MANIPULATOR COORDINATION

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COORDINATION IN A HIERARCHICAL MULTI-ACTUATOR CONTROLLER

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Abstract

A hierarchical multi-actuator controller is represented as a multi-resolutional information (knowledge) system utilizing a number of intelligent modules with decision making capabilities. The laws of multi-resolutional information (knowledge) organization and processing are presumed to be satisfied including the rules of dealing with redundant knowledge. A general case is considered in which a process to be controlled by a multiplicity of actuators is a distributed one and the condition of distribution can be formulated analytically. Operation of a lumped multi-actuator process is a particular case which has a broad practical application.

Key Words: *Coordination, Decision Making, Decoupling, Generalization, Interpretation, Knowledge, Multiresolutional, Negotiations, Representation, Sensor Integration.*

1. Introduction

This paper was motivated by a specifics of the coordination processes in the systems with decoupled subsystems (e.g. using feedback linearization, and decoupling, or FLDT as in [1]). It is tempting to consider the decoupled subsystems as independent decision makers (though with an intentionally distorted view of the world created by FLDT). Nevertheless one can expect that the process of negotiations among the "independent" decision makers can be simulated in an on-line intelligent controller. The controller is based upon the structure of "intelligent module" first presented in [2,3]. General familiarization with the paradigm of multiresolutional control systems can be done by reading [4].

The progress in technology in recent years can be characterized by the increase of interest to the problem of coordination. Our research was affected primarily by papers [5-7], and conceptually can be considered a further extension of [8] to the domain of multiresolutional control and simulation of the process of negotiating independent controllers.

Two types of coordination are analyzed in this paper: inter-level , and within-level coordination ILC and WLC. ILC is performed by distribution of information and decision making activities among the levels of resolution in such a way as to minimize the cost-functional (in our examples we consider two cost functionals: time of computation and time of operation). ILC does not necessarily require a subsystem of coordination: a set of rules can properly handle all ILC activities. WLC is dealing with multiple decision making agents at a level whose decisions affect each other and eventually affect the overall performance of the system. Thus, the amount of situation-related coordination activities is large even in comparatively simple cases, and a separate coordination subsystem of WLC is required.

WLC is performed by transforming the input information (knowledge) sets in such a way as to decouple the planning/control activities of the parallel agents, and make their decision making

C-4

processes independent of each other at each moment of time. An *intentionality map* is being developed and maintained by the subsystem of WLC for each decision making agent. (This map is becoming an important component in the subsystem of learning). Coordination based on intentionality map is illustrated for examples of parallel processing. A computer architecture of a nested hierarchical controller is introduced for a hierarchical multi-actuator system.

2. Structure of the system

The overall structure of the system under consideration is shown in Figure 1. The Knowledge Based Organizer, and the Dispatcher both are submitting information to the General Coordinator which provides joint consistent operation of the set of N Coordinators. Each of them coordinates activities of a set of m subsystems consisting of controllers, actuators, and sensors. Each elementary closed-loop subsystem of controller-actuator-sensor equips a particular elementary process which can be characterized by a relative local independence. Sensors provide information for closing the loop of the subsystem. Simultaneously all m systems of sensors merge their information within the system of Sensor Integration related to the particular Coordinator, and provide the main feedback for this Coordinator.

The procedures of the trajectory generation are based upon the concept of open loop controller. The desirable trajectory is planned based upon the principles of optimum (e.g. minimum time) control, and then it is inverted in order to find the input which is required to provide the optimum motion. Since the optimum trajectory is computed based upon definite assumptions the real values of physical parameters lead to deviations of real trajectory from the prescribed plan. Thus, the feedback control applied in this system is dedicated to only compensate the deviations from the prescribed plan.

The concept of minimum time control for a system with FLDT leads to a particular structure of a program: all compensations are supposed to be done by corrections in switching times. Thus, a number of problems typical for "tailoring" the appropriate trajectories is not necessary here.

All Sensor Integrators submit their information to the General Sensor Integrator which serves as a feedback for the General Coordinator. It transforms all multiplicity of sensor information into the language understandable for the General Coordinator. This type of structure can be applied within a variety of systems including multilink manipulators, autonomous robots, and complicated systems of material processing similar to the one described in [9] which employs the system shown in Figure 1.

