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PCSL — A Process Control Software Specification Language

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Abstract

This paper presents PCSL, a language for specification and design of process control software, and sketches analysis and reports based on this language. As an example, a system for process-data-collection is specified using PCSL.

PCSL, DSL and EPOS are reviewed with respect to PCSL. Finally, the current state of the project is depicted.

The appendix contains a short version of the PCSL-definition.

PCSL - Eine Prozeßrechner-Software-Spezifikationssprache

Zusammenfassung

Der Bericht beschreibt PCSL, eine Spezifikations- und Entwurfssprache für Prozeßrechnersoftware; Prüfungen und Reports, die auf dieser Sprache basieren, werden skizziert. Als Beispiel ist ein Datenerfassungssystem in PCSL beschrieben.

PSL, DSL und EPOS werden mit PCSL verglichen. Der Bericht schließt mit Angaben zum Stand der Arbeiten.

Eine Kurzfassung der PCSL-Definition ist als Anhang beigefügt.

Contents

1. Introduction

1.1 Needs of software-designers in our environment

Being a part of a nuclear research center, our task is to develop highly reliable process control systems for various applications in the area of nuclear power plants. Thus, any tool or method for our environment has to meet two requirements:

- it must reflect the particular needs of process control systems, and
- safety and security of the systems to be developed has to be its very first objective.

1.1.1 Process control systems

Process control systems differ from other computer systems, in particular from commercial ones, while operating systems are similar.

A typical process control system

- will work virtually forever, i.e. without a predetermined moment of termination,
- is event - or real-time-controlled, usually in several ways, making it necessary to introduce asynchronous tasks, which are almost (but in most cases only almost) independent from each other,
- is not very complicated from a mathematical or logical point of view, but moves lots of data both internally and across its very wide and complicated interfaces to the technical process and to the operators (dialogues),
- is even less testable than other computer systems due to its indeterminacy.

1.1.2 Safety and security

Our particular demand for safety and security makes it necessary

- to prevent by virtually all means errors from getting into the software, and
- to detect errors which got there anyway.

The lack of generally accepted methods and tools for the early stages of software development forced us to work in this field.

1.2 History of PSL at the IDT

In 1977, version 2.1 of the PSL/PSA-System /Teichroew, Hershey 77/ was installed on our IBM 370/168 which is used for batch-operation; it is usually controlled via TSO running on our 370/158. (Recently, the 168 has been replaced by a 3033, TSO is now on the 168.) In 1978, version 2.1 was replaced by 4.2.

PSL/PSA was used for a few sample applications. As a result, we found that batch is not as disadvantageous as expected. Users rather suffered from difficulties with the language: There are several data-types (set, entity, group, element, and also input and output) which confused us because in our field there is no application for them. On the other hand, we have many problems with control and time which are difficult to describe in PSL if at all.

Thus, we were quite excited when we heard about the META-System because we felt (and still feel) that this is our chance for a dedicated specification-system.

A first version of our language was designed in January 1978 /Ludewig, Streng - March 1978 (b)/ and processed by the META-Generator in August, the Generalized Analyzer was installed by the end of July this year (see 6. and Appendix 2). A revised version (PCSL.2) was introduced in October 1979.

This paper is based on PCSL.3 which contains some minor improvements. PCSL.3 is being prepared for installation.

2. Basic principles of PCSL

PCSL (Process Control Software Specification Language) was designed after reviewing the most popular approaches in this area /Ludewig, Streng - March 1978 (a) and April 1978/ and with our experiences with PSL and the problems of process control software in mind.

This chapter is not intended to encompass a complete description of PCSL. Its point is only to show the basic ideas.

2.1 The requirements a tool for process-control software-development must meet

Beyond generally used concepts like control structures etc. we need special means to express:

- sequential and parallel action,
- interaction of processes, in particular synchronization and start or termination,
- all relevants types of data flow in sufficient detail,
- sharing and mutual exclusion of resources.

2.2 A concept for active system components

When a large software system is decomposed, a hierarchy of programs will emerge.

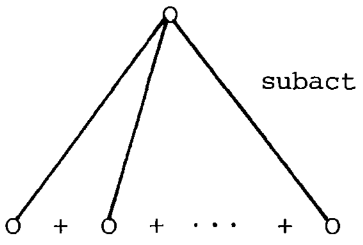
Every node is an active system component. Vertically adjacent nodes ('father' and 'son') may be related in different ways:

The son may be part of the father or just used by him. In the latter case, there may be several fathers for one son.

There are also different relations among 'brothers', i.e. sons of the same father. They may be active in parallel or sequentially or only one son is chosen for execution.

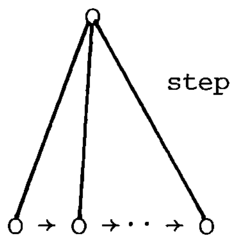
The approach of PCSL is restrictive in the way that every 'family' has to be of exactly one type:

The sons of each father form either a parallel group (in which case they are called ACTIVITIES) or a sequential group (then they are called STEPS) or an alternative group. In any case the father may be either a STEP or an ACTIVITY.



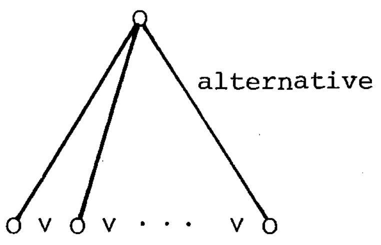
ACTIVITIES

parallel group



STEPS

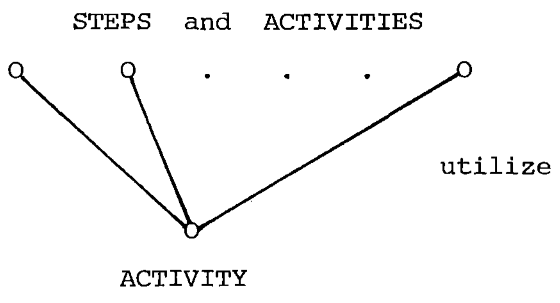
sequential group



(Same type as father)

alternative group

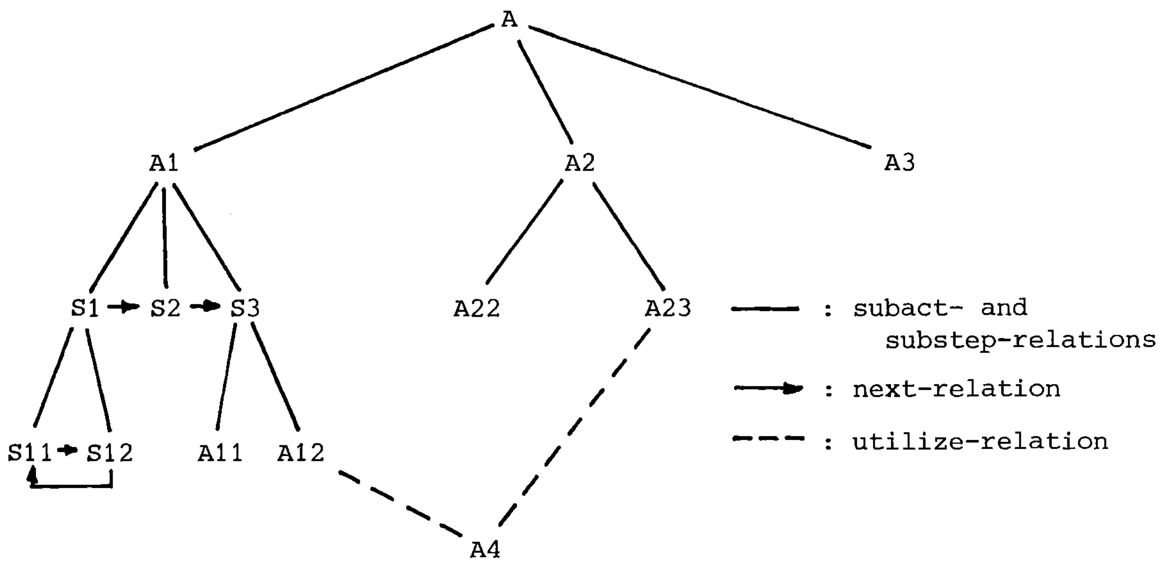
Those three relations are restricted to tree-structure, i.e. no son may have more then one father. Though such a tree-structure has many advantages, it is not sufficient for the modeling of real systems because there are usually some parts that do not belong to one branch or the other but to several branches of the tree. (Error handling is a well-known example.) That is why one more relation called 'utilize' is defined in PCSL:



Thus, the rules of PCSL concerning the structure of active system components can be summarized as follows:

Every STACT (which stands for STEP <u>or</u> ACTIVITY) may be decomposed into a parallel <u>or</u> sequential <u>or</u> alternative group, <u>or</u> it may utilize an ACTIVITY. Also, a STACT must not be a member of more than one group. If it is utilized, it must not be in any group.

