ off-Friday\ moved\ back\ to\ Thursday\ 73} \rangle \\
  & \quad \langle \text{Work,\ and\ normal\ and\ Sunday\ non-work,\ holiday\ 74} \rangle \\
  & \quad \langle \text{Monday/Friday\ extra\ day\ 75} \rangle \\
  & \quad \langle \text{Saturday\ non-work\ holiday\ 76} \rangle \\
  & \text{end if;} \\
  & \text{ii} \leftarrow \text{ii} + 1; \\
  & \langle \text{ugly} \rangle \ \text{exit\ when} \ (\text{ii} > 3); \\
  & \quad \langle \text{exit\ when}\ ((\text{hol}(\text{hmn}).\text{dy(\text{ii}) < 0}) \land (\text{ofrdy(\text{jj}) = UNST})); \\
  & \text{end loop;} \\
\end{align*}
\langle December\ processing\ 77 \rangle
This code is used in section 39.

68. \hspace{1em} \langle Types\ and\ Variables\ local\ to\ hol.dy\ 41 \rangle \equiv
\begin{align*}
  \text{ii}, \text{ho} : \text{integer};
\end{align*}
(Check for no more holidays 69) \equiv

if \ hol(hmn), dy(ii) < 0 then
  if (integer(Month) < 12) \lor (ofrdy(jj) < ndm(12)) then
    if ofrdy(jj) = Day then
      di(2) \leftarrow 2;
    if status = 0 then
      status \leftarrow 4;
    end if;
  end if;
jj \leftarrow jj + 1; \text{goto ugly};
else
  exit;
end if;
end if;

This code is used in section 67.
70.

\[
\text{(Holiday with fixed week day or fixed date 70) } \equiv \\
\text{if } \text{hol(hmn).wn(ii)} > 0 \text{ then} \\
\ \ \ \ dw \leftarrow \text{hol(hmn).dy(ii)}; \ text{date} \leftarrow dw - fdm + 1; \\
\text{if } \text{date} < 1 \text{ then} \\
\ \ \ \ \text{date} \leftarrow \text{date + 7}; \\
\text{end if;} \\
\text{date} \leftarrow \text{date} + (7 \times (\text{hol(hmn).wn(ii)} - 1)); \\
\text{if } \text{date} > \text{ndm(Month)} \text{ then } \{ \text{Takes care of Memorial Day}\} \\
\ \ \ \ \text{date} \leftarrow \text{date - 7}; \\
\text{end if;} \\
\text{else } \{ \text{Holiday with fixed date}\} \\
\ \ \ \ \text{date} \leftarrow \text{hol(hmn).dy(ii)}; \ dw \leftarrow (\text{date} - (8 - fdm)) \text{rem 7}; \\
\text{if } dw < 0 \text{ then} \\
\ \ \ \ \ dw \leftarrow (7 + dw) \text{rem 7}; \\
\text{end if;} \\
\text{if } \text{hol(hmn).fl(ii)} > 0 \text{ then } \{ \text{Take care of weekend holidays}\} \\
\text{if } dw = \text{DayOfWeek'pos(Sun)} \text{ then} \\
\ \ \ \ \ ho \leftarrow 1; \\
\text{elsif } dw = \text{DayOfWeek'pos(Sat)} \text{ then} \\
\ \ \ \ \ ho \leftarrow -1; \\
\text{else} \\
\ \ \ \ \ ho \leftarrow 0; \\
\text{end if;} \\
\text{end if;} \\
\text{end if;}
\]

This code is used in section 67.

71.

\[
\text{(Types and Variables local to hol.dy 41) } \equiv \\
\text{date, dw : integer;}
\]
§72. APPENDIX E

72.

(Exhaust any earlier off-Fridays 72)

\[ \text{while } ((\text{hol(hmn)}.f(i) > 0) \land ((\text{ho} \geq 0) \land \text{ofrdy(jj)} < \text{date}) \lor ((\text{ho} < 0) \land (\text{ofrdy(jj)} < (\text{date} - 1)))) \lor ((\text{hol(hmn)}.f(i) = 0) \land (\text{ofrdy(jj)} \leq \text{date}))) \text{ loop} \]

\[ \text{if } \text{ofrdy(jj)} = \text{Day} \text{ then} \]
\[ \text{di(2) } \leftarrow \text{ 2;} \]
\[ \text{if } \text{status} = 0 \text{ then} \]
\[ \text{status } \leftarrow \text{ 4;} \]
\[ \text{end if;} \]
\[ \text{end if;} \]
\[ \text{jj } \leftarrow \text{ jj + 1;} \]
\[ \text{end loop;} \]

This code is used in section 67.

73.

(Check if off-Friday moved back to Thursday 73)

\[ \text{if } (\text{ofrdy(jj)} > 1) \land (\text{hol(hmn)}.f(ii) > 0) \land ((\text{ofrdy(jj)} = \text{date}) \lor (\text{ofrdy(jj)} = (\text{date} + \text{ho}))) \]
\[ \text{then} \]
\[ \text{if } (\text{ofrdy(jj)} - 1) = \text{Day} \text{ then} \]
\[ \text{di(2) } \leftarrow \text{ 1;} \]
\[ \text{if } \text{status} = 0 \text{ then} \]
\[ \text{status } \leftarrow \text{ 4;} \]
\[ \text{end if;} \]
\[ \text{end if;} \]
\[ \text{jj } \leftarrow \text{ jj + 1;} \]
\[ \text{end if;} \]

This code is used in section 67.

74.

(Work, and normal and Sunday non-work, holiday 74)

\[ \text{if } (\text{ho} \geq 0) \land (\text{date} = \text{Day}) \text{ then} \]
\[ \text{di(0) } \leftarrow \text{ dw;} \]
\[ \text{di(1) } \leftarrow \text{ hol(hmn).iz(ii);} \]
\[ \text{status } \leftarrow \text{ 1 + 2 * (di(1)/JVAL);} \]
\[ \text{end if;} \]

This code is used in section 67.

75.

(Monday/Friday extra day 75)

\[ \text{if } (\text{ho} \neq 0) \land ((\text{date} + \text{ho}) > 0) \land ((\text{date} + \text{ho}) = \text{Day}) \text{ then} \]
\[ \text{di(0) } \leftarrow \text{ dw + ho;} \]
\[ \text{di(1) } \leftarrow \text{ hol(hmn).iz(ii);} \]
\[ \text{status } \leftarrow \text{ 2;} \]
\[ \text{end if;} \]

This code is used in section 67.
76. 
(Saturday non-work holiday 76) ≡
if \((ho < 0) \land (date = Day)\) then
\(di(0) \leftarrow dw; \ di(1) \leftarrow hol(hmn).iz(ii); \ status \leftarrow 1;\)
end if;
This code is used in section 67.

77. 
(December processing 77) ≡
if \(hmn = Dec\) then
(Is first of next year a Friday or Saturday and this is an off-Friday? 78)
(Weekday of December 31 79)
(December 31 a Friday the observe Saturday, January 1st 80) end if;
This code is used in section 67.

78. 
(Is first of next year a Friday or Saturday and this is an off-Friday? 78) ≡
if \(jj \neq 0\) then
if \((ofrdy(jj) = ndm(12))\) then
\(tmp \leftarrow 1;\)
else
\(tmp \leftarrow 0;\)
end if;
if \(((ofrdy(jj - 1) = (ndm(12) - 13)) \lor (ofrdy(jj) = ndm(12))) \land (ndm(12) - tmp = Day)\)
then
\(di(2) \leftarrow 1;\)
if \(status = 0\) then
\(status \leftarrow 4;\)
end if;
end if;
end if;
This code is used in section 77.

79. 
(Weekday of December 31 79) ≡
\(dw \leftarrow (ndm(12) - (8 - fdm)) \mod 7;\)
if \(dw < 0\) then
\(dw \leftarrow (7 + dw) \mod 7;\)
end if;
This code is used in section 77.
80.

(December 31 a Friday the observe Saturday, January 1st 80) ≡
if (\(dw = DayOfWeek'pos(Fri)) \land ndm(12) = Day\) then
  \(di(0) \leftarrow DayofWeek'pos(Fri); \ di(1) \leftarrow hol(Jan).ix(INYD); \ status \leftarrow 2;\)
end if;
This code is used in section 77.

81.

(Procedures and Tasks in calyr 39) +≡
procedure print_holidays (yr : in Year_Number; do_nps : in boolean) is
  (Variables local to print_holidays 84)
begin
  nps \leftarrow do_nps;  
  (Loop through months 82)
end print_holidays;

82. Straightforward.

(Loop through months 82) ≡
for mon ∈ Jan .. Dec loop
  if ~verbose then
    put(month'image(mon)); put(">");
  end if;
  (Loop through days of month 83)
  if ~verbose then
    put.line(";
  end if;
end loop;
This code is used in section 81.
83.
(Loop through days of month 83) ≡
for ii ∈ 1..(ndm(month'pos(mon) + 1)) loop
  holiday(yr, month'pos(mon) + 1, ii, 0.0, di, status);
  if ~verbose then
    if (status > 0) then
      put("day_{ii}=‎"); put(ii, 1); put("..\u200estatus_{ii}=‎"); put(status, 1);
      put("\u200edi_{ii}=‎");
      for i ∈ 0..2 loop
        put(di(i), i);
        if i < 2 then
          put("\u200e");
        end if;
      end loop;
      put_line("{}\u200e");
    end if;
  else
    (Print out first day of month 85)
    (Print out holidays, as necessarily 87)
  end if;
end loop;
This code is used in section 82.

84.
(Variables local to print_holidays 84) ≡
  status : integer;
  di : threearray;
See also section 86.
This code is used in section 81.

85.
(Print out first day of month 85) ≡
  if ii = 1 then
    put(month'image(mon)); put(ii, 3); put("\u200e"); hfdm ← DayOfWeek'val(fdm);
    put(DayOfWeek'image(hfdm)); put_line("\u200e");
  end if;
This code is used in section 83.

86.
(Variables local to print_holidays 84) +≡
  hfdm : DayOfWeek;
87. (Print out holidays, as necessarily 87) \equiv
   if \textit{status} > 0 then
     if \neg \textit{nps} then
       if (\textit{di}(2) > 0) then
         \textit{hfdm} \leftarrow \text{DayOfWeek}'\text{val}(\textit{di}(2) + 3); \text{put}(\text{DayOfWeek}'\text{image}(\text{hfdm})); \text{put}(\textit{ii}, 3);
         \text{put}("_\text{U}""); \text{put}_\text{line}("\text{Offday}");
       end if;
     end if;
   end if;
   if \textit{status} \leq 3 then
     \textit{hfdm} \leftarrow \text{DayOfWeek}'\text{val}(\textit{di}(0)); \text{put}(\text{DayOfWeek}'\text{image}(\text{hfdm})); \text{put}(\textit{ii}, 3);
     \text{put}("_\text{U}""); \text{put}(\text{S(holidays(di(1)))});
     if \textit{status} \neq 2 then
       \text{put}_\text{line}("\text{"");
     else
       \text{put}_\text{line}("\text{(Observed)"");
     end if;
   end if;
end if;
This code is used in section 83.

88. (Procedures and Tasks in \textit{calyr} 39) \equiv
   procedure \textit{caldate(Julian : Long\_integer; Month : out Month\_Number; Day : out Day\_Number; Year : out Integer) is}
         (Variables local to \textit{caldat} 90)
   begin
     if (\textit{julian} \geq IGREG) then
       (Correct for to Gregorian Calendar 89)
     else
       ja \leftarrow \textit{julian};
     end if;
   (Now finish computation 91)
end \textit{caldate};

89. (Correct for to Gregorian Calendar 89) \equiv
   jalpha \leftarrow \text{long\_integer}(((\text{float(julian} - 1867216) - 0.25)/36524.25) - 0.5);
   ja \leftarrow \textit{julian} + 1 + jalpha - \text{long\_integer}(0.25 * \text{float(jalpha}) - 0.5);
This code is used in section 88.
90.

\( \{ \text{Variables local to \textit{caldat}} \ 90 \} \equiv \)

\( \text{IGREG : constant } \text{long\_integer} \leftarrow (15 + 31 \times (10 + 12 \times 1582)) ; \)
\( \text{ja, jalpha : long\_integer} ; \)

See also section 92.

This code is used in section 88.

91.

\( \{ \text{Now finish computation} \ 91 \} \equiv \)

\( \text{jb} \leftarrow \text{ja} + 1524 ; \)
\( \text{jc} \leftarrow \text{long\_integer}((6680.0 + (\text{float}(\text{jb} - 2439870) - 122.1)/365.25) - 0.5) ; \)
\( \text{jd} \leftarrow (365 \times \text{jc}) + \text{long\_integer}(0.25 \times \text{float}(\text{jc}) - 0.5) ; \)
\( \text{je} \leftarrow \text{long\_integer}(\text{float}(\text{jb} - \text{jd})/30.6001 - 0.5) ; \)
\( \text{Day} \leftarrow \text{Integer}(\text{jb} - \text{jd} - \text{long\_integer}(30.6001 \times \text{float}(\text{je}) - 0.5)) ; \)
\( \text{TMonth} \leftarrow \text{Integer}(\text{je} - 1) ; \)
\( \text{if} (\text{TMonth} > 12) \text{ then} \)
\( \quad \text{Month} \leftarrow \text{Tmonth} - 12 ; \)
\( \text{else} \)
\( \quad \text{Month} \leftarrow \text{Tmonth} ; \)
\( \text{end if} ; \)
\( \text{Year} \leftarrow \text{integer}(\text{jc} - 4715) ; \)
\( \text{if} (\text{Month} > 2) \text{ then} \)
\( \quad \text{Year} \leftarrow \text{Year} - 1 ; \)
\( \text{end if} ; \)
\( \text{if} \ \text{Year} \leq 0 \text{ then} \)
\( \quad \text{Year} \leftarrow \text{Year} - 1 ; \)
\( \text{end if} ; \)

This code is used in section 88.

