THE MODEL COUPLING PROBLEM: METHODS USED IN SOME BUILDING ANALYSIS TOOLS AND THE ALMETH PROPOSITIONS.

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ABSTRACT

The model coupling problem (MCP) is a general non trivial problem raised by the universal choice of modularity as a conceptual base for object programming and search for efficiency in software tools development.

Despite the apparent universality of the problem, it does not lead to a clear common formulation; on the contrary numerous "schools" of developers seem to dig gaps among the IBPSA community.

We explore in this paper the origin of the misunderstanding, and propose a tentative conceptual tool aiming towards an international comprehensive articulation of BPSA projects.

INTRODUCTION

The ALMETH* coordinated Building Performance System Analysis (BPSA) tool development is by itself an inhomogeneous community of developers, from teams close to the professional world to university research ones. We had soon to overstep a priori contradictory points of view; these starting difficulties prompted us to develop comprehensive concepts and structures, to organize the unorganized.

One non negligible result of 4 years efforts was to reach a common conceptual environment for disputes, collaborations, and developments. We give this to the IBPSA community as a tentative to reach better understanding of the numerous international efforts.

DEFINITIONS AND CONCEPTS RELATED TO MODELLING PROCESS DESCRIPTION

We shall first give a short introduction to a five layer structure [Fig. I] allowing an efficient description of the modelling process, each layer taking the name of "world", and then point out their extensions, their internal coherence and completeness, as well as their relative distinctiveness.

It is ordinarily in the **technical world** that system analysis of a particular problem is conceptualized. For instance, in a building project, this is where components, identifiers and technical questions for which an answer is sought have to be specified. We gave this layer the short name of "**Technos**" (τ), or more generally "**Phaneros**" (Φ), where the action on the factual world takes place, or where we symbolize appearances of Reality.

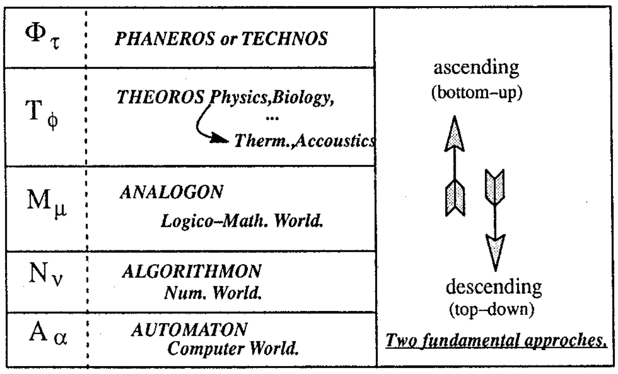

FIG. I The five layer structure.

Below this "world", we set a "**Theoros**" (**T**), a theoretical layer, which deals with Physics (φ). It is the one where models are built from a certain theoretical interpretation of the technical system. It allows formulating questions in such a way that scientific culture can bring out useful information. It is the place of formalization, where the scale of analysis has to be specified, the constitutive material laws found, etc. Thus, this layer is the one of the Greek "Physis" process.

With the mathematical layer (**M**μ), we step down to a more rigorous formalization, the benefit being, on one hand, having an access to solutions, and on the other, acquiring qualitative understanding of the processes, relations and structures involved. This world is the one of analogy and polysemy ; we name it **"Analogon"**.

For complex problems, the numerical layer (Nν) is devoted to computation methods leading to explicit numerical solutions, especially when analytic solutions are not obtainable. It is a recent fact that this being originally a sub-layer of the preceding one is now rapidly developing and becomes a very specific world, half way between mathematics and computers.

The deepest layer is the world of computing, called **"Automaton"** (**Aα**). The present tendency is to choose or even to build hardware systems dedicated to given numerical tasks (vectorised, parallelised, cellular, hypercube,... or analogic, as formal neuronal techniques).

Thus, the **descending process** (or top-down) proceeds from the technos to the production of data in the automaton. Each step downwards biases and reduces the image of the original system, simultaneously giving more and more precision and understanding. We could summarize the modelling problem as "how not to get infinite precision on a system having nothing to do with the original problem !" : any modelling is by essence a compromise.

The **ascending** (or bottom–up) approach is the reverse of what we just said : having as a base subroutines, algorithms, methods, equations knowledge, physical experience, how to choose, assemble and aggregate in order to produce pertinent information to answer technical questions ?

This 5 layer grid named **"semiological grid"** , taken in the ALMETH group as a tentative conceptual tool [LAH-87], turned out to be quite useful, and our proposition is to use it to progress substantially on the "Model Coupling Problem" [Fig. II].

