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by

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Introduction: What is the Ecological Approach?

The ecological approach to interface design is based on an area of psychology that attempts to explain how intelligent, goal-oriented humans interact with their environments by perceiving cues in the optical array that suggest what structures exist in environment, what can and cannot be done in that environment while attempting to achieve their goals. This area of psychology is called ecological psychology (Gibson, 1979). In order to explain the ecological approach to interface design, it is first necessary to explain the key concepts of ecological perception that are relevant to interface design.

The idea behind ecological psychology is that if we can perceive the structure of a domain, say in the physical world, the rivers, hills, valleys, cliffs, roads and the objects within that domain and show the functions that each object affords (its affordances), and the limitations on their use (constraints), the goal-oriented human can then perceive the situation in relation to his or her goals and devise a course of action to navigate through that domain towards the intended goal.

Take for example an explorer surveying the land before him. He may see hills, rivers, steep slopes, ravines, tracks used by animals. The tracks would afford him passage, and his movement through the land would be constrained by the rivers and ravines, unless he is able to utilise objects in the environment to traverse these constraining features. Such constraining features are also referred to as behaviour shaping constraints. Gibson also talks about invariants or sources of regularity. By this he means the structures that, regardless of the changes in lighting (e.g. day or night), perspective (where we view the ravine from, it is still a ravine), surface disturbances (e.g. camouflage) (Gibson, 1979) p310-311, these features of the landscape do not change, particularly in respect to what the, say explorer wishes to achieve, e.g. to get to the other side. Barriers will remain barriers that constrain movement, while paths will remain paths, affording travel regardless of how they are viewed, or how the information cues are perceived in the optical array, hence they are invariant.

In the landscape example, the explorer perceives the landscape and features directly. In control systems, the controller views the process (i.e. the domain) through an interface that is an abstraction of the process. Let's now look again the example of the explorer. Looking into a process through an interface can be akin to telling our explorer what and where each feature and landmark is but not showing him the actual landscape. To develop a mental picture of the landscape, our explorer has to re-construct the landscape in his mind from the descriptions (abstractions) given to him, establish a sense of scale and relationship between objects and features, interpret from the incomplete data what can be done, how it can be done, and what are the constraints on action. Only then will he be able to understand what opportunities and dangers lie before him in the terrain. Assuming our explorer wishes to navigate through this terrain with only information provided through the abstract interface, working with the incomplete data (because it is an abstraction), what would happen if he moved forward and then to the left? If the world was visible, he could immediately read the cues and interpret the affordances and constraints, run quick mental simulations to see if the intended action was possible, and

then made corrections as required. However, because all he has is an abstract description of the immediate surroundings, he is not able to perceive the loose rock on the path that he could slip on, or the fact that the bridge across the ravine (a domain invariant) is composed of rotting wood and hence will be unable to take the weight of the explorer.

A good abstract representation of the terrain should be able to tell our explorer information about the structural invariants, the affordances and constraints. The cues should span different levels of abstraction in order to permit different levels of response. For example, some cues may inform on intuitive or automatic responses, whereas other cues are needed to determine selection between limited choices, while other situational information may be needed for goal re-evaluation and activity planning.

This section has explained the basic concepts of ecological psychology and how humans perceive their environment and interact with it. If there are no intermediate abstractions and representations of that environment, the perception of cues often provides sufficient information for the goal-oriented human to identify what can and cannot be done, what structures define the key aspects of the terrain. However, when these concepts are applied from the physical world to abstract worlds, e.g. process control, a method is needed to enable visualisation of these affordances, constraints and invariants.

What is the Ecological Approach to Interface Design?