92.

\( \{ \text{Variables local to \textit{caldat}} \ 90 \} + \equiv \)

\( \text{jb, jc, jd, je : long\_integer} ; \)
\( \text{Tmonth : integer} ; \)
§93. PROCEDURES AND TASKS IN CALYR 39

function julian_day(Month : Month_Number; Day : Day_Number; Year : Integer) return long_integer is
begin
(Variables local to Julian_Day 94)
begin
(Variables local to Julian_Day 94)
end julian_day;

94.

 jul : long_integer;

See also sections 97 and 100.
This code is used in section 93.

95. There is no year zero!

if (Year = 0) then
raise BadYear;
end if;
This code is used in section 93.

96. I translated this from C. I don’t pretend to understand it.

if Year < 0 then
 TYear ← Year + 1;
else
 TYear ← Year;
end if;
if Month > 2 then
 jy ← TYear; jm ← Month + 1;
else
 jy ← TYear - 1; jm ← Month + 13;
end if;
This code is used in section 93.
97. (Variables local to Julian.Day 94) +≡
   TYear, jy, jm : integer;

   (Compute julian number 98) ≡
   jul ← long.integer(365.25 * float(jy) − 0.5) + long.integer(30.6001 * float(jm) − 0.5) +
   long.integer(Day + 1720995);
   This code is used in section 93.

99. Gregorian Calendar was adopted on October 15, 1582.
   (Test whether to change to Gregorian Calendar 99) ≡
   if long.integer(integer(Day) + 31 * (integer(Month) + 12 * Year)) ≥ IGREG then
     ja ← integer(0.01 * float(jy) − 0.5);
     jul ← jul + long.integer(2 − ja + integer(0.25 * float(ja) − 0.5));
   end if;
   This code is used in section 93.

100. (Variables local to Julian.Day 94) +≡
    IGREG : constant long.integer ← (15 + 31 * (10 + 12 * 1582));
    ja : integer;
101.

{Procedures and Tasks in calyr 39} +

function IsWorkDay(YrDate : Time; NRaD : boolean ← false;
  debug : boolean ← false) return boolean is
  {Variables local to IsWorkDay 103}
begin
  status ← 1; workday ← false; hol.dy(Current.Time, di, status);
  if debug then
    {Display hol.dy output 102}
  end if;
  dow ← GetDayOfWeek(YrDate);
  if status = 0 then
    {Make sure not a Saturday or Sunday 106}
  elsif nrad then
    {Look if NraD off-Friday (or off-Thursday if Friday a holiday) 107}
  else
    {See if federal holiday 108}
  end if;
  if debug then
    {Print if workday 104}
  end if;
  return workday;
end IsWorkDay;

102.

{Display hol.dy output 102} 

Split(Yrdate, Year, Month, Day, Seconds); put("Status=",); put(status, 1);
put("_di","f");
for i ∈ 0 .. 2 loop
  put(di(i),i);
  if i < 2 then
    put(",");  
  end if;
end loop;
put.line("I");
This code is used in section 101.
103.
(Variables local to IsWorkDay 103) ≡
  Year : Year_Number;
  Month : Month_Number;
  Day : Day_Number;
  Seconds : Day_Duration;
  dow : DayOfWeek;

See also section 105.
This code is used in section 101.

104.
(Print if workday 104) ≡
  print_date(Yrdate);
  if workday then
    put_line("is a workday.");
  else
    put_line("is NOT a workday.");
  end if;

This code is used in section 101.

105.
(Variables local to IsWorkDay 103) +≡
  status : integer;
  workday : boolean;
  di : threearray;
  Current_Time : Time ← YrDate;

106.
(Make sure not a Saturday or Sunday 106) ≡
  if (dow ≠ Sun) ∧ (dow ≠ Sat) then
    workday ← true;
  end if;

This code is used in sections 101, 107, and 108(2).

107. Make allowances for people (NRaD) working 5/4 weekly schedule.
(Look if NraD off-Friday (or off-Thursday if Friday a holiday) 107) ≡
  if status = 3 then
    (Make sure not a Saturday or Sunday 106)
  end if;

This code is used in section 101.
§108  APPENDIX E

108. If $\text{status} > 2$ could be Arbor Day, or other work holiday.

\[
\langle \text{See if federal holiday 108} \rangle \equiv \\
\text{if } \text{status} = 3 \text{ then} \\
\quad \langle \text{Make sure not a Saturday or Sunday 106} \rangle \\
\text{end if;}
\]

\[
\text{if } \text{status} = 4 \text{ then} \\
\quad \langle \text{Make sure not a Saturday or Sunday 106} \rangle \\
\text{end if;}
\]

This code is used in section 101.

109.

\[
\langle \text{Procedures and Tasks in calyr 39} \rangle \equiv \\
\text{function } \text{DurationToCalendarTime} (\text{StartDate} : \text{Time}; \text{dailyhours} : \text{WorkHours}; \\
\quad \text{hrs} : \text{Duration}; \text{NRaD} : \text{boolean}) \text{return } \text{Time} \text{ is} \\
\quad \langle \text{Variables local to DurationToCalendarTime 111} \rangle \\
\quad \text{begin} \\
\quad \langle \text{Find next work-day 110} \rangle \\
\quad \langle \text{Remove slop 112} \rangle \\
\quad \langle \text{Find next work-day 110} \rangle \\
\quad \langle \text{If partial day, account for it 114} \rangle \\
\quad \langle \text{Find next work-day 110} \rangle \\
\quad \langle \text{Find last work-day 116} \rangle \\
\quad \langle \text{Figure out partial day 117} \rangle \\
\quad \text{return } \text{Current\_Time;} \\
\quad \text{end DurationToCalendarTime;} \\
\]

110.

\[
\langle \text{Find next work-day 110} \rangle \equiv \\
\quad \langle \text{while } (\neg \text{IsWorkDay} (\text{Current\_Time}, \text{NRaD})) \text{ loop} \\
\quad \quad \text{Current\_Time} \leftarrow \text{IncrementDay} (\text{Current\_Time}); \\
\quad \text{end loop;}
\]

This code is used in sections 109(3) and 116.

111.

\[
\langle \text{Variables local to DurationToCalendarTime 111} \rangle \equiv \\
\quad \text{Current\_Time} : \text{Time} \leftarrow \text{StartDate;}
\]

See also sections 113 and 115.

This code is used in section 109.
112. If the start date was not a work day, and the the number of hours in Start Date is greater then zero, remove it. (Maybe this should be an error.)

\[
\text{Remove slop 112) } \equiv \\
\text{Split(Current.Time, Year, Month, Day, Seconds);} \\
\text{if Current.Time } \neq \text{ StartDate then} \\
\text{Seconds } \gets \text{ 0.0; Current.Time } \gets \text{ Time.of(Y Year, Month, Day, Seconds);} \\
\text{end if;}
\]

This code is used in section 109.

113.

\[
\text{Variables local to DurationToCalendarTime 111) } \equiv \\
\text{Year : Year.Number;} \\
\text{Month : Month.Number;} \\
\text{Day : Day.Number;} \\
\text{Seconds : Day.Duration;}
\]

114. If the StartDate has seconds > zero then this means we are starting a new task in the middle of the day.

\[
\text{(If partial day, account for it 114) } \equiv \\
\text{yhrs } \gets \text{ hrs; yrday } \gets \text{ GetDayOfWeek(Current.Time);} \\
\text{if (dailyhours(yrday) - seconds) > yhrs then} \\
\text{Current.Time } \gets \text{ Current.Time } + \text{ yhrs; yhrs } \gets \text{ 0.0;} \\
\text{else} \\
\text{Current.Time } \gets \text{ Current.Time } - \text{ Seconds;} \\
\text{Current.Time } \gets \text{ IncrementDay(Current.Time);} \\
yhrs } \gets \text{ yhrs - (dailyhours(yrday) - seconds);} \\
\text{end if;}
\]

This code is used in section 109.

115.

\[
\text{(Variables local to DurationToCalendarTime 111) } \equiv \\
yhrs : Duration; \\
yrday : DayOfWeek;
\]
116. (Find last work-day 116) \(\equiv\)

\[\begin{align*}
\text{yrday} & \leftarrow \text{GetDayOfWeek}(\text{Current.Time}); \\
\text{while } yhrs > \text{dailyhours(yrday)} \text{ loop} \\
   & yhrs \leftarrow yhrs - \text{dailyhours(yrday)}; \text{Current.Time} \leftarrow \text{IncrementDay(\text{Current.Time})}; \\
   & (\text{Find next work-day 110}) \\
   & yrday \leftarrow \text{GetDayOfWeek(\text{Current.Time})}; \\
   & \text{if } (\text{yrday} = \text{Sat}) \lor (\text{yrday} = \text{Sun}) \text{ then} \\
     & \text{put("ERROR!ERROR!ERROR!"); new_line;} \\
     & \text{put("For some reason failed to find next work-day for date \text{yrday} = \text{Sun}"}; \\
     & \text{print_date(\text{Current.Time})}; \\
     & \text{if } (\neg \text{IsWorkDay(\text{Current.Time}, \text{NRaD}, \text{True})) then} \\
     & \text{put("\text{NRaD is not a work-day.}");} \\
   & \text{else} \\
     & \text{put("\text{IS a work-day.}");} \\
   & \text{end if}; \\
   & \text{new_line; raise BadDay;} \\
   & \text{end if}; \\
\end{align*}\]

This code is used in section 109.

117. (Figure out partial day 117) \(\equiv\)

\[\begin{align*}
\text{if } yhrs > 0.0 \text{ then} \\
   & \text{Current.Time} \leftarrow \text{Current.Time} + yhrs; \text{yhrs} \leftarrow 0.0; \\
\end{align*}\]

This code is used in section 109.

118. (Procedures and Tasks in calyr 39) \(+\equiv\)

\[\text{function CalendarTimeToDuration(\text{StartDate : Time}; \text{dailyhours : WorkHours}; \text{EndDate : Time}; \text{NRaD : boolean}) return Duration is}\]

\[\begin{align*}
\text{(Variables local to CalendarTimeToDuration 121)} \\
\text{begin} \\
\text{(Assert that input dates are correct 119)} \\
\text{(Count work hours over total span of days 122)} \\
\text{end CalendarTimeToDuration;}
\end{align*}\]
119. The StartDate and EndDate must be valid work days and must have hours less than or equal to the total number of hours worked in a day. If this is not true, raise the BadDay exception.

\( \langle \text{Assert that input dates are correct 119} \rangle \equiv \)
\( \text{if } \neg \text{IsWorkDay}(\text{StartDate}, \text{NRaD}) \lor \neg \text{IsWorkDay}(\text{EndDate}, \text{NRaD}) \text{ then} \)
\( \quad \text{raise BadDay; } \)
\( \text{end if; } \)
\( \text{Split}(\text{StartDate}, \text{StartYear}, \text{StartMonth}, \text{StartDate}, \text{StartSeconds}); \)
\( \text{dow } \leftarrow \text{GetDayOfWeek}(\text{StartDate}); \)
\( \text{if } \text{StartSeconds} > \text{dailyhours}(\text{dow}) \text{ then} \)
\( \quad \text{raise BadDay; } \)
\( \text{end if; } \)
\( \text{Split}(\text{EndDate}, \text{EndYear}, \text{EndMonth}, \text{EndDate}, \text{EndSeconds}); \)
\( \text{dow } \leftarrow \text{GetDayOfWeek}(\text{EndDate}); \)
\( \text{if } \text{EndSeconds} > \text{dailyhours}(\text{dow}) \text{ then} \)
\( \quad \text{raise BadDay; } \)
\( \text{end if; } \)

See also section 120.

This code is used in section 118.

120. Also check that EndDate \( \geq \) StartDate.

\( \langle \text{Assert that input dates are correct 119} \rangle + \equiv \)
\( \text{if } \text{StartDate} > \text{EndDate} \text{ then} \)
\( \quad \text{raise BadDay; } \)
\( \text{end if; } \)

121.

\( \langle \text{Variables local to Calendar Time To Duration 121} \rangle \equiv \)
\( \text{StartYear, EndYear : Year.Number; } \)
\( \text{StartMonth, EndMonth : Month.Number; } \)
\( \text{StartDate, EndDate : Day.Number; } \)
\( \text{StartSeconds, EndSeconds : Day.Duration; } \)
\( \text{dow : DayOfWeek; } \)

See also sections 124 and 127.

This code is used in section 118.
\( \text{§122} \quad \text{APPENDIX E} \quad \text{CALYR BODY} \)

122. \( \langle \text{Count work hours over total span of days 122} \rangle \equiv \)
if \( \text{SameDay(StartDate, EndDate)} \) then
\( \langle \text{Figure out duration for same day 123} \rangle \)
else
\( \langle \text{Count work hours for first day 125} \rangle \)
\( \langle \text{Count work hours for intermediate days 126} \rangle \)
\( \langle \text{Count work hours for last day 128} \rangle \)
end if;
return \( hrs \);
This code is used in section 118.

123. Easy. Just Subtract.
\( \langle \text{Figure out duration for same day 123} \rangle \equiv \)
\( hrs \leftarrow \text{EndDate} - \text{StartDate}; \)
This code is used in section 122.

124. \( \langle \text{Variables local to CalendarTimeToDuration 121} \rangle + \equiv \)
\( hrs : \text{duration}; \)

125. \( \langle \text{Count work hours for first day 125} \rangle \equiv \)
\( \text{dow} \leftarrow \text{GetDayOfWeek(Start Date)}; \ hrs \leftarrow \text{dailyhours(dow)} - \text{StartSeconds}; \)
This code is used in section 122.

