Binding characteristics for planning diversity

Wout van Wezel & René Jorna
Faculty of Management and Organization
University of Groningen, The Netherlands

w.m.c.van.wezel@bdk.rug.nl
r.j.j.m.jorna@bdk.rug.nl

Abstract
Planning is a field of interest in many scientific disciplines. The ambition of this theoretical paper is to offer a conceptual structure underlying the various planning approaches. Although we value diversity, we believe that a general perspective on planning should contain the following distinctions. Planning implies modeling a plan and making a plan. Furthermore, planning can be done for yourself or for others. Finally, the planning entity can be a natural, artificial, or organizational agent (actor). In this paper we explain these distinctions in greater detail. The basic inspiration is our belief that planning in the real world deserves the use of various research fields in planning and vice versa.

1. Introduction

In the past decades, planning has been subject of research in several scientific areas. These scientific areas cover a multitude of planning approaches that at first sight do not have much in common: psycho-physiological analysis, organizational science, linguistics, cognitive science, operations research, and spatial science, to name just a view. Still, no matter the research field, planning always concerns anticipating on the future and determining courses of action, so at some level, there must also be similarities between the various approaches that deal with planning. In this paper, we will show that planning is always essentially similar, and that apparent different approaches are not as different as they seem to be.

First, in section 2, we discuss what planning is. Section 3 describes how planning can be modeled generically. Section 4 describes a number of characteristics of planning. These characteristics can be used as a first starting point to compare planning approaches. This is taken up in section 5 where we provide a short overview of some planning approaches that are predominant in literature. Section 6 summarizes our perspective that planning approaches are more similar than that they are different.

2. Definition of planning

Where will we go and how do we get there? This question is an inherent part of the functioning of humans and organizations. The ability to anticipate and plan is usually seen as a required and perhaps even essential feature of intelligent systems. It is the fundament of goal directed behavior; systems that pursue goals need to take the future into account.

Intelligent systems use predictive models to behave anticipatory rather than reactively. An anticipatory system is “a system containing a predictive model of itself and/or its environment, which allows it to change a state at an instant in accordance with the model’s predictions pertaining to a later instant” (Rosen, 1985). Our definition of planning will be built around this definition of anticipatory systems, by distinguishing four elements.

First, it is important to acknowledge that some entity must make the plan. Note that all kinds of entities can make plans, for example, humans, robots, computer programs, animals, organizations, etc. *Second*, someone or something must execute the plan, i.e., the intended future must somehow be attained. Again, this can be done by all kinds of entities, and the planning entities need not necessarily be involved in plan execution themselves. *Third*, the planning entity needs some kind of model of the future, since the future is essentially non-existent. This model should include states, possible actions of the executing entities and the effect of actions on the state they reside in, constraints, and goals. Planning and anticipation presume that such a predictive model is available, otherwise the chance that a plan can be executed as intended becomes a shot in the dark. The *fourth* element of planning is the plan itself. The plan signifies the belief that the planning entity has in the model of the future: the implicit or explicit actions in the plan will lead to the desired or intended future state. It can never be a full specification of the future itself because it can never be specified more precisely than the model of the future allows. It can, of course, be specified with less detail than the model of the future. Two kinds of plans are possible. First, the plan can specify the intended future state. The executing entity itself must determine how to get there. Second, the plan can specify the actions that the executing entity must perform. Although the desired future state is then not specified in the plan as such, it will, ceteris paribus, be reached by performing all specified actions.

3. Planning complexity and hierarchies

The four factors of planning entity, executing entity, model of the future, and plan are not only complex in their mutual relations, they are each also complex in themselves. Simon (1985) notes that complex systems are usually somehow ordered hierarchically in order to manage complexity. He uses the term hierarchy in the sense that a system is “composed of interrelated subsystems, each of the latter being in turn hierarchic in structure until we reach some lowest level of elementary subsystems" (op. cit., p. 196). Note that this not necessarily means hierarchic in the sense of an authority relation; it means an ordering of parts in wholes, and these wholes are in turn parts of other wholes. We argue that planning is no exception; set aside trivial planning problems, planning always takes place hierarchically for two reasons: uncertainty and complexity (Starr, 1979). We argue that much of the differences between planning approaches can be contributed to the way in which these approaches partition the planning problem in independently solvable sub-problems. We will discuss this by describing both the structure of planning decisions and the structure of the decision domain, after which the definition of planning roughly described in Section 2 will be elaborated with the generic hierarchical view.