When this concept is applied to software systems in a top-down direction, in the first step the whole system is represented by an ACTIVITY. In process control, the global system will usually consist of coexisting parts which can be represented by sub-ACTIVITIES (subact-relation). Refinement by subact-relation may be repeated in several levels until the sequence of execution becomes more important. From then, step-, alternative-, and utilize-relations will be preferred for decomposition.



When a STACT is terminated by some external event (e.g. an interrupt), all dependents are terminated implicitely. So the terminate-relation must be used with care.

When all active system components are represented in this way, it does not make sense to say that a STACT is started, because its father and brothers determine precisely the time it is started, and it cannot be started at any other time. Termination, on the contrary, is well defined.

However, for the sake of simplicitely a start-relation is allowed in PCSL for a situation when a STACT has to be executed cyclically, triggered by some event or condition.

Without the start-relation, this STACT had to be decomposed into two STEPS, one of which is the waiting state that is terminated by the event.

2.3 A concept for passive system components

In all software-systems, two types of data can be distinguished:

- 'static' data which is once initialized and then read and rewritten in an undefined order. Reading and writing does not change the quantity of data.
- 'dynamic' data which moves through the system. Such data is produced and consumed by reading and writing, i.e. if there is only space for one item, every write-access must be followed by a read-access and vice versa.

Non-computer-examples are

- information on a blackboard (static)
- products in a buffer area between a producing and a consuming process (dynamic).

Examples from process-control-software are

- a table containing scaling factors of some measuring instrument (static),
- values from the technical process, which are filtered, checked, stored, printed etc. (dynamic).

In PCSL, the terms VARIABLE and BUFFER are used. VARIABLES contain static data, BUFFERS contain dynamic data. STACTS can access VARIABLES by 'initialize', 'read', and 'write', BUFFERS by 'initialize', 'produce', and 'consume'.

A VARIABLE may consist of subparts which, again, are VARIABLES, or it may have a TYPE (like BUFFERS do).

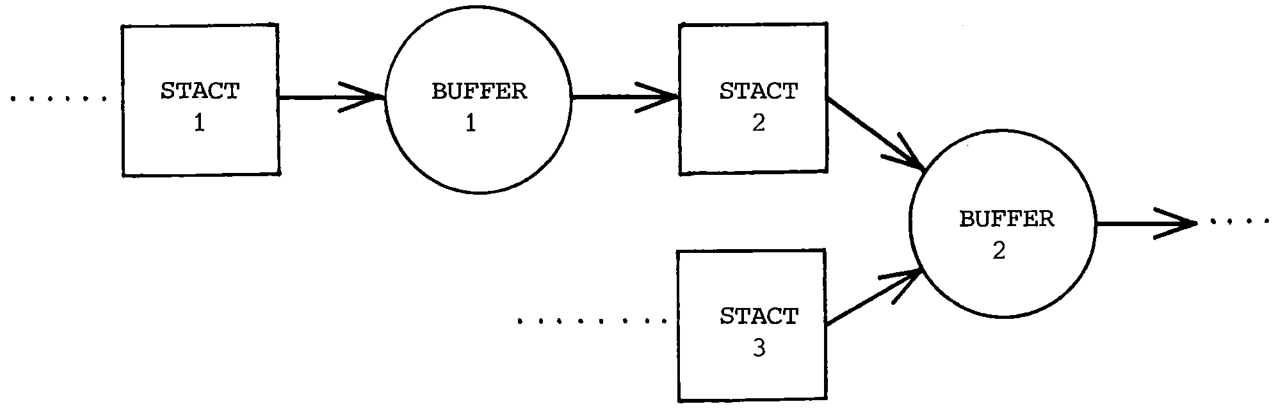
TYPES, also, may be refined by other TYPES.

In process control systems, BUFFERS are used for many kinds of data:

- messages to and from system-components
- input and output
- queues, also event-queues
- all kinds of data to be processed.

VARIABLES represent scaling factors, state-variables, switches, date and time.

BUFFERS are the links between cooperating STACTS. In a well structured system, such STACTS are executing in parallel. Their synchronization is done implicitely by communication via BUFFERS. A STACT should never consume from and produce for the same BUFFER!



BUFFERS can differ in several ways. If a buffer is full, a producer trying to deliver an item can either be blocked or not (in which case the item is lost).

The same is true for a consumer accessing an empty buffer. This can be expressed by the properties EMPTY and FULL, whose values can be either BLOCK or SKIP.

The items in some BUFFERS may be delivered and/or removed by several rather than just one access, e.g. messages to be output both on a screen and on a printer. In such cases, an INPUT-FAN and/or an OUTPUT-FAN may be specified in addition to the type of data in the BUFFER.

If a BUFFER can contain more than one item (CAPACITY), property ORDER (FIFO, LIFO or RANDOM) can be specified.

STACTS may occupy RESOURCES, e.g. memory or tape units. This can be stated in PCSL. Also, a VARIABLE or a BUFFER may be connected to a RESOURCE by the device-relation.

2.4 A concept for time, synchronization, and interaction

Time, synchronization, and interaction cannot be treated separately, because synchronization is a special case of interaction, and both deal with time.

EVENTS may be used to describe influences from outside or inside the system which terminate STACTS. (This means implicitly that either its successor is started or the upper STACT terminates.) The use of a start-relation has been restricted to cyclic STACTS, since we found that if allowed in other applications it is hard to provide a clear meaning.

INTERRUPTS are special events frequently found in process control applications. Examples are sensors which evoke an interrupt when a certain state transition has happened in the technical process, also the attention-key on the terminal.

The real-time-clock is an important source of signals triggering STACTS of the computer system. In PCSL, object-type TIMER is used to describe delayed and/or cyclic events. If no delay is specified, the TIMER will send the first pulse at the very begin of its activity; if no cycle is given, only one pulse is generated.

The time a TIMER or a STACT is active may be defined with respect to other STACTS by the as-long-as-relation.

Explicit description of synchronization by means of semaphores (Dijkstra 1968 (a)) or even more primitive tools tends to cause many bugs which are extremely difficult to detect. So we spent some time on the question which concepts might be both safe and easy to use.

In application software, most synchronization problems are either

- mutual exclusion or
- producer/consumer - access to some buffer or
- reader/writer - access to some data.

We think a concept which follows those three schemes will be sufficient and certainly safe and easy to use, because the user can just state <u>what</u> he wants the system to do rather than <u>how</u>. So we associate a predefined scheme of synchronization with all VARIABLES (reader/writer-scheme as described by

Courtois, Heyman, Parnas 1971), BUFFERS (producer/consumer-scheme, see e.g. Dijkstra 1968 (b)), and RESOURCES (mutual exclusion, expressed by the occupy-relation).

INTERVALS are used to define delays, cycles, etc.

2.5 Other elements of PCSL

KEYWORDS, MEMOS, and ATTRIBUTES with ATTRIBUTE-VALUES are just copied from PSL, also the text DESCRIPTION.

For alternatives and logical relations, CONDITIONS have been introduced. Primitive conditions are the RANGE-objects (RANGE-INT, RANGE-CNT, ...) which are subranges of the ranges of primitive variables (INTEGER, COUNT, REAL, BINARY, STRING).

E.g., a temperature T1 of type REAL may vary from 10 to 300 degree. If some action is required when T1 rises above 200 degree, a RANGE-REAL T1-normal can be defined with 200 degree as its upper bound. A STEP normal-step may depend on T1-normal (while-relation). Whenever T1 is not within T1-normal, normal-step is terminated, allowing its successor action-step to start.

Primitive variables (INTEGER etc.) can be restricted either to a range or to a list of values (BINARY and STRING only to a list).

PCSL contains also some elements intended for simulation-purposes, e.g. property MAXIMUM-DEVIATION for INTERVALS.

3. Analysis and reports

PCSL is not designed to be just the input language of an analyzer; its primary objective is to supply users with a set of concepts that allows simple but correct statement of well structured systems (thus preventing the design of badly structured systems).

But, of course, many evaluations and reports are desirable; some are necessary simply because it is not possible (at least not yet) to state semantical restrictions in the META-definition (e.g. when a relation is required to be tree-structured).

