Control and Command Systems Concepts from Early Work on a Mars Rover

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Abstract. We recover and develop some robotic systems concepts (on the light of present systems tools) that were originated for an intended Mars Rover in the sixties of the last century at the Instrumentation Laboratory of MIT, where one of the authors was involved.

The basic concepts came from the specifications for a type of generalized robot inspired in the structure of the vertebrate nervous systems, where the decision system was based in the structure and function of the Reticular Formation (RF).

The vertebrate RF is supposed to commit the whole organism to one among various modes of behavior, so taking the decisions about the present overall task. That is, it is a kind of control and command system.

In this concepts updating, the basic idea is that the RF comprises a set of computing units such that each computing module receives information only from a reduced part of the overall, little processed sensory inputs. Each computing unit is capable of both general diagnostics about overall input situations and of specialized diagnostics according to the values of a concrete subset of the input lines.

Slave systems to this command and control computer, there are the sensors, the representations of external environment, structures for modeling and planning and finally, the effectors acting in the external world.

1 Introduction and a General Structure

A research and development program being carried out at the Instrumentation Laboratory of MIT in the sixties, under the leadership of Louis Sutro [1–3], aimed at the communication of pictorial data from remote locations and to develop methods of making fast and appropriate decisions there. Both general aims were to be obtained by the use of biology as a source of ideas. Warren McCulloch, then a member of the group [4, 5], had concluded from his life-long study of the human nervous system that the essential properties of human computation must serve as the basis of the corresponding artificial systems. Although he was aware of the dangers involved in embodying mental functions in physical

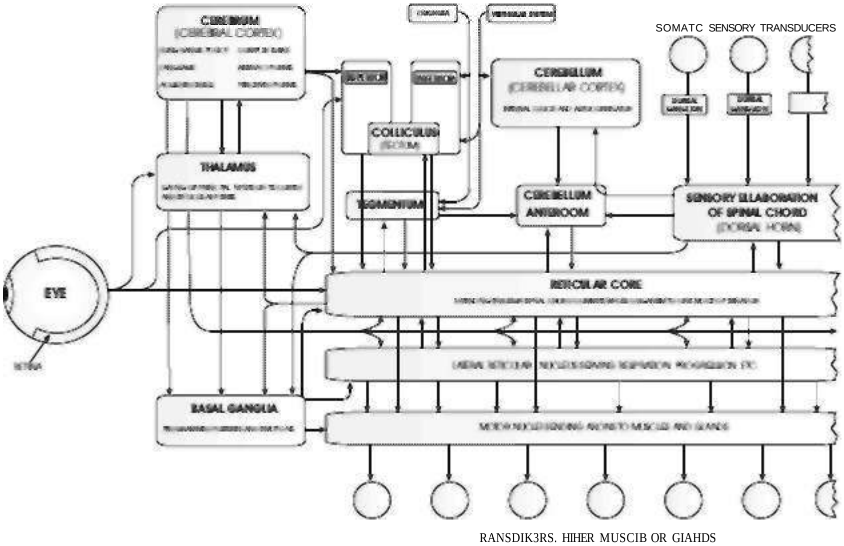

Fig. 1. Block diagram of generalized vertebrate nervous system

devices, he developed a simplified model of the vertebrate brain. His intention was merely to suggest an organizational hierarchy necessary for robot performance. Figure 1 is an outline of the model, where five principal computational areas and their connections are identified: the retina, the cerebrum, the reticular core, basal ganglia and cerebellum.

A diagram of a possible engineering equivalent, proposed by Louis Sutro, is shown in figure 2, where the equivalent substitutions beside the sensors are as follows: decision computer for reticular core; associative computer for cerebral cortex; timing, coordinating and autocorrelating computer for cerebellum; computer of effector sequences for basal ganglia and computer of specialized controls for lateral reticular nuclei. The memory is distributed and it should be associative.