Overview of the Ecological Approach to Interface Design

(Rasmussen, 1985) contends that the problem with a lot of interfaces for controlling complex systems is that they tend to be designed bottom-up, as represented by the typical single sensor, single indicator (SSSI) type of display. Such displays present a great deal of data about the states of individual components in a system. A user or operator then has to integrate all of the information mentally to build up a picture of the status of the system in relation to it achieving its overall goal. This is very much like the example of the explorer viewing the landscape through an interface which provides only an abstract description of what and where objects and features are, requiring him to re-construct the landscape in his mind in order to gain some understanding of layout and structure of the environment. Likewise, the operator presented with a SSSI type of display will need to expend a lot of cognitive and attentional resources to integrate mentally and construct a mental picture of the state of the process. Such an approach to interface design is considered inefficient. Instead, ecological protagonists believe that the information should be organised to portray the relationship and structure between states of physical components, the functions they serve, and the goals the system is to achieve. Then, through direct perception of the display, the operator can readily make assessments of how changes to states of the components affect the achievement of goals, and how changes in goals or the external environment need to be responded to and thereby suggesting changes to the configuration of the physical components.

To achieve this, the ecological approach to interface design does not analyse the work domain in the traditional methods where user tasks are broken down into sub-tasks and sets of procedures. Systems based on procedural descriptions can lead to failures when

it encounters unanticipated events.   Instead the ecological approach   starts analysing the work domain by identifying the goals and purposes of the system, and the priorities the system need to satisfy, the functions, then the processes and how the tasks are divided amongst the machines and personnel. This means activities are represented as typical work situations described in terms of the work domain and not the user. The outcome is a representation of the work domain as "an inventory map of all the options of the actors in all relevant work situations" (Rasmussen & Pejtersen, 1995). In the language of our explorer example, if we can represent the lay of the land in the interface, he can make the necessary situation assessments to respond to circumstances and to decide on appropriate courses of action. A map is more useful than a route description. This is the idea of ecological representations - to reveal the key features of the work terrain so that intelligent, goal-oriented actors in the domain can assess the situation and devise plans to deal with changing situations.

Types of Domains
(Rasmussen & Pejtersen, 1995; Rasmussen et al., 1994) describes three broad categories of work domains. These three categories of work domains can be described according to how tightly coupled, i.e. how inter-dependent, the sub-systems within each system are to one another. At one extreme we have tightly-coupled technical systems, and at the other extreme we have loosely-coupled workplaces. In between these two categories, we have the less-coupled work systems.

   a. <u>Tightly-coupled technical systems</u> are like process plants, and electricity generation systems. Such systems have been termed causal systems (Rasmussen, 1986), i.e. the outcomes of these systems may be predicted by the laws of nature acting through the cause-and-effect relationships between system components. For example, volume in a closed chamber may be controlled by altering pressure and temperature. In such systems, the human operator is part of the system's control loop, and therefore serves the system. Intentionality is embedded in control systems through direct connections between equipment and systems components.

   b. <u>Less-tightly coupled work systems</u> are characterised by work situations where the user may act autonomously but within social constraints. The user uses the system to control processes that are not directly hard-wired into the system.   Intentionality is exercised through the combination of socio-organisational rules and technical systems. Command and control systems like ambulance dispatch management systems would fall under this category. In this category of systems, outcomes cannot be predicted on the laws of nature. Functionality is defined by staff activity instead of mathematical relationships as in tightly coupled physical systems. Individual human motivations and intentions often influence outcomes as they seek to respond to events within their areas of the system. Such systems in the past have been referred to as intentional systems (Rasmussen, 1986).

   c. <u>Loosely-coupled systems</u> is a recent addition to Rasmussen's (1986) categories of systems. These systems exist purely to serve the user. The user decides on the task, and the place and time. Such systems are like public information systems like those found in libraries, or repositories of

information found on the world wide web. The system structure is defined by the user's intentions, rules and practices.

Understanding the types of works systems that exist is important as it provide clues to the sources, and the nature of the process invariants. For example, the invariants in technical systems like the control system for electricity generation are represented by mathematical formulae based on the laws of physics. Causality can be traced from changes in performance of the physical components right through to determine the effect on the system's goals. See (Vicente & Pawlak, 1994; Vicente & Rasmussen, 1990) for more details. However, in the case of intentional systems (less-tightly coupled systems), causality is represented through the decisions and activities of the staff, and the staff's execution of those decisions.