126. \( \langle \text{Count work hours for intermediate days 126} \rangle \equiv \)
\( \text{Current.Time} \leftarrow \text{Time.Of(Start Year, Start Month, Start Day, 0.0)}; \)
\( \text{Current.Time} \leftarrow \text{IncrementDay(CURRENT.Time)}; \)
while \( \neg \text{SameDay(CURRENT.Time, End Date)} \) loop
if \( \text{IsWorkDay(CURRENT.Time, NraD)} \) then
\( \text{dow} \leftarrow \text{GetDayOfWeek(CURRENT.Time)}; \ hrs \leftarrow hrs + \text{dailyhours(dow)}; \)
end if;
\( \text{Current.Time} \leftarrow \text{IncrementDay(CURRENT.Time)}; \)
end loop;
This code is used in section 122.

127. \( \langle \text{Variables local to CalendarTimeToDuration 121} \rangle + \equiv \)
\( \text{Current.Time} : \text{Time}; \)
128.
\[ \langle \text{Count work hours for last day 128} \rangle \equiv \]
\[ \text{hrs} \leftarrow \text{hrs} + \text{EndSeconds}; \]
This code is used in section 122.

129.
\[ \langle \text{Procedures and Tasks in calyr 38} \rangle \equiv \]
\[ \text{function SameDay}(\text{Time1}, \text{Time2} : \text{Time})\text{return boolean is} \]
\[ \langle \text{Variables local to SameDay 130} \rangle \]
\[ \text{begin} \]
\[ \text{Split(}\text{Time1}, \text{Year1}, \text{Month1}, \text{Day1}, \text{Seconds}); \]
\[ \text{Split(}\text{Time2}, \text{Year2}, \text{Month2}, \text{Day2}, \text{Seconds}); \]
\[ \text{if } (\text{Year1} = \text{Year2}) \land (\text{Month1} = \text{Month2}) \land (\text{Day1} = \text{Day2}) \text{ then} \]
\[ \quad \text{return true;} \]
\[ \text{else} \]
\[ \quad \text{return false;} \]
\[ \text{end if;} \]
\[ \text{end SameDay;} \]

130.
\[ \langle \text{Variables local to SameDay 130} \rangle \equiv \]
\[ \text{Year1, Year2 : Year.Number; } \]
\[ \text{Month1, Month2 : Month.Number; } \]
\[ \text{Day1, Day2 : Day.Number; } \]
\[ \text{Seconds : Day.Duration; } \]
This code is used in section 129.

131.
\[ \langle \text{Procedures and Tasks in calyr 38} \rangle \equiv \]
\[ \text{function GetDayOfWeek}(\text{Today} : \text{Time})\text{return DayOfWeek is} \]
\[ \quad \text{jul : long_integer;} \]
\[ \quad \text{Month : Month.Number;} \]
\[ \quad \text{Day : Day.Number;} \]
\[ \quad \text{Year : Year.Number;} \]
\[ \quad \text{Seconds : Day.Duration;} \]
\[ \quad \text{fday : DayOfWeek;} \]
\[ \text{begin} \]
\[ \quad \text{Split(}\text{Today}, \text{Year}, \text{Month}, \text{Day}, \text{Seconds}); \quad \text{jul} := \text{julian_day(}\text{Month}, \text{Day}, \text{Year}); \]
\[ \quad \text{fday} \leftarrow \text{DayOfWeek'}\text{val}(\text{jul + 1} \mod 7); \text{return fday;} \]
\[ \text{end GetDayOfWeek;} \]
132. Essentially converts hours to seconds.

(Procedures and Tasks in calyr 39) +

function ConvertHoursToDuration(hrs : natural)return Duration is
    dur : duration;
begin
    dur ← duration(hrs) * 3600.0; return dur;
end ConvertHoursToDuration;

133. Essentially converts seconds to hours.

(Procedures and Tasks in calyr 39) +

function ConvertDurationToHours(dur : Duration)return natural is
    hrs : natural;
begin
    hrs ← natural(float(dur)/3600.0); return hrs;
end ConvertDurationToHours;

134.

(Procedures and Tasks in calyr 39) +

Procedure Split(Seconds : Day_Duration; Hour : out Hour_Number; Minute : out
Minute_Number;
    Second : out Second_Number) is yrsecs : Day_Duration ← Seconds;
begin
    Hour ← integer(yrsecs)/3600; yrsecs ← yrsecs − Duration(Hour * 3600);
    Minute ← integer(yrsecs)/60; yrsecs ← yrsecs − Duration(Minute * 60);
    Second ← integer(yrsecs);
end Split;

135. Prints out the date.

<table>
<thead>
<tr>
<th>mm</th>
<th>Month number</th>
</tr>
</thead>
<tbody>
<tr>
<td>dd</td>
<td>Day number in the month</td>
</tr>
<tr>
<td>HH</td>
<td>Hour number (24 hour system)</td>
</tr>
<tr>
<td>MM</td>
<td>Minute number</td>
</tr>
<tr>
<td>SS</td>
<td>Second number</td>
</tr>
<tr>
<td>cc</td>
<td>Century minus one</td>
</tr>
<tr>
<td>yy</td>
<td>Last 2 digits of the year number</td>
</tr>
</tbody>
</table>

The month, day, year, and century may be omitted; the current values are applied as defaults. For example:

date 10080045

sets the date to Oct 8, 12:45 a.m. The current year is the default because no year is supplied.
136. This was written because there seemed to be an error in adding 86,400.0 seconds to a day and then expecting the answer to come out right. Errors occurred around April 7, 1997 and October 26, 1997. I believe it is a GNAT bug for version 3.09.

(Procedures and Tasks in calyr 39) +

function IncrementDay(YrDate : Time) return Time is
  jul : long_integer;
  Year : Year_Number;
  Day : Day_Number;
  Month : Month_Number;
  Seconds : Day_Duration;
begin
  Split(Yrdate, Year, Month, Day, Seconds); jul ← julian_day(Month, Day, Year);
  jul ← jul + 1; caldate(jul, Month, Day, Year);
  return Time_Of(Year, Month, Day, Seconds);
end IncrementDay;
(Procedures and Tasks in calyr 39) +calyr

procedure print_date(date : time) is
  (Variables local to print_date 138)
do_alternate : boolean ← true;
begin
  Split(date, Year, Month, Day, Seconds);
  if Month < 10 then
    put("0");
  end if;
  put(natural(Month),1); put("/");
  if day < 10 then
    put("0");
  end if;
  put(natural(Day),1); put("/"); put(natural(Year),4);
  Split(Seconds, Hour, Minute, Second);
  if do_alternate then
    put("+");
    if Hour < 10 then
      put("0");
    end if;
    put(natural(Hour),1);
  else
    put("-");
    if Hour < 10 then
      put("0");
    end if;
    put(natural(Hour),1); put(":");
    if Minute < 10 then
      put("0");
    end if;
    put(natural(Minute),1); put(":");
    if Second < 10 then
      put("0");
    end if;
    put(natural(Second),1);
  end if;
end print_date;
138.

(Variables local to print_date 138) \equiv
  Year : Year_Number;
  Month : Month_Number;
  Day : Day_Number;
  Seconds : Day_Duration;
  Hour : Hour_Number;
  Minute : Minute_Number;
  Second : Second_Number;

This code is used in section 137.
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(Procedures and Task in calyr 39) +−

procedure print_date(outfile : file_type; date : time) is
  (Variables local to fprint_date 140)
  do_alternate : boolean ← true;
begin
  Split(date, Year, Month, Day, Seconds);
  if Month < 10 then
    put(outfile, "0");
  end if;
  put(outfile, natural(Month), 1); put(outfile, "/");
  if day < 10 then
    put(outfile, "0");
  end if;
  put(outfile, natural(Day), 1); put(outfile, "/"); put(outfile, natural(Year), 4);
  Split(Seconds, Hour, Minute, Second);
  if do_alternate then
    put(outfile, "+");
    if Hour < 10 then
      put(outfile, "0");
    end if;
    put(outfile, natural(Hour), 1);
  else
    put(outfile, ":" );
    if Hour < 10 then
      put(outfile, "0");
    end if;
    put(outfile, natural(Hour), 1); put(outfile, ":");
    if Minute < 10 then
      put(outfile, "0");
    end if;
    put(outfile, natural(Minute), 1); put(outfile, ":");
    if Second < 10 then
      put(outfile, "0");
    end if;
    put(outfile, natural(Second), 1);
  end if;
end print_date;

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140.

\{ Variables local to fprint\_date 140 \} \equiv

\begin{align*}
\text{Year} & : \text{Year\_Number}; \\
\text{Month} & : \text{Month\_Number}; \\
\text{Day} & : \text{Day\_Number}; \\
\text{Seconds} & : \text{Day\_Duration}; \\
\text{Hour} & : \text{Hour\_Number}; \\
\text{Minute} & : \text{Minute\_Number}; \\
\text{Second} & : \text{Second\_Number};
\end{align*}

This code is used in section 139.

141.

\{ Procedures and Tasks in calyr 39 \} \equiv

function get\_date\( (\text{infile} : \text{file\_type}) \) return Time is

\{ Variables local to fget\_date 142 \}

begin

get(\text{infile}, ndum); Month \leftarrow ndum;

if \text{debug2} then

\text{put(\"Month\_u=n\"\);} \text{put(Month, 1); put\_line(\"\.");}
end if;

get\_immediate(\text{infile}, chr); get(\text{infile}, ndum); Day \leftarrow ndum;

if \text{debug2} then

\text{put(\"Day\_u=n\"\);} \text{put(Day, 1); put\_line(\"\.");}
end if;

get\_immediate(\text{infile}, chr); get(\text{infile}, ndum);

if ndum < 100 then

if ndum < 50 then

Year \leftarrow ndum + 2000;

else

Year \leftarrow ndum + 1900;
end if;
else

Year \leftarrow ndum;
end if;

if \text{debug2} then

\text{put(\"Year\_u=n\"\);} \text{put(Year, 1); put\_line(\"\.");}
end if;

get\_immediate(\text{infile}, chr); get(\text{infile}, ndum); Hour \leftarrow ndum;

return Time\_\text{Of}(\text{Year}, \text{Month}, \text{Day}, \text{ConvertHoursToDuration(Hour)});
end get\_date;
142.

(Variables local to \textit{fget\_date} 142) \equiv

\textit{ndum} : \textit{natural};
\textit{chr} : \textit{character};
\textit{Year} : \textit{Year\_Number};
\textit{Month} : \textit{Month\_Number};
\textit{Day} : \textit{Day\_Number};
\textit{Hour} : \textit{natural};

This code is used in section 141.
function get_date(str : in Ustring) return Time is
{ Variables local to get_date }
begin
if debug2 then
  put("Parsing Ustring : ") put(S(str)); put_line(" ");
end if;
tstr := str; get(S(tstr), ndum, Last); Month := ndum;
if debug2 then
  put("Month : ") put(Month, 1); put_line(" ");
end if;
ind := index(tstr,"/"); tstr := tail(tstr,length(tstr) - ind);
get(S(tstr), ndum, Last); Day := ndum;
if debug2 then
  put("Day : ") put(Day, 1); put_line(" ");
end if;
ind := index(tstr,"/"); tstr := tail(tstr,length(tstr) - ind);
get(S(tstr), ndum, Last);
if debug2 then
  put("Parsing Ustring : ") put(S(tstr)); put_line(" "); put("ndum : ");
  put(ndum, 1); put_line(" ");
end if;
if ndum < 100 then
  if ndum < 50 then
    Year := ndum + 2000;
  else
    Year := ndum + 1900;
  end if;
else
  Year := ndum;
end if;
if debug2 then
  put("Year : ") put(Year, 1); put_line(" ");
end if;
ind := index(tstr,"+"); tstr := tail(tstr,length(tstr) - ind);
get(S(tstr), ndum, Last); Hour := ndum;
return Time_Of (Year, Month, Day, ConvertHoursToDuration(Hour));
end get_date;
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144.

\{(Variables local to get_date 144) \equiv
  ndum : natural;
  Year : Year_Number;
  Month : Month_Number;
  Day : Day_Number;
  Hour : natural;
  Last : positive;
  tstr : ustring;
  ind : natural;\}

This code is used in section 143.
145. **Test Driver.** This is the main routine that starts everything.

146.

```ada
output to file main.adb
with Text_IO;
use Text_IO;
with Ada.Calendar;
use Ada.Calendar;
with calyr;
use calyr;
with ustrings;
use ustrings;
with getopt;
use getopt;
procedure main is
  (Variables local to main 150)
  package yr_io is new integer_io(Year_Number);
  use yr_io;
  package bool_io is new enumeration_io(boolean);
  use bool_io;
begin
  (Get options 147)
  print_holidays(yr, nps);
end main;
```

147.

(Get options 147) ≡
(Get year 148)
(Get nps 149)
This code is used in section 146.

148.

(Get year 148) ≡
if option_present(U("-year")) then
  get_option(U("-year"), param); get(S(param), yr, Last);
else
  yr ← 1997;
end if;
This code is used in section 147.
149.
(Get nps 149) ≡
  if option_present(U("-nps")) then
    get_option(U("-nps"), param); get(S(param), nps, Last);
  else
    nps ← false;
  end if;
This code is used in section 147.

150.
(Variables local to main 150) ≡
yr : Year_number;
param : Ustring;
Last : positive;
nps : boolean;
This code is used in section 146.
151. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make \texttt{MAIN} work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

152. RCS Keywords.

$\texttt{RCSfile: calyr.aweb,v}$

$\texttt{Revision: 1.1}$

$\texttt{Date: 1997/08/18 22:43:35}$

$\texttt{Author: evansjr}$

$\texttt{Id: calyr.aweb,v 1.1 1997/08/18 22:43:35 evansjr Exp evansjr}$

$\texttt{Locker: evansjr}$

$\texttt{State: Exp}$

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153. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

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§153  APPENDIX E

NAMES OF THE SECTIONS

( Assert that input dates are correct 119, 120 ) Used in section 118.
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(Variables local to DurationToCalendarTime 111, 113, 115) Used in section 109.

(Variables local to IsWorkDay 103, 105) Used in section 101.