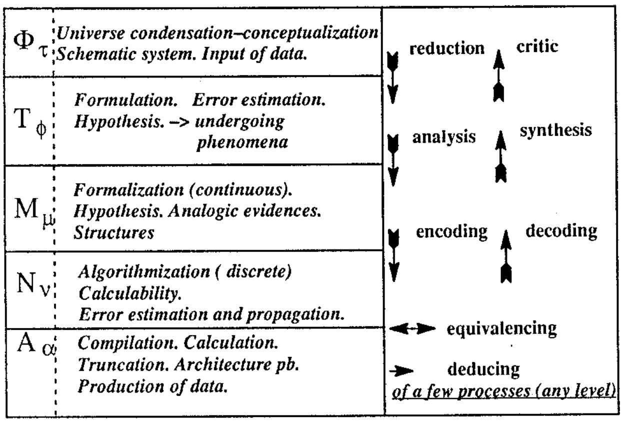

FIG. II Of some stratified operations.

THE MODEL COUPLING PROBLEM

Basically this problem arises as soon as a system is considered as made up of parts. Its general statement could be : "which procedure will allow gathering elementary knowledge in order to get a global system knowledge ?"

The ALMETH common belief is that this general problem :

i) has very different meanings among the various teams of the IBPSA community ;

ii) is the keystone to fruitful comparison between BPS analysis software tools.

"Fruitful comparison" should be understood a contrario to the 80's efforts of BPSA tools comparison, taking softwares for black boxes, and comparing results on a few building examples [KUS-81,ROU-83,DIA-86].

As a matter of fact a relevant methodological comparison should create constructive interactions and confrontations between developer points of view.

Moreover, we take as a hypothesis that each developing team is, consciously or not, being driven by some structuring meta-system, which in turn is closely related to a hierarchy of the five layer worlds. The semiotic analysis of the vocabulary, concepts, syntax, languages, generic tools chosen gives the clue to the meta-system. We will try to illustrate this through various examples, taking model coupling solutions as a guide, trying to situate some projects, and finally proposing some correspondences.

THE MCP IN THE TECHNOS

It is inherent to what is generally accepted as the "user's approach". A paradigm of this approach can be stated as in [LAR-88]: "Within a given context (...) the Building Performance Evaluation Tool has to behave ideally completely autonomous. By this we mean that the design–user must be able to "drive" the tool essentially without being aware of the underlying simulation and modelling process".

The more advanced developments consider the user as an expert, helped more or less by an expert system, playing with personal descriptions, rules, AI engines and CAD facilities, to raise more and more knowledge on its system. We believe that the "Intelligent Front End" of [RAN-87] belongs to this category.

In this view, the available simulation tools are not "on the user's black–board", are not integrated in the immediate environment, but may be called to ascertain some hypothesis or give final quantitative informations. In the ALMETH group, application of this descending approach has been explored by the CSTB, in collaboration with INRIA [DUB-90,FOR-90].

There also, an exotic coupling problem raises a hard and specific Object Oriented Language (OOL) problem in the name of "multiple inheritance", because of the relations between classes of objects giving cross specifications on coupled objects. Solutions of this has been given in [KRI-89] and [FOR-90].

The absence of correspondence between the user's system and the simulation tool raises an unsolved problem : sets of results obtained from simulation of a given system are in fact strongly coupled:

i) if the user wants to lower down some thermal leak, what will be the consequence on an HVACS performance component ...

ii) Is the precision on results of the same range ?

As a last remark, the ultimate requirement of the above described point of view is to be able to associate a calculable model to each technical component. The well known TRNSYS historical tool is an example of this.

THE MCP IN THE WORLD OF PHYSICS

In several BPSA dedicated codes, or general system-dynamics environment tools, this layer plays a leading part in the modelling process : ALLAN-NEPTUNIX [POT-88], ESP [CLA-83], SPANK [SOW-86], SYMBOL [EBE-91], ZOOM [BON-91].

As this layer has been deliberately chosen in ALMETH as the central project articulation of top-down and bottom-up developments, we started an intensive study of the physical coupling problem, reaching the necessity of a specific General Coupling Theory (GCT). As this work is under development within a European Network group [RES-90], detailed advances will be published later, and we shall here give only some major features.

Coupling methods have to restore an artificially partitioned system. This is at the heart of experimental approach and has epistemological implications. Many physical quantities are in fact essentially coupling quantities, invented to allow for a separable Universe (as forces, fluxes, ..., eventually space and time as well !).

