Abstract. Anticipation and planning have much in common. Anticipation means being ahead of things. Planning means not only on anticipating on things to come but also on trying to determine a course of action to reach a goal. Planning is investigated in many domains, for example, in economy, organization and management, biology, mathematics, computer science, and in cognitive sciences. Each of these domains uses its own research methodologies, languages, ontologies, and models. Examples are (mathematical) operations research models of production scheduling, task models of humans that plan organizational processes, and models of the physical processes of the human brain that relate to planning. Although there are many differences between the various approaches and models, there must of course also be similarities, since they all deal with establishing a future course of actions to reach a goal. We will describe and compare several planning approaches on a number of aspects, for example the kind of entity that makes the plan (natural or artificial), whether the plan is executed by the planner or by another entity, information processing mechanisms that are used, representational issues, and the domain that the plan is executed within. Our article focuses on analytical dimensions in the extended field of planning. We do not discuss empirical results.

1. Introduction
In this paper we will discuss various aspects of planning. Planning implies making representations of future states and investigating actions that will bring you from the present state into the future state. Making a representation of a future state can also be called anticipation. In our view planning, therefore, entails anticipation.

Planning is not a nicely ordered and well-defined subject. Various disciplines with various scientific backgrounds have dealt with planning, such as (cognitive) psychology, mathematics, economics, operations research, artificial intelligence (Rich & Knight, 1991) and management and organization. We try to take the various perspectives into account, by discussion three themes. In the first place we discuss the relation between planning and anticipation. We do this by discussing various details of the planning theme, such as planning and problem solving, planning and its domain and planning and actors. We do this in section 2. In the second place we discuss the framework of levels of description which we use to subdivide the kinds of entities that do the planning and for which the planning is done. Examples are a natural actor, an artificial actor and an organization. These themes are discussed in sections 3 and 4. In the third place we go into the details of various aspects of the actors that do the planning, such as the closed verus the open world assumption, the architecture, representations, communication and control. This is discussed in section 5. In section 6 we give conclusions. This paper is theoretical and gives classifications and comparisons in the discussions about planning and anticipation. It does not give empirical data, nor are software programs discussed.
2. Anticipation and planning

It almost is common sense to state that planning and anticipation have a lot in common. Anticipation means being ahead of things or events, whereas planning means intending to do or achieve something or to have a goal or purpose in mind. The interesting thing is that in the literature the notion of “anticipation” is not reserved for a field of study or a (sub-)discipline, whereas planning as an issue is a thoroughly investigated research topic in many domains, for example in economy, in organization and management science, in computer science and in cognitive science (Zweben & Fox, 1994). Because of the richness of entrances into the topic of planning we first start with perspectives on planning. After that we return to the relation between planning and anticipation.

Notwithstanding, or perhaps because of, the richness of the issue of planning, it is impossible to find one definition that is common to all fields. In organizational and economical perspectives (Anthony, 1965), mainly formulated in economic or financial terms, a distinction is made in planning and scheduling. Planning is often called: the determination of levels of production or resource quantities, whereas in this perspective scheduling is the allocation of resources to production processes on a time scale (Baker, 1974; Mintzberg, 1994; Allen et al., 1996). From a cognitive perspective planning contains the study of human (intelligent) activities (tasks). In this perspective the old definition of Miller, Pribram & Galanter (1960) is used, saying that a plan is a hierarchical process within an organism that controls series of operations. Hoc (1988) elaborates this definition and says that planning always involves anticipation and schematization. He particularly mentions “anticipation”. What he means is that planning is a parallel process working along two lines, in which a future state is taken into account (anticipation) and in which a (stored) mental schemes can be applied if a concrete planning problem arises. Therefore, Hoc talks about bottom-up and top-down processes that are always involved in making a plan.