(Variables local to Julian_Day 94, 97, 100) Used in section 93.

(Variables local to SameDay 130) Used in section 129.

(Variables local to caldat 90, 92) Used in section 88.

(Variables local to calyr 33, 34, 35, 36, 37, 38, 46, 48, 49, 50, 58, 65) Used in section 9.

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(Weekday of December 31 79) Used in section 77.

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# Probability Functions

[Ada '95—Version 1.0]

September 4, 1997

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This page intentionally left blank
1. **Introduction.** Here is the Ada code for routines used in calculating probability distributions. This code uses Donald Knuth's WEB format for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

   It is available on-line via the world-wide-web at URL:

   \[ \text{http://white.nosc.mil/~evansjr/literate/} \]

2. **WEB** is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called “Literate Programming.” For further information see the paper *Literate Programming*, by Donald Knuth in *The Computer Journal*, Vol 27, No. 2, 1984; or the book *Weaving a Program: Literate Programming in WEB* by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group *comp.programming.literate*. It has information on new tools and Frequently Asked Questions (FAQs).

3. The program consists of several packages that are declared right now; each of these packages and either the specification and the body of the packages are sent to a separate file. The main program itself is declared later. (Since the original AWEB package was written for Ada '83, it does not properly format new Ada '95 keywords `protected` and `private`. We remedy using the web format commands below.

   ```
   \text{format \texttt{protected} \equiv \texttt{procedure}}
   
   \text{format \texttt{private} \equiv \texttt{procedure}}
   ```

4. As a way of explanation, each “Module” within angle brackets (`< >`) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. You can treat the modules names as a PDL (Program Descriptor Language), a highly recommended way of writing and documenting code.

   (Package boiler-plate 5)
5. Probability Primitives.

\[ \text{(Package boiler-plate 5) } \equiv \]
\[ \text{output to file probability.ads} \]

\[ \text{(Needed packages 6)} \]
\[ \text{package probability is} \]
\[ \text{(Specification of types and variables visible from probability 7)} \]
\[ \text{(Specification of procedures visible from probability 8)} \]
\[ \text{end probability;} \]

\[ \text{output to file probability.adb} \]

\[ \text{package body probability is} \]
\[ \text{(Variables local to probability 10)} \]
\[ \text{(Procedures and Tasks in probability 11)} \]
\[ \text{end probability;} \]

This code is used in section 4.

6. Here is the specification for generics.

\[ \text{(Needed packages 6)} \equiv \]
\[ \text{with Ada.Numerics.Float_Random;} \]

See also section 12.

This code is used in section 5.

7. 

\[ \text{(Specification of types and variables visible from probability 7)} \equiv \]
\[ \text{type bool_array is array (integer range \texttt{<>}) of boolean;} \]

This code is used in section 5.

8. 

\[ \text{(Specification of procedures visible from probability 8)} \equiv \]
\[ \text{function Uniform(Low, High : Float)return float;} \]
\[ \text{function Uniform(Low, High : Natural)return Natural;} \]
\[ \text{procedure sample(M, N : in natural; yrsample : out bool_array);} \]

This code is used in section 5.
§9 APPENDIX F


10. 
(Variables local to probability 10) \equiv 
    debug : boolean \leftarrow false; 
    FirstTime : boolean \leftarrow true; 
This code is used in section 5.

11. 
(Procedures and Tasks in probability 11) \equiv 
    function Uniform(Low, High : Float) return float is 
        P1 : Uniformly_Distributed; 
        G : Generator; 
        answer : float; 
        tmp : float; 
        begin 
            Reset(G); P1 \leftarrow Random(G); tmp \leftarrow (High - Low); answer \leftarrow tmp \times (P1) + Low; 
            return answer; 
        end Uniform; 
See also Sections 13 and 14. 
This code is used in section 5.

12. 
(Needed packages 6) \equiv 
    with Text.IO; 
    use Text.IO;
13.

(Procedures and Tasks in probability 11) \(\equiv\)

```ada
function Uniform(Low, High : natural) return natural is
    use Ada.Numerics.Float_Random;
    P1 : Uniformly_Distributed;
    G : Generator;
    tmp, tmp2 : float;
    answer : natural;
    package flt_io is new float_io(float);
    use flt_io;
    begin
        if Low = High then
            answer \(\leftarrow\) Low;
        else
            if FirstTime then
                Reset(G, 68069); FirstTime \(\leftarrow\) false;
            else
                Reset(G);
            end if;
            P1 \(\leftarrow\) Random(G); tmp \(\leftarrow\) float(High - Low + 1); tmp2 \(\leftarrow\) (tmp * P1) - 0.5;
            if (debug) then
                put("Random generated\)
                put(P1); put_line("...");
                put("(high-low+1)\)
                put(tmp); put_line("...");
                put("(tmp*p1)\)
                put(tmp2); put_line("...");
            end if;
            answer \(\leftarrow\) natural(tmp2) + Low;
        end if;
        return answer;
    end Uniform;
```
14. Based on a routine from the September, 1987 Communications of the ACM.

\begin{verbatim}
(Procedures and Tasks in probability 11) +-
procedure sample(M, N : in natural; yrsample : out bool array) is
  t : natural;
  k : natural;
begin
  for j in 1..N loop
    yrsample(j) ← false;
  end loop;
  k ← N - M + 1;
  for j in k..N loop
    t ← uniform(1,j);
    if yrsample(t) then
      yrsample(j) ← true;
    else
      yrsample(t) ← true;
    end if;
  end loop;
end sample;
\end{verbatim}
15. **System-dependent changes.** This module should be replaced, if necessary, by changes to the program that are necessary to make `MAIN` work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

16. **RCS Keywords.**

```
$RCSfile: probability.aweb,v
$Revision: 1.1
$Date: 1997/08/03 21:35:14
$Author: evansjr
$Id: probability.aweb,v 1.1 1997/08/03 21:35:14 evansjr Exp evansjr
$Locker: evansjr
$State: Exp
```
17. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

answer: 11, 13.
bool_array: 7, 8, 14.
boolean: 7, 10.
debug: 10, 13.
false: 10, 13–14.
FirstTime: 10, 13.
float: 8, 11, 13.
Float: 8, 11.
float_io: 13.
Float_Random: 6, 11, 13.
Generator: 11, 13.
High: 8, 11, 13.
integer: 7.
j: 14.
Low: 8, 11, 13.
natural: 8, 13–14.
Natural: 8.
Numerics: 6, 11, 13.
private: 3.
probability: 5.
probability.adb: 5.
probability.ads: 5.
procedure: 3.
protected: 3.
put: 13.
put_line: 13.
Pl: 11, 13.
Random: 11, 13.
Reset: 11, 13.
sample: 8, 14.
system dependencies: 15.
Text_IO: 12.
tmp: 11, 13.
true: 10, 14.
uniform: 14.
Uniform: 8, 11, 13.
Uniformly_Distributed: 11, 13.
yrsample: 8, 14.
NAMES OF THE SECTIONS

(Needed packages 6, 12) Used in section 5.
(Package boiler-plate 5) Used in section 4.
(Procedures and Tasks in probability 11, 13, 14) Used in section 5.
(Specification of procedures visible from probability 8) Used in section 5.
(Specification of types and variables visible from probability 7) Used in section 5.
(Variables local to probability 10) Used in section 5.
APPENDIX G

getopt

[Ada '95—Version 1.0]

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1. Introduction. This package provides some primitive command-line processing typical of Unix commands.

2. This code is written using Donald Knuth's WEB paradigm for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

   It is available on-line via the world-wide-web at URL:

   http://white.nosc.mil/~evansjr/literate/

   p

3. WEB is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called "Literate Programming." For further information see the paper Literate Programming, by Donald Knuth in The Computer Journal, Vol 27, No. 2, 1984; or the book Weaving a Program: Literate Programming in WEB by Wayne Sewell, Van Nostrand Reinhold, 1989. Another good source of information is the Usenet group comp.programming.literate. It has information on new tools and Frequently Asked Questions (FAQs).

4. The program consists of several packages that are declared right now; each of these packages and either the specification and the body of the packages are sent to a separate file. The main program itself is declared later. (Since the original AWEB package was written for Ada '83, it does not properly format new Ada '95 keywords protected and private. We remedy using the web format commands below.

format protected ≡ procedure
format private ≡ procedure

5. As a way of explanation, each "Module" withing angle brackets (< >) is expanded somewhere further down in the document. Consider it a high-level PDL (Program Descriptor Language). The trailing number you see within the brackets is where you can find this expansion. It is top-down in appearance, and in actual fact.

6. All the modules follow the same, top-down format. I will group all the boiler-plate into one module, for the compiler, but you will see it with the packages, as they are described.

   (Package boiler-plate ?)
GETOPT SPECIFICATION


\(\langle\text{Package boiler-plate 7}\rangle \equiv\)
output to file getopt.ads
with Ustrings;
use Ustrings;
with TEXT_IO;
use TEXT_IO;
with Ada.Command_Line;
use Ada.Command_Line;
package getopt is
\(\langle\text{Specification of types and variables visible from getopt 8}\rangle\)
\(\langle\text{Specification of procedures visible from getopt 9}\rangle\)
end getopt;
output to file getopt.adb
\(\langle\text{Packages needed by getopt body 11}\rangle\)
package body getopt is
\(\langle\text{Variables local to getopt 12}\rangle\)
\(\langle\text{Procedures and Tasks in getopt 13}\rangle\)
end getopt;

This code is used in section 6.

8.

\(\langle\text{Specification of types and variables visible from getopt 8}\rangle \equiv\)

This code is used in section 7.

9.

\(\langle\text{Specification of procedures visible from getopt 9}\rangle \equiv\)
function option_present(option : in Ustring)return boolean;
function name_present(Num : natural)return boolean;
procedure get_option(option : in Ustring; param : out Ustring);
procedure get_name(name : out Ustring; Num : in natural);

This code is used in section 7.

11. (Packages needed by getopt body 11) ≡
   with Ada.Strings.Unbounded; Use Ada.Strings.Unbounded; with Ustrings;
   use Ustrings;

This code is used in section 7.

12. (Variables local to getopt 12) ≡
    debug : boolean ← false;

This code is used in section 7.

13. (Procedures and Tasks in getopt 13) ≡
    package natio is new integer_io(natural);

See also sections 14, 15, 16, and 19.

This code is used in section 7.

14. (Procedures and Tasks in getopt 13) +≡
    function option_present(option : in Ustring) return boolean is
      knl : natural;
      ispresent : boolean;
    begin
      knl ← Argument.Count; ispresent ← false;
      for i ∈ 1..knl loop
        if S(option) = Argument(i) then
          ispresent ← true; exit;
        end if;
      end loop;
      return ispresent;
    end option_present;
15. \[ (\text{Procedures and Tasks in } \text{getopt 13}) \equiv \]

```
procedure get_option(option : in Ustring; param : out Ustring) is
  knt : natural;
begin
  knt := Argument_Count;
  for i in 1..knt loop
    if S(option) = Argument(i) then
      param := U(Argument(i+1));
    end if;
  end loop;
end get_option;
```

16. \[ (\text{Procedures and Tasks in } \text{getopt 13}) \equiv \]

```
function name_present(Num : natural) return boolean is
  knt, ic : natural;
  i : natural := 1;
  fknnt : natural := 0;
  ispresent : boolean;
begin
  ispresent := false;
  if debug then
    put.line("name_present");
  end if;
  knt := Argument_Count;
  while (i <= knt) loop
    (If found option, skip it and its parameter 17)
    (if not option, must be name, return true if right number 18)
  end loop;
  if debug then
    put("Argument_"); natio.put(Num, 1);
    if ispresent then
      put.line("is_present.");
    else
      put.line("is NOT present.");
    end if;
  end if;
  return ispresent;
end name_present;
```
17. \(\text{(If found option, skip it and its parameter 17)}\) \(\equiv\)
\[
ic \leftarrow \text{Index}(U(Argument(i)),"-");\]
if \(ic > 0\) then
    \(i \leftarrow i + 2;\)
end if;
if \(\text{debug}\) then
    \(\text{put_line}("\text{Skipping first option.}"");\)
end if;
This code is used in sections 16 and 19.

18. \(\text{(if not option, must be name, return true if right number 18)}\) \(\equiv\)
if \(ic = 0\) then
    \(fknt \leftarrow fknt + 1;\)
    if \(fknt = \text{num}\) then
        if \(\text{debug}\) then
            \(\text{put_line}("\text{Found your input file name!}"");\)
        end if;
        \(ispresent \leftarrow \text{true};\) exit;
    end if;
    \(i \leftarrow i + 1;\)
end if;
This code is used in section 16.

19. \(\text{(Procedures and Tasks in getopt 13)}\) \(\equiv\)
\[
\text{procedure get_name(name : out Ustring; Num : natural) is} \]
\[
knt, ic : \text{natural};\]
\[
i : \text{natural} \leftarrow 1;\]
\[
fknt : \text{natural} \leftarrow 0;\]
begin
    if \(\text{debug}\) then
        \(\text{put_line}("\text{get_name}"")\);
    end if;
    \(knt \leftarrow \text{Argument.Count};\)
    while \((i \leq knt)\) loop
        (If found option, skip it and its parameter 17)
        (if not option, must be name, return if right number 20)
    end loop;
end get_name;
20.

