COMMUNICATION DISCIPLINES

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This lecture will be addressed to problems of a conceptual nature, all of which we constantly have to deal with in the context of computer usage. In my opinion it is very necessary to attack such problems in two directions simultaneously. Firstly we must collect the advice of the best professional workers in the field and act upon it, advice such as which is useful in guiding and structuring our thinking about the solving of today's tasks; and secondly to begin now to develop solid conceptual foundations and theories in the style of the exact sciences, the results of which would then be available for the use of the next generation and the solving of the tasks of tomorrow. Immediately, of course, comes the question: theories about what? It is clear that practical experience alone cannot tell us what should be the subject matter of such theories. We need, in addition, the highest level of today's 'philosophical' outlook on the historical development in order that we might appreciate what computers are good for.

And if someone says, 'well, computers are good for computing,' then my answer would be that they can do far more than computing (and that the question still stands: What is computing good for?). I shall be concentrating my attention on the upper levels of Figure 7 of my lectures, namely that of problems concerning human society and human organisation. By no means should this subject be considered to be exclusively concerned with computer science.

In answering the question, I shall first present a strictly subjective view of the position of computers in our social and technological system. According to this view computer technology supplies us not with a medium for artificial intelligence nor with

a machine which may be used solely for computation but with a medium for communication and for strictly organised information flow, a medium which may induce major changes in the modalities of co-operation between human beings. I also believe that these changes will be beneficial only if our understanding of the new medium of the computer in terms of communication is substantially increased. To promote this understanding I have tried to categorise a list of problems which have presented themselves to me; I would like to propose twelve disciplines of computer-mediated communication. These disciplines may be thought of as exactly those functions of the communications media which, apart from conventional functions such as information storage, transmission and message dissemination, are capable of strict formalisation.

First, however, let me say more about my opinion as to the role of the computer. There has been a development of such opinions varying from extreme to extreme but in my view converging to a certain point (Figure 1). In the beginning, the computer was considered merely as a fast, automatic and reliable calculator. A counter-movement heaved it up into heaven by hailing the computer as eventually being capable of surpassing every human in intelligence and of evolving a self-subsisting type of super-intelligence. There was then a violent reaction to that, in which the computer was considered as a mere tool in the hand of its user although capable of more than just computing. After the introduction of on-line computing, the computer was thought of as mainly a partner in communication. In my opinion this is still an overestimation; the computer cannot do certain things that we expect our human partners to be capable of doing, such as taking responsibility. People recognising this developed the notion of the computer as a generalised communication medium, that is a communication medium in the conventional sense but with a few extra facilities and functions.

Extrapolating from this development, it is my guess that in the long run the computer will be seen as a general medium for strictly organised information flow.