Designing Interfaces through the Ecological Approach

The ecological approach to interface design has been called Ecological Interface Design (Vicente & Rasmussen, 1992), and Cognitive Systems Engineering (Rasmussen et al., 1994). The ecological approach in both instances does not inform on how specifically to visually code the interface (Vicente, 1995). For example, where do you place a piece of information vis-a-vis the rest of the display? The approach does not specify visual layout guidelines. It relies on other display design guidelines to create the visual representations. Instead, it provides a framework to analyse the work domain in order to determine what information should be representative of the ecology of the domain, and very importantly, how the information about objects, processes and goals should relate to one another.

The framework starts with a work domain analysis, a decision analysis, which then identifies the information and knowledge requirements that the displays must satisfy. The next analysis is done to distinguish between information needed to support skill-based behaviour, rule-based behaviour, and knowledge-based behaviour. Such information support is necessary to allow natural problem solving strategies to occur, e.g. like zooming in to details and zooming out to see the overall situation.

Work Domain Analysis

The work domain analysis examines the work environment and organises the outcome of such an examination around two dimensions: the Abstraction Hierarchy (AH) and the Part-Whole Decomposition dimension. The AH is a five-level representation of the system. Each level of the AH is connected by a *structural* means-ends link to the next upper or lower level. Each level therefore represents the structures or objects that are the means by which the next higher level end is achieved. To differentiate between structural means and actions, Vicente gives the example that a fireplace and a furnace are the structural means by which we can satisfy the goal of warmth. Structures also suggest what actions are afforded or constrained. Whereas, lighting a fire, or walking downstairs to the basement furnace, are actions by which the goal of warmth is satisfied (Vicente, in preparation, 1998). This distinction is important because representing procedures or sets of actions, limits our ability to deal with unanticipated events. Instead if we identify the structures available, the intelligent goal-oriented actor can

devise alternative plans as necessary. These structural links are known as the invariants - they do not change despite changes in the environment. Invariants are the relationships between objects, the processes, and system goals that exist regardless of how we view the process. In physically-coupled systems, causality is observed through the invariants which are usually based on laws of nature, and hence may be mathematically computed and future system states predicted. However, in human-activity systems, causality is observed through the interaction of social rules between groups of participants, and hence future states of the system cannot be similarly predicted.

The Part-Whole dimension decomposes the system into sub-systems and physical components. Such a decomposition is useful as it shows how the various components in the system are organised to perform various functions and processes. It also shows their relationship with the higher order goals of the system. Separate sub-systems e.g. a heating sub-system, a water-flow subsystem, a steam generation sub-system in a electricity generation plant, interact to generate electricity. Failures in one of the components of a sub-system can be located and its effects on other parts of the system can be traced and anticipated.

This framework thus defines how the objects and participants in the system, are linked through functions and processes that guide the interaction with these objects in achievement of the system's goals and purposes. Figure 1 shows how form (decomposition) and function (AH) of a work domain can be represented.

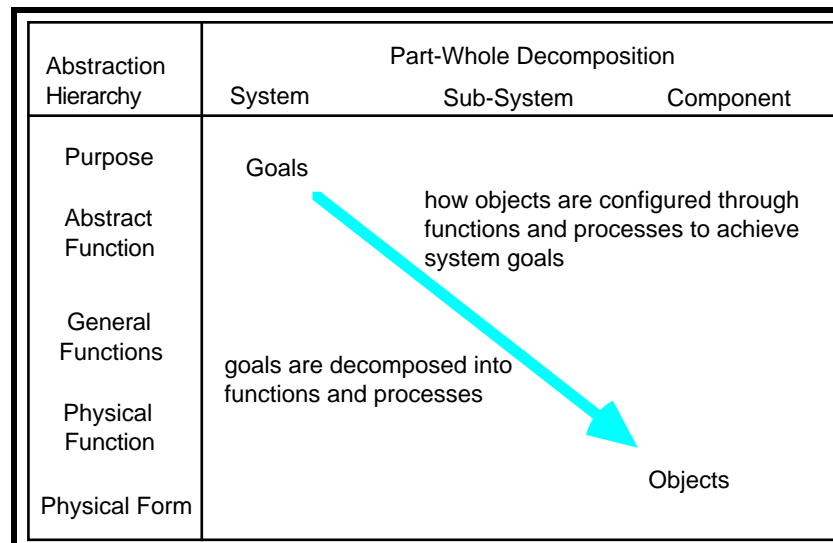| Abstraction Hierarchy	Part-Whole Decomposition		
	System	Sub-System	Component
Purpose	Goals		
Abstract Function		how objects are configured through functions and processes to achieve system goals	
General Functions			
Physical Function	goals are decomposed into functions and processes		
Physical Form			Objects