Making the plan: decision of the planning entity. A planning decision is a decision that determines the future. Although this sounds straightforward, there is a catch. This feature is common to all decisions, and common sense tells us that not all decisions are planning decisions. For now, we will overcome this confusion by defining a planning decision as a decision that is part of a collection of planning decisions. This is of course not a satisfactory definition due to its recursive nature. Therefore, we will get back to this issue shortly, but for now it will help us to understand and model planning decisions.

Due to the hierarchical nature of planning decisions, there are two kinds of such decisions. The first kind of decision is: *setting constraints*. A constraint is a rule that restricts the possible plan alternatives. Constraints can be determined beforehand as inherent part of the model of the future, but they can also be set during the process of plan creation. In fact, this latter type of constraint is what defines hierarchical relations between decisions; a decision at the higher hierarchical level constrains the search space for decisions at the lower level. In this way, the plan can be made stepwise. The second kind of decision is: *plan determination*. These are decisions that are not specified in greater detail by the planning entity. Note that the plan can need more detail during the execution of the plan. There are two reasons to separate constraint posing from making assignments. First, an assignment will not bring more detail in the planning. Therefore, if a planning problem is disposed of all intermediate levels, the assignments remain. Second, a constraint is a decision that should be able to handle feedback (in the planning process), if the constriction is too severe and if at a lower level a solution can not be found. Assignments should also be able to handle feedback, but only for events that arise during the execution of the plan and not during the process of plan creation.

In Figure 1 three decisions with their relations and characteristics are shown:

- There are two kinds of decisions in a hierarchy: imposing constraints (decision A in Figure 1), and making assignments (could be decision B and/or decision C in Figure 1, although these decisions could also pose constraints for further sub-decisions).
- A hierarchical planning decision is defined as a decision that constraints another decision (arrow 1). Therefore, the hierarchical relation between two decisions is based on the fact that a decision's solution space is restricted by the other decision.
- It might be difficult or impossible to make a decision within the imposed restrictions. Then, somehow this must be fed back to the decision that imposed the constraint (arrow 2).
- Decisions that share constraints must somehow be co-ordinated because their combined decisions determine whether the constraint is violated or not (arrows 3 and 4).

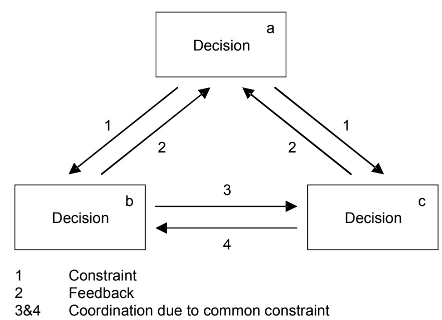

Figure 1. Basic hierarchic decision model

The significance of Figure 1 is that decision B and decision C can be decomposed in hierarchical structures themselves, and that decision A can be a sub-decision in a higher hierarchical structure. A collection of decisions with their hierarchical relations constitutes the way that a planning problem is tackled. The model in Figure 1 provides a structure that can be applied for all planning decisions on all planning levels. This view on planning implies that decisions are always structurally the same regardless of the decision level (Van Wezel, 2001).

Modeling the plan: states of the planning entity. With the notion of what a planning decision is, we can now describe (at least partly) what the decisions are about by describing the decision domain. *First*, planning is a synthetic (design) rather than an analytic (diagnosis) or modification (repair) task (Clancy, 1985). *Second*, planning involves decisions about the future and not the execution of these decisions. *Third*, an important feature of planning is that it is about choosing one alternative out of a huge number of alternatives that are structurally similar. Determining why a motor does not work is not planning (it is a diagnosis task), building a house is not planning (it is a synthetic task: however, it does not concern decisions making), but routing trains, making a production schedule, making a staff schedule, and determining the trajectory of an automatic vehicle are planning tasks (these are synthetic tasks and concern choosing one out of a number of similar alternatives of future states without executing them).

With this demarcation we can further define planning, by explaining what is meant by ‘structurally similar alternatives’. The vague connotation of the word ‘similar’ already indicates that it is not inherently clear whether a problem is a planning problem or not, but that in itself is not important. We propose to model a planning problem as follows. *A planning problem consists of groups of entities, whereby the entities from different groups must be assigned to each other. The assignments are subject to constraints, and alternatives can be compared on the level of goal realization*. For example, production scheduling is a problem where orders must be assigned to machines, in a shift schedule people are assigned to shifts, and in task planning tasks are assigned to time slots and resources. Different plan alternatives have the same structure (e.g., orders are assigned to machines), but a different content (e.g., in plan alternative A, “order 1” is assigned to “machine 1”, and in plan alternative B, “order 1” is assigned to “machine 2”). This definition also precludes some areas that are commonly regarded as planning, for example strategic planning and retirement planning. Although the boundaries are debatable, such problems do not exhibit the third feature of planning, that is to say that alternatives are structurally similar.