Because of the terminology he uses, Hoc is implicitly taking a position in the complex debate about planning. This debate involves four closely related topics. The first deals with the question whether planning is a form of problem solving (Newell & Simon, 1972) or whether planning and problem solving only overlap (Das, Kar & Parrila, 1996). The second is about the question whether human planners work hierarchically (Newell & Simon, 1972) or whether they plan opportunistically or even chaotically (Hayes-Roth & Hayes-Roth, 1979). The third topic relates to the domain of the planning. In what sense does the domain in which the planners are working effect their problem solving behavior? The fourth topic relates to the entity that makes the plan. Is planning as a process similar for a human information processing system, an artificial information processing system, and an organizational information processing system?

Planning and problem solving. Newell, Shaw & Simon (1958) described the planning method as a part of a general problem solving technique. It consisted of a reformulation of the problem in more abstract and restricted terms, its solution in a simplified problem space, its re-translation into the original problem situation and subsequently its solution. In later papers Newell & Simon (1972) renamed the planning method as problem abstraction, necessary if the problem was not solvable within its original state space. Because planning as well as problem solving means searching for routes, i.e., sequences of actions, that lead to a solution or a goal state, the explicit distinction between planning and problem solving disappears in the later work of Newell & Simon. Planning is just one very interesting example of the general problem solving approach. Das et al. (1996) argue against this “planning is a subset of problem solving” approach in saying that a difference exists in problems to prove and problems to find. According to Das et al. (1996, p. 40) “Planning is a more pervasive, general regulating process than problem solving, with problem solving being a part of a planning process.” Planning includes anticipation and overview.
and refers to future actions, whereas these components seem to be absent in problem solving. According to us this may almost be a game with words, because one could state that searching and trying to reach a goal and constructing a problem space with states and operators, imply future actions and anticipation. We will not settle the discussion, here. Das et al., however, may have a point in one aspect of this debate. An enigmatic element in the problem solving approach of Newell & Simon has always been the starting point of the problem solving process. How does a problem solver construct a problem space? Where does the choice for a particular problem space come from? Why does a problem solver construct this special problem space and not another? In terms of Newell & Simon the question is how a task environment gets its representation in a state space description. It is easy to say that one has a new problem here, which requires a second order state space description. Although this might be true in the strict sense of the word, it does not solve the issue. Perhaps something like what Das et al. (1996) called “overview” and “having a higher perspective” or perhaps even “anticipation” is necessary. Therefore, it might be insightful to distinguish planning as second order problem solving from “ordinary” problem solving. If, in line with Newell & Simon, one considers the planning task in organizations and institutions to be a problem solving process, the question appears how planners construct an initial representation. Do they start with an overview or are they just trying? In the first situation there is an explicit state space to start with. In the second situation the state space is reformulated again and again. We will come back to this issue in Section 5.

Hierarchical or opportunistic planning. The discussion about the relation between planning and problem solving is closely connected to the way the problem solving procedure is carried out in practice: hierarchically, opportunistically or even chaotically. In the first place because the suggestion may be present that solving a problem with or without an overview is done straightforward. One just has to follow a couple of rules from top to bottom and one ends up with a solution. In the second place the issue of the overlap between planning, problem solving, and execution very much depends on the format of representations in the information processing system of the human planner. Do planners use production rules? How are these rules controlled? Or do planners use schemata and frames? Both issues come together in the discussion started by Hayes-Roth & Hayes-Roth (1979) about hierarchical and opportunistic planning.

Hierarchical planning means that there is a nested number of goal and sub-goal structures or a hierarchy of representations of a plan. The highest level in the hierarchy may be a simplification or an abstraction, whereas the lowest level is a concrete sequence of actions to solve (a part of) the planning problem. One solves a planning problem by starting at the highest level and then one continues by realizing sub-goals until one reaches the final solution. Hayes-Roth & Hayes-Roth relate this to a distinction in the overview and the action aspect of plans that they successively call plan-formation and plan-execution.

Unjustly, but quite understandably, the hierarchical approach is attributed to Newell & Simon. They started to talk about problem solving in terms of problem spaces, goal hierarchies and universal sub-goaling. We consider this attribution to be completely wrong - one only has to recall Simon’s bounded rationality concept, but we are not going to discuss the issue here (Jorna, 1990).

