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CANDIDE: OVERALL PLAN FOR POSSIBLE DEVELOPMENTS OF
LINKAGE OF THE CETIS ANALOG AND DIGITAL COMPUTERS

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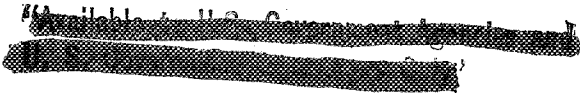
A. Riotte *Jan 1964*

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du couplage des calculateurs analogiques et digitaux du CETIS^{me}

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON	January 1964
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CANDIDE: OVERALL PLAN FOR POSSIBLE DEVELOPMENTS OF
LINKAGE OF THE CETIS ANALOG AND DIGITAL COMPUTERS

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1963

Centre Commun de Recherche Nucléaire
Etablissement d'Ispra - Italie
Centre Européen de Traitement des Informations Scientifiques-CETIS

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LINKAGE OF THE CETIS ANALOG AND DIGITAL COMPUTERS

SUMMARY

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The studies required for development of linkages between the CETIS analog and digital computers are described. Two types of linkage are distinguished:

1. One-directional static or structural linkage by which the analog computer is placed under the direct or indirect control of the digital computer for the set-up phase. The problem is furnished to the computer in the form of a digital program in APACHE code, and
2. Dynamic two-directional linkage. The digital computer after analog-digital conversion processes the analog values and restores others by digital-analog conversion, thus acting as a function generator.

A study plan to divide the theoretical and practical work into stages is presented, with time estimates.

Author

Since the association of teams specializing in the two types of computers at CETIS has already born fruit in the form of the APACHE code, the need arises for establishment of an overall plan for development of a direct analog-digital linkage.

For several years, the bringing together of the two disciplines has been attempted in various ways, either by considering the ordinator as a digital computer in real time, simulating the part of the problem processed digitally in reality (control of machinery, for example, Ref. 1), or by splitting up the problem into sequences of successive analog schemas, a digital memory connecting the preceding with that which follows (Ref. 5). Other methods have been investigated: one of them which is well known consists in organizing a digital computer as an analog computer with a view to parallel functioning of the circuits (Digital Differential Analyzer). Attempts have been made at digital programming before analog set-up (Refs. 4, 8). Finally, in the course of preliminary study from which the present report derives, there has been an opportunity to become acquainted with a project (Ref. 9) whose goals and approach parallel ours, but without sufficient detail to permit an exact comparison.

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The following study plan was established primarily to exploit with maximum effectiveness the analog complex existing at CETIS and to increase its potentialities and the reliability of its use by means of linkage with the powerful neighboring digital installation.

1. Present Position of the APACHE Code

APACHE 1 is being used. It permits preparation of the setup and static check of a problem on an analog computer by means of IBM 1620 (Ref. 7). It must be regarded as a code for intra-CETIS use, permitting those who apply it to draw from it experience that is requisite for construction of the definitive APACHE 2 code. Indeed, although it functions adequately within initially fixed limits, it is to be wished that two different types of codes will not be started which refer to two stages of the same problem. Moreover APACHE 2 in the course of definition at the Computer Center will respond to requirements clearly more ambitious than those imposed upon APACHE 1. Intended to be used on IBM 7090, it will allow:

1. Direct processing of high order differential equations without breakdown into equations of the first order,
2. Writing with marked variables, and
3. Introduction of subroutines corresponding to library block diagrams.

The first condition will radically ease the writing of the program. It will also allow:

1. In addition to processing of data furnishing setup coefficients of the potentiometers and the static check (these already provided by APACHE 1), an automatic addressing of the elements of the analog computer: amplifiers, potentiometers, logical functions, nonlinearities,
2. An optimizing of the beta factor, representing the relationship of machine time to the independent variable of the problem, and
3. A preparation of stages of computation by partial modifications of the program.

Finally an adaptation of this definitive code for its use on IBM 1620 with punched card inputs and outputs, indirect addressing system and 40,000 memory positions is envisioned as of now, in order to permit a possible spread to analog computer centers. Indeed, these centers can contemplate acquisition of such a machine that would justify itself by the substantial increase of power, reliability and speed of the installation.