In an ascending modelling process, coupling methods depend on the homogeneity of the nature of elementary models ; in addition of classical intrinsic models, they represent a supplemental category models,"coupling or interfacing models", of an extrinsic nature, taking often the form of static constraints.

Within an homogeneous object class, the same physical law can be used to express intrinsic model evolution as well as the coupling constraints; the most classical example being conservation law and its corollary continuity relation (that is, two different mathematical forms of the same physical law).

Coupling of models originating from different fields may require change in scale, or compound variables or even induce theoretical development [ex. : power expression to link thermal, mechanical, electrical ... processes].

But even homogeneous models may bring an impossibility of simple coupling: it is the case for simplified models, when we have for instance to interface an incompressible flow model with a compressible one [BON-89]. In aerothermodynamics, coupling of the 3 layers of the triple deck model makes use of a devoted mathematical theory, the Matched Asymptotic Expansion [MAE].

On another hand, physicists recognize the coupling characteristics to be as important as elementary models to impel system understanding. The ALMETH-ZOOM project [BON-91] has clearly taken this approach as the leading structure of development.

Another point of view may be to focus on the dynamic characteristic of the models, as in the Modal analysis (ALMETH-SYMBOL project [FLA-91]). The coupling problem translates here in how can we find the eigenmodes of coupled models knowing each de-coupled model ones, truncated or not ? (Modal Synthesis).

Deep, awkward or basic physical coupling problems are related to error analysis, model reduction, command theory, model identification among lots of others. More fundamentally, the coupling problem is central in theoretical physics efforts towards Unification.

MCP IN THE MATHEMATICAL WORLD

We already mentioned a theory developed to meet fluid mechanic model coupling, the Matched Asymptotic Expansion [MAE]. Unfortunately, these techniques do not lead so far to numerical solutions.

The general facility of getting system eigen elements offers decoupling possibilities, but then coupling of elementary model may become difficult, as for spectral methods.

More generally the construction of orthogonal basis gives mathematical ways for decoupling : transfer functions express a compound coupling between in and out vectors.

A specific field of Domain Decomposition Techniques is presently under rapid development from the numerical problems raised by large meshed systems treatment [GLO-88]. Of course, the decomposition techniques are coupling techniques as well! From the historical Schwartz coupling method, where the coupling is not associated with a specific local relation, but with relaxation minimizing some function, the recent trends are to enhance the idea of specific interface models [DOR-89] and some corresponding mathematical tools as the Trace operator, the Poincaré–Steklov operator.

MCP IN THE NUMERICAL WORLD

There we are concerned again as solver users or developers. As an example, the so efficient z–transform restricts greatly the possible coupling quantities and their dynamics, down to the in / out type of interfacing ; such a method structures deeply (and irreversibly) software tools based on linear system solvers.

For meshed system, pragmatic search for solutions – as the Schwartz technique – are still raising the need for mathematical developments, towards preconditioning techniques, functional minimization ; actually coupling constraints are de facto expressed solely by relaxation techniques.

MCP IN THE AUTOMATON

We will not insist on the fact that first generation softwares were entirely structured by the limit of computers, so that the technos was restricted to the set of modelizable components, and the models to their simplest linear expression.

This has completely changed, and this layer is the most concept, language, and even "philosophy" creative. And the danger is high to take "computer world solutions, still ignoring the problem !".

Such concepts as OOL, AI, Actors, Messages, Cells are often semantically rich, and may lead to poor practice if not carefully used. We will leave here more computer science coupling problems as synchronization, distributed computing power, etc., to take the example of Actor and Message way of programming elementary models.

An interface process consists then of sending-receiving a message, and reacting to it. If it gives an elegant way to build distributed algorithms, it does not specify what is the nature of the coupling problem. [SEN-89] and [EBE-91] give an example of the potentialities of this programing method.