Figure 1 The Abstraction Hierarchy and the Part-Whole Decomposition shows the relationship between form and function in a work domain.

It should also be noted that the framework identifies the components of work and their relationships, rather than the sets of procedures used in performing the work. Data flow diagrams are task models. The AH and Part-whole decomposition instead diagrams the *structural* relationships between components and sub-systems with what must be achieved at each level.

Decision Analysis

Following the specification of the work domain via the AH, decisions made during prototypical work situations in that domain are then identified and analysed. This analysis produces a decision ladder which identifies decision nodes from which knowledge and information requirements can be specified. The decision ladder in Figure 2, represents the sequence of information processing tasks that occur during decision making (Rasmussen et al., 1994).
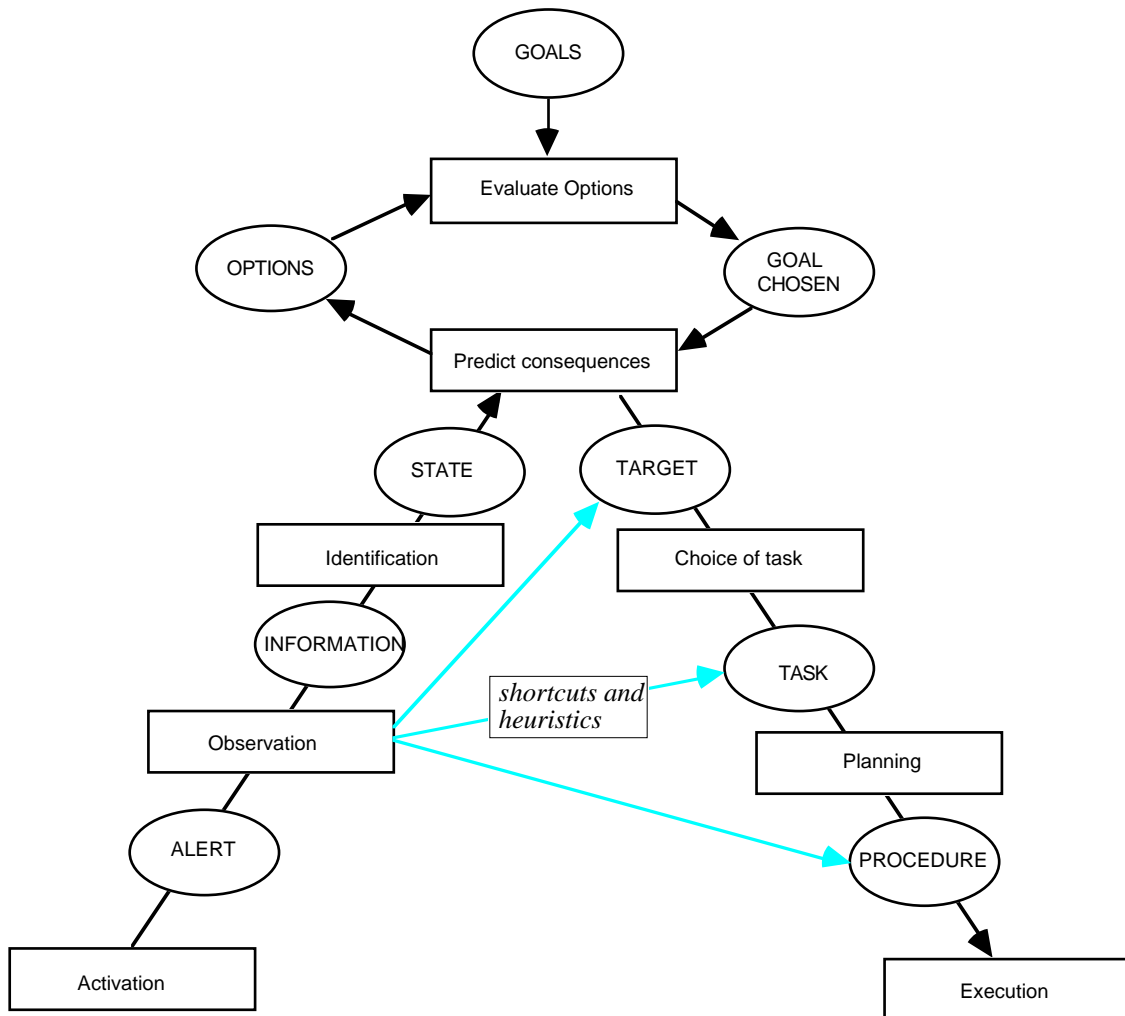