(if not option, must be name, return if right number 20) \equiv

if ic = 0 then
  fknt \leftarrow fknt + 1;
  if fknt = num then
    if debug then
      put_line("Found your input file name!");
    end if;
    name \leftarrow U(Argument(i)); exit;
  end if;
  i \leftarrow i + 1;
end if;

This code is used in section 19.
21. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

22. RCS Keywords.

```
$RCSfile: getopt.aweb,v
$Revision: 1.1
$Date: 1997/09/05 00:28:36
$Author: evansjr
$Id: getopt.aweb,v 1.1 1997/09/05 00:28:36 evansjr Exp evansjr
$Locker: evansjr
$State: Exp
```
23. Index. Here is a cross-reference table for the MAIN program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

Ada: 7, 11.
Argument_Count: 14–16, 19.
boolean: 9, 12, 14, 16.
Command_Line: 7.
debug: 12, 16–20.
false: 12, 14, 16.
fint: 16, 18–20.
get_name: 9, 19.
get_option: 9, 15.
getopt: 7.
getopt.adb: 7.
getopt.ads: 7.
i: 14, 15.
Index: 17.
ispresent: 14, 16, 18.
knt: 14–16, 19.
name: 9, 19–20.
name_present: 9, 16.
natio: 13, 16.
natural: 9, 13–16, 19.
num: 18, 20.
Num: 9, 16, 19.
option: 9, 14–15.
option_present: 9, 14.
param: 9, 15.
private: 4.
procedure: 4.
protected: 4.
put: 16.
Strings: 11.
system dependencies: 21.

TEXT.IO: 7.
true: 14, 18.
Unbounded: 11.
Use: 11.
Ustring: 9, 14–15, 19.
Ustrings: 7, 11.
(If found option, skip it and its parameter 17) Used in sections 16 and 19.
(Package boiler-plate 7) Used in section 6.
(Packages needed by getopt body 11) Used in section 7.
(Procedures and Tasks in getopt 13, 14, 15, 16, 19) Used in section 7.
(Specification of procedures visible from getopt 9) Used in section 7.
(Specification of types and variables visible from getopt 8) Used in section 7.
(Variables local to getopt 12) Used in section 7.
(if not option, must be name, return if right number 20) Used in section 19.
(if not option, must be name, return true if right number 18) Used in section 16.
Capabilities Package

[Ada '95—Version 1.0]
September 18, 1997

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</table>
1. **Introduction.** Here is some code to test capabilities. It is written using Donald Knuth's WEB format for literate programming. To compile and link the code in its present format you will need the Ada version of the WEB tool.

   It is available on-line via the world-wide-web at URL:

   ```
   http://white.nosc.mil/~evansjr/literate/
   ```

2. **WEB** is a literate programming paradigm for C, Pascal or Ada, and other languages. This style of programming is called "Literate Programming." For further information get the book *Literate Programming*, by Donald Knuth, published by the Center for the Study of Language and Information, Stanford University, 1992. Another good source of information is the Usenet group *comp.programming.literate*. It has information on tools and answers to frequently asked questions (FAQs).

3. **Who should use the WEB paradigm for programming?** Well, not everybody. Here are a few paragraphs from Donald Knuth's book that explains it best.

4. **Retrospect and Prospects.** Enthusiastic reports about new computer languages, by the authors of those languages, are commonplace. Hence I'm well aware of the fact that my own experiences cannot be extrapolated too far. I also realize that, whenever I have encountered a problem with WEB, I've simply changed the system; other users of WEB cannot operate under the same ground rules.

5. However, I believe that I have stumbled on a way of programming that produces better programs that are more portable and more easily understood and maintained than ever before; furthermore, the system seems to work with large programs as well as with small ones. I'm pleased that my work on typography, which began as an application of computers to another field, has come full circle and become an application of typography to the heart of computer science; I like to think of WEB as a neat "spinoff" of my research on TeX. However, all of my experiences with this system have been highly colored by my own tastes, and only time will tell if a large number of other people will find WEB to be equally attractive and useful.
6. I made a conscious decision not to design a language that would be suitable for everybody. My goal was to provide a tool for system programmers, not for high school students or for hobbyists. I don’t have anything against high school students and hobbyists, but I don’t believe every computer language should attempt to offer all things to all people. A user of WEB needs to be good enough at computer science that he or she is comfortable dealing with several languages simultaneously. Since WEB combines \TeX and Pascal with a few rules of its own, WEB programs can contain WEB syntax errors. \TeX syntax errors, Pascal syntax errors, and algorithmic errors; in practice, all four types of errors occur, and a bit of sophistication is needed to sort out which is which. Computer specialists tend to be better at such things than other people. I have found that WEB programs can be debugged rapidly in spite of the profusion of languages, but I’m sure that many other intelligent people will find such a task difficult.

7. In other words, WEB seems to be specifically for the peculiar breed of people who are called computer scientists. And I’m pretty sure that there are also a lot of computer scientists who will not enjoy using WEB; some of us are glad that traditional programming languages have comparatively primitive capabilities for inserted comments, because such difficulties provide a good excuse for not documenting programs well. Thus, WEB may be only for the subset of computer scientists who like to write and to explain what they are doing. My hope is that the ability to make explanations more natural will cause more programmers to discover the joys of literate programming, because I believe it’s quite a pleasure to combine verbal and mathematical skills; but perhaps I’m hoping for too much. The fact that a least one paper has been written that is a syntactically correct ALGOL 68 program encourages me to persevere in my hopes for the future. Perhaps we will even one day find Pulitzer prizes awarded to computer programs.

8. Donald Knuth goes on to write about his hopes for the future of WEB programming. In an interview with Donald Knuth by Amazon Books on the release of a new edition of Volume 1 of *The Art of Computer Programming* (July 1, 1997) he was asked:

**Amazon.com:** What do you see as the most interesting advance in programming since you published the first edition?

**Donald Knuth:** It’s what I call literate programming, a technique for writing, documenting, and maintaining programs using a high-level language combined with a written language like English. This is discussed in my book Literate Programming.

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9. In the same book, *Literate Programming*, there is a chapter called *How to read a WEB*. But it is actually quite straightforward.

10. Very briefly, each "Module" within angle brackets (< >) is expanded somewhere further down in the document. The trailing number you see within the brackets is where you can find this expansion. This provides a type of PDL (program descriptor language) for your program and greatly aids modularity and readability. It is also a highly effective method of top-down programming. The first module here is expanded further down, and contains most of the structure in standard Ada packages.

   (Package boiler-plate 11)
11. Capabilities specification.

(Package boiler-plate 11) \equiv
output to file capability.ads
with TEXT_IO;
use TEXT_IO;
with test_io_pkg;
use test_io_pkg;
with generic_set_pkg;
with generic_map_pkg;
with ustrings;
use ustrings;
package capability is
  (Specification of types and variables visible from capability 12)
  (Specification of procedures visible from capability 14)
private
  (Specification of private types in capability 21)
end capability;

output to file capability.adb
with unchecked_deallocation;
with generic_map_pkg;
with Ada.Strings.Unbounded; Use Ada.Strings.Unbounded; with Ustrings;
use ustrings;
with Ada.Strings;
use Ada.strings;
with Ada.Characters.handling;
use Ada.Characters.handling;
package body capability is
  (Variables and types local to capability 23)
  (Procedures and Tasks in capability 28)
begin
  (Initialize capabilities 42)
end capability;

This code is used in section 10.

12.

(Partitioning of types and variables visible from capability 12) \equiv
  type devel_num is private;
type AString is access String;
type ExpertiseLevel is (low, medium, high);
package cap_map is new generic_map_pkg(key \Rightarrow AString, result \Rightarrow ExpertiseLevel);

See also section 13.

This code is used in section 11.
13. 
(Specification of types and variables visible from capability 12) \[\equiv\]
\[ \text{badid} : \text{exception}; \]
\[ \text{parsecapabilityerror} : \text{exception}; \]

14. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{procedure create_developer}(\text{developer} : \text{in String}; \text{yrid} : \text{out natural}); \]

See also sections 15, 16, 17, 18, 19, and 20.
This code is used in section 11.

15. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{procedure add_capability}(\text{id} : \text{in natural}; \text{yrcap} : \text{String}; \text{exp} : \text{ExpertiseLevel}); \]
\[ \text{procedure add_capability}(\text{yrid} : \text{in devel_num}; \text{yrcap} : \text{cap_map.map}); \]
\[ \text{procedure add_capability}(\text{yrtask} : \text{in out cap_map.map}; \text{yrcap} : \text{String}; \]
\[ \text{exp} : \text{ExpertiseLevel}); \]

16. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{procedure copy_capability}(\text{yrid} : \text{in natural}; \text{yrcap} : \text{out cap_map.map}); \]

17. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{procedure print_capabilities}(\text{id} : \text{natural}); \]
\[ \text{procedure print_capabilities}(\text{yrtask} : \text{cap_map.map}); \]
\[ \text{procedure print_capabilities}(\text{fd} : \text{file_type}; \text{yrtask} : \text{cap_map.map}); \]
\[ \text{procedure print_developers}; \]
\[ \text{function get_developer_name}(\text{id} : \text{natural})\text{return ustring}; \]

18. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{function is_qualified}(\text{yrtask} : \text{cap_map.map}; \text{id} : \text{natural})\text{return boolean}; \]

19. 
(Specification of procedures visible from capability 14) \[\equiv\]
\[ \text{procedure get_capability}(\text{str} : \text{in String}; \text{yrcap} : \text{out cap_map.map}); \]
\[ \text{procedure get_capability}(\text{fd} : \text{file_type}; \text{yrcap} : \text{out cap_map.map}); \]

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20. 
(Specification of procedures visible from capability 14) \(\equiv\)
   \begin{itemize}
   \item procedure get_developers(infile : string);
   \item function get_num_developers return natural;
   \end{itemize}

21. 
(Specification of private types in capability 21) \(\equiv\)
   \begin{itemize}
   \item package cap_set is new generic_set_pkg(Astring);
   \item type capability is new cap_set.set;
   \item max_developers : constant natural \(\leftarrow\) 20;
   \item type devel_num is new natural range 1 .. max_developers;
   \end{itemize}

This code is used in section 11.

23. 
\(\{\text{Variables and types local to capability 23}\}\) \(\equiv\)
\[
\text{debug : boolean } \leftarrow \text{false}; \\
\text{debug2 : boolean } \leftarrow \text{false}; \\
\text{gstring : Ustring};
\]
See also sections 24, 25, 26, and 27.
This code is used in section 11.

24. Maintain a global set of capabilities;
\(\{\text{Variables and types local to capability 23}\}\) \(\equiv\)
\[
\text{globalcaps : cap.set.set}; \\
\text{total.developers : natural } \leftarrow 0;
\]

\(\{\text{Variables and types local to capability 23}\}\) \(\equiv\)
\[
\text{function } '+'(\text{str : string})\text{return Astring is} \\
\text{begin} \\
\text{return new string'}(\text{str}); \\
\text{end } '+';
\]

26. 
\(\{\text{Variables and types local to capability 23}\}\) \(\equiv\)
\[
\text{MAXCAPS : constant natural } \leftarrow 30; \\
\text{type cap.num is new natural range } 1..\text{MAXCAPS}; \\
\text{type cap.array is array (cap.num) of Astring}; \\
\text{capabilities : cap.array } \leftarrow (\text{"Ada", "Database", "XWindows", "Graphics",} \\
\text{ "Unix", others } \Rightarrow \text{null}); \\
\text{mycaps : cap.set.set}; \\
\text{total.caps : cap.num } \leftarrow 5;
\]

27. 
\(\{\text{Variables and types local to capability 23}\}\) \(\equiv\)
\[
\text{type cap.rec is} \\
\text{record} \\
\text{inuse : boolean } \leftarrow \text{false}; \\
\text{name : Astring}; \\
\text{cmap : cap.map.map}; \\
\text{end record}; \\
\text{type developer.array is array (devel.num) of cap.rec}; \\
\text{developers : developer.array};
\]

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28.

\[
\text{procedures and tasks in capability 28}\equiv
\]

\[
\text{procedure create_developer(developer : in String; yrid : out natural) is}
\]

\[
knt : \text{devel.num};
\]

\[
tmpcap : \text{cap.map.map};
\]

begin

\[
\langle \text{fetch an unused developer 29}\rangle
\]

\[
\langle \text{assign capabilities to him 30}\rangle
\]

\[
\langle \text{create capability out of his name 31}\rangle
\]

end create_developer;

See also sections 33, 34, 35, 41, 44, 45, 46, 47, 48, 49, 50, 52, 62, 63, and 69.

This code is used in section 11.

29.

\[
\langle \text{fetch an unused developer 29}\rangle \equiv
\]

\[
knt \leftarrow 1;
\]

\[
\text{while developers(knt).inuse loop}
\]

\[
knt \leftarrow knt + 1;
\]

end loop;

\[
\text{developers(knt).inuse } \leftarrow \text{true}; \text{total.developers } \leftarrow \text{total.developers } + 1;
\]

\[
yrid \leftarrow \text{natural(knt)};
\]

This code is used in section 28.

30.

\[
\langle \text{assign capabilities to him 30}\rangle \equiv
\]

\[
\circ\{\text{for } i \in 1 \ldots \text{total.caps} \text{ loop}
\]

\[
\text{cap.map.bind(capabilities(i), low, developers(knt).cmap)};
\]

end loop;

\[
\circ\}
\]

This code is used in section 28.

31.

\[
\langle \text{create capability out of his name 31}\rangle \equiv
\]

\[
\text{total.caps } \leftarrow \text{total.caps } + 1; \text{capabilities(total.caps)} \leftarrow +\text{developer};
\]

\[
\text{cap.map.bind(capabilities(total.caps), high, developers(knt).cmap)};
\]

\[
\text{cap.set.add(capabilities(total.caps), globalcaps)};
\]

\[
\text{developers(knt).name } \leftarrow \text{capabilities(total.caps)};
\]

\[
\langle \text{add this capability to all the other developers 32}\rangle
\]

if debug then

\[
\text{print.developers}
\]

end if;

This code is used in section 28.
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CAPABILITY BODY

32.

(Add this capability to all the other developers 32) ≡

@{for i ∈ devel_num loop
    if (developers(i).inuse) ∧ (i ≠ id) then
        if debug2 then
            put("Adding®, capability`, capability", put(puts) , put(puts)
            put(puts(developers(i).name.all)) . put_line(", .");
        end if;
        cap_map.bind(capabilities(total_caps), low, developers(i).cmap);
    end if;
end loop;
@}

This code is used in section 31.