Each of the controllers has a structure demonstrated in Figure 2,a. Information from sensor S is being processed in a multiresolutional fashion as described in [2-4] interacting with the domain and context knowledge within the multiresolutional hierarchy of K, generating plans and controls within the similar p/c subsystem. The simplified representation of this system is shown in Figure 2,b. It is essential for understanding the processes of control in a multiresolutional system that the system shown in Figure 2,a can be considered as a system with three parallel loops as shown in Figure 3. These parallel loops are working (and designed) as if they were independent control loops. Coordination is provided by maintaining consistency of using generalization rules within the hierarchies P, K, and P/C. Resolution levels of these systems (tessellata) are communicating with each other.

Figure 1 can be redrawn in a simplified form using notation Figure 2,b. It is shown in Figure 4. From this illustration it is clear that coordinator is the real controller of the overall process. The horizontal lines show coupling which takes place between knowledge bases, perceptual systems, planning/control systems, sensors, actuators, and especially within the process where coupling is usually playing very important role, seriously affecting the design of controllers as well as motion control programs. Using principles demonstrated in [1] for a multilink manipulator, we apply method of generalized transformation for developing a system of linearization and decoupling.

The decoupled system is shown in Figure 5. It incorporates a new subsystem: a Decoupler which contains a multiplicity of look-up tables computed off-line in order to provide pseudo-independent actuation of the machine. Interestingly enough, the process is being decomposed in a multiplicity of pseudo-independent fictitious processes that can be controlled by 'independent" decision-makers.

3. Process of Coordination

In such a system each of the actuators is working in its own state space and has a)its own pseudo-goal, as well as b) its own system of constraints. Both position of the goal and configuration of constraints must be constantly recomputed under supervision of Decoupler and Coordinator. Assume the initial and the goal location are shown by the circles (see Figure 6). Configuration of the obstacles is shown by the bold line. In the beginning the subsystem of P/C computes the path to be traversed. Then the FLDT driven controller computes the system of jerks, accelerations, and speeds to be followed in order to provide minimum time operation (also bold lines on time diagrams). The algorithm of coordination works in the following steps.

Step 1. Coordinator builds the set of intentionality maps for all subsystems (parallel operation is presumed).
Step 2. Intentionality maps are distributed among the subsystems.
Step 2. Planning/control subsystem in each of the controllers performs the set of planning/control procedures (top-down in each tessellatum of the whole set of multiresolutional intentionality map).
Step 4. All actuators perform their first step of the motion.
Step 5. Sensors submit information to the subsystems of perception, subsystem of knowledge organization updates map, map is submitted to Coordinator.
Step 6. Together with FLDT system Coordinator transforms these maps into the updated Intentionality maps (parallel operation is presumed).
Step 7. Go to Step 1.

As soon as the motion started, Coordinator recomputes the configuration of the constraint boundary taking in account the information about motion of all actuators of the system. It is done by creating the "Intentionality Map" for each of the actuators. Planning/control subsystem replans the path for the new configuration of constraints. Then Decoupler recomputes the switching times, and the motion continues in a little bit different direction. This process is repeating each discrete of time accepted in the system. As a result the trajectory of real motion has a configuration which under no circumstances could be computed in the beginning unless the process of negotiations would not be provided in a comprehensive way. The problem is not yet solved concerning the degree of optimality in the set of trajectories obtained in this way.

When the set of coordinators has a General Coordinator above them the system operates as follows.

Step 1. Process the set of changes in the sensor information delivered from each of the particular sensors into a set of increments of the actuator trajectories which serve as descriptions of the motion of the all set of actuators (parallel operation is presumed).
Step 2. Generalize the set of increments of the actuator trajectories into an increment of the vector-trajectory which serves as a description of the overall process development.
Step 3. Submit to the General Coordinator the set of all increments of the vector-trajectory for the process (parallel operation is presumed).
Step 4. Develop the set of Coordinator Intentionality maps (parallel operation is presumed).
Step 5. Submit the set of Coordinator Intentionality maps to all Coordinators (parallel operation is presumed).

The system of coordination described in this paper is flexible since it allows for constant updating of the information in all subsystems during the process of MRKP with no interruptions, or delays.