Figure 2 The decision ladder.

When an operator or decision maker is alerted to an event or a change in state, she observes the situation to determine whether the situation is familiar. If it is, she simply responds by initiating an established set of procedures. There is no higher level evaluation. She just responds to the event. On the decision ladder, she traverses from the observation stage through to the procedure and execution stage. Such behaviour is referred to as skill-based behaviour, where the responses are intuitive, or near automatic. For example from an ecological perspective, when walking along a street, we are alerted to a change. There is now the gravel on the footpath. We have walked many times on footpaths covered with gravel, and the cues presented by the situation conform with similar experiences in the past that suggest the gravel covered footpath is

traverseable without slipping if certain precautions are taken. She steps forward cautiously, executing the 'cautious' set of procedures, and continues on her journey.

If the situation is not totally familiar, or if there is some ambiguity in the information, more consideration is required. This results in a re-consideration of the task or a search for more information. The decision maker cuts across the ladder again from the observation or information stage to the task stage to modify the task or its procedures. For instance, there may be too much gravel on the footpath to walk safely with a pair of high-heeled shoes. We may examine the situation for more information about the environment, consider a limited number of alternatives to continue onto our destination. The situation may indicate that there is a "safer" path to the side of the gravel-covered footpath. The selection between these options are now based on some rules, e.g. can I get across without slipping? without dirtying my shoes? Such behaviour is know as rule-based behaviour.

If the situation that our pedestrian encounters is unexpected, e.g. an accident has occurred near where a group of workmen were digging up the footpath to replace underground power cables. The decision maker needs to assess the situation and determines the environmental state that the footpath can no longer be used because of the hole in the ground, and whether she should stop to assist with the accident. She will traverse up the ladder to re-evaluate or re-select goals in view of the new situation.   She will now examine what options are available with respect to his goals. She may mentally rehearse the options to determine if the options are workable with respect to her goals, and if not modify the options until it appears to satisfy the achievement of the goal or result in a re-selection of the goals. She then executes that new plan or activity. Such behaviour is known as knowledge-based behaviour, where one runs though the entire decision ladder, evaluating the novel situation to find an appropriate way to deal with it.

Designing the Display

The process of mapping the mental strategies onto the decision ladder provides a structure to show what knowledge and information is used during decision making. This guides the designer in making available the types and the level of information needed during decision making. Information required for each level of cognitive activity - skill-based, rule-based and knowledge-based behaviours - is identified and collated according to the respective levels of cognitive processing they support. These levels of information (signals, signs and symbols) are then organised to support thinking in terms of the systems invariant structures by mapping them to the goals, abstract functions, general functions, physical functions, and physical configuration. Finally, while the framework does not explicitly provide guidance for visually coding the interface (Vicente, 1995), the framework does provide principles for translating the information content into a display that takes advantage of powerful human pattern recognition and psychomotor abilities. These design principles are listed below (Rasmussen & Pejtersen, 1995; Rasmussen & Vicente, 1989; Vicente, 1995; Vicente & Rasmussen, 1990):

      a.   Use the means-ends hierarchy to represent the work domain as a hierarchy of nested affordances. This representation specifies the content and

structure of the interface and serves as an externalised mental model that will support knowledge-based problem solving.