In contradistinction to the hierarchical view on plan execution, Hayes-Roth & Hayes-Roth proposed a so called opportunistic approach to planning. This non-hierarchical planning assumes that a plan is executed with the help of some kind of mental blackboard where pieces of information, relevant cues, and possible sub-goals are stored. They claimed and showed that planning happens asynchronously and is determined by the momentary aspects of the problem. No fixed order of operations exists; the plan execution and the steps to be taken, grow out of the problem stage at hand. When planners solve a planning problem, they may start with the top-goal, but very
soon they loose track of the goal structure and then they continue to fulfill the goals that are reachable within reasonable time. The hierarchy very soon vanishes and what remains is some sort of heterarchy. For that reason this planning behavior is called opportunistic.

Although the contrast with the hierarchical approach may be large, a strong similarity is also present. In the hierarchical as well as in the opportunistic approach the fundamental assumption is that planning is problem solving, that can best be described in terms of problem spaces, production rules and goals. That is to say that the basic descriptive structure is the same for both, but that real behavior within the problem space is executed differently.

With regard to the problem space description, hierarchical as well as opportunistic planning differ from the perspective defended by Riesbeck & Schank (1989). The representation of planning problems is described in terms of scripts and frames consisting of objects, slots, and relations. The information in the cognitive system, necessary to make a plan, is semi-hierarchically structured. This means that some kind of representational skeleton or framework is retrieved from memory. Stored plans contain guidelines for resolution of sorts of problems. In this process two stages exist. First a skeleton plan is found, and second the abstract steps in a plan are filled with concrete operations. Although general cognitive processing is involved in making a plan the emphasis in this approach is on the memory system. Plans at different levels of abstraction and in different formats are stored in and retrieved from memory. There are strong similarities with the approach to planning that Hoc (1988) proposed.

Domain of planning. The issue whether the domain for which the planning is done strongly determines the planning process by the planners is normally answered affirmatively. Planning one’s own actions, planning patient admission for hospitals or planning rush orders in the cardboard industry are completely different in process not only in the cognitive system of the planners, but also in its organizational structure. We argue against this strong domain dependency for the following reason. From a generic task perspective (CommonKADS (Schreiber et al., 1993)) planning is a synthetic task. In this task various “things” have to be put together. This synthetic task has a generic structure in which several sub-tasks have to be executed. The implemented models and the empirical evidence suggest that the “what” (the domain) is rather unimportant. Our own research (Van Wezel & Jorna, 1996/1998; Van Wezel, 2001) indicates outcomes in the same direction. The domain and its characteristics determine the constraints the goal functions, but the solution processes in terms of task strategy and task execution are not determined by the domains.

The planning entity (actor). The fourth issue concerns the characteristics of the planning entities. Are human planners, artificial planners, and (professional) organizational planners, although different in nature similar in the characteristics of their processes? Here, again the common sense answer seems to be that of course they are different. The following question then is in what respect are they different. We discuss the details of this question in section 4.

The four points of discussion regarding planning indicate that the kind of process, the strategy within the process, the domain of planning, and the planning actor are not solved issues. On the contrary, one could say. If we redirect our focus of interest from planning to anticipation, we saw that some authors consider anticipation to be a sub-activity within planning. On the other hand, from a higher perspective it could be argued that planning always is a kind of anticipation for which the adequate actions are not foreseen. This might bring us in a similar situation as with planning and problem solving. The one can be defined in terms of the other and the other way around. We would like to argue that planning incorporates anticipation. Anticipation means making a representation of a future situation, but it not necessarily involves the implementation of or the search for the sequence(s) of action that makes the anticipated situation to become true.
This means that a discussion of anticipation implies a discussion about future states which normally always implies (mental) representations, whereas a discussion about planning implies a discussion about goals in the sense of future states, implying representations, and the adequate actions to get to these states. Planning is anticipation in terms of future states as mental representations plus actions. For that reason it suffices that we continue our discussion in terms of the concepts of planning.