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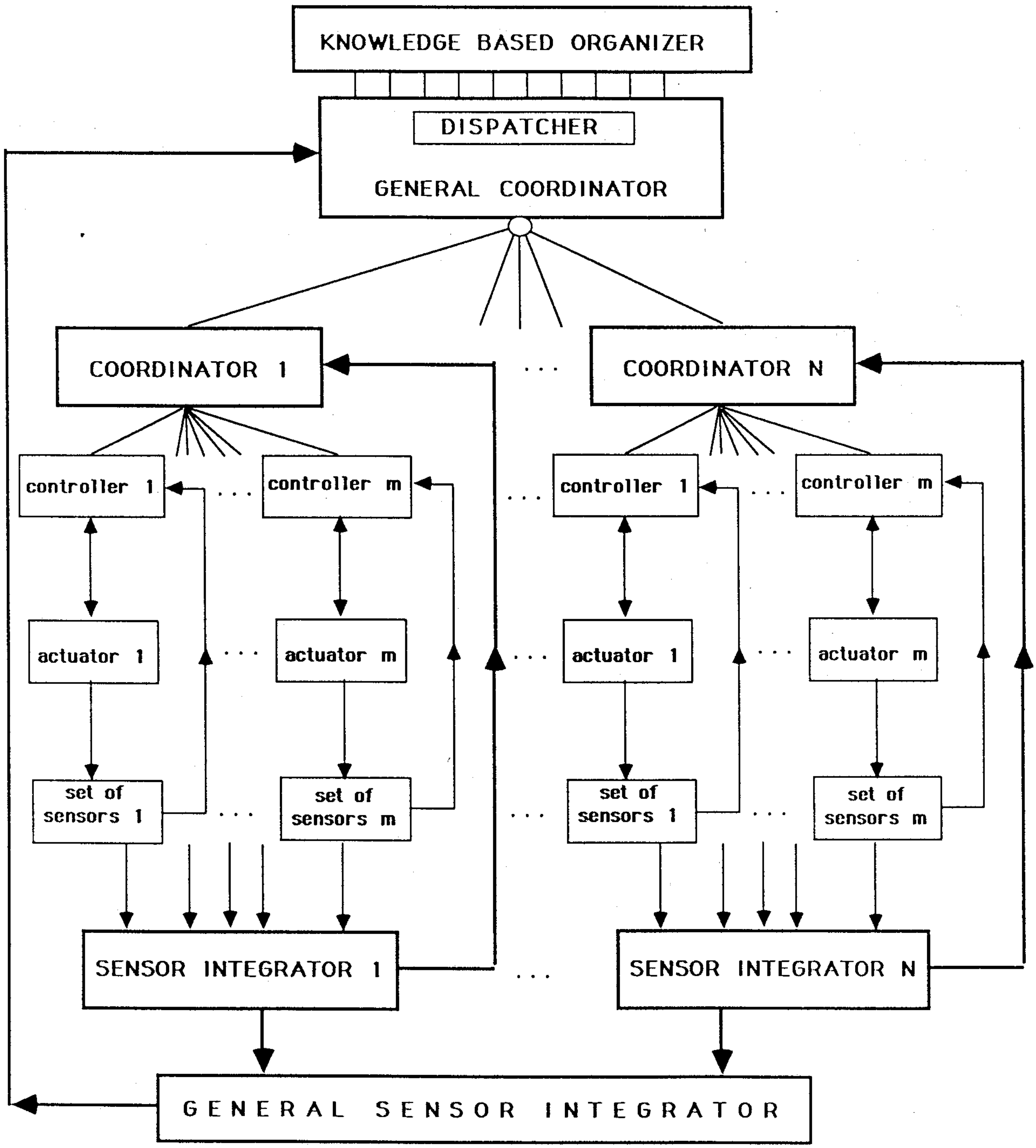


Figure 1. The structure of Multiactuator multiresolutional control system with two levels of coordination.

a)

b)