We will arbitrarily retain from this layer the coupling problem raised from the modularity concept in the form of re-usability of pieces of software. This idea leads to various concepts :

- to the specification of objects from classes, hierarchy and OOL
- to the genericity of software tools
- to integrable standard (and flexible) packages
- to library concepts

TRNSYS EXAMPLE

The well known and used TRNSYS simulation tool may be used to illustrate what we mean by "situation on the grid":

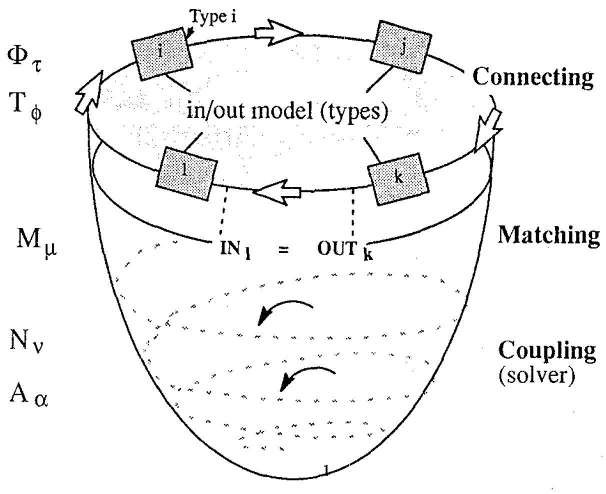

FIG. III Matching and Coupling in TRNSYS.

- Components in TRNSYS. Model type components refers to the technos : solar-collectors, pipes, storage...
- Model description. A Users' Manual describes the physical hypothesis and the calculus. The models are written directly in Fortran, a model corresponding to a subroutine.
- Linking the component. By connecting scalar physical quantities as in and out going variables. The out going variable sensitivity to the input variable is implicit.
- Coupling. Connections are translated in mathematical matching [Fig. III]. The coupling is in fact obtained from a relaxation loop on the global system. Thus, the coupling model is partially within the component out/in sensitivity and in the solving process. Nevertheless, the Jacobian matrix seals some coupling information, not currently used by users.

In conclusion, there is no transparent correspondences between the 5 layers, but a mixing of concepts between them and processes. The absence of specific interfacing models restrains coupling to very simple ones, coherently with the "component" appellation of models.

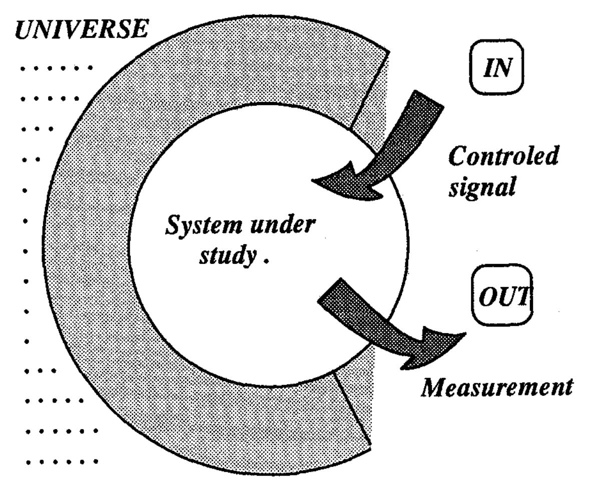

FIG. IV A prepared Experimentation.

USING AN EXPERIMENTAL PROCESS AS AN ALTERNATIVE ILLUSTRATION

Experiment design and analysis is another instance where the coherence between modelling, level of problem analysis and relevance of expected results plays an important role [DUF-90].

First it should be noted that the concepts of coupled and decoupled objects are the very basis of experiment design. As a matter of fact, the purpose of experiment is, after identification of a part of the universe as having some intrinsic characteristics, (i) to decouple this part from environment, by boundary condition control (Preparation); (ii) to study its response to controlled or measured input quantities (Measurement)[Fig. IV].

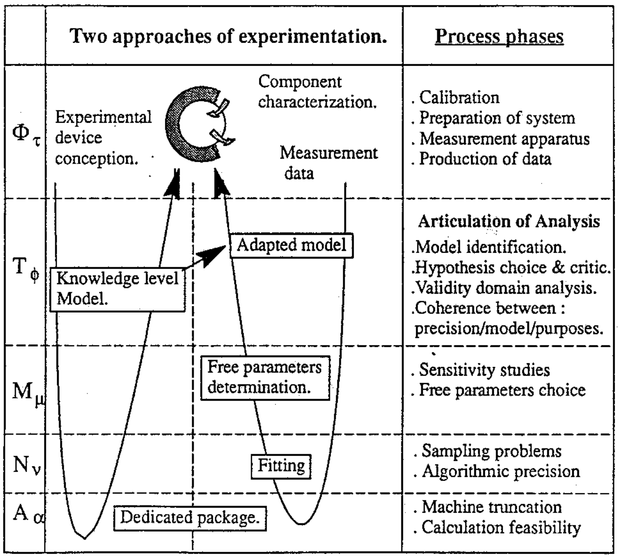

FIG. V Of some operations along an experimental process.