Goals formulated as representations, the intended actions to reach the goals and the processes involved all point toward an actor. This actor is the cohesive entity that with certain processes makes the planning of himself for himself or others. The problem is that the actors are different of nature. This implies that we have to look for a conceptual framework to determine and discuss various aspects of the nature of the actors. We do this by “carving nature at its edges”, meaning that we use an analysis of entities in terms of the levels of description of the actors.

3. Levels of description

The kind of actors we are dealing with in the case of making plans are humans, (complicated) software systems, and organizations. These actors can be subdivided along two fundamental dimensions. The first is a physical/biological one, where we discern natural from artificial actors. The second is an ontological one, where we discern individuals from collectives or organizations. For both dimensions we can separate various levels of description. In our discussion we start with the physical/biological dimension. How can we describe various aspects of biological and natural planning entities?

The use of various levels of description is an important means of investigating complex phenomena. The behavior of celestial bodies can be described at a different level compared to that of the behavior of an organization or the behavior of a biological cell. Complex phenomena have to be described at different levels. In the case of actors, also called cognitive systems - for the moment consisting of humans and intelligent software - the levels of description are in general terms a) a (neuro-)physiological/physical description, b) a functional description and c) a behavioral description. Dennett (1978) subsequently speaks of an intentional, a functional and a physical stance and Pylyshyn (1984) describes the levels as the semantic, the syntactic/symbolic and the biological/physical respectively. Newell (1990) uses comparable levels in talking about the knowledge level, the symbol or representational level and the physical/physiological level. We follow the formulations of Dennett (1978).

Descriptions at a physical level occur, according to Dennett (1978, 1987), if we start from the laws of nature. If we have to say why a system does not work anymore, we can use the laws of nature which are formulated in physical terms, that is to say in terms of mechanics, of electromagnetism or of chemistry. Examples of descriptions on this level are "the car does not go any more because the ignition-mixture contains water" or "the computer has no power because there is no net-voltage" or "his motor coordination is bad since not enough neuro-transmitters are released".

Another level of description is the functional level. Dennett (1978) also refers to this as the design stance. A description at a functional level only shows how a system functions properly for a specific task. Within certain boundaries neither the physical realization of mechanisms and/or processes nor the precise physical structure are of importance. One only reverts to physiology or physics if the input-output combination does not do what it is supposed to do. In a functional description, it is important to know what the components of the system are, how they are defined and how the components are connected with each other. In other words, if the input and output of every component is known, it is possible, given a certain input at the beginning of the system, to predict the resulting behavior on the basis of the properties of the states. Examples of statements
of this type are "the programme is such that a change of the printing page always requires a stop for one second" or "I cannot retain the ten-digit telephone number because my short term memory has a limited capacity" or (Dennett, 1978, p. 4): "as the typewriter carriage approaches the margin, a bell will ring" (because of its design).

Dennett's third level of description is the intentional level. This level does not describe in a factual sense, but it ascribes to a system. A system can be considered as an intentional system if wishes, intentions, considerations, and expectations are ascribed to it. This occurs if the system has become so complex that we no longer describe its behavior at the physical or the functional level. Systems that can be approached in this way are computers, dogs, organizations, and humans. For example, if we want to describe the behavior of a chess computer, we cannot learn anything about the analysis of the moves in the system by giving a description at a physical level. A description at the functional level is as problematic as that at the physical level, because the system has become so complicated that one needs a help system in order to keep track of all the input-output combinations of the sub-components. The only thing that can be done is to give a description of the chess computer as an intentional system. However interesting though this intentional position may be, Dennett argues that, in the case of cognitive systems, we are on quicksand, because the description of a "rational" system in terms of rationality means that we keep going round in circles which is the main characteristic of a homuncular explanation. For this reason an intentional ascription must be viewed as a "scientific" loan which has to be repaid in due time.