Simulation is a highly desirable but also very complicated way of analysis.

Thus, three types of analysis can be distinguished:

- checks for semantic correctness
- checks for completeness and consistency
- simulation.

3.1 Checks for semantic correctness

Since only very few semantical restrictions can be expressed in the META-language (namely in the CONNECTIVITY-statement), checks are necessary to ensure the proper use of PCSL.

The semantical rules are concerned with

- hierarchical structures of STACTS, VARIABLES and TYPES
  (e.g. any STEP must be contained within one and only one STACT).
- logical and numerical consistency
  (e.g. the sum of the probabilities of several alternatives must not be higher than 1.

  A VARIABLE which is KEPT from one execution of the program until the next one (property CREATION) cannot consist of VARIABLES which are LOST every time).

- proper use of interdependent relations (a STEP can be connected to its 'father' either by 'initstep' or by 'step' or by 'waitstep', but only one is allowed.

  If it is connected by 'step', it must be mentioned in a next-relation of at least one other STEP.)

All rules of this kind have been stated in /Ludewig 1978/ in a formal notation. Cp. the last example above:

$$(x,s_0) \in \text{initstep} \wedge (x,s_n) \in (\text{step} \cup \text{waitstep})$$
$$s_1,\ldots,s_k\colon \forall\, j=1,\ldots,k\colon$$
$$(s_{j-1},\ s_j) \in (\text{next} \cup \text{alternative}) \wedge s_k=s_n;$$

which is more precise (and more restrictive) then the informal statement above.

'initstep' is the set of ordered pairs the second of which is the initial STEP of the first (the order is defined elsewhere).

3.2 Checks for completeness and consistency

As far as possible completeness and consistency should be checked by automated tools. In the PSA-system, many reports serve this purpose, e.g. the data-process-interaction-report. In PCSL, we can check

- if there is only one root in the hierarchy of STACTS,
- if all VARIABLES are both written and read,
- if all BUFFERS are both produced for and consumed from,
- if all RESOURCES are occupied at least once, also if all other objects are connected in any way,
- if all BUFFERS with space for more than one item have a defined order (e.g. FIFO) etc.

If an object is PERIPHERAL to the system (e.g. a display which is read by a person not defined in the system) completeness is not required (e.g. within the system the display may be only written). Thus the property POSITION

(PERIPHERAL or INTERNAL) determines which checks are necessary. The same applies also to other properties.

Like the rules in 3.1, these rules are collected in /Ludewig 1978/.

3.3 Simulation

Since our ideas about simulation are still rather vage, only the outline of our approach is sketched in the following.

All relations describing actions of any type, e.g. execution of STACTS, reading and writing, etc., are defined as operations of a - virtual - PCSL-machine described in /Ludewig 1978/. In particular, this machine simulates all synchronization implicitly defined by the use of VARIABLES, BUFFERS, and RESOURCES (cp. 2.4) and the delays caused by program execution, transfers and waiting conditions. At decision points, control is passed either to the operator or to a random number generator which may be controlled by parameters (e.g. property PROBABILITY of CRITERIA).

As a result of this simulation, we expect indications of bottle-necks, of system parts which are critical with respect to execution time and others which are not, and also indications of structures that are not safe against deadlocks.

Simulation can also be used to compare different designs.

Many questions are not yet answered:

1. How shall the technical process be simulated?
   (cp. /Baumann 1978/ for one possible way)
2. Should the simulation be restricted to actions as sketched above or should it also include data handling (i.e. deal with the <u>content</u> of data rather than with its mere existence)?
3. Should the simulator be implemented from scratch or on top of a system based on Petri-nets that was developed in our institute (Schumacher 1978)?