These general diagrams are still nowadays very much inspiring. For the sake of simplification, we shall reduce it to a diagram showing the specific counterparts in robotic and artificial intelligent tools that each one of the large components may have. This is shown in figure 3.

In this proposal, the overall system presents a set of "modes of behavior" that mimic the accepted model of behavior of the vertebrates [6, 7], The selection of a particular mode is performed by the command and control system, based mostly in present sensorial information (S.D.) and the status of the system. An external input (EI) is allowed from the external world (in practice, it should came from operator's console) to modulate the selection of a mode.

Information concerning the selected mode (M) is sent to the sensors, which are to be tuned to optimize the data acquisition pertinent to the mode of action. It is also sent to the component labeled Files of World Representations, in which the appropriate model of the environment and of the system in the

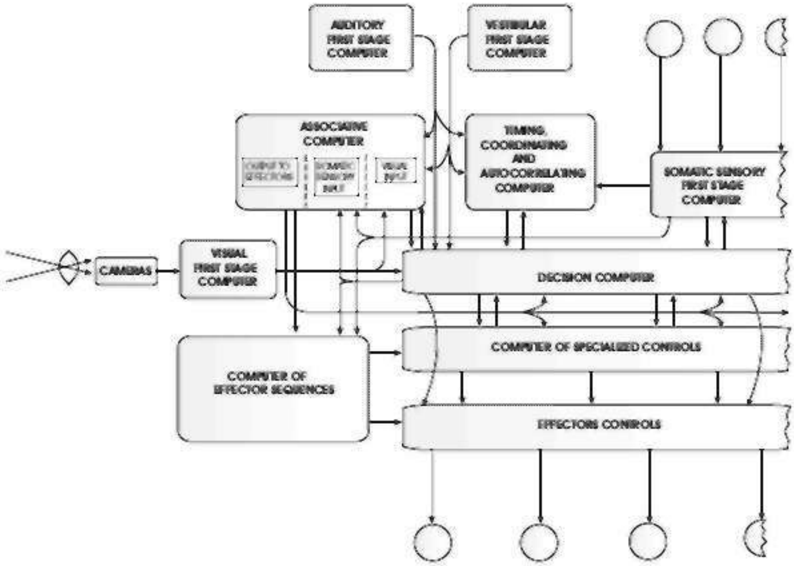

Fig. 2. Block diagram employing functional engineering nomenclature

environment is selected to be sent to the component labeled Planning in Present World Representation. Finally, the selected mode commands and controls the process of establishing goals according to the mode, the process of planning and the execution of the plan, by taking into account continuous highly processed sensory data (S). Updated world representations are sent back through W.R. lines when the mode changes. There are also direct connections between sensors and actuators (line R) which are equivalent to reflex paths. Line E provides for high level instructions to the effectors according to the plan of action, which are to be decoded into concrete motor-effector actions.

An appropriate computer architecture to embody such a system is shown in Figure 4. There are two types of specialized processors concerning the sensory data and concerning the effectors, which hung on the corresponding buses.

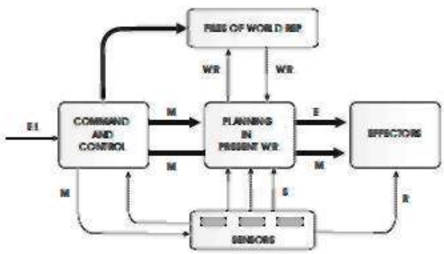

Fig. 3. A diagram showing the specific counterparts in robotic and artificial intelligent tools

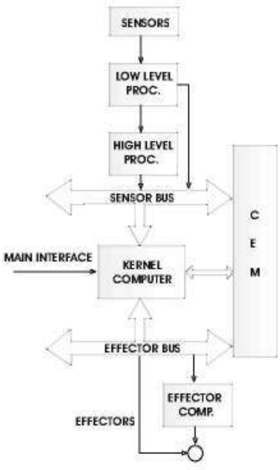

Fig. 4. Computer architecture for an integrated system

Command and control, as well as planning is performed by the Kernel, while computations corresponding to models of the environment are performed in the unit labeled C.M.E. (Computer Models of the Environment).