Two types of sub-plans can be distinguished in a planning hierarchy: aggregation and decomposition. In *aggregation*, the dimensions that exist in the planning problem stay the same, but individual entities of a dimension are grouped. Aggregation can be used to establish boundaries or constraints for individual assignments of entities that fall within an aggregated group. In this way, several stages of aggregation can be sequentially followed whereby each stage creates boundaries for the next stage.

In the second type of sub-plan, *decomposition*, a subset of the entities that must be planned is considered as a separate planning problem. Decomposition can deal with all entities of a subset of the dimensions, all dimensions with a subset of the entities, or a combination of subsets of dimensions and entities.

The planning definition reconsidered. We now have described what planning is:

1. Planning means that a *planning entity* determines a future course of actions for an *executing entity*. These actions should lead to the desired future situation. This is based on the *model of the future* of the planning entity. The future course of actions or the desired future state is expressed by the *plan*.
2. Planning is a complex activity and often involves reasoning with incomplete information. Plans are usually made hierarchically.
3. A plan contains the assignments of entities of different categories.
4. The assignments are subject to constraints.
5. Alternatives can be compared on the level of goal realization.
6. During the process of plan creation, sub-plans can be created at other hierarchical levels than the final plan exposes.
7. Constraints and goals are visible at each hierarchical level.
8. Decisions either provide constraints for other decisions, or assign entities.
9. Partitioning takes place by disaggregation or by decomposition.

Figure 2 summarizes the elements of planning.

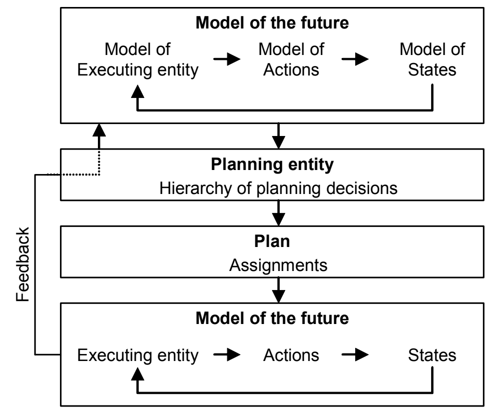

Figure 2: Elements of planning

In section 4 and section 5, we first introduce a number of generic characteristics that can be derived from this model, and then discuss some planning approaches concisely. The short introduction of the approaches serves to demonstrate our point of view that planning can be described from a generic perspective. The diversity in the planning approaches will become clear by stating questions that are based on the model in Figure 2, for example:

1. What is the planning entity? Is it a natural entity (human) or artificial entity? How does it make decisions? How is the planning decomposed; what are the partitioning criteria? In what order are the decisions made?
2. What is the executing entity? Is it an organization or an individual? Is it perhaps the planning entity itself? Do multiple executing entities have to coordinate or are they independent?
3. What kind of model of the future does the planning entity have? How flexible is the model with respect to adjustment?

The answers to such questions will bring forward not only the differences between, but also the similarities of (at first sight differing) planning approaches.

4. Generic planning characteristics

In this section, we describe a number of processing characteristics of the planning entity and of its relation to the environment. The characteristics that will be discussed are: a) closed versus open world assumption; b) the information processing mechanism of the planning entity and its architectural components, e.g., memory and attention; c) representation; d) communication, meaning and interpretation; e) characteristics of coordination; and f) aspects of the execution of the plan.