THE ROLE OF THE COMPUTER

"Convergence" of opinions on its potential

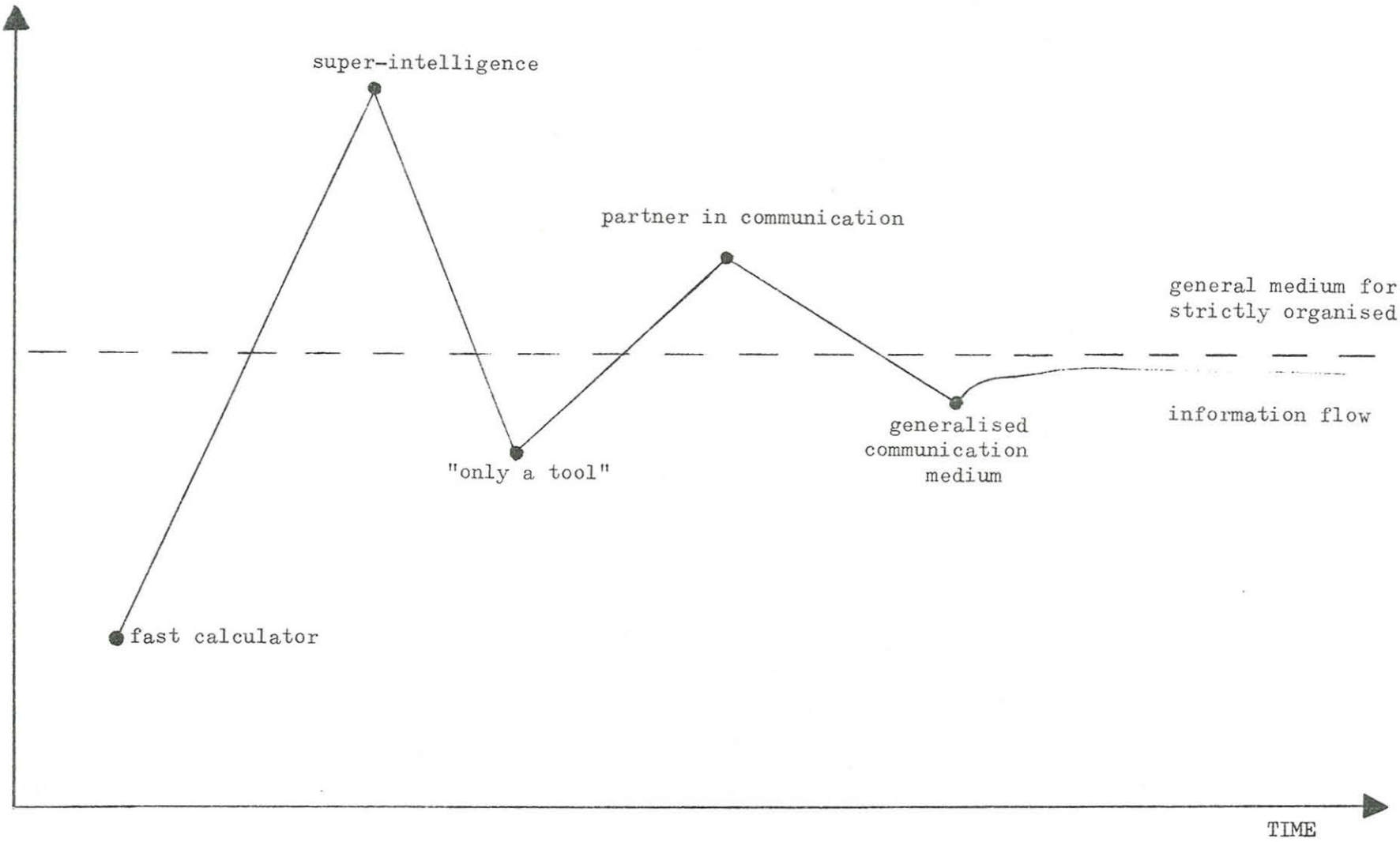

Figure 1

All these ideas would be mere opinions, and technically useless, were it not that we can observe different kinds of activity, mainly isolated from each other, each of which is based on one of these views. The great intellectual effort to investigate the limitations of computability stems from the viewpoint that the computer is good for computing. If, on the other hand, somebody considers the computer as a medium capable of evolving some high kind of intelligence then he is likely to put his money into projects concerning artificial intelligence. The currently existing large body of down-to-earth software is based on the idea of the computer as a tool. I don't wish to say that all these standpoints are wrong; rather, they evolved and have all existed historically. If you consider the computer a generalised communications medium you will quite likely have to develop new software ideas and to construct quite a different kind of hardware. I am glad, however, to observe that most hardware and software in use is constructed below the 'line of convergence' of Figure 1; that is, on the safe side, in terms of raised expectations.

Having thus established the role of the computer, I shall now go on to try and determine the functions of a generalised medium of communication. First let us state the functions of the conventional media of communications which are transmission, storage and dissemination of messages. We are interested in the additional functions of a generalised medium.