4. PUES - a sample application of PCSL

A good example should exhibit all characteristics in a real-life-application. It should nevertheless be small and understandable for everybody. In this sense, we did not find a good example to date. The following one is a compromise: PUES (Prozeß-Überwachungssystem = process monitoring system /Borrmann 1978/) is being used as a test-object for PCSL in a master thesis (/Vinzentz 1979/). PUES will be implemented at our institute for application in the nuclear research center Karlsruhe.

```
###******************************************************************###
###                                                                  ###
###   General remarks:                                               ###
###                                                                  ###
###   Since this is a real application, it does not exhibit all      ###
###   features of PCSL. Only ACTIVITY dialog-input-processing        ###
###   has been extended to show the use of STEPS. (The example       ###
###   did not contain any STEPS before because they usually do       ###
###   not arise before a lower level of abstraction is reached.)     ###
###                                                                  ###
###   We do not pretend that this is a correct description of a      ###
###   correct design because the design is still in progress,        ###
###   and there is no other formal specification as a reference.     ###
###                                                                  ###
###   Though a similar description in PCSL.2 was successfully        ###
###   supplied to the Generalized Analyzer, there may be syntac-     ###
###   tical errors in this input because we do not yet hold the      ###
###   META-tabels of PCSL.3, the improved language.                  ###
###                                                                  ###
###                                                                  ###
###                                                                  ###
###   The input is structured for the reader's convenience.          ###
###   The most important objects are listed below:                   ###
###                                                                  ###
###           process monitoring-system              0.              ###
###                                                                  ###
###           technical process                      1.1             ###
###           operator                               1.2             ###
###                                                                  ###
###           measured-value-processing              2.              ###
###           measured-value-logging                 2.1             ###
###           data-preparation                       2.2             ###
###           recording                              2.3             ###
###           life-display                           2.4             ###
###           error-handling                         2.5             ###
###                                                                  ###
###           alarm-handling                         3.              ###
###                                                                  ###
###           dialogue                               4.              ###
###           dialogue-input-processing              4.1             ###
###           dialogue-output-processing             4.2             ###
###                                                                  ###
###           output-periphery                       5.              ###
###                                                                  ###
###           input-buffer                           6.1             ###
###           raw-data-buffer                        6.2             ###
###           result-buffer                          6.3             ###
###           status-information-buffer              6.4             ###
###           output-buffer                          6.5             ###
###                                                                  ###
###           control-information-block              7.              ###
###           order-tabel                            7.1             ###
###           parameter-tabel                        7.2             ###
###           hardware-tabel                         7.3             ###
###                                                                  ###
###******************************************************************###
```

```
## ****************************************************************** ##
##    TOP-LEVEL                                                        ##
## ****************  0.  ******************************************** ##
DEF ACTIVITY                  process-monitoring-system;

DESCRIPTION;
              This system monitors the state of the technical process
              by cyclic aquisition of measured values and state-infor-
              mation. The values are transformed to physical units and
              printed at the operator-terminal, also recorded on exter-
              nal memory.
           ;

              SUBACTS ARE     technical-process,
                              operator,
                              measured-value-processing,
                              alarm-handling,
                              dialogue,
                              output-periphery;


## ****************************************************************** ##
##    ENVIRONMENT                                                      ##
## ****************  1.1  ******************************************* ##
DEF ACTIVITY                  technical-process;

              POSITION        PERIPHERAL;

              PRODUCES FOR    input-buffer;

              EXECUTING       REPEATEDLY;


## ****************  1.2  ******************************************* ##
DEF ACTIVITY                  operator;

              EXECUTING       REPEATEDLY;

              CONSUMES FROM   teletype-printer;

              PRODUCES FOR    teletype-keyboard;
```

```
## ******************************************************************* ##
##   MEASURED-VALUE-PROCESSING                                         ##
## ****************  2.  ********************************************* ##
DEF ACTIVITY                      measured-value-processing;

              SUBACTS ARE         start-data-logging,
                                  data-preparation,
                                  recording,
                                  life-display;


## ****************  2.1  ******************************************** ##

DEF ACTIVITY                      start-data-logging;

              CARDINALITY         number-of-orders;

              EXECUTING           REPEATEDLY;

              STARTED BY          trigger;

              WRITES              index-of-order;

              UTILIZES            measured-value-logging;
              OCCUPIES            measured-value-logging;

DESCRIPTION;
              There is one trigger and one start-data-logging for every
              order, but all are executed by measured-value-logging.
              In the implementation, there will probably be only one
              start-data-logging to handle all orders.
           ;

              ## ************************************** ##
DEF TIMER                         trigger;

              CARDINALITY         number-of-orders;

              LOCAL TO            measured-value-processing;

              CYCLE               cycle-of-order;
              DELAY               delay-of-order;

              ## ************************************** ##
DEF VARIABLE                      index-of-order;

              LOCAL TO            measured-value-processing;

DESCRIPTION;
              index-of-order must be one of the order-identifications
              which might be of type COUNT or STRING.
           ;
```

```
              ## *************************************** ##
DEF ACTIVITY                  measured-value-logging;

DESCRIPTION;
              Program that reads in process data and stores them ordered
              in the raw-data-buffer.

              The process data consists of the values measured and
              converted to digital representation, and the status
              information which is  a true/false-statement about the
              state of the process or plant. The data is supplied by
              process-interfaces.

              The program will get its particular task from the data-
              aquisition-order, the index of which was passed as a
              parameter. In case of errors, the questionable data
              are marked to avoid misinterpretation by the receiver.
          ;

              READS           data-aquisition-order,
                              index-of-order,
                              time,
                              hardware-tabel,
                              priority;

              PRODUCES FOR    raw-data-buffer;

              ALTERNATIVE     error-proc-in-mvl;


DEF ACTIVITY                  error-proc-in-mvl;

              DEPENDING ON    error-in-mvl;

              WRITES          control-information-block;

              UTILIZES        error-handling;


## *****************  2.2  ******************************************* ##
DEF ACTIVITY                  data-preparation;

DESCRIPTION;
              Program that checks and converts the data read in. It is
              controlled by the presence of data in the raw-data-buffer,
              which are copied to a work-area and finally as physical
              values put out to the result-buffer.
          ;

              EXECUTING       REPEATEDLY;

              READS           evaluation-parameters;

              CONSUMES FROM   raw-data-buffer;

              OCCUPIES        work-area;
```

```
                PRODUCES FOR    result-buffer,
                         FOR    status-information-buffer;

                WRITES          previous-values;

                ALTERNATIVE     error-proc-in-dpr;


DEF ACTIVITY                    error-proc-in-dpr;

                DEPENDING ON    error-in-dpr;

                WRITES          control-information-block;

                UTILIZES        error-handling;


                ## ************************************** ##
DEF RESOURCE                    work-area;

DESCRIPTION;
                 Used to store intermediate results of data preparation.
            ;

                 LOCAL TO       data-preparation;


## ****************  2.3  ****************************************** ##
DEF ACTIVITY                    recording;

DESCRIPTION;
                All data in the result-buffer will be recorded on a tape
                or a disk.
            ;

                EXECUTING       REPEATEDLY;

                CONSUMES FROM   result-buffer;

                CONSUMES FROM   external-memory;

                PRODUCES FOR    output-buffer;

                ALTERNATIVE     error-proc-in-recording;


DEF ACTIVITY                    error-proc-in-recording;

                DEPENDING ON    error-in-recording;

                WRITES          control-information-block;

                UTILIZES        error-handling;
```

```
                 ## *************************************** ##
DEF BUFFER                      external-memory;

DESCRIPTION;
              The external memory is treated as a buffer rather than
              a resource, because it is only occupied but not released
              by this system.
           ;

              LOCAL TO         recording;

              POSITION         PERIPHERAL;

## ****************  2.4  ******************************************* ##
DEF ACTIVITY                    life-display;

DESCRIPTION;
              Output of a subset of all the values in the result-buffer.

              'Characteristic values' are predetermined results which
              are plotted or printed or displayed.
           ;

              EXECUTING        REPEATEDLY;

              READS            control-information-block;

              CONSUMES FROM    result-buffer;

              PRODUCES FOR     output-buffer;

              ALTERNATIVE      error-proc-in-l-display;

DEF ACTIVITY                   error-proc-in-l-display;

              DEPENDING ON     error-in-l-display;

              WRITES           control-information-block;

              UTILIZES         error-handling;
```

```
## ****************  2.5  ******************************************** ##
DEF ACTIVITY                    error-handling;

DESCRIPTION;
             Sends error-messages to the control-desk and handles those
             error-situations that cannot be resolved by the programs
             internally. May be called by any other system component.
             All information about the error is passed via parameters
             in the control-information-block.
             This routine may influence the data-aquisition by changes
             in the control-information-block.

             An error is a situation in which the aquisition and trans-
             mission of data does not accord to the schedule. This may
             be caused by one of the following two reasons:
             1. breakdown of hardware-components,
             2. wrong parameters supplied from the user that cannot be
                identified by the checks for plausibility of the
                dialogue-system.
             In any case, the error must be handled by an operator's
             action as soon as possible. An error-message is generated.
           ;

             READS           control-information-block;

             PRODUCES FOR    output-buffer;

## ****************  3.  ********************************************* ##
DEF ACTIVITY                    alarm-handling;

DESCRIPTION;
             User-oriented routines that handles alarms from the
             technical process. The steps to be taken may be either
             independent (including I/O), or may influence the actions
             of the data-aquisition-system via the content of the
             control-information-block.
           ;

             EXECUTING       REPEATEDLY;

             STARTED BY      alarm;

             WRITES          control-information-block;

             PRODUCES FOR    output-buffer;

## ****************  3.1  ******************************************** ##

DEF INTERRUPT                   alarm;

             LOCAL TO        alarm-handling;
```

```
## ****************  4.  ******************************************** ##
DEF ACTIVITY                   dialogue;

DESCRIPTION;
              Module for communication with the operator. Both control-
              and evaluation-parameters may be modified. The actual
              state of the process and the system may be inquired.
              The dialogue is triggered by input from the keyboard.

              Users define and change orders for data-aquisition in a
              dialogue, promted by the system.

              SUBACTS ARE      dialogue-input-processing,
                               dialogue-output-processing;


DEF RESOURCE                   teletype;

              LOCAL TO         dialogue;


## ****************  4.1  ******************************************* ##
DEF ACTIVITY                   dialogue-input-processing;

              EXECUTING        REPEATEDLY;

              STARTED BY       attention-key;

              INITSTEP         read-input;
              SUBSTEPS         input-check;

DEF INTERRUPT                  attention-key;
              LOCAL TO         alarm-handling;


## ****************  4.1.1  ***************************************** ##
DEF STEP                       read-input;

              OCCUPIES         teletype;
              CONSUMES FROM    teletype-keyboard;
              WRITES           line-buffer;
              NEXT STEP        input-check;


## ****************  4.1.2  ***************************************** ##
DEF STEP                       input-check;
              READS            line-buffer;

              ALTERNATIVES     input-error,
                               data-aquisition-order-proc,
                               evaluation-parameters-proc,
                               system-state-inquiry-proc;
              ## ************************************** ##
DEF STEP                          input-error;
              NEXT STEP           read-input;

DEF STEP                          data-aquisition-order-proc;
              WRITES              data-aquisition-order;

DEF STEP                          evaluation-parameters-proc;
              WRITES              evaluation-parameters;

DEF STEP                          system-state-inquiry-proc;
              WRITES              system-state-inquiry;

              ## ************************************** ##
DEF BUFFER                        teletype-keyboard;

DESCRIPTION;
              the keyboard is used to enter
              * data-aquisition-orders
              * evaluation-parameters
              * system-state-inquiries
            ;

              CONSUMED BY         read-input;

              PRODUCED BY         operator;

              CAPACITY            1 OF input-line;


DEF TYPE                          input-line;

              CONSISTS OF         80 OF input-character;


## ***************  4.2  ****************************************** ##
DEF ACTIVITY                      dialogue-output-processing;

              EXECUTING           REPEATEDLY;

              CONSUMES FROM       status-information-buffer;

              OCCUPIES            teletype;

              PRODUCES FOR        teletype-printer;
              ## ************************************** ##
DEF BUFFER                      teletype-printer;

DESCRIPTION;
              The teletype-printer is used to transmit
              * status-informations
              * error-messages
           ;

              CONSUMED BY       operator;

              CAPACITY          1 OF output-line;


DEF TYPE                        output-line;

              CONSISTS OF       120 OF output-character;


## ****************  5.  ******************************************* ##
DEF ACTIVITY                    output-periphery;

              SUBACTS ARE       display-drive,
                                printer-drive;

## ****************  5.1  ****************************************** ##
DEF ACTIVITY                    display-drive;

              EXECUTING         REPEATEDLY;

              CONSUMES FROM     output-buffer;

              PRODUCES FOR      display;


DEF BUFFER                      display;

              POSITION          PERIPHERAL;

              LOCAL TO          display-drive;

## ****************  5.2  ****************************************** ##
DEF ACTIVITY                    printer-drive;

              EXECUTING         REPEATEDLY;

              CONSUMES FROM     output-buffer;

              PRODUCES FOR      printer;


DEF BUFFER                      printer;

              POSITION          PERIPHERAL;

              LOCAL TO          printer-drive;
```

```
## ****************************************************************** ##
##    DEFINITION OF MAIN-DATA-AREAS                                   ##
## ****************    6.1   ******************************************* ##
DEF BUFFER                    input-buffer;

              PRODUCED BY     technical-process;

              CONSUMED BY     measured-value-logging;

              CAPACITY        size-input-data-buffer OF input-data;

DESCRIPTION;
              The input-data may be either
              * measured values     or
              * status-information
           ;


## ****************    6.2   ******************************************* ##
DEF BUFFER                    raw-data-buffer;

              LOCAL TO        measured-value-processing;

              PRODUCED BY     measured-value-logging;

              CONSUMED BY     data-preparation;

              CAPACITY        size-raw-data-buffer OF raw-data;


              ## **************************************** ##
DEF TYPE                      raw-data;

              CONSISTS OF     time-record-2,
                              order-identification-2,
                              raw-data-2;


## ****************    6.3   ******************************************* ##
DEF BUFFER                    result-buffer;

DESCRIPTION;
               The output-fan indicates that both recording and life-
               display get every item in the buffer;
           ;

               OUTPUT-FAN     2;

               LOCAL TO       measured-value-processing;

               PRODUCED BY    data-preparation;

               CONSUMED BY    recording,
                        BY    life-display;

               CAPACITY       size-result-buffer OF result;
```

```
                ## ************************************* ##
DEF TYPE                        result;

                 CONSISTS OF    time-record-1,
                                order-identification-1,
                                result-1;

DESCRIPTION;
                 The results are in physical units.
          ;

## **************** 6.4 ******************************************* ##
DEF BUFFER                      status-information-buffer;

                 PRODUCED BY    data-preparation;

                 CONSUMED BY    dialogue;

                 CAPACITY       size-status-information-buffer
                       OF       status-information;

DESCRIPTION;
                status-information-buffer contains status-information.
          ;

## **************** 6.5 ******************************************* ##
DEF BUFFER                      output-buffer;

                OUTPUT-FAN      2;

                PRODUCED BY     life-display,
                         BY     alarm-handling,
                         BY     error-handling,
                         BY     recording;

                CONSUMED BY     display-drive;


                CAPACITY        size-output-buffer OF output-data;

DESCRIPTION;
                output-buffer may contain

                * process-state-descriptions
                * sample-values
                * event-messages
          ;
```

```
## ****************  7.  ******************************************** ##
DEF VARIABLE                  control-information-block;

DESCRIPTION;
              Central information that specifies the monitoring and
              processing to be done. In particular, the control-
              information-block contains all parameters for control
              contains all parameters for control and evaluation that
              and evaluation that may be subject to modifications.
              The content of the control-information-block may be
              modified by alarm-handling, dialogue, and error-handling.
           ;

              SUBPARTS ARE    order-tabel,
                              parameter-tabel,
                              hardware-tabel;


## ****************  7.1  ******************************************* ##
DEF VARIABLE                  order-tabel;

              SUBPARTS        data-aquisition-order;

              ## ************************************** ##
DEF VARIABLE                  data-aquisition-order;

              CARDINALITY     number-of-orders;

              SUBPARTS ARE    list-of-measuring-points,
                              order-identification,
                              priority;


## ****************  7.2  ******************************************* ##
DEF VARIABLE                  parameter-tabel;

              SUBPARTS ARE    tabel-of-standard-values,
                              previous-values,
                              scaling-factor;


## ****************  7.3  ******************************************* ##
DEF VARIABLE                  hardware-tabel;

              SUBPARTS ARE    hardware-adresses,
                              dma-numbers,
                              bit-numbers,
                              distorsion-factor;


##******************************************************************** ##
##******************************************************************** ##
```