"Closed world" versus "open world": As we already indicated the planning task itself can be called a synthetic or configuration task. In the previous section, we described a way to model plans and planning decisions. Each assignment problem consists of choosing from alternatives that are structurally the same. In classical terms this means "searching through a problem space", or, more specifically, finding a sequence of operators that modifies the current state into the goal state. From a decision perspective realizing a suitable plan or solving a planning problem requires three nearly decomposable phases. In state space descriptions the first phase is the design of a (complex) initial state, of goal state(s), and of admissible operations to change states. The second phase is, given the admissible operations, to search for an (optimal) solution. The search process may be done by exhaustive computation or by adequate evaluation functions. In many cases search does not give an optimal solution. The most one may get is a satisfying solution and even that is often not possible. Then, the third phase starts in which one goes back to the initial state and the admissible operations. Another route is chosen in the hope that a solution is found. Formulated in other words, the phases of (1) initial state, (2) search, no solution and (3a) start again with the initial state, follow the so-called "closed world" assumption. This is the necessary sequence if algorithms are applied. However, there is another way of dealing with the third phase which is more usual if humans have to make a plan. If, given the constraints and goal functions, the second phase does not give an optimal or satisfactory outcome, the planner already is so much involved in the planning process, that because he has a glimpse of the solution given the constraints, he takes his "idea" of a solution for compelling. He therefore changes the initial state(s) and the admissible operations, that is the constraints, in such a way that they fit the preconceived solution. This order of phases can be named the "open world" approach. It consists of (1) initial state, (2) search, including not finding a "real" solution and (3b) adjustment of the initial state according to the "fixed or preconceived" solution reality. In other words, the model of the future in Figure 2 is not fixed because rules are adjusted. This sequence of activities is what human planners whether in industry, in transportation planning, or in staff scheduling frequently and with great success do, but formalizing such knowledge for use in a computer program or robot is difficult. In AI the issue described above is also known as the reformulation problem.

Information processing mechanism and architectural components: During problem solving, the planning entity must process information. An information processing mechanism operationalizes the way information is selected, combined, created, and deleted. The mechanism itself needs a physical or physiological carrier. Examples are the brain as our neurological tissue, the layered connection system of a chip in a computer, a human individual in an organization, or a group of interconnected individuals in an organization. This is of course relevant when we realize that the contents of the model of the future can be restricted by the physical, physiological, or functional properties of the carrier. The most relevant distinction is the one in internal and external mechanism. With internal we mean that there is no direct access to the system from outside. Internally controlled, but not directly visible processes (not cognitively penetrable as Phylyshyn (1984) called it) take place in the system. The cognitive system and the chip are internal and consist of various architectural components, but they differ in the sense that the latter is designed which means that its operations are verifiable. External are information processing mechanisms such as groups of individuals or organizations. With respect to planning, this distinction is of course relevant if one realizes that if the plan needs to be communicated, a translation is necessary between the physical carrier and the receiver, which must be taken into account during planning. This is the case when a planning entity makes a plan that is executed by others.

(Internal) representations: Mostly, plan execution takes place in the environment of an entity. An entity that makes a plan for itself can of course misinterpret its position in the environment. Furthermore, an entity that makes a plan for others can additionally have this problem with respect to the entities that must execute the plan. In other words, the model of the future might not be accurate enough to accurately predict the result of actions on states. Representations are also immediately relevant for anticipation. A description of a future state in whatever symbol system or sign system is the core of any discussion on anticipation.

In cognitive science the conceptual framework to deal with representations can be found in the approaches of classical symbol systems, connectionism, and situated action. (Posner, 1989; Newell, 1990, Smolensky, 1988; Jorna, 1990). The basic idea in classical symbol systems theory is that humans as information processing systems have and use knowledge consisting of representations and that thinking, reasoning, and problem solving consist of manipulations of these representations at a functional level of description. Representations consist of sets of symbol structures on which operations are defined. Examples of representations are words, pictures, semantic nets, propositions or temporal strings. A representational system learns by means of chunking mechanisms and symbol transformations (Newell, 1990). A system is said to be autonomous or self-organized, if it can have a representation of its own position in the environment. This means that the system has self-representation. Connectionism and situated action are attacks on missing elements within the classical symbol system approach. Connectionism criticizes the neglect of the neurological substrate within the symbols approach and defends the relevance of sub-symbolic processing or parallel distributed processing. Situated action criticizes the neglect of the environment within the symbol approach and emphasizes the role of actions, situatedness and "being in the world".

Communication, meaning, and interpretation: Communication means the exchange of information between different components. Depending on whether we are talking about internal or external information processing entities, communication means possibilities for and restrictions on the kinds of symbols or signs (the codes) that are used for the exchange. If we relate this to the aforementioned discussion about representations, the various kinds of signs have different consequences. Unambiguous communication requires sign notations (Goodman, 1968; Jorna, 1990), but we know that all communication between humans is not in terms of notations. If computers require sign notations and humans work with sign systems, then if the two have to communicate, the one has to adjust to the other. Until recently, most adjustments consist of humans using notations. Now, interfaces are designed that allow computers to work with (in terms of semantic requirements) less powerful, but more flexible sign systems. This means that computers can now better deal with ambiguity. For mental activities no explicitness (channels, codes etc.) is necessary; for planning as an external task it is essential.