33.

(Procedures and Tasks in capability 28) ≡

procedure add_capability(yrtask : in out cap_map.map; yrcap : String;
    exp : ExpertiseLevel) is
    acap : Astring;
    is_member : boolean;
    knt : cap_num;
begin
    (First convert to upper-case 37)(See if already in capabilities array 38)
    if ~is_member then
        total_caps ← total_caps + 1; capabilities(total_caps) ← acap;
        cap.set.add(capabilities(total_caps), globalcaps); knt ← total_caps;
    end if;
    cap_map.bind(capabilities(knt), exp, yrtask);
end add_capability;
34. <Procedures and Tasks in capability 28> +≡

procedure add_capability(yrid : in devel.num; yrcap : cap.map.map) is
  exp1 : ExpertiseLevel;
  id : natural;
begin
  id ← natural(yrid);
  for i ∈ 1 .. total_caps loop
    if cap_map.member(capabilities(i), yrcap) then
      exp1 ← cap_map.fetch(yrcap, capabilities(i));
      add_capability(id, capabilities(i).all, exp1);
    end if;
  end loop;
end add_capability;

35. <Procedures and Tasks in capability 28> +≡

procedure add_capability(id : in natural; yrcap : String; exp : ExpertiseLevel) is
  acap : A.string;
  is_member : boolean;
  knrt : cap.num;
  yrid : devel.num;
package enum_io is new enumeration_io(ExpertiseLevel);
begin
  yrid ← devel.num(id);
  if ~developers(yrid).inuse then
    raise badid;
  end if;
  (First convert to upper-case 37)(See if already in capabilities array 38)
  if ~is_member then
    total_caps ← total_caps + 1; capabilities(total_caps) ← acap;
    cap.set.add(capabilities(total_caps), globalcaps); (Add to all developers 40)
  else
    (Update capabilities of this developer 39)
  end if;
end add_capability;
§36.  
(Convert to upper-case 36) ≡

```
declare
  tstr : string ← yrcap;
  name : ustring;
begin
  name ← get_developer_name(natural(yrid));
  if tstr ≠ $iset(name) then
    for $j ∈ 1 .. yrcap'length loop
      tstr(j) ← to_upper(tstr(j));
    end loop;
  end if;
  acap ← +tstr;
end;
```

37.
(First convert to upper-case 37) ≡

```
declare
  tstr : string ← yrcap;
begin
  for $j ∈ 1 .. yrcap'length loop
    tstr(j) ← to_upper(tstr(j));
  end loop;
  acap ← +tstr;
end;
```
This code is used in sections 33 and 35.

38.
(See if already in capabilities array 38) ≡

```
is_member ← false;
for i ∈ 1 .. total_caps loop
  if (capabilities(i).all = acap.all) then
    acap ← capabilities(i); kni ← i; is_member ← true; exit;
  end if;
end loop;
```
This code is used in sections 33 and 35.
39.
\[
\langle \text{Update capabilities of this developer 39} \rangle \equiv \\
\text{if } \text{debug} \text{ then} \\
\text{put("Updating capabilities of developer: ");} \\
\text{put(S(get.developer.name(natural(\text{yrid}))); put("\text{u}"); put(capabilities(knt).all); put("=\text{u}"); enum.io.put(exp); new.line;} \\
\text{end if;}
\]
\[
\text{cap.map.bind(capabilities(knt), exp, developers(yrid).cmap);} \\
\text{This code is used in section 35.}
\]

40.
\[
\langle \text{Add to all developers 40} \rangle \equiv \\
\text{for } i \in \text{devel.num loop} \\
\text{if } (i \neq \text{yrid}) \text{ then} \\
\text{if } (\text{developers}(i).inuse) \text{ then} \\
\text{cap.map.bind(capabilities(totals.caps), low, developers(i).cmap);} \\
\text{end if;}
\]
\[
\text{else} \\
\text{cap.map.bind(capabilities(totals.caps), exp, developers(i).cmap);} \\
\text{end if;}
\]
\text{end loop;}
\]
\text{This code is used in section 35.}

41. Copy everything but developer’s name.
\[
\langle \text{Procedures and Tasks in capability 28} \rangle + \equiv \\
\text{procedure copy.capability(yrid : in natural; yrcap : out cap.map.map) is} \\
\text{exp1 : ExpertiseLevel;} \\
\text{yr : devel.num;} \\
\text{name1, name2 : ustring;} \\
\text{begin} \\
\text{yr } \leftarrow \text{devel.num(yrid);} \\
\text{for } i \in 1 \ldots \text{totals.caps loop} \\
\text{if } \text{cap.map.member(capabilities(i), developers(yr).cmap) then} \\
\text{name1 } \leftarrow U(capabilities(i).all); \text{name2 } \leftarrow \text{get.developer.name(yrid);} \\
\text{if } \text{name1 } \neq \text{name2} \text{ then} \\
\text{exp1 } \leftarrow \text{cap.map.fetch(developers(yr).cmap, capabilities(i))} \\
\text{add.capability(yrcap, capabilities(i).all, exp1);} \\
\text{end if;}
\]
\text{end if;}
\text{end loop;}
\text{end copy.capability;}
\]
42.

\( \text{Initialize capabilities 42} \) \equiv 
\[
\text{cap\_set}\_\text{empty}(\text{globalcaps});
\]
\[
\text{for } i \in 1 \ldots \text{total\_caps} \text{ loop}
\]
\[
(\text{Convert to uppercase 43})
\]
\[
\text{capabilities}(i) \leftarrow +S(gstring); \quad \text{cap\_set}\_\text{add}(\text{capabilities}(i), \text{globalcaps});
\]
\[
\text{end loop}
\]
This code is used in section 11.

43.

\( \text{(Convert to uppercase 43)} \) \equiv 
\[
\text{declare}
\]
\[
\ tstr : \text{String} \leftarrow \text{capabilities}(i)\_\text{all};
\]
\[
\ chr : \text{Character};
\]
\[
\text{begin}
\]
\[
\text{for } j \in 1 \ldots tstr\_\text{length} \text{ loop}
\]
\[
\ chr \leftarrow tstr(j); \quad tstr(j) \leftarrow \text{to\_upper}(chr);
\]
\[
\text{end loop}
\]
\[
\ gstring \leftarrow U(tstr);
\]
\[
\text{end};
\]
This code is used in section 42.
(Procedures and Tasks in capability 28) \(\equiv\)

function is_qualified(yrtask : cap_map.map; id : natural) return boolean is
    exp1, exp2 : ExpertiseLevel;
    answer : boolean \= true;
    yrid : devel_num;
begin
    yrid \= devel_num(id);
    for i \in 1..total_caps loop
        if cap_map.member(capabilities(i), yrid) then
            exp1 \= cap_map.fetch(yrtask, capabilities(i));
            if cap_map.member(capabilities(i), developers(yrid).cmap) then
                exp2 \= cap_map.fetch(developers(yrid).cmap, capabilities(i));
            else
                exp2 \= low;
            end if;
            if exp2 < exp1 then
                answer \= false; exit;
            end if;
        end if;
    end loop;
    return answer;
end is_qualified;
(Procedures and Tasks in capability 28) \(\equiv\)

```plaintext
procedure print_capabilities(yrtask : cap_map.map) is
  exp : Expertiselevel;
  package exp_io is new enumeration_io(Expertiselevel);
  use exp_io;
  knt1, knt2 : cap_num;
begin
  knt1 ← 1; knt2 ← 1;
  for i ∈ 1 .. total_caps loop
    if cap_map.member(capabilities(i), yrtask) then
      knt1 ← knt1 + 1;
    end if;
  end loop;
  put("{\n");
  for i ∈ 1 .. total_caps loop
    if cap_map.member(capabilities(i), yrtask) then
      put(capabilities(i).all); put(":{\n"); exp ← cap_map.fetch(yrtask, capabilities(i));
      put(exp); knt2 ← knt2 + 1;
      if knt2 < knt1 then
        put("},\n");
      end if;
    end if;
  end loop;
  put("}\n");
end print_capabilities;
```
CAPABILITY BODY

46.

(Procedures and Tasks in capability 28) +−

procedure print_capabilities(fd : file_type; yrtask : cap_map.map) is
    exp : Expertiselevel;
    package exp_io is new enumeration_io(Expertiselevel);
    use exp_io;
    knt1, knt2 : cap_num;
begin
    knt1 ← 1; knt2 ← 1;
    for i ∈ 1 .. total_caps loop
        if cap_map.member(capabilities(i), yrtask) then
            knt1 ← knt1 + 1;
        end if;
    end loop;
    put(fd, "{");
    for i ∈ 1 .. total_caps loop
        if cap_map.member(capabilities(i), yrtask) then
            put(fd, capabilities(i).all); put(fd, ":";");
            exp ← cap_map.fetch(yrtask, capabilities(i)); put(fd, exp); knt2 ← knt2 + 1;
            if knt2 < knt1 then
                put(fd, ";,\";");
            end if;
        end if;
    end loop;
    put(fd, "}\"");
end print_capabilities;

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procedure print_capabilities (id : natural) is
  exp : Expertiselevel;
  package exp_io is new enumeration_io (Expertiselevel);
  use exp_io;
  knt1, knt2 : cap_num;
  yrid : devel_num;
begin
  yrid ← devel_num (id); knt1 ← 1; knt2 ← 1;
  for i in 1 .. total_caps loop
    if cap_map.member (capabilities (i), developers (yrid).cmap) then
      knt1 ← knt1 + 1;
    end if;
  end loop;
  put ("\n");
  for i in 1 .. total_caps loop
    if cap_map.member (capabilities (i), developers (yrid).cmap) then
      put (capabilities (i).all); put (":\u201c\u201d");
      exp ← cap_map.fetch (developers (yrid).cmap, capabilities (i)); put (exp);
      knt2 ← knt2 + 1;
      if knt2 < knt1 then
        put ("\n");
      else
        put ("\n");
      end if;
    end if;
  end loop;
  put ("\n");
  end print_capabilities;

procedure print_developers is
  name : ustring;
begin
  for i in 1 .. total_developers loop
    name ← get_developer_name (i); put (S (name)); put ("\n"); print_capabilities (i);
    new_line;
  end loop;
  end print_developers;
49.

<Procedures and Tasks in capability 28> \equiv

function get_developer_name(id : natural) return ustring is
    yrid : devel.num;
begin
    yrid \leftarrow devel.num(id); return U(developers(yrid).name.all);
end get.developer_name;

50.

<Procedures and Tasks in capability 28> \equiv

procedure get_capability(fd : file_type; yrcap : out cap.map.map) is
    <Variables local to fget_capability 51>
begin
    chr \leftarrow "; ";
    while chr \neq "{" loop
        get.immediate(fd, chr);
    end loop;
    j \leftarrow 1; newstr(j) \leftarrow "{";
    while chr \neq "}" loop
        j \leftarrow j + 1; get.immediate(fd, chr); newstr(j) \leftarrow chr;
    end loop;
    declare
        newstr2 : String(1 .. j);
    begin
        for k \in 1 .. j loop
            newstr2(k) \leftarrow newstr(k);
        end loop;
        tstr \leftarrow U(newstr2);
    end;
    if debug then
        put("get_capabilities(file)\ calling\ get_capabilities\ (string)\ with");
        put("ustring\=ustring\=u"); put(S(tstr)); new_line;
    end if;
    get_capability(S(tstr), yrcap);
end get_capability;

51.

<Variables local to fget_capability 51> \equiv

j : positive;
chr : character;
newstr : String(1 .. 80);
tstr : ustring;

This code is used in section 50.
(Procedures and Tasks in capability 28) \( \equiv \)
procedure get\_capability(str : in String; gycap : out cap\_map.map) is (Variables local to get\_capability 53)
begin
  tstr \( \leftarrow \) U(str); ind1 \( \leftarrow \) index(tstr,"\{"); ind2 \( \leftarrow \) index(tstr,"\}"");
  tstr \( \leftarrow \) U(slice(tstr,ind1,ind2));
  if debug2 then
    put("Parsing\_string\_\""); put(S(tstr)); put_line("\.");
  end if;
  tstr \( \leftarrow \) tail(tstr,length(tstr) – ind1); finished \( \leftarrow \) false; while \( \neg \)finished loop
  (Get capability name pairs 54) end loop; end get\_capability;

(Variables local to get\_capability 53) \( \equiv \)
  tstr : ustring;
  ind1 : natural;
  finished : boolean;
See also sections 56, 58, and 60.
This code is used in section 52.

(Get capability name pairs 54) \( \equiv \)
  (Check if finished 55)
  if \( \neg \)finished then
    (Get capability 57)(Get ExpertiseLevel 59)(Add new capability to map 61)
  end if;
This code is used in section 52.

Each name pair is separated by a colon ' : '. It it is not there, then we are finished.
(Provided we didn't look past the brace ' \} ').
(Check if finished 55) \( \equiv \)
  ind2 \( \leftarrow \) index(tstr,"\ :"); ind3 \( \leftarrow \) index(tstr,"\}"");
  if (ind2 = 0) \vee (ind2 > ind3) then
    finished \( \leftarrow \) true;
  end if;
  if ind3 = 0 then
    raise parse\_capability\_error;
  end if;
This code is used in section 54.
56.

\( \text{Variables local to get\_capability 53} \) \( +\equiv \)

\( \text{ind2} , \text{ind3} : \text{natural} ; \)

57.

\( \text{Get capability 57} \) \( \equiv \)

\( \text{ind1} \leftarrow \text{index\_non\_blank(tstr)} ; \text{tstr2} \leftarrow U(\text{slice(tstr, ind1, ind2 - 1})) ; \)

\( \text{if debug2 then} \)

\( \text{put("tstr2=\_\_\_"}); \text{put}(S(tstr2)); \text{new\_line}; \)

\( \text{end if} ; \)

\( \text{tstr} \leftarrow \text{tail(tstr, length(tstr) - ind2)} ; \)

\( \text{if debug2 then} \)

\( \text{put("tstr=\_\_\_"}); \text{put}(S(tstr)); \text{new\_line}; \)

\( \text{end if} ; \)

\( \text{This code is used in section 54.} \)

58.

