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INFORMATION STRUCTURES IN DECISIONMAKING ORGANIZATIONS*

by

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ABSTRACT

Analytical models of teams of well-trained human decisionmakers executing well-defined information-processing and decisionmaking tasks require the precise specifications of the information structures of the organization and the associated protocols. In larger organizations, especially decentralized ones, the assumption of a high degree of synchronization is not realistic. Thus, it has become necessary to develop a methodology for characterizing and analyzing asynchronous processing of subtasks within the organization. Data flow concepts from computer science are introduced to describe in a precise analytical manner the protocols of the interactions between the organization members.

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I. Introduction

Information processing and decisionmaking organizations are designed and formed because the given task or tasks to be performed exceed the capabilities of a single decisionmaker. In designing an organizational structure for a team of decisionmakers, two interrelated issues must resolved: who receives what information and who is assigned to carry out which decisions. The resolution of these issues must be made so that the organization can accomplish its task with minimal delay and without overloading any of its members by exceeding their individual processing limitations.

A command and control organization and the C^3 system which supports it is an example of a structure designed to accomplish a complex decisionmaking task. Information is collected from many sources, distributed to appropriate units in the organization, and used by commanders and their staff to make decisions. These decisions are in turn passed to the respective units responsible for carrying them out, some of which are the same units which have collected and forwarded the original data. In addition, the inherent nature of a tactical situation, i.e. a fast tempo of operations, requires that the C^3 organization accomplish its task in a timely manner.

A basic model of an interacting decisionmaker, appropriate for the study of command and control organizations, was introduced by Boettcher and Levis [1]. Subsequent work [2]-[4] has considered the modeling of organizations consisting of several decisionmakers who form a team, and the evaluation of alternative organizational structures. In this paper, emphasis is placed on the modeling of information structures in an organization, including the protocols for information exchange. In the sections which follow, the basic structure of the interacting DM model is briefly reviewed. Next the problem of modeling the flow of information is considered and a representation using Petri-net [5] and data-flow [6],[7] concepts is introduced which explicitly models the information exchange in the organizations being considered. An organizational structure previously analyzed is re-examined using the data-flow representation and the usefulness of the framework for the analysis of information structures more general than those previously considered is discussed.

II. Model Structure

The overall decisionmaking process of an interacting organization member is modeled as shown in Figure 1 [1]. In general, each decisionmaker receives

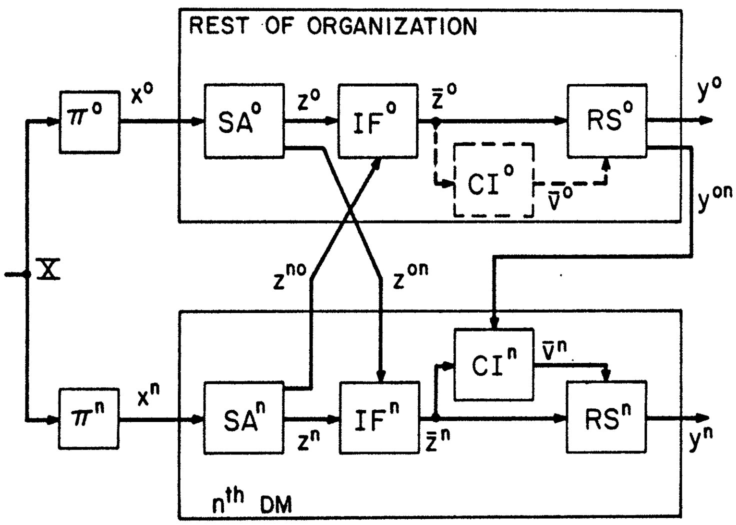

Figure 1. Structure of interacting decisionmaker model of the n^{th} organization member.

a measurement x^n of his environment and processes it in the situation assessment (SA) stage to obtain z^n. Next, supplementary situation data received from the rest of the organization (z^{on}) is incorporated in an information fusion (IF) processing stage. Based on the resulting final assessment $\bar{z}^n$, a decision response is determined in the response selection (RS) stage. The possibility of receiving commands from other organization members is modeled by the variable v^{on} and a command interpretation (CI) stage of processing is necessary to combine $\bar{z}^n$ and v^{on} to arrive at the choice ($\bar{v}^n$) of the appropriate procedure to use in the RS stage.