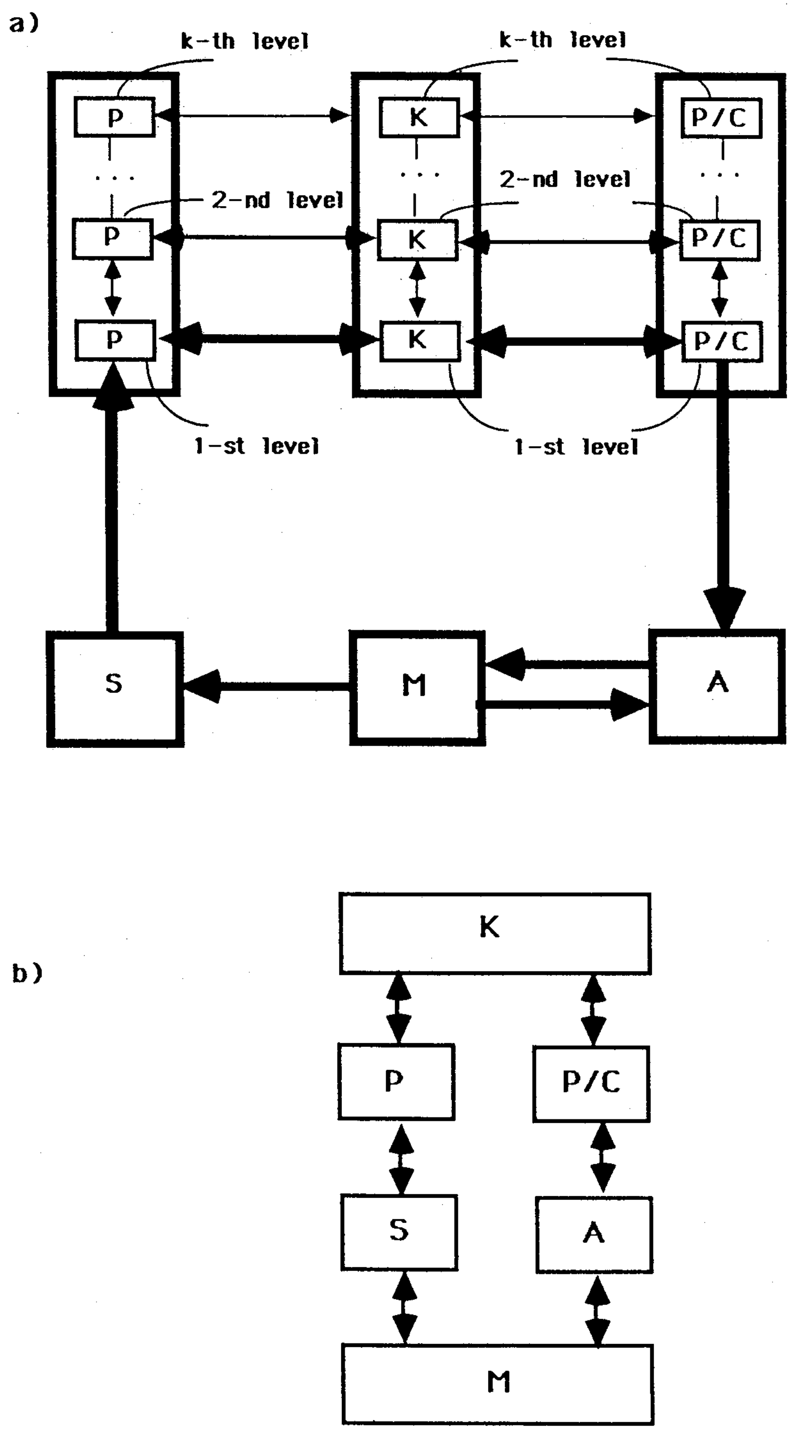


Figure 2. Structure of a single controller

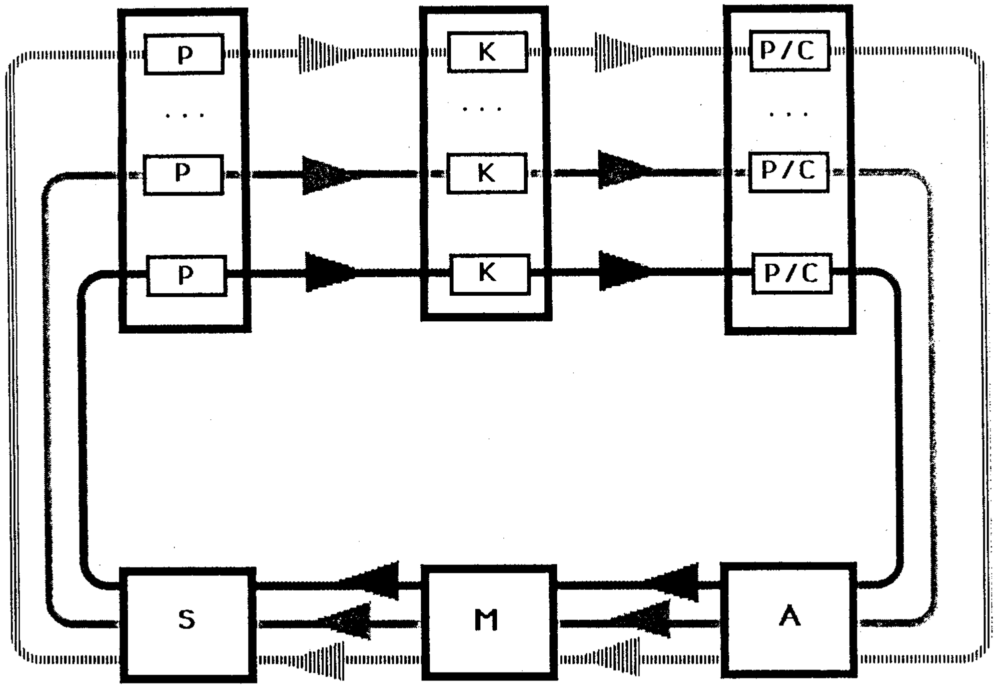