5. PCSL versus PSL, DSL and EPOS

In this chapter, PCSL is compared with PSL (its 'father'), (its 'older brother') and EPOS, a system which is being developed at the Stuttgart-University (its 'colleague').

PSL, DSL and PCSL are very similar as far as style and structure of the languages are concerned, because they all have to be defined by the META-system which implies many restrictions (structure of sections and statements, relations, etc.). Such similarities are not discussed here.

5.1 PSL

PCSL differs from PSL:

- in the object-types for data: Instead of a large number of object types related to data base terminology, only VARIABLES and BUFFERS are available; (COUNT, INTEGER, REAL, BINARY, STRING are just primitive VARIABLES.)
- in its means to handle time and synchronization which are very poor in PSL;
- in the distinction of two object types instead of PROCESS. This allows to describe parallelism easily;
- in the presence of logical relations (while, while not etc., object-types CRITERION, RANGE-INT etc.); In PSL, logical relations are only described by informal texts.

In general, PCSL is more restricted to a special area than PSL. As a benefit from this restriction, a more precise meaning can be attached to all elements of the language.

5.2 DSL

Similar to PCSL, DSL /Bodart, Pigneur 1979 a, b/ is based on PSL. (Neither PCSL nor DSL is a superset of PSL!) Also, DSL stresses the dynamic system aspects in order to allow more dynamic analysis and simulation which is impossible with PSL as it is. PCSL and DSL differ slightly in their means and goals:

PCSL is less analysis-oriented than DSL, we tried to develop a language which is useful even if used without any tools for analysis, just by the concepts which (hopefully) contribute to reliability because they are easy to understand and restrict their users to reliable constructions.

The focal point of DSL seems to be on analysis and simulation. EVENTS and RESOURCES are most important, the use of RESOURCES can be described in more detail than in PCSL, but there is no bias for contructs that hide details of implementation within complex operations like 'produce' and 'consume' in PCSL do.

DSL consists of two levels, the one for the GA, and the so-called nested language for simulation. A similar approach will be necessary for PCSL, though we tried to have most information for simulation on the primary level.

5.3 EPOS

EPOS /Biewald et al. 1979/ is a system for specification and design of process control software. It is directed towards PEARL, a process control programming language supported by our government.

EPOS consists of a language (with different parts for requirements and design), an analysis-system which encompasses a simulator, a report generator, and a user interface for controlling the whole system.

EPOS is being implemented in PEARL on a minicomputer AEG 80-20. It is planned to be used in life-size-applications in 1980.

EPOS-R, the subsystem for requirements, acts as a text- and graphic editing facility with little relational and logical capabilities.

Such capabilities are found in EPOS-S. (This name is inconsistently used for both the language and the system to process it.) Object-types are ACTION, DATA, INTERFACE, EVENT, CONDITION.

There are relations for data-flow (INPUT,OUTPUT), control (TRIGGERED), processing (PROCESSED) and decomposition.

ACTIONS are decomposed in a procedural way (sequence, if-then-else, etc.).

Apparently, relations can be specified only in one direction (not from either end).

EPOS-A (analysis) and EPOS-D (documentation) correspond to the analysis- and report-generation-capabilities of PSA. In the paper cited above, seven types of analysis are listed, including syntax check, consistency checks and simulation. Much plotted output is planned.

Compared to PCSL, EPOS differs in many ways. Its major advantage is its installation on a minicomputer. Also, the distinction (and tracing) between requirements and design seems to be a good feature. Finally, the hierarchically structured informal information (e.g. DESCRIPTION = PURPOSE + DATA + FULFILS + TEST + PERFORMANCE + NOTE) and the closed syntactical constructs (e.g. DESCRIPTION ... DESCRIPTIONEND) should be noted.

On the other hand, the means of PCSL for data flow and resource allocation are more elegant because they encompass all synchronization needed. The PSL - like languages are more flexible because they allow for stepwise accumulation of the problem statement, 'complementary relations', and implicit declaration.

6. Current state of PCSL

6.1 The language

PCSL was defined in August 1978 /Ludewig, Streng - Oct. 1978/; recently (July 1979) a minor revision was made to remove some mistakes from the first version and to change some keywords. (This paper is based on the revised version.)

6.2 The Generalized Analyzer

By July 1979, the most important parts of the Generalized Analyzer (GA) were operational at IDT /Berliner, Ludewig, Pozzi 1979/:

IP	(Input PSL)
DBSM	(Data Base Summary)
NS	(Name Selection)
FS	(Formated Statement).

DP and RP (Delete and Replace) will follow soon. Thus, PCSL is available at IDT. A command-language interpreter for our batch-installation is being developed.

6.3 Analysis-tools

No steps towards design and implementation of modules for analysis and report-generation have been taken beyond the formal specifications given in /Ludewig 1978/.