The analytical framework used to describe the processing within an organization member is that of n-dimensional information theory [8]. The probabilistic characteristics of the inputs to organization members, together with internal choices made in the SA and CI stages induce distributions on the internal variables within each stage of processing. Total activity is defined as the sum of the marginal uncertainty (entropy) of each internal variable and is taken as a measure of the DM's workload. Complementary to individual workload is organizational performance. Corresponding to each input to the organization there is assumed to be a desired response. By comparing the actual response with the desired one and assigning a performance value, a measure on the overall performance can be obtained by averaging over the input ensemble.

The emphasis in previous work [2]-[4] has been the analysis and construction of performance-workload relationships, and the evaluation of organizational structures using measures derived from these quantities. Specification of a structure includes the determination of procedures, or algorithms, that individual members will use to accomplish their respective tasks (the problem of who is assigned to carry out which decisions and how). However, the second aspect of the structure which must be specified is the sequence of task execution within the organization, that is, the protocols for information exchange among members (the problem of who receives what information, from whom, and when). It is the latter aspect which is the subject of the next section.

III. Information Structures

Properties

The information structure of an organization includes the partition of the organization input for distribution among members. It has been shown that the general case can be described using a single source and sets of partitioning matrices [9]. A second element of the information structure is the specification of what information is to be passed among individual members as the organizational task is performed. Finally, it is necessary to specify exactly the sequence of processing events implied by the structure so that both information processing and exchange are well-defined for the execution of the organization's task. This sequence refers to the standard operating procedure (SOP) or execution and communication protocol of the organization.

For the class of organizations considered, several properties are inherent in the information structures which can be modeled. One such property is that of synchronization. Inputs are assumed to arrive at a fixed average rate of one every τ units of time, and the organization is constrained to produce outputs at the same average rate. Since the overall response is made up in general of the responses of several members, each member is assumed to complete the processing corresponding to a particular input at the same average rate.

Within this overall rate synchronization, however, processing of a specific input symbol or vector takes place in an asynchronous manner. If the requisite inputs for a particular stage of processing are present, then processing can begin without regard to any other stage, which implies that concurrent processing is present. For example, as soon as the organization input arrives and is partitioned through π^n, SA^n begins processing x^n to obtain z^n; similarly, the determination of z^{on} from x^o is begun. The IF^n stage must wait, however until both the z^n and z^{on} values are present. Each stage of processing is thus event-driven; a well-defined sequence of events is therefore an essential element of the model specification.

Another property of the information structures being considered is that they are acyclic, i.e. their graphs have no loops. This requirement is made to avoid deadlock, the condition which exists when one decisionmaker is waiting for the result of another who is in turn waiting for the result from the first.

Representation

The system theoretic (block diagram) representation of the model (Figure 1) is particularly useful for showing the various processing stages or subsystems. (More detailed block diagrams have been used for the SA and RS stages which delineate individual procedures [1].) Evaluation of the various information theoretic quantities, including total activity, is also conveniently accomplished along subsystem lines using the decomposition property of the mathematical framework [8]. However, except for the partition of the organization input, the information structure of the organization is not clearly represented in block diagram terms. For example, it was stated earlier that both z^n and z^{on} must be present before IF^n processing can begin. This is not apparent from Figure 1. An alternate representation will now be discussed which explicitly shows the information structure without compromising the usefulness of the information theoretic decomposition property.

Petri-nets have been developed as a model of information flow, and are particularly useful for systems with asynchronous, concurrent processing activities [5]. Three basic elements are used in their structure: places, transitions, and directed arcs which connect the two. In general, places and transitions represent conditions and events, respectively. No event occurs unless the requisite conditions are met, but the occurrence of an event gives rise to new conditions. Tokens are used to mark which conditions are in effect; when all input places to (conditions for) a transition contain a token (are satisfied), then the event can occur, which in turn results in the generation of tokens for output places.

The data-flow schema [6],[7] modifies the basic Petri-net formalism so that tokens are carriers of data. Each transition is then a processor which generates a result from the input data and deposits it on an output token, which then moves according to the schema's structure along a directed arc to the next stage of processing. Thus, the data-flow schema is a model of asynchronous, concurrent processing structures.