All that precedes constitutes the language permitting digital processing of information bits contained in the data. The result determines

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The setup of functions of two or more variables can be carried by various procedures, depending upon the required precision, to a fragment of the block diagram that uses the existing units including function generators, within the range of the available materiel.

2.1.1.4 Register of various cases of computation

It can be characterized by modifications of parameters, of initial conditions, of block diagram, of setup of function generators. The first two cases occur with the introduction of a new perforated tape in the ADIOS console, while the last two necessitate a manual intervention.

2.1.2 Results in static output

When the 231R's are stopped in the course of computation, either at the end of a predetermined period or by comparison of a variable with a preset value, the ADIOS console allows numerical readout, printed by a typewriter, of values taken by all the variables in play at the moment of halting, and their transfer on perforated tape according to a reading program that states the units of which the output value is desired.

2.1.3 Results in dynamic output

They are obtained in a purely analog form: output voltage of the computer amplifiers developing between + and - 100 V with an operational frequency range limited to 100 cycles.

2.2 Arithmetical computers

The customary input and output supports are:

1. Perforated tapes (1620),
2. Punched cards (7090 and 1620 with extension), and
3. Printer or typewriter.

2.2.1 Static linkage

The use of punched cards for intermediate phases where the information support makes manual transport possible will be generalized.

To eliminate this support, the definitive stage will necessitate the creation of direct transcoding apparatus, using electric signals before card punching, but the communication path will be at the level of the punch and reader.

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involved by the development of the linkage, it is preferable to establish a succession of well defined stages.

As has been seen, two linkage types are presented, bound to the computer concept:

1. A one-way digital-analog linkage permitting automatic setup of the problem, which could be described as an "analog structure linkage,"
2. A two-directional linkage in which analog variables can be treated by the digital computer, which after processing of these data can:
 - a. Either act via the structural linkage, or
 - b. Reintroduce new variables at the level of the analog items.

Up to a certain point these problems are independent. In fact, with the restriction of abandoning the structural linkage in the second possible arrangement, and of not contemplating digital participation except as a sophisticated organ of analog computation, the latter could be developed before the former.

We will however keep the order in this discussion that corresponds to the growing closeness of the linkage, even if its order must be modified in the course of actual embodiment.

3.1 Linkages in the digital-to-analog direction

3.1.1 SATANAS project (Semi AuTomatic ANalog Setting)

A first rapidly accessible embodiment is the exploitation of information of address of elements furnished by APACHE 2, reducing the setup of patchboards to a purely manual operation.

A panel with luminous points will be controlled by a relay decoder starting from punched cards furnished by the program and indicating the start and the completion of each connection to be established. A patent application for this will be filed immediately. The inexpensive assembling has the advantage of development within a reasonable time. Though the automation thus obtained is only a semi-automation in which manipulation still occurs at the levels of: Transfer of punched cards, and Setup of the patchboard and its installation on the machine; it does already permit testing of the operation of the "address" part of APACHE 2, and the acquisition of experience for the succeeding phase. In this stage, the addressing consists simply in the assignment of analog items according to availability, after preliminary selection of types of nonlinearities upon reduction of the program. A limited number of simple rules will permit rational organization of a panel.

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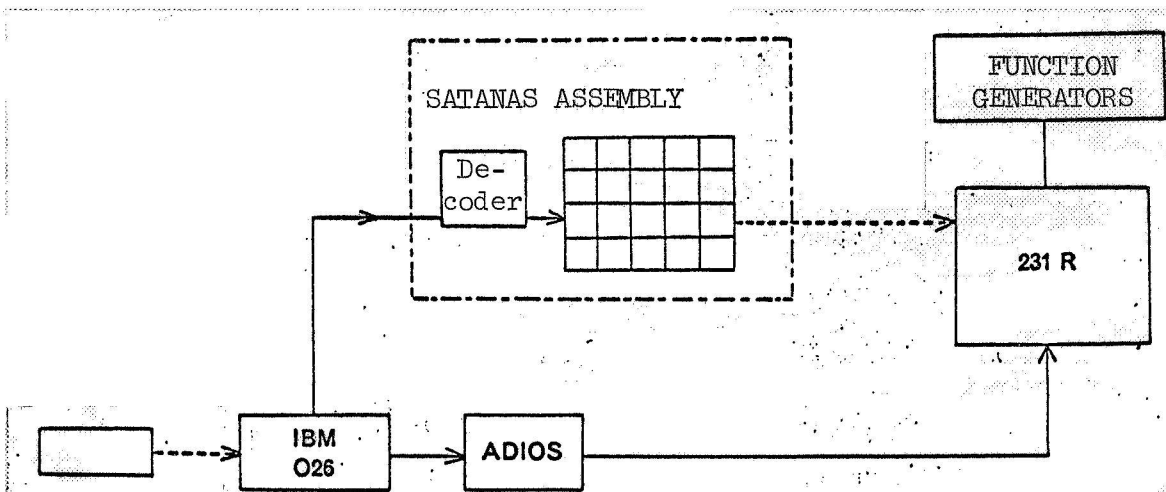