7. References

Baumann, R.: Computer-aided design and implementation of control algorithms. in: A. Niemy (ed.): IFAC 78, Vol. I, p. 649-655, Helsinki, Juni 1978

Biewald, J., P. Göhner, R. Lauber, H. Schelling: EPOS - A specification and design techniques for computer controlled real-time automation systems. Proc. of the 4th Int. Conf. on Software Engineering, München, Sept. 1979, p. 245-250

Bodart, F., Y. Pigneur: A model and a language for functional specification and evaluation of information system dynamics. IFIP TC8 W.G. 8-1. Working conf. on formal models and practical tools for information system design. Oxford, April 1979

Bodart, F., Y. Pigneur: Dynamic specification language and a simulation model analyzer for an information system. Inst. d'Informatique, FNDP, Namur, Sept. 1979

Courtois, P.J., F. Heymans, D.L. Parnas: Concurrent control with 'readers' and 'writers'. Commun. of the ACM, Vol. 14, No. 10 (1971), p. 667-668

Dijkstra, E.W.: The structure of the THE-multiprogramming-system. Commun. of the ACM, Vol. 11, No. 5 (1968), p. 341-346

Dijkstra, E.W.: Cooperating sequential processes. in: Genuys, F. (ed.): Programming languages. Academic Press, London, New York 1968, p. 43-112

Ludewig, J., W. Streng: Überblick und Vergleich verschiedener Mittel für die Spezifikation und den Entwurf von Software. KfK 2506, March 1978

Ludewig, J., W. Streng: Methods and Tools for Software Specification and Design - A Survey. European Purdue Workshop, TC for Safety and Security (TC 7), Paper No. 149, Zürich, April 1978

Schumacher, F.: Beschreibung und Auswertung diskreter dynamischer Systeme. KfK 2635, March 1978

Teichroew, D., E.A. Hershey III: PSL/PSA: a computer-aided technique for structured documentation and analysis of information processing systems. IEEE Trans. SE-3, No. 1 (1977), p. 41-48

Vinzentz, H.: Entwicklung zuverlässiger Prozeßrechner-Software durch den Einsatz von Spezifikations- und Entwurfssprachen. Diplomarbeit, Universität Karlsruhe 1979

The primary reports listed below contain information of a provisional nature and were compiled primarily to promote the up-to-date internal exchange of information among the institutes and external partners cooperating with the Karlsruhe Nuclear Research Center. Any dissemination of these reports or its contents requires the consent of the Patents and Licenses Department of KfK.

Berliner, E., J. Ludewig, U. Pozzi: Die Installation des Generalized Analyzers, April 1979

Borrmann, H.: Konzept der Meßwerterfassung und -bereitstellung im Rahmen eines universellen Prozeßüberwachungssystems, August 1978

Ludewig, J.: Definition der Struktur und Semantik von PCSL, August 1978

Ludewig, J., W. Streng: Extensions of PSL/PSA for Process Control Applications - A Proposal, March 1978

Ludewig, J., W. Streng: META-Definition von PCSL, October 1978

Appendix: A PCSL-summary

```
##########################################################################
###                                                                    ###
###   This is a short but almost complete definition of PCSL;          ###
###   only the synonyms of keywords are missing. It was derived        ###
###   from META-definition by deleting all information relevant        ###
###   for database-organisation and error-handling but not for         ###
###   the language itself. All relevant parts have been compressed     ###
###   without loss of information.                                     ###
###                                                                    ###
###   The connectivity is stated in the headers corresponding to       ###
###   the sequence of components in the COMBINATION-statements.        ###
###   (e.g. MANY,ONE means the 2nd component of the relation may       ###
###   be connected to several 1st components, but for every 1st        ###
###   component, only one 2nd is allowed).                             ###
###                                                                    ###
###   Lines starting with a number in parentheses describe state-      ###
###   ments for the relation defined before; the number indicates      ###
###   the component to which the statement applies (i.e. in whose      ###
###   section the statement may appear).                               ###
###                                                                    ###
###                                                                    ###
###   Parentheses indicate parts of statements that may be repeated    ###
###   n times, n = 0,1,2,...  Parts in square brackets are optional.   ###
###                                                                    ###
##########################################################################
```

```
########################################################################
#######   App. 1    NOISE-WORDS   ######################################

       ARE, IN, IS, OF, ON, TO;

### Noise-words may be inserted in any statement without any meaning ###


########################################################################
#######   App. 2    OBJECT-TYPES   #####################################

       ACTIVITY,  STEP,

       BUFFER,    VARIABLE,  RESOURCE,  TYPE,

       BINARY,    COUNT,     INTEGER,   REAL,      STRING,

       EVENT,     INTERRUPT, TIMER,     INTERVAL,

       CONDITION,

       RANGE-BIN, RANGE-CNT, RANGE-INT, RANGE-REAL, RANGE-STR,

       KEYWORD,   MEMO,      ATTRIBUTE, ATTRIBUTE-VALUE,

       FUNCTION,  PROCESS-VARIABLE;

#### Since object-type VARIABLE may be replaced by the simple-typed ####
#### variables BINARY, COUNT, INTEGER, REAL, and STRING, in most    ####
#### applications, ANY-VARIABLE ist used for the whole set.         ####


########################################################################
#######   App. 3    TEXTS and the object-types they are allowed with  ##


       ALGORITHM         (FUNCTION);

       DESCRIPTION       (ALL);

       OBJECTIVE         (ACTIVITY, STEP);

       CODE              (ACTIVITY, STEP);

       SIMULATION        (ALL);
```

###
####### App. 4 ### PROPERTIES ##################################

### .1 PROPERTIES and their values (object-types in parentheses) ###

BIAS:	READER, WRITER	(ANY-VARIABLE);
CREATION:	SUPPLIED, KEPT, LOST	(ANY-VARIABLE);
EMPTY:	BLOCK, SKIP	(BUFFER);
FULL:	BLOCK, SKIP	(BUFFER);
FAN-IN:	INTEGER 1 THRU 1000000	(BUFFER);
FAN-OUT:	INTEGER 1 THRU 1000000	(BUFFER);
ORDER:	FIFO, LIFO, RANDOM, BY-PRIORITY	(BUFFER);
POSITION:	INTERNAL, PERIPHERAL	(ANY-VARIABLE, BUFFER, ACTIVITY,STEP);
EXECUTING:	ONCE, REPEATEDLY	(ACTIVITY,STEP);
PRIORITY:	INTEGER 1 THRU 1000000	(ACTIVITY,STEP);
STATUS:	NEW, EXISTING	(ACTIVITY,STEP);
MAXIMUM-DEVIATION:	NUMBER 0.0 THRU 1.0	(INTERVAL);
PROBABILITY:	NUMBER 0.0 THRU 1.0	(CONDITION);