Coordination: Coordination concerns attuning, assigning, or aligning various entities that are not self-evident unities. Information processing in a cognitive system is a kind of coordination mechanism (with no direct access). It is internal (or mental). The coordinating processor is cognition itself. No explicit code is necessary. If the code is made explicit and obeys the requirements of a notation we can design an artificial intelligent agent that in its ultimate simplicity could be a chip. In case of a set of entities that not by themselves are a coherent unity (for example individuals in an organization), various coordination mechanisms can be found, such as a hierarchy, a meta-plan, mutual adjustment, a market structure, and many others (Gazendam, 1993). The important difference with the single agent is that these coordination mechanisms are external and of course with direct access.

Planning, execution, and control: Making a plan, executing it, and monitoring the outcomes in reality are valued differently in planning your own actions and in planning actions of others (i.e., organizational processes). Planning in organizations usually is decoupled from the execution of the plan. There are two main reasons why the planner is someone else than the one who executes the plan. First, planning is a difficult job that requires expertise and experience. This is the organizational concept of task division. Second, a planner must be able to weigh the interests of many parties. Therefore, he must have knowledge about things that go beyond the limits of the individual tasks that are planned. The consequence of this decoupling is almost always inflexibility with respect to adaptation. For simple tasks as doing errands the possible division in terms of sub-tasks may be interesting, but can in reality be intertwined with flexible adaptation after unforeseen events. If the controlling entity is itself a unity, discussions about transfer, communication, sign systems to do the communication, and representations are almost trivial. This does not make the planning task itself simpler; it only prevents the occurrence of ambiguity, interpretation, and meaning variance between making the plan and executing the plan.

In the following section, we discuss a number of planning approaches. Our starting point is that planning is always in essence about the same thing: anticipating the future and determining courses of action. Still, the various planning approaches use different languages, ontologies, and descriptions of real world objects. The above discussed characteristics allow us to determine the similarities and dissimilarities of the various planning disciplines and perspectives.

5. Planning entities and planning approaches

In our definition of planning as decisions related to anticipating the future we discussed several characteristics of planning in general, and we made a distinction in decisions and states of the planning entity. Planning approaches in literature basically describe how a planning entity searches for solutions of planning problems, i.e., makes decisions about states. For example, a mathematical algorithm that calculates the optimal plan, a human that makes a shopping list, or a robot that mows my lawn. A first distinction in planning approaches is the kind of planning entity. It can either be natural or artificial. A second distinction is the executing entity. It can be the planning entity itself or it can be executed by one or more other entities. In this section we will discuss four forms: planning for yourself in a) a natural agent and b) an artificial agent, and planning for others in organizations by c) a natural agent, and d) an artificial agent (i.e., computer software).

Planning in the cognitive and behavioral sciences: Many studies in cognitive sciences deal with planning. Miller et al. (1960) define planning as a "hierarchical process in the organism that can control the order in which a sequence of operations is to be performed". Das et al. (1996) relate planning to the control of human information processing. They state that the plan is essential to connect knowledge, evaluation, and action. Newell & Simon (1972) go one step further, by describing a planning heuristic that is used by their General Problem Solver (GPS), which is used "to construct a proposed solution in general terms before working out the details. This procedure acts as an antidote to the limitation of means-ends analysis in seeing only one step ahead." (op. cit., p. 428). Basically, this heuristic uses abstract reasoning to overcome the complexity of the real world.

Early models of planning presume that planning is always a hierarchical process that proceeds according to successive refinement. Sacerdoti (1975) implemented such an approach in his computer program NOAH. Hayes-Roth & Hayes-Roth (1979) found empirical evidence that humans do not always follow such a hierarchy, but that humans tend to plan opportunistically. Humans do not work solely linear but appear to switch in levels of abstraction and move both forward and backward in time in successive reasoning steps. Some behavior that can be explained by their model is multi-directional processing in addition to top-down processing, incremental planning, and heterarchical (i.e., network) plan structures.

Riesbeck & Schank (1989) argue that planning is based on scripts. Instead of thinking up a new plan for each problem, humans try to find a plan that is used for a previously solved comparable planning problem. Then, the basic planning activity is adaptation rather than construction. In this paradigm, planning is about memory, indexing, and learning (Hammond, 1989; Veloso, 1996). These issues are very much interrelated. Plans should be stored in such a way that it becomes easy to find an existing plan on the basis of a comparison of the new goal with already handled goals.

The discussion until now describes a number of planning issues from a cognitive perspective. Although they are sometimes approached as contradictory they are, in fact, not. More likely, the different approaches are complementary in the sense that they apply to different stages or phases of the planning process. Together, they compose a comprehensive (but not complete) model of human planning.