Then we may proceed to the stemological characterization of the experimental process. It appears that the physics layer plays a leading part. This is the world were problems are stated, as physical questions (or translated into physical questions) : hence it is the start point of an ascending way toward experimental system design. It is also the start point of a descending movement toward model design and experiment analysis for which it yields intelligence of the system and of the measurement devices. As illustrated in the table of Fig. V, lots of to and fro processes within the 5 layer grid are involved.

The conclusion that may be drawn from this example is three fold: (i) the world layer structure is a useful framework for the experimental process description as well as for the modelling process ; (ii) the coupling concept applies both to the technical world (experiment design) and to the physics world; (iii) Each layer contributes with its own particularities to the overall process.

EMERGENCE OF SYSTEMIC CONCEPTS FROM BPSA TOOLS

We shall call systemic what has good correspondences in different worlds of our grid.

They will appear from a comparison table (Fig. VI) of MCP specific layers position.

Some concepts are easily drawn from the correspondences:

. Objects :

Intrinsic versus extrinsic

(Components, cells...) . (Coupling constraints, transfers...)

Let us mention that the creation of elementary objects from the technos is not evidently self–consistent : a counter example is the well known Young two-slit, for which a two elements model does not lead to a pertinent physics decomposition...

. Coupling – Connecting – Matching

The in/out type of connection is the most often met : in the technical world, it corresponds to mechanical or electrical connections supporting matter, energy or information transports. In the opposite layer (automaton), it is now the rule in recent languages to use exclusively in and out variables, whereas the old FORTRAN was using common variables.

This way of connecting has a clear correspondence in Physics for propagation phenomena ; as a matter of fact, it has been systematically enhanced by the bond graph modelling approach.

The in/out connecting is indeed a very particular coupling scheme corresponding to component–based systems, whereas common physics situations exhibit strongly coupled distributed interactions. Thus, the wider term coupling will be retained as the systemic term; connecting could then be defined as "putting in relation" and relationing as "giving the coupling constraints" ; matching is then a particular mathematical relationing in which coupling takes the shape of equality between connected variables.

More generally, "coupling" includes the connected object modifications induced by the coupling process.

	Φτ	Tϕ	Mμ	Nν	Aα
PARTITIONING	Genericity of technical objects. Experimental decoupling.	Separability. Choice of canonical forms. (decoupling variables choice)	Variable separation. Eigen values and eigen vectors. Domain Decomposition Methods.	Schwarz and pragmatic techniques of Domain Decomposition.	Modularity, re–usability. Object oriented programming. Actors programming
RELATIONING	Components linking. Complex coupling.	Physical problems of coupling and interfacing. –> Physical homogeneity of objects.	Specific interfaces operators: Trace and Poincare–Steklov operators.	Inter–boundary domain constraints.	Multiple inheritances . Message programming.
METHODOLOGIES	Divide and conquer.	Nesting of decomposition. "Divide and couple".	Matching Nested factorization of Matrices. Tree structures of partitioning. Graphic analysis.	Preconditioning. Relaxation methods.	Computers architectures Nodal,cellular,parallelized...

FIG. VI Model Coupling Problem correspondences.

. Nesting

If the term "system" entails partitioning and relationing, the intuitive recursivity of this process leads us to propose "nesting" as a systemic one. It is associated to questions of the User at different levels of zooming on the problem. Thus, to have any chance of answering without bias or opacity, the recursive partition structure should have a correspondence in each layer. Machine parallelization opens already this possibility down to the automaton [CHA-89]. (Of course, this increases the MCP because the component driven tree partition is broken with transverse links, and dual transfer–oriented structures have to be explored as well).

FINAL CONCLUSIONS

For BPSA project developers, the 5 layer grid should allow a better definition of fundamental choices and point out the implicit ones.

Moreover, since the systemic approach exhibits concepts relevant in all world layers, it should allow each BPSA developer :

(i) to draw from his project, once positioned in the grid, the main concepts or new ideas to be developed.

(ii) to integrate systemic concepts in his project.

As far as multi-lab collaboration is concerned, the grid should :

(i) induce more intense exchanges at the project development level instead of limited exchanges at the final stage of result production.

(ii) create a strong link between bottom-up and top-down approaches, which would avoid sterile disputes about subjects such as the relative importance of experimentation and modelling

* ALMETH: "Atelier Logiciel pour la Modélisation Energétique et Thermique de l'Habitat"; French national coordinative club sponsored by the A.F.M.E. (French Agency for Energy Conservation), which gather developers of BPSA codes and, more recently, modelling environment tools designers.

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