One approach would be to add some new functions in order merely to be able to include conventional computers in the resulting notion of a generalised communications medium. These functions would be calculation (which is something that cannot be readily expressed in terms (mere transmission etc.) of messages) and ordering (for example sorting). Apart from specifying these additional functions we would also have to concoct criteria which would allow us to define the 'good-ness' of the medium; namely that it performs its functions quickly, reliably and at low cost. At this point we realise that this approach is rather trivial and is going to get us nowhere; and

accordingly I abandoned it and took another direction instead.

In this second approach I tried to classify practical problems from my long list, according to my stated viewpoints of the role of the computer. I call the classes into which the problems could be divided communications disciplines and I wish to use the word 'discipline' in both its senses; that of 'subarea of the same science' and 'restraint of behaviour'. These are the areas upon which we should concentrate our attention in order to put restraints on communication so that the latter be successful. I shall now shortly describe them.

1. Synchronisation: this discipline is concerned with getting proper timing restraints for different activities. In some cases, the use of clocks may serve for synchronising all activities. But what should we generally understand by the term 'synchronisation'? My answer is that the precise definition of the term should be based upon the partial ordering in terms of causality as opposed to an ordering in terms of time. On this basis a theory of synchrony has been developed which is, in my opinion, fairly completed.

2. Identification: this discipline is concerned with well-known questions such as: "identify the sources of a letter" or: "identify a firm's name given its customer number". Thus, we speak of an identification process which must take place if a message is received from outside. In general, this involves demonstrating the identity of the source or the destination of phenomena down to the mere technical details. For example, the question whether an electrical potential corresponds to a given value, has a non-trivial part of this discipline. This discipline covers the question of pattern recognition as well as problems of proving the competence of agencies with regard to certain actions.

3. Copying: this should be regarded as a separate discipline because here we are not dealing with messages in abstracto but message-occurrences within a definite pragmatic context. therefore from now

on I prefer to speak of documents instead of messages. For example, you can easily copy data without affecting their formal content but you cannot copy a banknote without affecting its pragmatic context. Thus, it is not really the bit pattern or arrangement of characters on the banknote but rather the special quality of the banknote within a legal context which cannot be copied. Documents are supposed to flow through a net of agencies and channels and it is an attribute of each document on which channel it resides. Referring to net theory, we might make use of its basic concepts so that documents may be thought of as being used by agencies and transmitted through channels and that usage consists of handling documents (and not abstract information or data) by an agency. Then I contend that the low-level concepts of concession, contact, conflict and confusion have a definite meaning even on the highest level of human interests and organisations if we 'add' pragmatics.

In support of the idea that copying is a discipline that must be observed rather than a mere technological problem I would add that since only specific offices are permitted to copy certain documents it follows that in order to do so they must obey certain rules. It also follows that we need a discipline of authorisation as well. The reason for introducing this discipline is, of course, a practical necessity in banking, administration and so on.

4. Addressing: by this we mean the description of routes or systems of paths through a net of channels and agencies. An organisational unit or the result of an act of organising something may be represented as a net of agencies connected by channels and communicating through them. At first glance, addressing seems unproblematic but stating necessary and sufficient conditions for proper addressing is not altogether simple.

5. Naming: here, this is conceived as the act of giving names, and will be subject to a discipline because not everybody may arbitrarily name entitities, not everyone may distribute customer numbers or personal identifiers. Naming is understood as denoting objects and

structures by parts of documents. A typical question would be: how can we understand the incompatible naming of files in different computer systems as consequences of only one naming discipline? Another question that belongs to this discipline is: exactly how much freedom exists when names are given? The question arises: how is the scope of names related to the notion of a channel?