Analyses of human problem solving and planning have been used as input for simulations of human problem solving, and after that as a way to direct the behavior of artificial agents such as robots. The results of such simulations and applications are sometimes used in cognitive sciences to further analyze and explain behavior models. This is partly the cause that the demarcation between models of human reasoning and models of reasoning by artificial agents is not very clear.

Simulations and Robots: The planning entities that are dealt with within Artificial Intelligence (AI) are very much related to the entities that occur in the human sciences. This is not surprising, since the aim in AI is to mimic natural intelligence (Meystel, 1987). As a result, the cognitive architecture that is commonly used to describe human reasoning, is more or less simulated in AI. Artificial agents that plan their own behavior need (just as humans that plan their own task) to be able to deal with uncertainty and incomplete information. For such agents, planning is a means to reach the goal, just as it is with human problem solving. Due to the close resemblance of humans and artificial agents, planning of artificial agents is very much related to the problem solving approaches. Techniques from AI are used to let such agents function more or less independently in their environment, and react to unforeseen events (Sacerdoti, 1975; Curry & Tate, 1991; Beetz, 2000). Much of the planning research in AI stems from the wish to let autonomous actors or agents (such as robots) perform tasks without prescribing how the task should be carried out (Fikes & Nillson, 1971). Important in this respect is the work of Brooks (1999). He showed that the implicit sub-division of an intelligent system into perception, cognition, and action (motor) components does not hold. The intelligent systems he developed only had perception and action parts. "It posits both that the perception and action sub-systems do all the work and that it is only an external observer that has anything to do with cognition, by way of attributing cognitive abilities to a system that works well in the world, but has no explicit place where cognition is done." (Brooks, 1999, p. X). Recently this approach also emerged in cognitive science, especially from a physiological and neurological perspective. The 'cognition box' is opened in such a way that this box consisted of further sub-divided perception and action parts.

The planning task in organizations: In the same way as with the cognitive and behavioral sciences, the organizational sciences deal with planning at multiple time scales differently (Anthony, 1965). A common ground for planning problems in organizations is that they basically concern the coordination of supply and demand, whereby (a) the supply consists of scarce capacity and (b) the way in which this capacity is put to use can make a difference with respect to the goals in the organization (Smith, 1992; Verbraeck, 1991). Examples are producing at low costs at a production facility, having enough phone operators at a call center, or taking care that all employees work the same amount of night shifts. The way in which the coordination takes place (in other words, the planning process or the planning task) determines to a large extent the plan that eventually is executed. Not much literature or theory exists about the relations between the planning domain, the planning task, the organization of the planning, and the performance of plan execution (Jorna et al., 1996; Van Wezel, 2001). Most analyses are limited to task models, for example, McKay et al. (1995), Mietus (1994), and Sundin (1994). Lack of a theory to explain the relation between planning complexity, planning organization, task performance, and planning support makes it difficult to pinpoint the cause of the planners' dissatisfaction, to attribute the causes of poor organizational performance to the planning, or to analyze and design planning practices.

In order to make generic statements about the planning task, it is important to know what the task performance depends upon. It should be noticed that by performance we mean execution without a qualitative connotation. According to Hayes-Roth & Hayes-Roth (1979), the determinants of the planning task are problem characteristics, individual differences, and expertise. That the task performance depends upon individual differences and expertise is no surprise. This applies to all tasks. But the fact that the task performance also depends on problem characteristics leads to the statement that it is possible to describe a planning problem, at least partly, independent from the planner.

Plan generation for organization planning: It is widely accepted now that computer programs will not be able (in the foreseeable future) to replace human planners that plan organizational processes. Still, much research focuses on plan generation techniques, as it is seen as an important part of computerized planning support. There are two mainstream approaches in plan generation techniques.

The first is about making a quantitative model that can search efficiently for good solutions. At first glance, the same kind of reasoning is used as in cognitive science: a problem space is set up and the aim is to find a state that satisfies all constraints and scores on goal functions. The states are (just like in the cognitive problem solving approaches) transformed by operators. The difference is that states and operators comprise something else than the ones in cognitive science, namely values on variables and mathematical operations (Sanderson, 1989; Baker, 1974). Most techniques are somehow limited in the kinds of characteristics they can handle. A linear programming model can not deal with nonlinear constraints, and temporal reasoning is difficult to implement in many mathematical techniques. Therefore, the domain analysis must somehow be translated into the quantitative model, and the solution must be translated back to the application domain (Prietula et al. 1994; Fox, 1983).