It is very important to separate the levels of description very carefully, because the conceptual confusion of levels of description leads to category mistakes on the theoretical side and ill-functioning systems on the practical side. To provide an example, if, in describing a memory process, one speaks of components and their input and output representations, no intentional terms, such as "signal-readers, message-understanders or commanders" (Dennett, 1978, p. 12) should appear in the description of the process. Including intentional terms does not explain anything, it only adds terms which have to be explained.

The three levels make it possible to analyze systems from different perspectives. One could even argue that various scientific disciplines match the different levels of description. Psychology for the intentional level, cognitive science and artificial intelligence for the functional level and neurology, biology, chemistry and physics for the physiological/physical level. The common theme in analyzing the actors within the biological/physical level is that the actors are coherent entities. Therefore, this dimension can also be called the individual dimension. The levels of description are related to a coherent entity, whether it concerns a human information processing system or an “intelligent” and complex piece of software and hardware. The other dimension is the ontological dimension. The big separation in this dimension is in individual and organization. The individual can contrast with the organization in that the first is a “natural whole”, whereas the second is not. The question is what do we mean with organization.

Everybody is talking about organizations, but where is the organization? When does an organization exist? Everybody will agree that Shell as an organization not only exists from nine to five and is closed on Saturdays and Sundays. Neither are the buildings and the other artefacts the reason that we can say that Shell exists. In organizational literature (Daft, 2000) it is argued that an organization exists because of the many processes that are carried out. Organizations in this sense are collections of processes. Sometimes the processes themselves are conceived of as independent entities. Daft (2000), for example, says that “organizations are social entities that are goal directed, are designed as deliberately structured and coordinated activity systems and are linked to the external environment” (p. 12). Sorge (in Sorge & Warner, 2001) says that two
meanings of organization should be discerned: organization may refer to a social unity (or collectiveness) and organization may refer to organizational properties. In more general terms an organization can be defined as “the simultaneous functionalization and coordination of human actions with regard to objective goals.” (van Dale, 1995, p. 2144). In this definition the emphasis is on actions that can be gathered in tasks that are constituting elements of processes. In the definition also goals and coordination are mentioned. A goal is immediately related to a primary process, that is to say the reason that the organization exists. Coordination is needed because “entities,” such as actions, tasks, or processes, do not form natural units. They need some kind of coherence or cohesion structure. This coherence can be organized externally, in a legal or financial way, or internally by an interpreting and meaning given entity, which is an actor.

In general, the structural (organizational) coherence is in processes executed by humans and machines, consisting of actions and tasks. This means that ultimately an organization is a construction or a construct.

The returning cornerstone in definitions of “organization” is the process. A process is “an action in its progress” (van Dale, 1995, p. 2378). We want to argue that in the analysis of processes - that is to say the collection of action sequences - the executing entity often is neglected. Often the realization of processes is a highly abstract, almost metaphysical affair in many organizational studies (see Sorge & Warner, 2001). An organization is rooted in the individuals that are part of the organization and can think of the organization. Without thinking of an organization, there is no organization, even if there are constructs and artifacts as buildings and machines. As Sorge (2001, p. 7) says “Of course, there would not be any organization behavior without human behavior.” The basic ingredients of an organization are the intelligent actors. This means that there exists a nesting of a) actors within organizations and b) organizations within actors. The first nesting means that an organization always consists of a collection or group of actors. This makes an organization a multi-actor system. The second means that a set of actors can form an organization, but only in the sense that an actor can think of and reason about what the other actors can do. The other actors in turn have opinions and beliefs, that is to say representations, about the first actor. This implies that an organization as a construct consists of the overlap and sharing of individual representations. The key notions, here, are representation and interpretation. An organization is a representation (and an interpretation) in the eyes of (intelligent) actors. As a consequence, our perspective of organization implies that we can only analyze and study an organization as a multi-actor system.