6. Cancellation: initially this notice has its customary meaning: the cancellation of an order. This means, that sometimes two documents multiply each others effects. We must regulate cancellation globally if it is to take place in a coherent whole and is to achieve the results expected. There is a difference, however, between regulations for error corrections and regulations for the case that an agency 'changes its mind'. If somebody has ordered something but needs it no longer or considers it more worthwhile to order it somewhere else, then he must cancel his order. Then one may ask: What is the difference between an error correction and the cancellation just described? Another question arises in this context, namely if we should send the cancelling message after the original document or if we should send it along the causal chain in the opposite direction such that it will somewhere encounter the original document and cancel it. In the latter case we must ensure a priori that all documents run along cyclic structures, that is that their effects return to the author, and we must ensure that there is a path along which a document can be sent to meet the original one. In the former case, however, we do not need this knowledge about the channel structure but we must ensure somehow that the new message will reach the old one sometime.

7. Composition: this discipline is concerned with determining the structure of documents relative to a material or conceptual carrier. It has been most intensively studied for a protracted period in computer science; unfortunately only the sufficiency, not the necessity of formatting or composing documents has been investigated. Is it necessary at all that there be a fixed format? Where do criteria

for this necessity for determination come from? The following topic has also been disregarded: there is a close connection between the design of data structures and messages on the one hand and modelling as a whole on the other.

8. Modelling: most of the people I have spoken to do not even realise that there can be something like a discipline of modelling. Two advances have been made in this area: we are able to talk in a more precise way about documents containing measurement data; and we are able to deal with mathematical models in which the notion of a temporal ordering is replaced by that of an ordering in terms of causality. These latter models enable us to describe or specify many important parts of a system structure without requiring an ability to measure or to prescribe precise time intervals. Here, modelling appears as a discipline of its own since communicative media must be constructed in such a way that they reflect or model part of their environment according to their purpose. Are there any general schemata for doing so? Modelling is done according to a scheme which normally has come into existence through a historical process running independently of conscious methodical technology. The results of these processes, our 'models of thinking', tend to gain some illegitimate independence once they have proved successful on a particular field, and are then - per analogy but without care - transferred to other fields.

9. Authorisation: this discipline is concerned not only with assigning and schematically representing access rights but also with scheduling obligations which are consistently connected with access rights and authorisations for issuing directives, and with the rules for an adequate basis of supervision. The question is: where do the principles stem from? In this area, distinct groups usually talk and judge in totally different ways; for example, it appears as though legal or ethical restrictions on the one hand and economic-technological restrictions on the other hand were entirely different things. There is, of course, another way of viewing these two aspects (legal or ethical restirctions and technical control), namely as something

closely related or even ultimately the same. This way of thinking, however, is implausible in my opinion. It would imply, within the frame of the application of such theoretical considerations, that the distinction between personal and non-personal agencies will continue to retain its full significance.

10. Valuation: this discipline is perhaps the most important one since we know least about it, compared with others. How can we grasp such a discipline? Isn't it a fact that the precise nature of the relation between information and its value is not yet established? The theory of preferences does not apply here; if a piece of information is presented to an observer and he is asked to attach a value to the information, the question becomes meaningless because at the instant the information is registered by the observer it already looses its value because it may not be presented anew.

The mathematical theory to be developed starts with the notion of resource; under this notion the theory comprises many different things, including things which no-one would normally call 'resources'. Resource is everything which may become scarce. Because of this scarcity, projected measures may not be carried out, or, conversely, deliberately imposed scarcity would imply restrictions for organisations. A theory in this area must treat the exchangability of resources and its modalities. If one sees the discipline of valuation from this standpoint one rapidly obtains a basis and mathematical starting point which I cannot show in detail here. As has been said, this theory starts with the forms of usage of resources.

11. Delegation: this means the delegation of tasks from one agency to another one, for example by programming from a personal to a non-personal agency. A main thing to note is that delegation must be viewed as a continuously running process although the low frequency of this process suggests that one would tend to speak of singly delegated measures only. If somebody delegates something, this has, of course, formally comprehensible consequences for synchronisation, addressing and other disciplines.