2 Command and Control

The basic function of a command and control system is to commit the whole system to one overall mode of behavior belonging to a not very large set. This is what enables it to behave as a well-integrated unit instead of a loose connection of separate sensors, effectors and processors. In this sense, a command and control computer is a close paradigm to the operation of the reticular formation in vertebrates [8]. Any mode of behavior is incompatible with any other. Some general properties can be established for such a computer. First, it receives relatively unprocessed information from all of the sensors situated in sensory and effector sub-systems. Second, it gives signals, which control, tune and set the filters of all external inputs. In McCulloch words [4], “this is the structure that decides what to look and having looked, what to heed”. It also controls all the information flow from and to higher level computers. This is similar to the problem of decision and attention [9, 10].

From a structural point of view, the command computer must have a modular architecture, or, at least, it must simulate it. The basic idea is that a set of computing units (C.U.) is such that each computing module receives information only from a reduced part of the overall, little processed sensory inputs (see figure 5).

Each computing unit is capable of both general diagnostics about overall input situations and of specialized diagnostics according to the values of a concrete subset of the input lines.

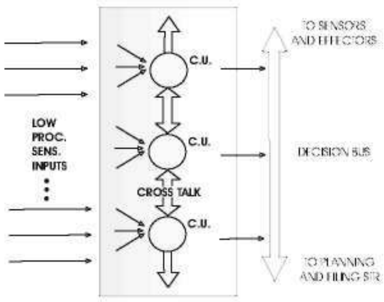

Fig. 5. Structure for a command and control computer

A crucial point is that a consensus of the diagnostics, which corresponds to the selection of a single mode of behavior, must be reached by the computing units in a relatively short time. This requires a very strong crosstalk among the computing units, which is a peculiar feature of the so-called cooperative processors [4]. There are two basic properties of the computing modules that can be stated easily by means of the terminology common in expert system.

In fact, we can look at the computing units as if they were simplified experts systems working on their own databases and with their own inference engines on their specialized domain of sensory inputs [11, 12]. But they are capable also of giving up before the evidence in diagnostics by other units, which show to have more relevant information for the case. This “giving up” must be understood in the sense of a recruiting of the rest of the modules by those having more confidence about their diagnostic. As it was stated by McCulloch [6], modules having the information pertinent to the case “cry louder”, and doing so, they recruit the rest. The result of this strong crosstalk is that the system converges into one mode, in the sense that practically all the units decide the same mode of behavior, though with perhaps different degree of confidence.

Modularity and division of expertise, with overlapping among the computers units, are the two basic features of a cooperative processing system. Also, appropriate crosstalk rules are the necessary addendum to achieve convergence. This architecture is supposed to provide for two main goals: first, to speed up the decision process by which a mode of behavior is selected; second, the system is supposed to present high reliability, in such a way that it will arrive into an appropriate consented mode, even when some of the expert units are destroyed.

This second aspect, that is, the reliability intrinsic to distributed expertise, precludes any decision based upon a single majority organ, because its malfunction will imply total inoperability. That is, the conclusion that a consensus has been reached cannot be the output of any special testing unit receiving its inputs from the expert units. Instead, the decided modes must be appropriately labeled according to their origin to prevent mixing, and be present in a non-computing structure, that is, a set of wires, or axons, or in other words, in a kind of decision bus. From this, it becomes clear that reaching a rapid consensus in the mode of behavior at the command and control computer is absolutely necessary for the