Figure 2. "SATANAS" Project

In parallel, the organization of the address code will be completed to take into account restrictions, exclusions and a relative optimization of the application of the computer elements. The first stage of this study will consist in simulating on the IBM 7090 the various possible arrangements of automatic patchboards and comparing their efficiency and simplicity of principle. A basic redesign of the present computer structure required by the exigencies of technology is not ruled out.

At the conclusion of this study a setup system will be available that is completely freed from the manual intervention of the operator. Only the transfer of punched cards will be necessary (Figure 3).

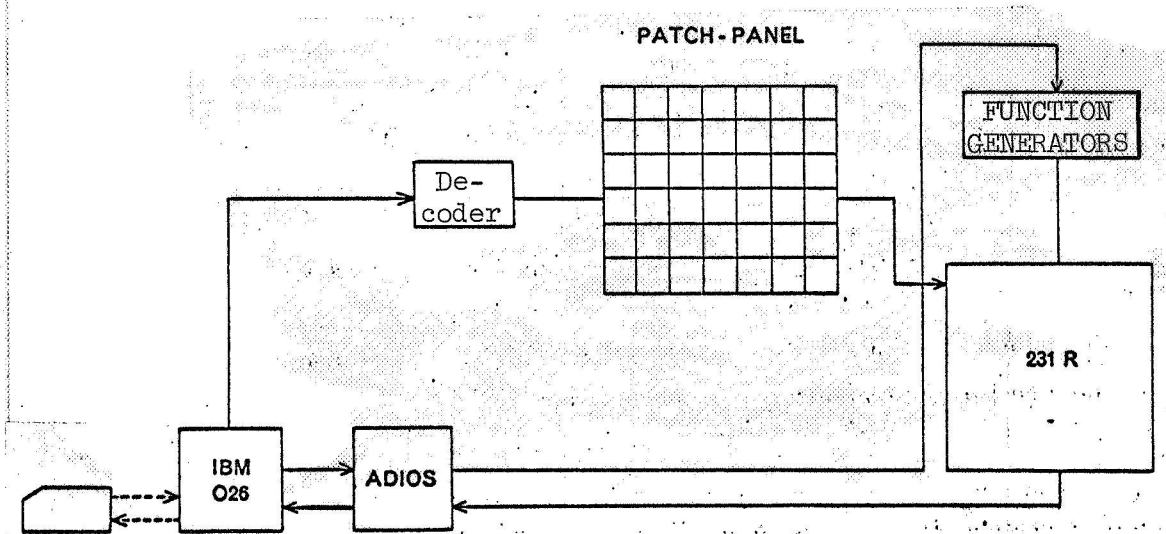


Figure 3. "ATANASE" Project. AuTomatic ANALog Setting

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But it is well to stress the technical difficulties presenting a multiplicity of problems in the development of the setup panel: contact quality, command systems, quantity of materiel, organization of the address system, possible parallel manual intervention, method of control.

3.2 Two-way linkage

3.2.1 CRESSIDA project (Couplage REVerSible StatIque Digital Analog) (Two-way static digital-analog linkage)

In the two preceding projects the transfer of information from the digital computer to the analog input elements is effected by means of two successive supports, punched cards, perforated tape.

Another possibility ought to be the elimination of this double translation which can be considered as practically independent. Indeed, a minimal modification of the ADIOS system makes it possible for word-for-word acceptance of coded information. This information can be furnished directly without the perforated tape phase, starting from a perforator assembly adjacent to the reader; the furnished electric signals would be substituted for the signals furnished by the ADIOS reader. Similarly, output data from ADIOS would be taken ahead of its perforator system and referred to the card punch. Human intervention would be confined to the carrying of cards between 1401 and the perforator.