12. Finally I would like to mention the discipline of Re-organisation and give a low-level example of the use of such a discipline. Suppose you have a system of pipes and tubes in a chemical factory and that you wish to attach a new tube to the system. A specification that a certain subset of valves must be closed in order to cut off flow from the part of the system that is being altered is inadequate; it must also be specified that while the new tube is being fitted the valves must remain under control in order that nobody can open them, that is, that no other independent activity be allowed to interfere disastrously. (As a court of law recently stated, this discipline is not being observed in all nuclear power plants.)

I will conclude my lecture by presenting a small piece of theory. which is being used in transforming the verbal descriptions of Communication Disciplines into mathematical theories. Many of the results in formal pragmatics are based upon a distinction rooted in the level of information flow graphs (see Figure 7). There are two types of information flow, one being covariant and the other being invariant with respect to time reversal. The following simple example will make this clear: imagine a cine-film featuring a father and his son. The film shows the father drinking a glass of beer and then spanking his son. If we let the picture run backwards we are witness to the unpleasant sight of beer flowing from the father's mouth into the glass (this flow is covariant; it is tied up with the direction of time) but we will still see the blows 'flowing' from father to son. This corresponds to an invariant flow of information.

The distinction may be traced down below the level of switching logic; the simplest strictly formal example is shown in Figure 2. (See also Figure 11 of the previous talk and its accompanying text.) The agency in Figure 2(a) can be viewed as a switching element taking as input the bits A and B and outputting a copy of A and the 'exclusive or', $A \oplus B$, of A and B: if we reverse the horizontal flow arrows, A and B can be computed from the outputs (now inputs) A and $A \oplus B$. Informally speaking, A and B give rise to a 'horizontal A-flow' and a

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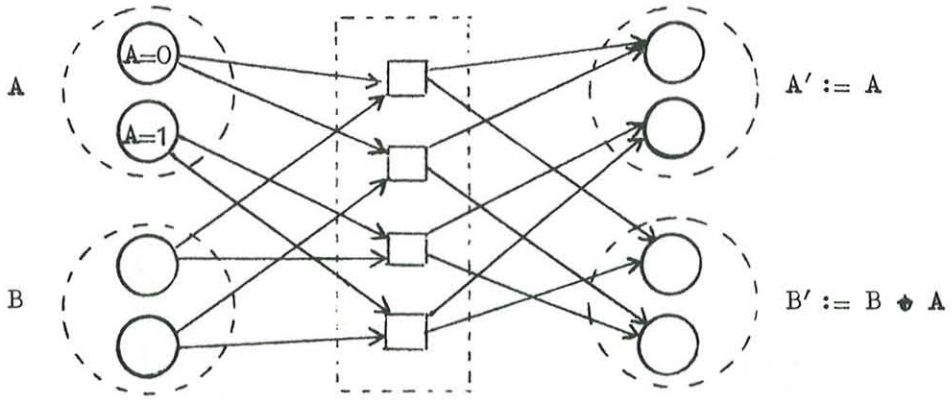

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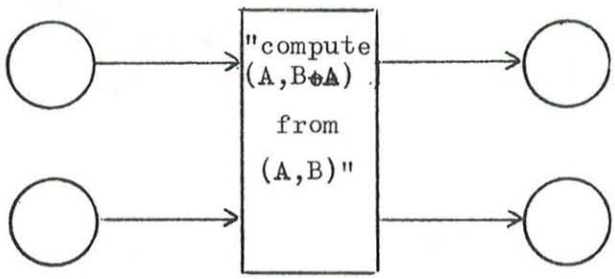

new notation for activity defined above:

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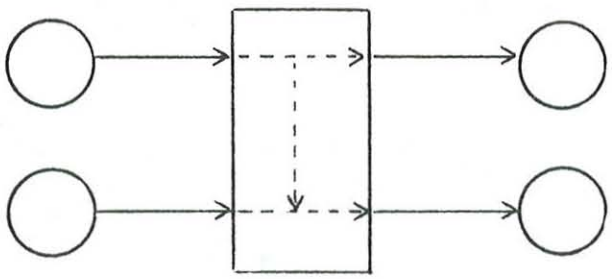


abstracted notation for information flow:

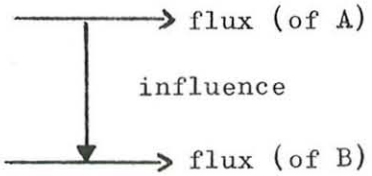
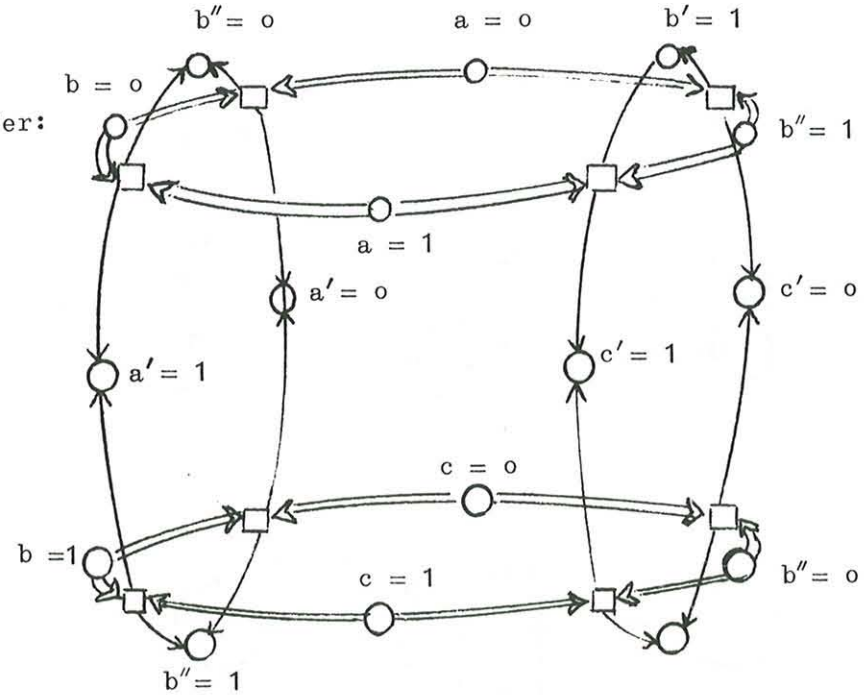


Figure 2

CONSTRUCTION OF QUINE TRANSFER Figure 3

Quine transfer:



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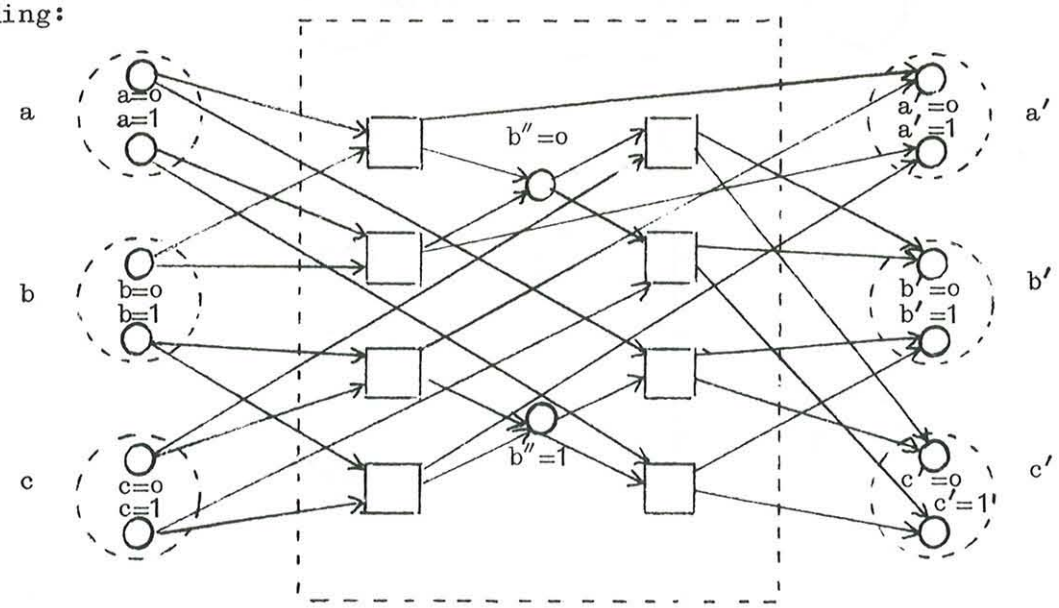