Figure 3. Parallel control loops in a multiresolutional controller

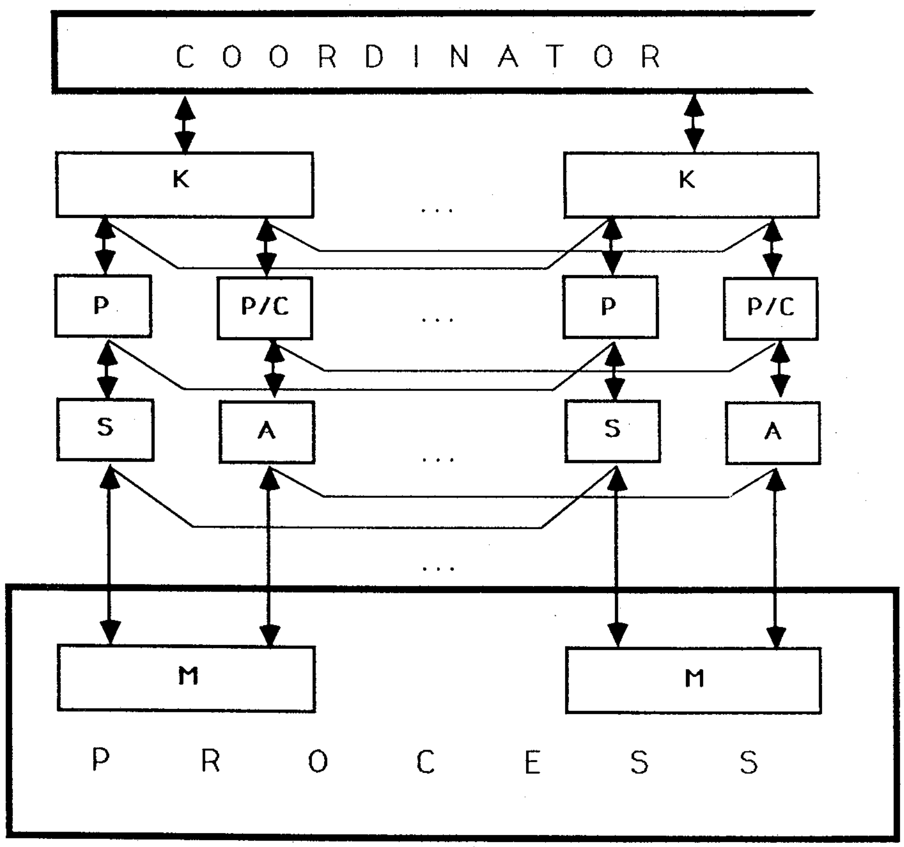


Figure 4. Coupled control structure of the overall process.