Finally a detailed study of the electric signals should make it possible to develop an adapter to assure direct static connection with channel 7090 as indicated in Figure 1.

3.2.2 CANDIDE project (Couplage ANalog DIgital Dynamique) (Dynamic analog-digital linkage)

The problem is to cause all or part of the analog values simultaneously in play to be communicated to the digital computer either as a discrete sample or continuously. Several types of high speed converters already exist, for example, ADDALINK converters built by Electronic Associates and ADDAVERTER (EPSCO), etc. Thus there could be used:

1. Either a number of converters equal to the analog channels to be translated to digital and vice versa (continuous linkage), or
2. Multichannel electronic commutation devices each followed by a single converter (sampling linkage).

A problem of operations synchronization is added to the problem of apparatus:

1. Clearing the memories of the 7090,

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2. Setting into operation the program that answers the digital part of the analog problem, and

3. Orders for initiation and ending computation transferred to the 7090.

All the above constitutes only a bare outline of the problem (speed, synchronization, compatibility of signals, study of specific programs, etc.) which should be examined in detail.

In fact this dynamic linkage has already been used in special cases (Ref. 5) but not with possible digital processing of the results and reactions on the block diagram structure. The definitive stage would consist in putting simultaneously into play this dynamic linkage using the digital computer as a "super-generator of functions" with extensive possibilities during the computer phase and hence a dependence upon the analog installation, and as a "structure corrector" taking into account a congeries of results to prepare a new setup in the static phase, under the direct control of the digital installation.

The synoptic schema of the installation would then be as appears in Figure 4.

4. Ancillary Studies

A whole series of problems could be attacked in parallel with the technical studies of linkage. Among others they relate to:

1. Automatic verification of functioning of the analog materiel,
2. Constitution of a library of subroutines in APACHE 2,
3. Special programs related to problems to be solved,
4. A mathematical analysis of the new tool thus constituted in its two aspects, structural linkage, dynamic linkage, and their application, and
5. Special application of the linkage of project CARN.

4.1 Automatic verification of analog function

4.1.1 Automatic maintenance

To save time in the effective utilization of analog machines, it is possible to bring up the problem of automatic maintenance. This could be accomplished by:

1. A scheme for putting the whole of the materiel into play by means of a setup panel with special fixed wiring,
2. An ADIOS tape setting up all the potentiometers from a special APACHE program and fixing the necessary computing operations,