####### .2 PROPERTIES used only as types and their values ##########

BINARY-RANGE:	STRING;
COUNT-RANGE:	INTEGER 0 THRU 1000000;
INTEGER-RANGE:	INTEGER;
REAL-RANGE:	NUMBER;
STRING-RANGE:	STRING;
TIME-UNIT-RANGE:	M-SEC, SEC, MIN, HOURS, DAYS, WEEKS, MONTHS, YEARS;
ARITH-COMPARATOR:	EQ, NE, GE, LE, GT, LT;
LOGIC-COMPARATOR:	EQ, NE;

```
########################################################################
#######   App. 5       ###   RELATIONS and STATEMENTS                ###
########################################################################


########################################################################
#######   App. 5.1     ###   alternative-relation   (ONE,MANY)   #######

   COMBINATION alternative-father ACTIVITY
          WITH alternative-son    ACTIVITY;
   COMBINATION alternative-father STEP
          WITH alternative-son    STEP;

   (1) ALTERNATIVES ARE alternative-son (, alternative-son );

   (2) FACULTATIVE IN alternative-father;


########################################################################
#######   App. 5.2     ###   attribute-relation   (MANY,MANY,ONE)   ####

   COMBINATION attribute-left-hand-part ALLBUT ATTRIBUTE
          WITH attribute-part           ATTRIBUTE
          WITH attribute-value-part     ATTRIBUTE-VALUE;

   (1) ATTRIBUTE attribute-part attribute-value-part
              (, attribute-part attribute-value-part );

   (2) VALUES ARE attribute-value-part FOR attribute-left-hand-part
               (, attribute-value-part FOR attribute-left-hand-part );


########################################################################
#######   App. 5.3     ###   capacity-relation   (MANY,MANY,ONE)   #####

   COMBINATION capacity-buffer BUFFER
          WITH capacity-unit   TYPE
          WITH capacity-count  COUNT VALUE-FOR COUNT-RANGE;

   (1) CAPACITY capacity-count OF capacity-unit;

   (2)    capacity-count ITEMS IN capacity-buffer
       (, capacity-count ITEMS IN capacity-buffer );


########################################################################
#######   App. 5.4     ###   cardinality-relation   (MANY,ONE)   #######

   COMBINATION card-subject-part ACTIVITY, ANY-VARIABLE, BUFFER,
                                 TIMER, RESOURCE
          WITH cardinality-part  COUNT VALUE-FOR COUNT-RANGE;

   (1) CARDINALITY IS cardinality-part;

   (2) APPLIES TO card-subject-part (, card-subject-part );
```

```
###############################################################################
#######   App. 5.5      ###    consume-relation    (MANY,MANY,ONE)      ######

   COMBINATION consumer    ACTIVITY, STEP
          WITH cons-buffer BUFFER
          WITH cons-count  COUNT VALUE-FOR COUNT-RANGE;

   (1) CONSUMES [ cons-count [ OF BUFFER-UNIT ]] FROM cons-buffer
             (, [ cons-count [ OF BUFFER-UNIT ]] FROM cons-buffer );

   (2) CONSUMED [ cons-count [ OF BUFFER-UNIT ]] BY consumer
             (, [ cons-count [ OF BUFFER-UNIT ]] BY consumer );


###############################################################################
#######   App. 5.6      ###    contain-relation    (MANY,MANY,ONE)      ######

   COMBINATION containing-part      VARIABLE, TYPE
          WITH contained-part       TYPE
          WITH con-repetition-part COUNT VALUE-FOR COUNT-RANGE;
   COMBINATION containing-part      INTERVAL
          WITH contained-part       INTERVAL VALUE-FOR TIME-UNIT-RANGE
          WITH con-repetition-part COUNT VALUE-FOR COUNT-RANGE;

   (1) CONSISTS OF [ con-repetition-part ] contained-part
                (, [ con-repetition-part ] contained-part );

   (2) CONTAINED [con-repetition-part [TIMES]] IN containing-part
              (, [con-repetition-part [TIMES]] IN containing-part );


###############################################################################
#######   App. 5.7      ###    control-relation    (MANY,MANY,ONE)      ######

   COMBINATION controled-var PROCESS-VARIABLE, ANY-VARIABLE
          WITH controler     ANY-VARIABLE
          WITH control-fct   FUNCTION;

   (1) CONTROLED BY controler [ USING control-fct ]
                 (, controler [ USING control-fct ] );

   (2) CONTROLS controled-var [ USING control-fct ]
             (, controled-var [ USING control-fct ] );


###############################################################################
#######   App. 5.8      ###    criterion-relation    (MANY,ONE)     #########

   COMBINATION alternative-part ACTIVITY, STEP
          WITH criterion-part   CONDITION;

   (1) DEPENDING ON criterion-part;

   (2) APPLIES TO alternative-part (, alternative-part );
```

```
########################################################################
#######   App. 5.9     ###   cycle-relation   (MANY,MANY,ONE)   ########

   COMBINATION cycle-timer     TIMER
          WITH cycle-time-unit INTERVAL VALUE-FOR TIME-UNIT-RANGE
          WITH cycle-count     COUNT VALUE-FOR COUNT-RANGE;

   (1) CYCLE [ cycle-count OF ] cycle-time-unit;


########################################################################
#######   App. 5.10    ###   delay-relation   (MANY,MANY,ONE)   ########

   COMBINATION delayed-timer   TIMER
          WITH delay-time-unit INTERVAL VALUE-FOR TIME-UNIT-RANGE
          WITH delay-count     COUNT VALUE-FOR COUNT-RANGE;

   (1) DELAY [ delay-count OF ] delay-time-unit;


########################################################################
#######   App. 5.11    ###   device-relation   (MANY,MANY)   ###########

   COMBINATION device-content ANY-VARIABLE, BUFFER
          WITH device         RESOURCE;

   (1) DEVICE device (, device );

   (2) HOUSES device-content (, device-content );


########################################################################
#######   App. 5.12    ###   implies-relation   (MANY,MANY)   ##########

   COMBINATION implies-step      STEP, CONDITION
          WITH implies-condition CONDITION,
                                 RANGE-INT,
                                 RANGE-CNT,
                                 RANGE-REAL,
                                 RANGE-BIN,
                                 RANGE-STR;

   (1) IMPLIES implies-condition (, implies-condition );

   (2) IMPLIED BY implies-step (, implies-step );
```

```
###########################################################################
#######   App. 5.13    ###   inhibit-relation    (MANY,MANY)    ##########

   COMBINATION inhibiter       ACTIVITY, STEP
          WITH inhibited-event EVENT, TIMER, INTERRUPT;

   (1) INHIBITS inhibited-event (, inhibited-event );

   (2) INHIBITED      BY  inhibiter (, inhibiter );


###########################################################################
#######   App. 5.14    ###   initiate-relation    (MANY,MANY)    #########

   COMBINATION initiater      ACTIVITY, STEP
          WITH data-initiated ANY-VARIABLE;

   (1) INITIATES data-initiated (, data-initiated );

   (2) INITIATED BY initiater (, initiater );


###########################################################################
#######   App. 5.15    ###   initstep-relation    (ONE,ONE)    ###########

   COMBINATION init-father ACTIVITY, STEP
          WITH init-son    STEP;

   (1) INITIAL-STEP IS init-son;

   (2) FIRST-STEP OF init-father;


###########################################################################
#######   App. 5.16    ###   intvl-def-relation    (MANY,MANY,ONE)    ####

   COMBINATION defined-interval INTERVAL
          WITH intvl-def-unit   VALUE-FOR TIME-UNIT-RANGE
          WITH intvl-def-count  VALUE-FOR COUNT-RANGE;

   (1) AVERAGE-LENGTH [ intvl-def-count OF ] intvl-def-unit;


###########################################################################
#######   App. 5.17    ###   intvl-use-relation    (MANY,ONE)    #########

   COMBINATION intvl-user    ACTIVITY, STEP, BUFFER, EVENT, INTERRUPT
          WITH used-interval INTERVAL;

   (1) INTERVAL used-interval;

   (2) APPLIES TO intvl-user (, intvl-user );
```

```
##########################################################################
#######   App. 5.18   ###   keyword-relation   (MANY,MANY)   ##########

   COMBINATION keyed-part   ALLBUT KEYWORD
          WITH keyword-part KEYWORD;

   (1) KEYWORD ARE keyword-part (, keyword-part );

   (2) APPLIES TO keyed-part (, keyed-part );



##########################################################################
#######   App. 5.19   ###   local-relation   (MANY,ONE)   #############

   COMBINATION local-object ALLBUT ACTIVITY, STEP
          WITH local-stact  ACTIVITY, STEP;

   (1) LOCAL TO local-stact;

   (2) LIMITS local-object (, local-object );



##########################################################################
#######   App. 5.20   ###   memo-relation   (MANY,MANY)   #############

   COMBINATION memo-part   MEMO
          WITH memoed-part ALLBUT MEMO;

   (2) SEE-MEMO memo-part (, memo-part );

   (1) APPLIES TO memoed-part (, memoed-part );



##########################################################################
#######   App. 5.21   ###   next-relation   (MANY,ONE)   ##############

   COMBINATION precessor STEP
          WITH successor STEP;