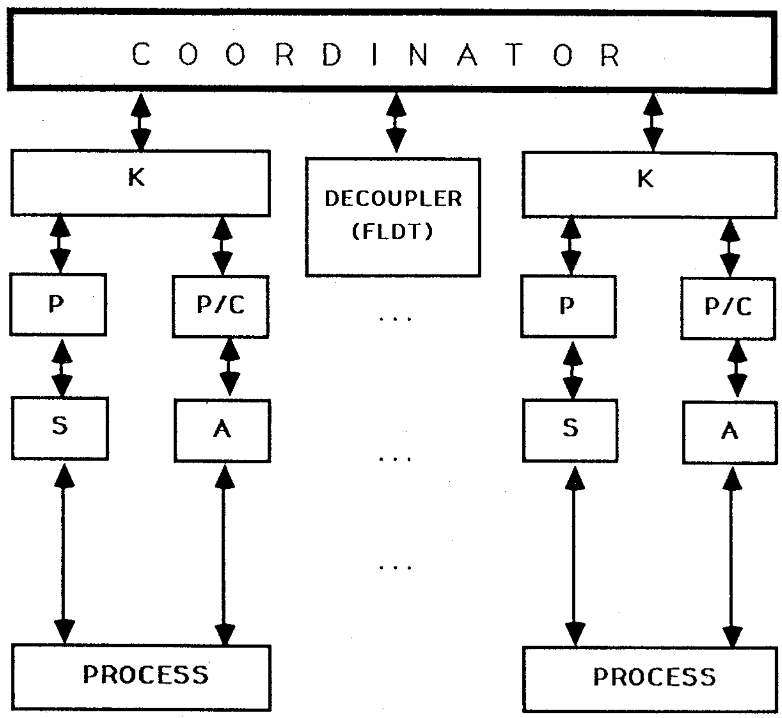
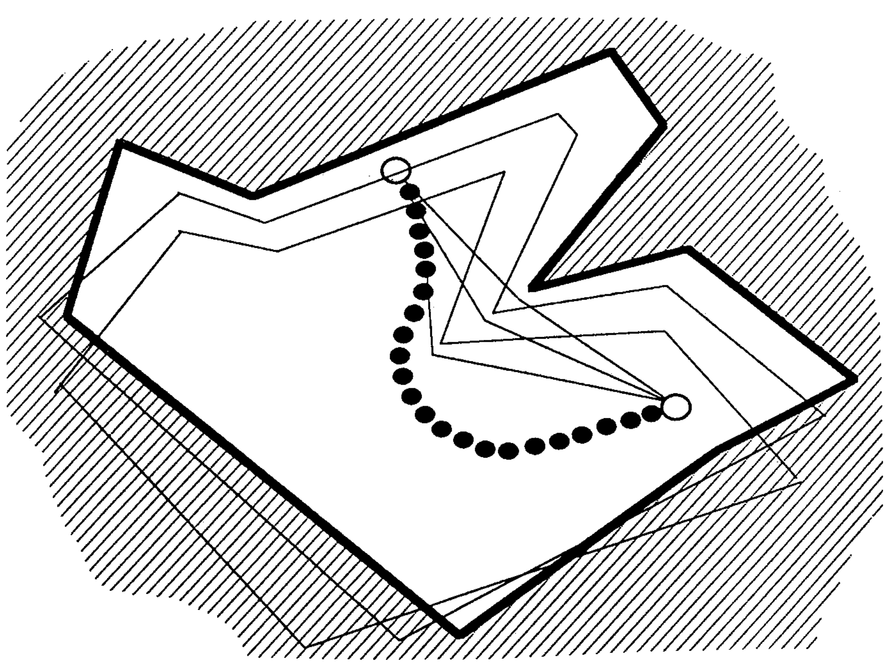
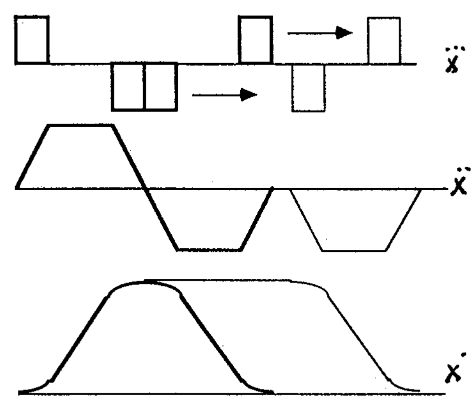


Figure 5. Decoupled control structure





graph of jerk (x''')

graph of acceleration (x'')

graph of speed (x')

[bold-planned control,
thin lines-postponed deceleration]

Figure 6. Motion shown on an intentionality map