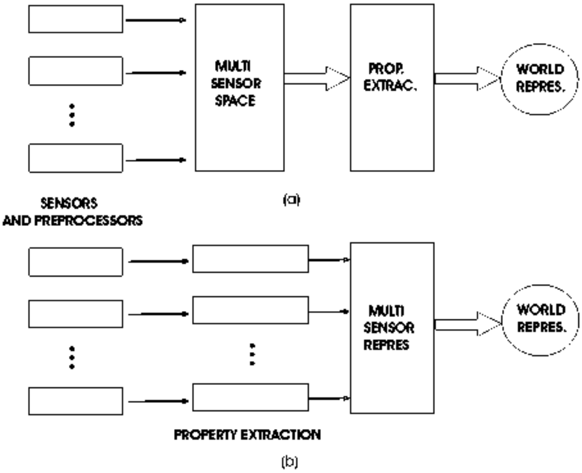

Fig. 6. Illustration of two mechanisms for representing multi-sensorial data

rest of the system to operate coherently, because, otherwise, the various higher and lower subsystems to be controlled, will have a high probability of picking up operation instructions from the decision bus, which belong to different exclusive modes of behavior, such that a kind of neurotic situation will be created.

In sum, the role of the command and control computer is to sense crude sensorial data, and to decide modes of behavior sending them to the decision bus, through a strong crosstalk among units to converge into a single mode, so that coherent behavior is secured.

3 Multi-sensorial Environment Representation

There are two basic ways to structure multi-sensorial information which, in turn, admit different levels of representation, from geometric to highly symbolic. These two ways correlate with the finality of the representation which may tend to be optimal for discriminating among environment patterns or to be a representation to optimize the acquisition of clues for actions. These correspond to:

a) Integrated representation, both at low levels of acquisition and a high level of the processing of sensory data.
b) Step by step representation, in which integration only occurs at high level, that is in symbolic structures.

In other words, and putting aside for the moment all natural systems, we may either represent the sensed environment by means of a multidimensional space where all sensory modalities are present with their own resolution at low level, while all high level processing is performed directly in this space [13]. Or we can construct a high level inter-sensorial representation space by previously extracting properties; classifying and labeling each sensory modality separately. These two options are illustrated in figure 6(a) and 6(b).

These two possibilities seem to coexist in the highly parallel computing structures of natural systems. Thus, when trying to explain the strong discriminating power of the nervous system at high recognition and perception levels, it seems logically necessary to admit that a kind of integrated representation is present, because low level, almost primarily sensed clues, like a pitch or a color, are definite clues to identify high level situations. And also, there are very fast responses of natural systems to key overall internal-external situations that cannot be explained if elaborate computation in multi-sensorial representation spaces where required. In any case, it seems that the two coexisting mechanisms have a type of principle of constancy, in the sense that increasing one of them implies decreasing the other. A more detailed treatment of said mechanisms was presented in [14].

The above duality is, in fact, embodied in the general structure proposed in figure 1. Thus, the command and control computer will operate on data which follow the representation scheme of figure 6(b), while the Files of World Representations, and, subsequently, the Planning Systems [15], operate according the scheme of figure 6(a). This implies that, when setting the mode of operation, different sensory modalities are taking separately the task of extracting medium level descriptors, which are necessary for the operation of the command and control computer. But, once the mode is decided upon, representation and planning structures shall take again the sensory data without much processing to "navigate" in a multi sensorial space where to perform processes, from low levels to high levels.

This interpretation helps to understand how the nervous system is capable of sharing high level computing structures after depression or destruction of primary sensory channels [16]. That is, the so called inter-sensorial transformations can only occur in an integrated representation space as is shown in figure 6(b). Therefore, the command and control computer in natural systems has not the ability to use directly the expertise of computing units acting upon sensory data which are depressed, while in the planning and representation spaces, this is a possibility. In other words, there seem to be two different mechanisms for attaining reliability and speeding up a decision and/or recognition process. That is, the command and control system operates with expert units which receive very restricted data, while the planning and higher structures have general purpose units which may work on almost row data form different sources.

The above systems concepts are presently developed to obtain specific artificial intelligence symbolic models and neural nets representations.

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