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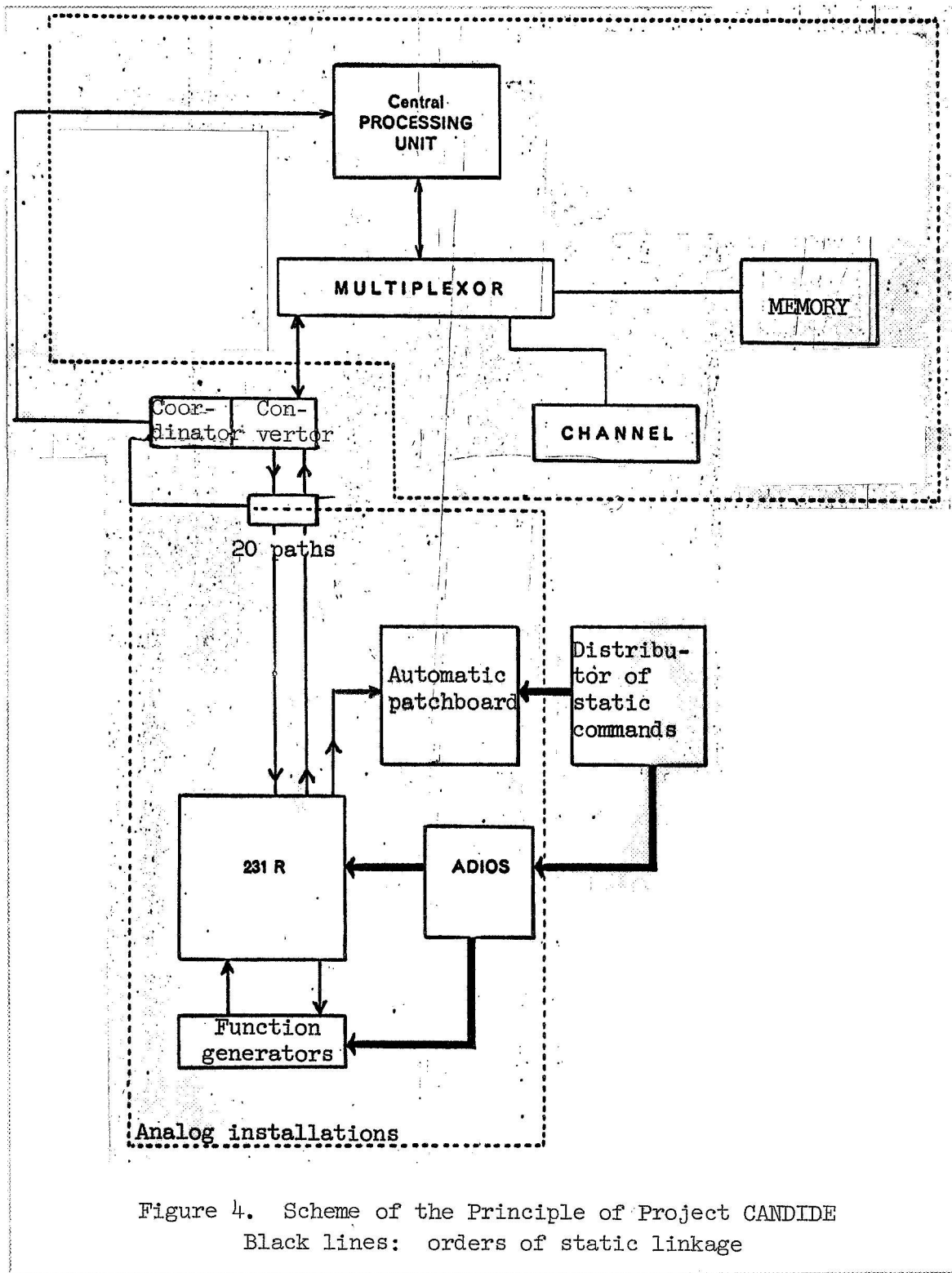


Figure 4. Scheme of the Principle of Project CANDIDE
 Black lines: orders of static linkage

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classic methods: generation of variable delays, optimization of coefficients of differential equations from a known response, synthesis of transfer functions taking into account the pulsed response of a system (Refs. 13, 14).

4.5 Application to the CARN project

The most important application of the linkage technique is clearly a contribution to Calcul Automatique de Reacteurs Nucleaires (Automatic Computation of Nuclear Reactors) towards which development all the partial studies already described ought to be directed: optimization of coefficients, equation system synthesis, variable delays, processing of partial derivative equations. A possible study of additive linkage of a resistor network (Ref. 12) to the hybrid installation already described ought to afford greater potentialities for this (simulation of reactors in theory to two groups, heterogeneity of media, etc.).

Certain new techniques concerning active networks using a time quantification according to a principle derived from digital methods (Ref. 11) could acquire flexibility and speed by linkage with a digital computer. It is indeed possible to attack parabolic and hyperbolic equations with these techniques with an assured loop stability from one stage to the other.

5. Conclusions

A single line of attack emerges immediately from the congeries of problems posed by the linkage of the two types of computers. In fact, the distinction between structural linkage and dynamic linkage permits a parallel development: the SATANAS project being immediately obtainable, while projects CRESSIDA and CANDIDE 1 can be advanced independently of project ATANASE concerning which fundamental questions of construction still exist.

In any case, the conjunction of CRESSIDA and CANDIDE 1 will already offer extensive possibilities in the realm of automatic advance projects, and the study of its application to CARN will indicate a line of procedure in reference to special efforts to be carried out for the definitive realization of CANDIDE 2.