\( \text{Variables local to get\_capability 53} \) \( +\equiv \)

\( \text{tstr2} : \text{ustring} ; \)

59.

\( \text{Get ExpertiseLevel 59} \) \( \equiv \)

\( \text{ind1} \leftarrow \text{index(tstr, ",", \"\")}; \text{ind2} \leftarrow \text{index(tstr, \"\")}; \)

\( \text{if ind1 = 0 then} \)

\( \text{ind1} \leftarrow \text{ind2} ; \text{finished} \leftarrow \text{true} ; \)

\( \text{end if} ; \)

\( \text{tstr3} \leftarrow U(\text{slice(tstr, 1, ind1 - 1}) ; \)

\( \text{if debug2 then} \)

\( \text{put("tstr3=\_\_\_"}); \text{put}(S(tstr3)); \text{new\_line}; \)

\( \text{end if} ; \)

\( \text{enum\_io\_get}(S(tstr3), \text{exp}, \text{Last}); \text{tstr} \leftarrow \text{tail(tstr, length(tstr) - ind1)} ; \)

\( \text{if debug2 then} \)

\( \text{put("tstr=\_\_\_"}); \text{put}(S(tstr)); \text{new\_line}; \)

\( \text{end if} ; \)

\( \text{This code is used in section 54.} \)

60.

\( \text{Variables local to get\_capability 53} \) \( +\equiv \)

\( \text{tstr3} : \text{ustring} ; \)
\( \text{exp} : \text{ExpertiseLevel} ; \)
\( \text{package enum\_io is new enumeration\_io(ExpertiseLevel)} ; \)
\( \text{Last} : \text{positive} ; \)
61.  \( \langle \text{Add new capability to map } 61 \rangle \equiv \)
\[
\text{add\_capability} (yrcap, S(tstr2), exp);
\]
This code is used in section 54.

62.  \( \langle \text{Procedures and Tasks in } \text{capability } 28 \rangle \equiv \)
\[
\text{function } \text{get\_num\_developers } \text{return } \text{natural is}
\begin{align*}
\text{begin} \\
\text{return } \text{total\_developers} ; \\
\text{end } \text{get\_num\_developers} ;
\end{align*}
\]

63.  \( \langle \text{Procedures and Tasks in } \text{capability } 28 \rangle \equiv \)
\[
\text{procedure } \text{get\_developers} (\text{infil} : \text{string}) \text{is}
\begin{align*}
\text{Variables local to } \text{get\_developer } 65 \}
\text{begin} \\
\text{(Open file 64)} \langle \text{Read in developers 66} \rangle \\
\text{end } \text{get\_developers} ;
\end{align*}
\]

64.  \( \langle \text{Open file 64} \rangle \equiv \)
\[
\text{open} (\text{data\_file}, \text{in\_file}, \text{infil}) ;
\]
This code is used in section 63.

65.  \( \langle \text{Variables local to } \text{get\_developer } 65 \rangle \equiv \)
\[
\text{data\_file} : \text{file\_type} ;
\]
See also section 68.
This code is used in section 63.

66.  \( \langle \text{Read in developers 66} \rangle \equiv \)
\[
\begin{align*}
\text{while } \lnot \text{end\_of\_file} (\text{data\_file}) \text{ loop} \\
\text{(Get developer's name and capabilities 67)} \\
\text{end loop} ;
\end{align*}
\]
This code is used in section 63.
67. \( (\text{Get developer's name and capabilities 67}) \equiv \)
\[
\begin{align*}
\text{get_line(data_file,new_str,Last); } tstr & \leftarrow U(\text{new_str}); \text{ ind2 } \leftarrow \text{index(tstr, "\{}\"}); \\
\text{ind1 } & \leftarrow \text{index.nul_blank(tstr); } \text{name } \leftarrow U(\text{slice(tstr, ind1, ind2 } - 1)); \\
tstr & \leftarrow \text{tail(tstr, length(tstr) } - \text{ ind2 + 1}); \\
\text{declare} \\
\text{ yrcap : cap_map.map;}
\end{align*}
\]
\[
\begin{align*}
\text{begin} \\
\text{get\_capability(S(tstr), yrcap); } \text{create\_developer(S(name), dummy);} \\
\text{add\_capability(devel\_num(dummy), yrcap);}
\end{align*}
\]
\text{end;}

This code is used in section 66.

68. \( (\text{Variables local to get\_developer 65}) \equiv \)
\[
\begin{align*}
\text{Last : natural;}
\text{new\_str : String(1 .. 132);}
\text{ind1, ind2 : natural;}
\text{name, tstr : ustring;}
\text{dummy : natural;}
\end{align*}
\]

69. \( (\text{Procedures and Tasks in capability 28}) \equiv \)
\[
\begin{align*}
\text{procedure put\_developers(outfile : string) is} \\
\text{data\_file : file\_type;}
\text{begin} \\
\text{create(data\_file, outfile, outfile);} \\
\text{end put\_developers;}
\end{align*}
\]
Appendix H

70. Test capabilities driver. Here, finally, is the boilerplate. The Ada WEB tool
atangle reads this and knows to write out two separate files, the specification and the
body. (The Ada WEB tool awear will write out just one documentation file.)

output to file testcap.adb

pragma suppress(all_checks);
with ustrings;
use ustrings;
with text_io;
use text_io;
with capability;
use capability;
procedure testcap is (Instantiate generic packages 71) (Variables local to testcap 73)

begin
  (Test if items are in set 72)
  (Create a task map and see if any developers qualify 76)
  (Print out items in set 74)
  (Check qualifications 75)
  (Try reading in some capabilities 78)
end testcap;

71.
(Instantiate generic packages 71) ≡
package nat_io is new integer_io(natural);
use nat_io;

This code is used in section 70.

72.
(Test if items are in set 72) ≡
create_developer("Bill Gates", myid); add_capability(myid, "Breathing", High);
create_developer("Scott McNealy", myid2); add_capability(myid2, "Java", high);
create_developer("Bill Joy", myid3); add_capability(myid3, "Unix", high);
add_capability(myid3, "Systems programming", high);

This code is used in section 70.

73.
(Variables local to testcap 73) ≡
  myid, myid2, myid3 : natural;

See also sections 77 and 79.

This code is used in section 70.
(Print out items in set 74) ≡
  new_line; print_capabilities(myid); new_line; print_capabilities(myid2); new_line;
  print_capabilities(myid3); new_line; print_capabilities(task1); new_line;
This code is used in section 70.

(Check qualifications 75) ≡
  if is_qualified(task1, myid) then
    put_line("Bill Gates is qualified.");
  end if;
  if is_qualified(task1, myid2) then
    put_line("Scott McNealy is qualified.");
  end if;
  if is_qualified(task1, myid3) then
    put_line("Bill Joy is qualified.");
  end if;
This code is used in section 70.

(Create a task map and see if any developers qualify 76) ≡
  add_capability(task1, "Unix", medium);
This code is used in section 70.

(Variables local to testcap 73) ≡
  task1 : cap_map.map;

(Try reading in some capabilities 78) ≡
  create_developer("John Evans", myid1); get_capability(testcapstr, task2);
  print_capabilities(task2); new_line;
  put_line("Here is Bill Joy's capabilities again");
  print_capabilities(myid3);
  put_line("Here are all the developer's capabilities again.");
  print_developers; get_developers("developers.txt"); print_developers;
This code is used in section 70.

(Variables local to testcap 73) ≡
  testcapstr : String ←
  task2 : cap_map.map;
  myid1 : natural;
80. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make TESTCAP work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody's version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

81. RCS Keywords.

$$\textit{RCSfile: capability.aweb,v}$$
$$\textit{Revision: 1.1}$$
$$\textit{Date: 1997/09/05 00:31:42}$$
$$\textit{Author: evansjr}$$
$$\textit{Id: capability.aweb,v 1.1 1997/09/05 00:31:42 evansjr Exp evansjr}$$
$$\textit{Locker: evansjr}$$
$$\textit{State: Exp}$$
INDEX

82. Index. Here is a cross-reference table for the TESTCAP program. All modules in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in module names are not indexed. Underlined entries of subprograms and packages correspond to sections where this entity is specified, whereas entries in italic type correspond to the section where the entity's body is stated. For any other identifier underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code" are indexed here too.

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Task Generator

[Ada '95—Version 2.0]
September 4, 1997
1. Introduction. This routine generates a number of tasks for which a valid schedule exists. The output of this routine is fed into the scheduling algorithm to test its performance. This particular version uses the capability model described in my thesis.

2. This is the main routine that starts everything.

```ada
output to file task_generator.adb
pragma Unsuppress(all_checks);
with CALENDAR;
use CALENDAR;
with text_io;
use text_io;
(Needed packages 10)
procedure task_generator is
    package nat_io is new integer_io(natural);
    use nat_io;
    package flt_io is new float_io(float);
    use flt_io;
    package bool_io is new enumeration_io(boolean);
    use bool_io;
    (Variables local to task_generator 6)
    (Functions local to task_generator 33)
begin
    (Get input parameters 4)
declare
    (Allocate a static array to hold tasks for schedule 12)
begin
    (Compute earliest available time (EAT) in resource matrix 15)
    R ← lazity;
    for i ∈ 1..tasks loop
        (Generate another task 16)
    end loop;
    if do_alternate then
        (Convert to calendar time 35)
    end if;
    (Print out results 34)
end;
end task_generator;
```

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3. This routine takes two input parameters. (1) "tasks" the number of tasks to generate; and (2) "laxity" the laxity, or tightness, parameter. This is formally defined as

$$T_D = T_{est} + T_P$$

where $T_D$ is the deadline, $T_{est}$ is the earliest start-time, and $T_P$ is the processing time. It is computed a priori by the task generator.

$$T_D = (1 + R) \times SC$$

where $R$ is an input parameter, and $SC$ is the shortest completion time.

4. The input values are read in using the routines in package getopt. I read in the number of tasks to compute, the "laxity" of the schedule, and a "seed" for the random number generator.

```plaintext
( Get input parameters 4 )
\begin{verbatim}
tasks ← 10;
if option_present(U("-tasks")) then
  get_option(U("-tasks"), param); get(S(param), tasks, Last);
end if;
laxity ← 0.0;
if option_present(U("-laxity")) then
  get_option(U("-laxity"), param); get(S(param), laxity, Last);
end if;
seed ← 68069;
if option_present(U("-seed")) then
  get_option(U("-seed"), param); get(S(param), seed, Last);
end if;
( Get NRaD option 5 )
( Get developer file 7 )
( Get developers 8 )
\end{verbatim}
```

This code is used in section 2.

5.

```plaintext
( Get NRaD option 5 )
\begin{verbatim}
if option_present(U("-nrad")) then
  get_option(U("-nrad"), param); get(S(param), nrad, Last);
else
  nrad ← true;
end if;
\end{verbatim}
```

See also section 45.

This code is used in section 4.
6.  
\[ \text{Variables local to } \text{task}\_\text{generator 6} \equiv \]
\[ \text{tasks : natural;} \]
\[ \text{laxity : float;} \]
\[ \text{Last : positive;} \]
\[ \text{param : Ustring;} \]
\[ \text{seed : natural;} \]
\[ \text{nrad : boolean;} \]
See also sections 9, 13, 18, 19, 22, 26, 29, 30, 32, 37, 41, 44, and 46.
This code is used in section 2.

7.  
\[ \text{Get developer file 7} \equiv \]
\[ \text{if name\_present}(1) \text{ then} \]
\[ \text{get\_name(devfile, 1);} \]
\[ \text{else} \]
\[ \text{raise nofilename;} \]
\[ \text{end if;} \]
This code is used in section 4.

8.  
\[ \text{Get developers 8} \equiv \]
\[ \text{get\_developers}(S(devfile)); \]
\[ \text{num\_developers} \leftarrow \text{get\_num\_developers;} \]
This code is used in section 4.

9.  
\[ \text{Variables local to } \text{task}\_\text{generator 6} \equiv \]
\[ \text{nofilename : exception;} \]
\[ \text{devfile : ustring;} \]
\[ \text{num\_developers : natural;} \]

10.  We need some more packages to read in the parameters. Specifically the package 
\text{getopt} written by this student; and the package \text{Ustrings}—used for manipulating “unbounded” strings.
\[ \text{Needed packages 10} \equiv \]
\[ \text{with Ustrings;} \]
\[ \text{use Ustrings;} \]
\[ \text{with GetOpt;} \]
\[ \text{use GetOpt;} \]
See also sections 11, 14, 24, and 39.
This code is used in section 2.
11. We also add the following package to enhance the capability model the scheduler (and task_generator) can use.

\[(\text{Needed packages 10}) + \equiv\]
\[\text{with capability};\]
\[\text{use capability};\]

12.

\[(\text{Allocate a static array to hold tasks for schedule 12}) \equiv\]
\[\text{sched} : \text{array} (1..\text{tasks}) \text{ of StepRecord};\]
\[\text{newsched} : \text{array} (1..\text{tasks}) \text{ of NewStepRecord};\]
\[\text{mysample} : \text{bool array}(1..\text{tasks});\]

See also section 31.
This code is used in section 2.