b. Map the semantics of the ecology onto the geometry of the interface in order to reveal the affordances of the work domain in a way that exploits direct perception. By providing a consistent one-to-one mapping between the work domain constraints and the cues or signs provided by the interface, i.e. to faithfully represent the internal state of affairs of the work system with reference to its sources of regularity (the functional and intentional invariants and the available means for action, the affordances), it allows for rule-based behaviour where recognition of system states can initiate familiar sets of actions. The goal is to "make visible the invisible". (Vicente & Rasmussen, 1990) gives an example of how causal invariants can be represented as object or configural displays that directly maps the ecology of the work domain onto the interface so that the operator can directly perceive when the constraints on the system state have been violated.

c. To support skilled-based behaviour or interaction via the perception-action cycle, operators should be able to act directly on the display, and the structure of the displayed information should be isomorphic to the part-whole structure of movements.

This section has briefly explained that the ecological approach to interface design is a framework for analysing the work domain to identify structural links between the objects and abstract functions of the domain. While it does not explicitly define how the interface is to be visually coded, it specifies the principles by which the interface should be designed. An ecologically designed interface should allow direct perception of system state (as one would in the physical world), should allow multiple levels of analysis of system state (zooming in and zooming out, changing focus between a 'forest view and trees views'). Finally, because of its ecological nature, it should also support the adaptation of cognitive work as the situation in the domain changes. Such an approach will overcome the problems of brittleness, or the inability to cope with unanticipated events, when the system breaks down due to actions that have not be catered for. The next section attempts to use the Rasmussen and Vicente's Abstraction Hierarchy to analyse the ambulance dispatch management process and to evaluate the usefulness of the AH in an intentional domain.

The Abstraction Hierarchy of the Ambulance Dispatch Management Process

The ambulance dispatch management process was studied to identify the structural linkages in the process. The result is two slightly different AHs which attempted to link the objects in the environment to the goals of the system.

Figure 3 shows the outcome of this analysis. The goal of the system is to dispatch ambulances to medical emergencies. The types of medical emergencies range from small single person accidents like heart attacks or an elderly person with a fractured leg following a fall, to major incidents where many people are injured. In the case of major incidents, the dispatcher may be required to dispatch a number of ambulances drawn from the surrounding region.