Second, approaches can focus on imitating the human problem solving processes in so called rule bases or expert systems, also called the transfer view (Schreiber et al., 1993), because the knowledge is extracted from a human and transferred into a computer program. For this approach, the problem solving behavior of the human scheduler must be analyzed. In terms of the human problem solver (Newell & Simon, 1972), this means that the problem space and operators must be traced and implemented. In the resulting plan generators, the available computational capacity is not used since the computer is used as a symbolic processor. It is, however, understandable for the human planner why a generated plan looks as it looks, because he would have made it more or less in the same way.

Table 1 contains the scientific planning fields that were discussed in this section and how they relate to general planning characteristics described in Section 4.

6. Conclusions

Planning approaches and planning perspectives are very different. That is an obvious conclusion if one studies planning literature. We want to challenge this conclusion by starting at the basic notion of planning. Planning is anticipating the future, implying that one has a model or representation of a future and a set of actions to get to a goal state in (the model of) the future. Within this circumscription three bifurcation points are relevant. The first relates to the distinction in modeling the plan (states of the planning entity) and making the plan (decisions of the planning entity). The second relates to planning for yourself or planning for others. The third point of bifurcation refers to the kind of entity that is making the plan: natural agent and artificial agent. This makes the confusion and the seemingly incommensurable positions more transparent.

We have three reasons for presenting the above binding perspective. In the first place there exists a growing distance between the academic world dealing with planning and real world planning issues. Misunderstanding is a bad teacher for successful mutual fertilization. In the second place the need for adequate planning analysis and planning support is growing. The simple reason is that more and more organizations are becoming closer connected to other organizations and firms require a better kind of planning (and scheduling) at all levels. In the third place we see that good ideas in one planning approach are not used in other planning approaches, simply because for example organization science (dealing with planning in organizations) has nothing to do with operations research (dealing with algorithms to solve planning problems). We do not believe in this kind of rigid separation. In this paper we wanted to present a conceptual framework in order to bridge the gaps and the seemingly incommensurabilities.

Scientific field	Cognitive & behavioural sciences	Organization planning	Robotics	Plan generation
Kind of planning entity	Natural	Natural	Artificial	Artificial
Kind of executing entity	Same as planning entity	Group of humans / organizational processes	Same as planning entity	Group of humans / organizational processes
Close vs. open world	Fixing the reality to the solution that is found; reformulate the starting-point		Searching for a solution that fits the (modelled) reality	
Information processing mechanism	Neurological: memory structures, attention processors	Translation of internal internally coded information is necessary	Information processing needs not to reckon with the outside world	Translation of internally coded information is necessary. Is designed explicitly
Architectural components	Memory, perception, motor, and central processors	Individuals and artefacts	Electronic: memory structures, attention processors	Program components: procedures, variables
Representations	Self-representation	Representation of others	Self-representation	Representation of others
Communication, meaning, and interpretation		Mostly communication with sign systems or sign sets		Communication with sign notations
Coordination	Only with respect to anticipated actions	Coordination of actions of others	Only with respect to anticipated actions	Coordination of actions of others
Planning, execution, and -control	Intertwined	Separated	Intertwined	Separated

Table 1 Characteristics of kinds of actors related to what they are planning

This is not to say that research in the planning approaches should stop, on the contrary. However, it might be the case that unknown fellow travelers exist in parallel research domains. A common conceptual framework is the basis for understanding.

References

Anthony, R.N. (1965). *Planning and Control Systems. A framework for Analysis*. Boston: Harvard.

Baker, K.R. (1974). *Introduction to sequencing and scheduling*. New York: John Wiley & Sons.

Beetz, M. (2000). Concurrent Reactive Plans. *Lecture Notes in Artificial Intelligence*. Berlin: Springer-Verlag.

Brooks, R.A. (1999). *Cambrian Intelligence: The early history of the new AI*. Cambridge: The MIT Press

Clancey, W.J. (1985). *Heuristic classification*. Stanford, CA: Stanford University.

Curry, K.W. & A. Tate (1991). O-Plan: The Open Planning Architecture. *Artificial Intelligence*, 51, 1.

Das, J.P., Karr, B.C. & Parrila, R.K. (1996). *Cognitive Planning*. New Delhi: Sage.

Fikes, R.E., & N.J. Nillson (1971). STRIPS: a New Approach to the Application of Theorem Proving to Problem Solving. *Artificial Intelligence,* 2, pp 189-208.

Fox, M.S. (1983). *Constraint-Directed search: A Case Study of Job-Shop Scheduling*. Ph.D. Thesis, Carnegie Mellon University.

Gazendam, W.H.M. (1993). *Variety controls variety: on the use of organizational theories in information management*. Groningen: Wolters-Noordhoff.