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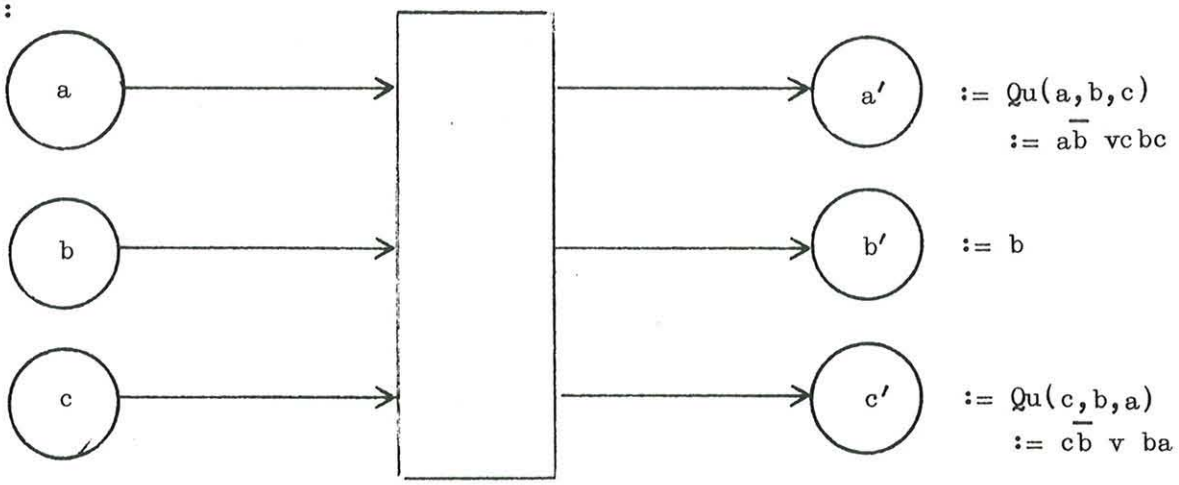

'horizontal B-flow' and in addition the A-flow affects the B-flow 'vertically' (Figure 2(b)). The vertical flow denotes that B may be replaced by its opposite value depending upon the value of A. The horizontal flows are time-reversal-covariant while the vertical flow is time-reversal-invariant with respect to the above recomputing of the inputs from the outputs, since $B = A \oplus (A \oplus B)$. I call time-reversal-invariant information flow influence and time-reversal-covariant information flow flux.

We specify this little piece of 'hardware' by drawing a condition-event net, thereby tracing the distinction down to lower levels; and if we can show that there are elements of this type which are sufficient to compose all kinds of switching functions then we have shown that in fact all information flow is comprised of a time-reversal-covariant part and a time-reversal-invariant part.

There is in fact a single switching element into which all switching functions can be decomposed, the Quine-transfer, in which there is both flux and influence. The condition-event net for this transfer is shown in Figure 3; as you can see it has a high geometrical symmetry. Thus one might guess that the distinction between flux and influence has something fundamental to do with the structure of time and space. If we want more than a guess, we can take a look at the axiom system for relativistic space-time set up by Robb, Reichenbach and Russell fifty years ago; this describes the structure of event-occurrences. We replace here the axiom that events lie dense in time, by the axiom that events are separated by conditions; this replacement yields an axiom system for occurrence nets, from which every construction used in my lectures can be derived by net mappings.