To represent the information theoretic decisionmaking model using a data-flow formalism, a simple translation in structure is made: distinct inputs and outputs of each subsystem are assigned places and the processing within a subsystem is represented by a transition. Associated with each transition is the set of internal variables of the subsystem, exclusive of the input variables, which are accounted for separately by the input places. By assuming a probability distribution on the organization's inputs, distributions are also induced on the places in the structure. Therefore, distributions are also present on subsystem variables, and all information theoretic quantities are well-defined and can be computed as before.

Example and Discussion

To illustrate the approach, an organization structure previously analyzed [2] has been represented in data-flow terms and is shown in Figure 2. In addition to places, transitions, and directed arcs, the structure con-

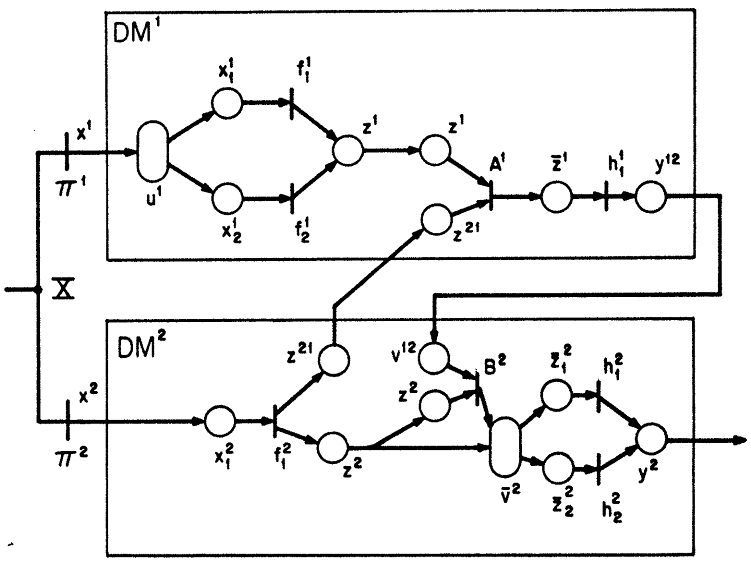

Figure 2. Data-flow representaion of organization structure.

tains two new elements, the switches u^1 and $\bar{v}^2$. These are logical elements which direct the flow of tokens. The switch u^1 takes values independently while the value of $\bar{v}^2$ is determined as a result of the processing by algorithm B^2 contained in CI^2. The structure shown in Figure 2 is equivalent to the system theoretic structure in [2]. Thus the internal variable definition and all information theoretic quantities remain unchanged. However, Figure 2 makes explicit the information structure of the organization. Once an input X is partitioned, the processing by each DM in his respective SA stage (algorithms f) begins concurrently and asynchronously. The information fusion processing (algorithm A^1) must wait until both z^1 and z^{21} have arrived at the input places of IF^1. Similarly, DM^2 must wait until DM^1 issues a command input v^{12} before the process of command interpretation can begin. This sequence of processing is evident from the representation. Note that because of the synchronization assumed with respect to organization inputs (τ), there can be at most one data token in any single place. In Petri-net terminology, such a structure is called a safe net. Finally, the structure is obviously acyclical and deadlock in the organization is prevented.

While the data-flow framework described above is an equivalent representation of the class of information structures modeled previously, it is also able to model more general structures, many of which are of interest in the context of organizations. For example, the framework can easily model the cyclic structures which arise when a two-way exchange of information is present in an organization. Such SOP's are, of course, common. In addition, fully asynchronous structures can be represented within the framework. Since it is not always the case that all the organization's members operate at the same rate (same tempo), asynchronous processing is of interest in this context, also. The study of these structures and their implications in terms of the n-dimensional information theoretic framework are subjects of current research.

IV. Summary

This paper has discussed several aspects and issues relating to the explicit analytical modeling of information structures of organizations. A representation which has been introduced using data-flow concepts and the previously used system-theoretic representation has been translated to the alternate formalism as illustrated by example. The ability to model more general structures using the data flow framework has been discussed, expecially those of interest from the viewpoint of organization analysis and design.

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