Goodman, N. (1968). *Languages of Arts.* Brighton, Sussex; The Harvester Press.

Hammond, K.J. (1989). Chef. In: Riesbeck, C.K. & Schank, R.C. (1989). *Inside case-based reasoning*., Chapter 6. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Hayes-Roth, B. & Hayes-Roth, F. (1979). A cognitive model of planning. *Cognitive Science, 3*, pp. 275-310.

Jorna, R. J. (1990). *Knowledge representation and symbols in the mind*. Tübingen: Stauffenburg Verlag.

Jorna, R.J., Gazendam, H., Heesen H.C.& Wezel W. van (1996). *Plannen en Roosteren: Taakgericht analyseren, ontwerpen en ondersteunen*. Lansa: Leidschendam. (*Planning and Scheduling: task oriented analysis, design and support*).

McKay, K.N., F.R. Safayeni & J.A. Buzacott (1995). 'Common sense' realities of planning and scheduling in printed circuit board production. *International Journal of Production Research.* Vol. 33, Nr. 6, pp. 1587-1603.

Meystel, A.M. (1987). Theoretical foundations of planning and navigation for autonomous robots. *International Journal of Intelligent Systems*, 2, pp. 73-128

Mietus, D.M. (1994). *Understanding planning for effective decision support*. Groningen: Ph.D. thesis, University of Groningen.

Miller, G.A., Galanter, E. & Pribram, K.J. (1960). *Plans and the structure of behavior*. Holt, Rinehart & Winston.

Newell, A. (1990). *Unified Theories of Cognition*. Cambridge: Harvard University Press.

Newell, A. & Simon, H.A. (1972). *Human Problem Solving*. Englewood Cliffs, New Jersey: Prentice-Hall.

Posner, M.I. (Ed.). (1989). *Foundations of cognitive science*. Boston, Mass.: The MIT-Press.

Prietula, M.J., W. Hsu & P.S. Ow (1994). MacMerl: Mixed-Initiative Scheduling with Coincident Problem Spaces. In: Zweben, M. & Fox, M.S. *Intelligent Scheduling*. San Francisco: Morgan Kaufman.

Pylyshyn, Z.W. (1984). *Computation and Cognition*. Cambridge: The MIT Press.

Riesbeck, C.K. & Schank, R.C. (1989). *Inside case-based reasoning*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Rosen, R. (1985). *Anticipatory systems; philosophical, mathematical, and methodological foundations*. IFSR International Series on Systems Science and Engineering – Volume 1. Oxford: Pergamon Press.

Sacerdoti, E.D. (1975). The Nonlinear Nature of Plans. *Proceedings of the Fourth International Joint Conference on Artificial Intelligence*, pp. 206-214.

Sanderson, P.M. (1989). The Human Planning and Scheduling Role in Advanced Manufacturing Systems: An Emerging Human Factors Domain. *Human Factors,* 31 (6), pp. 635-666.

Schreiber, G., B. Wielinga & J. Breuker (1993). *KADS. A principled approach to knowledge-based system development*. London: Academic Press.

Simon, H.A. (1985). *The sciences of the artificial*. Cambridge, Massachusetts: The MIT Press.

Smith, S.F. (1992). Knowledge-based production management: approaches, results and prospects. *Production Planning & Control*, 3, 4, pp. 350-380.

Smolensky, P. (1988). On the proper treatment of connectionism. *Behavioral and Brain Sciences, 11*, pp. 1-74.

Starr, M.K. (1979). Perspectives on disaggregation. In: L.P. Ritzman, L.J. Krajewski, W.L. Berry, S.H. Goodman, S.T. Hardy & L.D. Vitt (eds.). *Disaggregation. Problems in Manufacturing and Service Organizations*. Bosten: Martinus Nijhoff Publishing.

Sundin, U. (1994). Assignment and Scheduling. In: Breuker, J. & W. van der Velde (Eds.) *CommonKADS library for expertise modeling: reusable problem solving components*. Amsterdam: IOS Press.

Van Wezel, W. (2001). *Tasks, hierarchies, and flexibility. Planning in food processing industries*. Capelle a/d IJssel: Labyrint Publication.

Veloso, M.M. (1996). Towards Mixed-Initiative Rationale-Supported Planning. In: Tate, A. (Ed.). *Advanced Planning Technology*. Menlo Park, CA: AAAI Press.

Verbraeck, A. (1991). *Developing an Adaptive Scheduling Support Environment*. Delft: Ph.D. Thesis, University of Delft.