Abstraction Hierarchy of Ambulance Dispatch Management

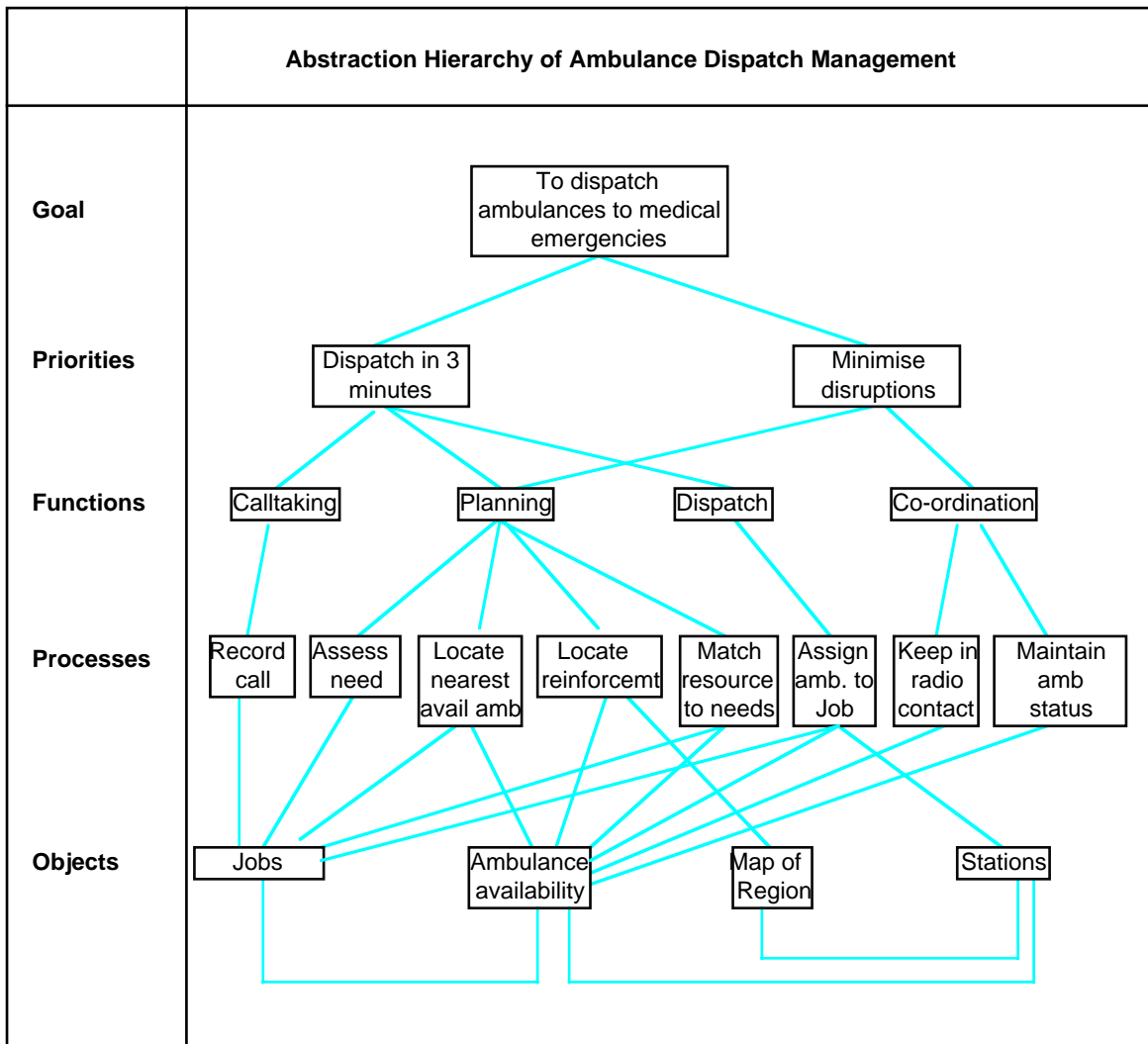|	
Goal	To dispatch ambulances to medical emergencies
Priorities	Dispatch in 3 minutes — Minimise disruptions
Functions	Calltaking — Planning — Dispatch — Co-ordination
Processes	Record call — Assess need — Locate nearest avail amb — Locate reinforcemt — Match resource to needs — Assign amb. to Job — Keep in radio contact — Maintain amb status
Objects	Jobs — Ambulance availability — Map of Region — Stations

Figure 3 The Abstraction Hierarchy of Ambulance Dispatch Management

The next level down the AH is the priorities with which the ambulances need to be dispatched. There are two main priorities: Dispatch the ambulance within three minutes of the call, while minimising disruptions to other on-going activities. The second priority implies that unless absolutely necessary, the dispatcher should not assign an ambulance that is already performing a task to another job. It also implies that regions should not be totally depleted so that there is no ambulance coverage in these regions.

In order to dispatch ambulances (the goal) within three minutes of receiving a call (constraint #1) while minimising disruptions to on-going activities (constraint #2), ambulance dispatch management is organised into four general functions: Calltaking, Planning, Dispatch, and Co-ordination. To respond to calls within three minutes, the dispatcher must receive the appropriate details from the call (Calltaking), assess the need, identify the nearest available resources (Planning), and then dispatch it to the incident (Dispatch). While planning, the dispatcher will have to consider how to minimise the effect of his plan on current and future activities. The dispatcher also needs to co-ordinate with other ambulances that are already out, maintaining an up-to-

date picture of what each ambulance is doing and where they are at any point in time. This knowledge will help the dispatcher minimise any disruptions to on-going activities.