13.

\[(\text{Variables local to task_generator 6}) + \equiv\]
\[\text{type NewStepRecord is}\]
\[\text{record}\]
\[\text{CalDuration : Duration};\]
\[\text{CalStartTime : Time};\]
\[\text{CalDeadLine : Time};\]
\[\text{end record};\]

14.

\[(\text{Needed packages 10}) + \equiv\]
\[\text{with generic_set.pkg};\]
\[\text{with SchedPrims};\]
\[\text{use SchedPrims};\]

15.

\[(\text{Compute earliest available time (EAT) in resource matrix 15}) \equiv\]
\[\text{MATRX.MIN}(\text{EAT}, \text{Min}, \text{COL});\]

This code is used in sections 2 and 28.
16. (Generate another task 16) ≡
   (Compute duration of task T.p 17)
   (Compute predecessors 25)
   (Compute earliest start time 20)
   (Compute deadline T.D 21)
   (Compute priority P 23)
   sched(i).StepID ← i; sched(i).Deadline ← T.D; sched(i).Priority ← P;
   sched(i).EstimatedDuration ← T.p; (Assign expertise level 27)
   (Update resource matrix 28)

This code is used in section 2.

17. The duration varies in length between MIN.D and MAX.D. The duration will not
    go over the maximum task deadline (MTD).
   (Compute duration of task T.p 17) ≡
   T.p ← uniform(MIN.D, MAX.D);  {duration}

This code is used in section 16.

18. Minimum task duration.
   (Variables local to task_generator 6) +≡
   Min.D : natural ← 2;

19. Maximum task duration.
   (Variables local to task_generator 6) +≡
   Max.D : natural ← 10;

20.
   (Compute earliest start time 20) ≡
   for j ∈ 1 . . . (i − 1) do loop
      if not set member(j, sched(i).predecessors) then
         if Sched(j).deadline > sched(i).EarliestStartTime then
            sched(i).EarliestStartTime ← Sched(j).Deadline;
         if debug then
            put("Modified Sched."); put(i,1); put("\to\be\wider");
            put(sched(i).EarliestStartTime,1); put_line(" .");
         end if;
      end if;
   end loop;

This code is used in section 16.
21. The deadline \( T.D \) is a function of the duration and the least value of a resource in the resource matrix.

\[
\begin{align*}
\text{(Compute deadline } T.D \text{ 21) } \equiv \\
TT & \leftarrow \text{integer(float}(T.p)* (1.0 + \text{lazity})) \\
\text{if } \text{debug then} \\
& \text{put("Old deadline is "); put(sched(i).Deadline,1); put(". ");} \\
\text{end if;} \\
\text{if sched(i).EarliestStartTime > EAT(COL) then} \\
& T.D \leftarrow TT + sched(i).EarliestStartTime; \\
\text{else} \\
& T.D \leftarrow TT + EAT(COL); \\
\text{end if;} \\
\text{if debug then} \\
& \text{put("New deadline is "); put(T.D,1); put.line(" . ");} \\
\text{end if;}
\end{align*}
\]

This code is used in section 16.

22.

\[
\begin{align*}
\text{(Variables local to task generator 6) } \equiv \\
& \text{debug : boolean } \leftarrow \text{false;} \\
& \text{debug2 : boolean } \leftarrow \text{false;}
\end{align*}
\]

23. A random value.

\[
\begin{align*}
\text{(Compute priority } P \text{ 23) } \equiv \\
P & \leftarrow \text{uniform}(4,10); \\
\text{This code is used in section 16.}
\end{align*}
\]

24.

\[
\begin{align*}
\text{(Needed packages 10) } \equiv \\
& \text{with Probability;} \\
& \text{use Probability;}
\end{align*}
\]
25. I choose to select $M$ out of $N$ tasks as predecessors. $M$ has an upper limit of $Max\_Predecessors$ and $N$ is the number of previous tasks assigned. If the number of previous tasks scheduled is less than $Max\_Predecessors$ then the minimum is selected then the upper limit is the number of previous tasks scheduled. $M$ is selected randomly.

(Compute predecessors 25) $\equiv$

```plaintext
if do_predecessor then
  if i $\leq$ Max\_Predecessors then
    ptasks $\leftarrow$ ($i - 1$);
  else
    ptasks $\leftarrow$ Max\_Predecessors;
  end if;
  nsamp $\leftarrow$ uniform(0, ptasks);
  if i $> 1$ then
    sample(nsamp, i - 1, mysample);
    for $j \in 1..(i - 1)$ loop
      if mysample(j) then
        t1 $\leftarrow$ nat_set.size(Sched(i).Predecessors);
        t2 $\leftarrow$ nat_set.size(Sched(j).Successors);
        if (t1 $< Max\_Predecessors$) $\land$ (t2 $< Max\_Predecessors$) then
          nat_set.add(j, Sched(i).Predecessors); nat_set.add(i, Sched(j).Successors);
        end if;
      end if;
    end loop;
  end if;
end if;
```

This code is used in section 16.

26. (Variables local to task_generator 6) $\equiv$

$$Max\_Predecessors : constant natural \leftarrow 0;$$
$$ptasks, nsamp : natural;$$
$$t1, t2 : natural;$$

27. (Assign expertise level 27) $\equiv$

```plaintext
declare
tmpcap : cap_map.map;
begincopy\_capability(COL, sched(i).ExpLevel);
end;
```

This code is used in section 16.
(Update resource matrix 28) ≡
if debug then
  put("Before, Update: "); put("EAT("; put(COL, 1); put("\),$=\,$");
  put(EAT(COL), 1); put_line(".,");
end if;
EAT(COL) ← T.D;
if debug then
  put("After, Update: "); put("EAT("; put(COL, 1); put("\),$=\,$");
  put(EAT(COL), 1); put_line(".,");
end if;
(Compute earliest available time (EAT) in resource matrix 15)

This code is used in section 16.

29.
(Variables local to task_generator 6) +≡
  R : float ← 0.7;
  R3 : natural ← 3;  {laxity}
  UU : natural ← 1;
  UI : natural ← 3;  {seed}
  U2 : natural ← 1;
  type RESOURCE_MATRIX is array (POSITIVE range <>) of natural;
  do_predecessor : BOOLEAN ← true;

30. Max task deadline.
(Variables local to task_generator 6) +≡
  MTD : natural ← 70000;

31. The way this is defined, it “hard-codes” the maximum number of designers per level to ‘2.’ (Must be in concordance with the maximum number of designers defined above.)
(Allocate a static array to hold tasks for schedule 12) +≡
  EAT : RESOURCE_MATRIX(1..num.developers) ← (others ⇒ 0);

32.
(Variables local to task_generator 6) +≡
  P, T.D, T.p, R1, R2, C : natural;
  Min : natural ← 0;
  COL : natural ← 1;
  COUNT : natural ← 0;
  TT : integer;
§33. This finds the smallest value in the resource matrix and returns the index of the minimum value.

(Functions local to task_generator 33) \equiv

procedure MATRIX_MIN(MATRIX : in RESOURCE_MATRIX; MIN : out natural; K1 : out natural) is
  Min1 : natural ← MATRIX(1);
begin
  K1 ← 1;
  for j ∈ 2 \ldots MATRIX'Length loop
    if Min1 > MATRIX(j) then
      Min1 ← MATRIX(j); K1 ← j;
    end if;
  end loop;
  MIN ← Min1;
end MATRIX_MIN;

This code is used in section 2.

34. Procedure Put_set is declared in package schedprims.

(Print out results 34) \equiv

for i ∈ 1 \ldots tasks loop
  if not do_alternate then
    put(sched(i).Deadline,4); put(sched(i).Priority,4);
    put(sched(i).EstimatedDuration,5); put(sched(i).EarliestStartTime,5);
    { earliest start time }
    put("\_\_\_\_\_"); put_set(Sched(i).Predecessors); put("\_\_\_\_\_\_"); put_set(Sched(i).Successors);
    put("\_\_\_\_"); print_capabilities(Sched(i).ExpLevel); new_line;
  else
    print_date(newsched(i).CalDeadline); put(sched(i).Priority,5);
    put(sched(i).EstimatedDuration,5); put("\_\_\_\_\_");
    print_date(newsched(i).CalStartTime); put("\_\_\_\_\_\_\_"); put_set(Sched(i).Predecessors);
    put("\_\_\_\_\_\_\_\_\_"); put_set(Sched(i).Successors); put("\_\_\_\_\_\_");
    print_capabilities(Sched(i).ExpLevel); new_line;
  end if;
end loop;

This code is used in section 2.
35. \(\text{Convert to calendar time 35} \equiv\)
\(\text{Get start date 36} \)
\(\text{Start\_Time} \leftarrow \text{Current\_Time} ;\)
\(\text{for } i \in 1 \ldots \text{tasks} \text{ loop}\)
\(\text{Convert Start Time to Calendar Time 43}\)
\(\text{Convert Task Duration to Duration type 42}\)
\(\text{Convert Deadline to Calendar Time 47}\)
\(\text{end loop}\);
This code is used in section 2.

36. For now "hard-code" a date (July 1st, 1997).
\(\text{Get start date 36} \equiv\)
\(\text{Current\_Time} \leftarrow \text{Time\_of}(1997,7,3); \text{ (Find first work-day 38) if debug2 then (Print out first work day 40) end if;}\)
This code is used in section 35.

37. \(\text{Variables local to task\_generator 6} \equiv\)
\(\text{Current\_Time}, \text{Start\_Time} : \text{Time};\)
\(\text{do\_alternate} : \text{boolean} \leftarrow \text{false};\)

38. \(\text{Find first work-day 38} \equiv\)
\(\text{while } \neg \text{IsWorkDay(C current\_ Time, nrd)} \text{ loop}\)
\(\text{Current\_Time} \leftarrow \text{Current\_time} + \text{Day\_Duration}'\text{Last};\)
\(\text{end loop}\);
This code is used in section 36.

39. Package to find federal off-days till year 2099 (barring acts of God, or Congress).
\(\text{Needed packages 10} \equiv\)
\(\text{with calyr};\)
\(\text{use calyr};\)

40. \(\text{Print out first work day 40} \equiv\)
\(\text{Split(Current\_Time, Year, Month, Day, Seconds); put("The first work\_day is \text{"}); put(Month, 3); put("/"); put(Day, 3); put("/"); put(Year, 4); put\_line(".");}\)
This code is used in section 36.

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(Variables local to task_generator 6) \equiv
  Year : Year_number;
  Month : Month_number;
  Day : Day_Number;
  Seconds : Day_Duration;

(Convert Task Duration to Duration type 42) \equiv
  newsched(i).CalDuration ← ConvertHourostoDuration(sched(i).EstimatedDuration);

This code is used in section 35.

(Convert Start Time to Calendar Time 43) \equiv
  TotalTime ← ConvertHourostoDuration(Sched(i).EarliestStartTime);
  newsched(i).CalStartTime ← DurationToCalendarTime(Start_Time, dailyhours, TotalTime, NRaD);
  if debug2 then
    testduration ← CalendarTimetoDuration(Start_Time, dailyhours, newsched(i).CalStartTime, NRaD);
    testhours ← ConvertDurationToHours(testduration);
    if sched(i).EarliestStartTime \neq testhours then
      put("ERROR: in CalendarTimetoWorkHours"); new_line;
      put("CalendarTime returned"); put(testhours);
      put("should have returned"); put(sched(i).EarliestStart_Time);
      put("."); put("NRaD"); put("NRaD"); put("."); new_line;
      put("The Start Time is"); print_date(Start_Time);
      put("The Total Time is"); put(float(TotalTime));
      put("In hours that is"); put(ConvertDurationToHours(TotalTime));
      put("."); new_line;
    end if;
  end if;

This code is used in section 35.

(testduration : Duration;
  testhours : natural;
45.
\[(\text{Get NRaD option 5}) \equiv \]
\[
\text{for } \text{day} \in \text{Mon} .. \text{Thu} \text{ loop}
\]
\[
\text{if } \text{nrad} \text{ then}
\]
\[
dailyhours(\text{Day}) \leftarrow 9.0 \times \text{SecondsPerHour};
\]
\[
\text{else}
\]
\[
dailyhours(\text{Day}) \leftarrow 8.0 \times \text{SecondsPerHour};
\]
\[
\text{end if};
\]
\[
\text{end loop;}
\]
\[
dailyhours(\text{Fri}) \leftarrow 8.0 \times \text{SecondsPerHour};
\]

46.
\[(\text{Variables local to task_generator 6}) \equiv \]
\[
dailyhours : \text{Workhours};
\]
\[
\text{SecondsPerHour} : \text{constant } \text{Duration} \leftarrow 3600.0;
\]
\[
\text{TotalTime} : \text{duration};
\]

47.
\[(\text{Convert Deadline to Calendar Time 47}) \equiv \]
\[
\text{TotalTime} \leftarrow \text{ConvertHoursToDuration}(\text{Sched}(i).\text{Deadline});
\]
\[
\text{newsched}(i).\text{CalDeadline} \leftarrow \text{DurationToCalendarTime}(\text{Start.Time}, \text{dailyhours},
\]
\[
\text{TotalTime}, \text{NRad});
\]
This code is used in section 35.
§48  APPENDIX I  SYSTEM-DEPENDENT CHANGES

48. System-dependent changes. This module should be replaced, if necessary, by changes to the program that are necessary to make MAIN work at a particular installation. It is usually best to design your change file so that all changes to previous modules preserve the module numbering; then everybody’s version will be consistent with the printed program. More extensive changes, which introduce new modules, can be inserted here; then only the index itself will get a new module number.

49. RCS Keywords.

$RCSfile: task_generator.aweb,v$
$Revision: 1.3$
$Date: 1997/09/05 00:35:25$
$Author: evansjr$
$Id: task_generator.aweb,v 1.3 1997/09/05 00:35:25 evansjr Exp evansjr$
$Locker: evansjr$
$State: Exp$

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50. Index. Here is a cross-reference table for the MAIN program. All modules in which
an identifier is used are listed with that identifier, except that reserved words are indexed
only when they appear in format definitions, and the appearances of identifiers in module
names are not indexed. Underlined entries of subprograms and packages correspond to
sections where this entity is specified, whereas entries in italic type correspond to the
section where the entity’s body is stated. For any other identifier underlined entries
correspond to where the identifier was declared. Error messages and a few other things
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