Finally, the analysis of methods using passive and active impedance networks and investigation of their possible linkage with the two types of computers envisioned in this report will be able to provide a still greater development of the tools of a great Computer Center. It is possible indeed to imagine a meshed network representing a heterogeneous medium to which would be applied conditions at the limits and injections at

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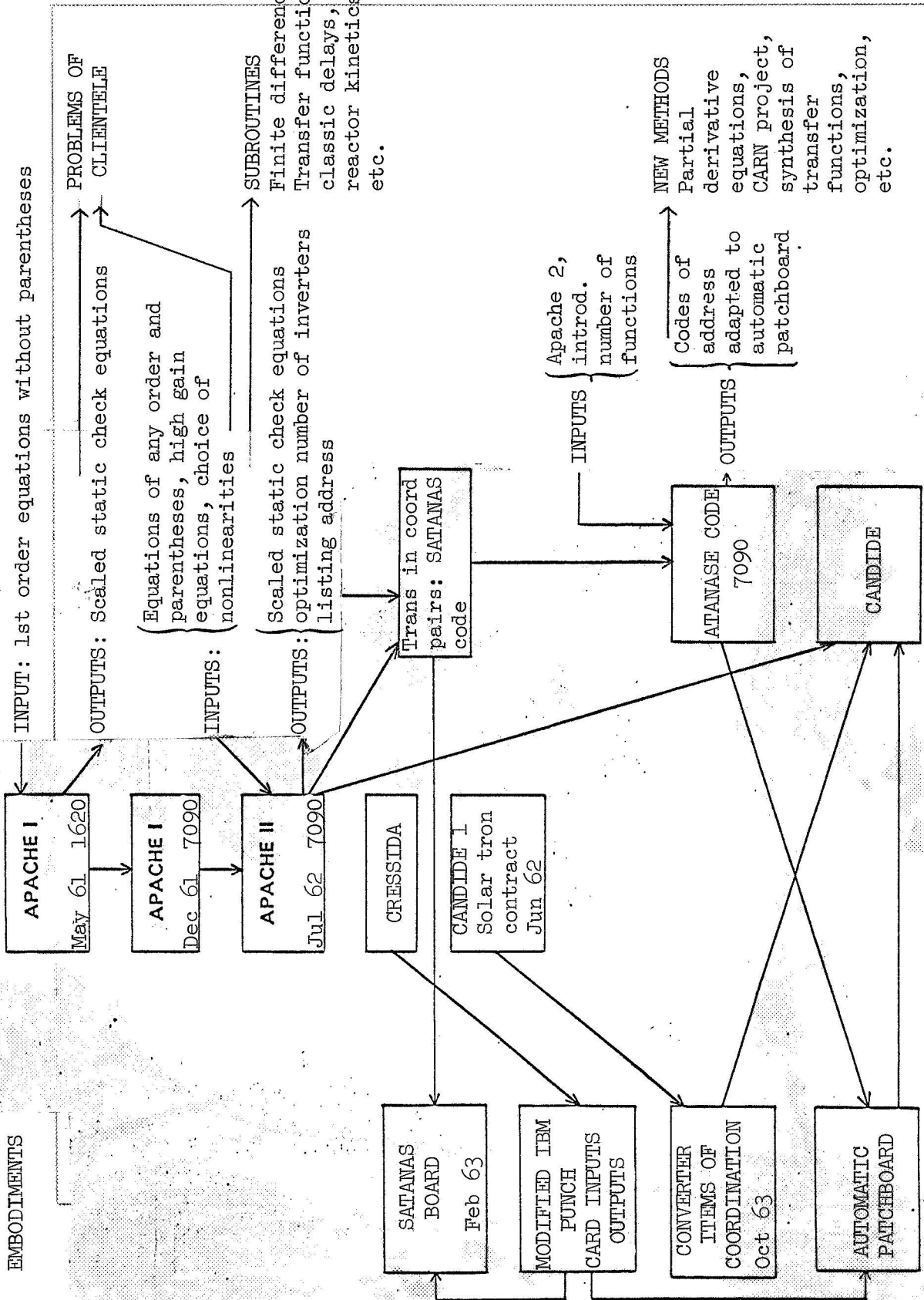


Figure 5. Synoptic Table of Projected Studies for the Linkage

the nodes ("second member" terms) which would be variable as a function of time, furnished by an analog computer. The exploitation of the results (inventory of the field in special areas, interpolation being assured by the digital computer which could--on condition of the compatibility of computing time--furnish new data for the limiting conditions to the analog computer. A retroaction of the field on limiting conditions would then be feasible.

In any case, the conjunction of the two computer disciplines cannot but be fruitful through the changes of viewpoint that it requires of the respective specialists.

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