In order to perform any of these processes, the dispatcher needs to have information about the objects within the domain. The dispatcher needs to know about the jobs that have to be done, where they are, and how severely injured the casualties are. The dispatcher also needs to know about the ambulances, their availability, their locations, and the jobs assigned to them. Of use would be a map of the terrain that shows the relationship between the ambulances, the ambulance stations, and the jobs.

Issues

Figure 1 above shows a 'map' of the functional and structural relationships in ambulance dispatch. It raises the following issues:

1. How does this structural map help a dispatcher reason through and respond to unanticipated situations?

2. While the trajectory (assessment path) taken by an operator during 'disturbance control' cannot be predicted, can we 'exercise' with this map to anticipate how an operator might do so?

3. the map shows a functional decomposition of functions through to tasks. While they don't show procedure, they show what each task is composed of. Does this make it a 'map' rather than a set of route instructions?

These issues lead to other questions. What are 'disturbances' in an intentional context? Also, after attempts to 'exercise' with the map, to see how an operator will respond to a major incident, I concluded that the map will provide very little guidance on what needs to be done, e.g. what resources are available to send to the major incident? Is this AH incorrectly drawn?

The problem in dispatch management is not attempting to identify what went wrong in a system (e.g. which valves are not working, and therefore caused the overheating problem) but rather, when a major incident occurs, e.g. a train de-railment, what resources do I have, and where can I get them from so that I can respond within 3 minutes, while minimising disturbances to activities?

In causal systems, the system is what the operator seeks to control. The system is "static" in the sense that the resources and their linkages do not move about spatially in the domain the way ambulances or fighter aircraft do. They will, however, change in the values of their relationships over time. Hence, understanding how the various 'static' components relate to one another, how they relate to functions and processes, and how they change their states as a result of changes in controls, is vital to ensure safe and efficient performance of the system as it produces its outputs. The display representation based on an AH will make it easier to determine sources of anomalies as the effects can be traced through causal links from the observed effect through to the location or configuration of the components and their status.

However, in intentional systems such as military or emergency command and control, the focus of interest is not the system of procedures, processes, and functions, that

controls the movement of troops and vehicles. The operators' goals is to control the movement of the troops and vehicles that reside outside the system. The focus of interest is what events are occurring, what the vehicles and or troops are doing, and how they are doing it. When the commander or decision maker diagnoses a problem, the problem is about troop or vehicle deployment, rather than malfunctioning of the physical links. Usually, these movements are in response to environmental changes such as enemy launches an attack, or an airliner crashing into a hill. While important, having a good representation of the processes and how they link up to the components of the system offers little assistance to the commander or operator trying to decide on a course of action to rescue the passengers of the crashed airliner. This is because the events are happening outside the system, per se. The events are happening in the environment in which the troops and vehicles are operating.

What is needed in such intentional systems is an abstract representation of what is happening outside the system, i.e. a representation of the terrain that shows where the troops and vehicles are, and what they are doing (unit status). In military command and control, army commanders map out the ground by drawing in what we call intentional constraints, e.g. the FEBA (Forward Edge of Battle Area, or the boundary between opposing forces), objectives to be achieved, e.g. a hill that is to be attacked and the enemy on it eliminated, or defence lines that must not be breached.   Such a representation is a map. It should show where each unit is deployed, and what it is doing. It will also show the terrain features, e.g. rivers, ravines, roads, swamps, from which it will provide cues about what movements the terrain will afford the troops. The intentional constraints, boundaries, defended positions, further defines the appropriate actions allowable.

Re-examining the Abstraction Hierarchy illustrated in Figure 3, it could be pointed out that the representation does not reflect the physical form and configuration of the system, i.e. the "… appearance, condition, location and anatomical configuration … the spatial relationship between the components." (Vicente, in preparation, 1998) (p28). Perhaps the Physical Form cannot be represented by the single words "Ambulance", or "Stations", but should instead show each of the 42 ambulances in relation to one another, and their status – just as one would represent the numerous valves and pumps in a physical system. Even if this were the case, how would the AH help the decision maker decide on a plan to deploy which specific ambulances if a major incident occurred?

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