   (1) NEXT [ STEP ] IS successor;

   (2) ENTERED FROM precessor (, precessor );
```

```
##########################################################################
######   App. 5.22   ###   observe-relation   (MANY,MANY,ONE)   ######

   COMBINATION observed-var PROCESS-VARIABLE, ANY-VARIABLE
          WITH observer     ANY-VARIABLE
          WITH observe-fct  FUNCTION;

   (1) OBSERVED BY observer [ USING observe-fct ]
             (, observer [ USING observe-fct ] );

   (2) OBSERVES observed-var [ USING observe-fct ]
          (, observed-var [ USING observe-fct ] );


##########################################################################
######   App. 5.23   ###   occupy-relation   (MANY,MANY,ONE)   #######

   COMBINATION occupier          ACTIVITY, STEP, BUFFER, VARIABLE
          WITH occupied-resource RESOURCE, ACTIVITY
          WITH occupy-count      COUNT VALUE-FOR COUNT-RANGE;

   (1) OCCUPIES [ occupy-count OF ] occupied-resource
          (, [ occupy-count OF ] occupied-resource );

   (2) OCCUPIED BY occupier [ occupy-count ITEMS ]
             (, occupier [ occupy-count ITEMS ] );


##########################################################################
######   App. 5.24   ###   produce-relation   (MANY,MANY,ONE)   ######

   COMBINATION producer   ACTIVITY, STEP
          WITH prod-buffer BUFFER
          WITH prod-count  COUNT VALUE-FOR COUNT-RANGE;

   (1) PRODUCES [ prod-count [ OF BUFFER-UNIT ]] FOR prod-buffer
          (, [ prod-count [ OF BUFFER-UNIT ]] FOR prod-buffer );

   (2) PRODUCED [ prod-count [ OF BUFFER-UNIT ]] BY producer
          (, [ prod-count [ OF BUFFER-UNIT ]] BY producer );


##########################################################################
######   App. 5.25   ###   read-relation   (MANY,MANY,ONE)   #########

   COMBINATION reader        ACTIVITY, STEP
          WITH data-read     ANY-VARIABLE
          WITH read-interval INTERVAL;

   (1) READS data-read [ INTERVAL read-interval ]
        (, data-read [ INTERVAL read-interval ] );

   (2) READ BY reader [ INTERVAL read-interval ]
          (, reader [ INTERVAL read-interval ] );
```

```
########################################################################
#######   App. 5.26    ###   start-relation   (MANY,MANY)   ############

   COMBINATION starting-part EVENT, TIMER, INTERRUPT
          WITH started-part  ACTIVITY, STEP;

   (1) STARTS started-part (, started-part );

   (2) STARTED BY starting-part (, starting-part );



########################################################################
#######   App. 5.27    ###   step-relation   (ONE,MANY)   ##############

   COMBINATION step-father ACTIVITY, STEP
          WITH step-son    STEP;

   (1) SUBSTEPS ARE step-son (, step-son );

   (2) STEP OF step-father;



########################################################################
#######   App. 5.28    ###   subact-relation   (ONE,MANY)   ############

   COMBINATION activity-father ACTIVITY, STEP
          WITH activity-son    ACTIVITY;

   (1) SUBACTS ARE activity-son (, activity-son );

   (2) PARALLEL IN activity-father;



########################################################################
#######   App. 5.29    ###   subpart-relation   (ONE,MANY)   ###########

   COMBINATION top-part VARIABLE
          WITH sub-part ANY-VARIABLE;

   (1) SUBPARTS ARE sub-part (, sub-part );

   (2) PART OF top-part;
```

```
###########################################################################
###   App. 5.30    ###    subrange-relation     (MANY,MANY,ONE,MANY)    ####

   COMBINATION range-object INTEGER
          WITH range-name   RANGE-INT
          WITH cmp-operator         VALUE-FOR ARITH-COMPARATOR
          WITH cmp-value    INTEGER VALUE-FOR INTEGER-RANGE;
   COMBINATION range-object COUNT
          WITH range-name   RANGE-CNT
          WITH cmp-operator         VALUE-FOR ARITH-COMPARATOR
          WITH cmp-value    COUNT   VALUE-FOR COUNT-RANGE;
   COMBINATION range-object REAL
          WITH range-name   RANGE-REAL
          WITH cmp-operator         VALUE-FOR ARITH-COMPARATOR
          WITH cmp-value    REAL    VALUE-FOR REAL-RANGE;
   COMBINATION range-object BINARY
          WITH range-name   RANGE-BIN
          WITH cmp-operator         VALUE-FOR LOGIC-COMPARATOR
          WITH cmp-value    BINARY  VALUE-FOR BINARY-RANGE;
   COMBINATION range-object STRING
          WITH range-name   RANGE-STR
          WITH cmp-operator         VALUE-FOR LOGIC-COMPARATOR
          WITH cmp-value    STRING  VALUE-FOR STRING-RANGE;

   (1) SUBRANGE range-name IF cmp-operator cmp-value
            (, range-name IF cmp-operator cmp-value );

   (2) IF range-object cmp-operator cmp-value;



###########################################################################
#######   App. 5.31    ###    terminate-relation     (MANY,MANY)    ########

   COMBINATION terminating-part EVENT, TIMER, INTERRUPT
          WITH terminated-part  STEP, ACTIVITY;

   (1) TERMINATES terminated-part (, terminated-part );

   (2) TERMINATED BY terminating-part (, terminating-part );



###########################################################################
#######   App. 5.32    ###    true-while-not-relation     (MANY,MANY)    ###

   COMBINATION twn-condition CONDITION
          WITH twn-subrange  CONDITION,  RANGE-INT, RANGE-CNT,
                             RANGE-REAL, RANGE-BIN, RANGE-STR;

   (1) TRUE-WHILE NOT twn-subrange ( NOR twn-subrange );

   (2) NEG-RELATED TO twn-condition (, twn-condition );
```

```
############################################################################
#######   App. 5.33    ###   true-while-relation    (MANY,MAY)    ########

   COMBINATION tw-condition CONDITION
          WITH tw-subrange  CONDITION,  RANGE-INT, RANGE-CNT,
                            RANGE-REAL, RANGE-BIN, RANGE-STR;

   (1) TRUE-WHILE tw-subrange ( AND tw-subrange );

   (2) POS-RELATED TO tw-condition (, tw-condition );


############################################################################
#######   App. 5.34    ###   utilize-relation    (MANY,MANY)    ##########

   COMBINATION utilizing-part ACTIVITY, STEP
          WITH utilized-part  ACTIVITY;

   (2) UTILIZED BY utilizing-part (, utilizing-part );

   (1) UTILIZES utilized-part (, utilized-part );


############################################################################
#######   App. 5.35    ###   value-list-relation    (MANY,MANY)    #######

   COMBINATION value-object INTEGER
          WITH actual-value VALUE-FOR INTEGER-RANGE;
   COMBINATION value-object COUNT
          WITH actual-value VALUE-FOR COUNT-RANGE;
   COMBINATION value-object REAL
          WITH actual-value VALUE-FOR REAL-RANGE;
   COMBINATION value-object BINARY
          WITH actual-value VALUE-FOR BINARY-RANGE;
   COMBINATION value-object STRING
          WITH actual-value VALUE-FOR STRING-RANGE;

   (1) VALUE-LIST IS actual-value (, actual-value );


############################################################################
#######   App. 5.36    ###   value-range-relation    (MANY,ONE,ONE)    ###

   COMBINATION valued-are-part INTEGER
          WITH value1-part     INTEGER VALUE-FOR INTEGER-RANGE
          WITH value2-part     INTEGER VALUE-FOR INTEGER-RANGE;
   COMBINATION valued-are-part COUNT
          WITH value1-part     COUNT   VALUE-FOR COUNT-RANGE
          WITH value2-part     COUNT   VALUE-FOR COUNT-RANGE;
   COMBINATION valued-are-part REAL
          WITH value1-part     REAL    VALUE-FOR REAL-RANGE
          WITH value2-part     REAL    VALUE-FOR REAL-RANGE;

   (1) VALUE-RANGE value1-part THROUGH value2-part ;
```

```
########################################################################
#######   App. 5.37    ###   waitstep-relation   (ONE,ONE)   ###########

   COMBINATION wait-father ACTIVITY
          WITH wait-son    STEP;

   (1) WAITING-STEP IS wait-son;

   (2) WAITING IN wait-father;



########################################################################
#######   App. 5.38    ###   while-relation   (MANY,MANY)   ############

   COMBINATION while-step      STEP, CONDITION
          WITH while-condition CONDITION,
                               RANGE-INT,
                               RANGE-CNT,
                               RANGE-REAL,
                               RANGE-BIN,
                               RANGE-STR;

   (1) WHILE while-condition ( OR while-condition );

   (2) GUARANTEES while-step (, while-step );



########################################################################
#######   App. 5.39    ###   write-relation   (MANY,MANY,ONE)   ########

   COMBINATION writer         ACTIVITY, STEP
          WITH data-written   ANY-VARIABLE
          WITH write-interval INTERVAL;

   (1) WRITES data-written [ INTERVAL write-interval ]
           (, data-written [ INTERVAL write-interval ] );

   (2) WRITTEN BY writer [ INTERVAL write-interval ]
               (, writer [ INTERVAL write-interval ] );



########################################################################
########################################################################
```