If we return to the physical, functional and intentional level of description, the question is how this does apply to the organization. We believe that unquestionably only the intentional level of description can be used for an organization. Because an organization has no physical or physiological carrier, it cannot be described at the functional or physiological level. If an organization is described at the functional level it is directed toward processes and actors and here the biological/physical level comes into play. We can summerize our analysis in table I. In the table + indicates that the level of description can be applied, whereas - denies that.

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4. Entities that make plans and entities that are planned

In Section 2, we described four research topics of planning: a) the relation between planning and problem solving, b) the characteristics of the process of planning, c) the relation between the planning domain and the planning task, and d) the characteristics of the entity or actor that makes the plan. This last topic was discussed very concisely.

In this section the topic of the entity that makes the plan is elaborated in greater detail. Thereby, we take the stance that it makes a difference whether you make a plan for your own activities, or a plan for activities that are performed by others (for example, organizational processes). Research indicates that, for the latter case, there are several activities that must be performed (Mietus, 1994). Examples are information collection, capacity determination, sequencing, etc. Somehow, the order of those activities must be determined. In other words, the activities to make the plan must be planned themselves. Is this latter type of planning the same as the former type? The answer “yes” leads to an endless recursion, because planning would be a part of itself. We would be forced to plan the planning activities, and therefore, to plan the planning of the planning activities, and plan the planning of the planning of the planning activities. In earlier work, we have used this 'recursive planning paradox' to assume that planning your own activities is something else than planning the activities that others must perform (Van Wezel, 2001; Van Wezel & Jorna, 2001). In this section, we will describe the differences between the actors with respect to planning from the perspective whether they plan for themselves or plan for others. Furthermore, as follows from section 3, there are all kinds of differences between natural actors, artificial actors, and multi-actor constellations. Singular actors can both plan for themselves and for others. In the discussion whether organizations can plan or not, we take the position that an organization consists of multiple singular actors that perform the planning. This, however, does not imply that organizations can’t be planned for, although a plan that is created for an organization must be executed by it’s members. Therefore, we describe four categories of planning entities: a) humans that plan for themselves, b) humans that plan organizational processes, c) artificial actors that plan for themselves, and d) artificial actors that plan organizational processes.

Humans that plan for themselves: The discussion in Section 2 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.

The discussion whether planning is a form of problem solving or the other way around (Newell & Simon, 1972) can be tackled by stating that both are true. Planning is one of the phases of a problem solving cycle, and because such a planning phase can be a quite complex problem itself, it can be solved by an “inner” problem solving cycle. For example, someone can make a plan for the whole day (go shopping, go to work, make dinner), where distinct planning problems occur that can be tacked separately (e.g., making a separate plan how to make the dinner). This partitioning of a problem also shows why the hierarchical, opportunistic, and heterarchic approaches do not preclude each other (Hayes-Roth & Hayes-Roth, 1979). Parts of a planning problem can be solved hierarchically, and other parts can be solved opportunistically. A human planner can even try to solve it opportunistically first, but when he fails, try it hierarchically. Or the strategy can change due to time pressure: a problem that is usually solved hierarchically is
perhaps tackled opportunistically under time pressure. 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 more adaptation than it is construction from scratch. In this paradigm, planning is about memory, indexing, and learning (Hammond, 1989). Obviously, when a skeleton solution can not be found, a plan must be created from scratch, which places more emphasis on problem solving and less on memory retrieval operations. Thus, plans should be stored in memory 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. There are two senses of learning in the case-based planning paradigm. First, solutions must be remembered so they can be used for new problems. Second, a failure to execute the plan provides an indication that the knowledge that the planner has of the execution world could be faulty. Thus, script models can be seen as adding learning to the paradigms already discussed.

Together, the paradigms of Newell & Simon (1972), Hayes-Roth & Hayes-Roth (1979) and Hammond (1989) provide a cognitive model for human planning. In this model, planning is about how to find the actions that solve a problem or, more general, reach a goal. The process of planning is not neatly hierarchical, but switches in level of abstraction and in the time frame under consideration. The process itself is about formulating goals, finding similar solved goals, finding existing plans, adapting plans, and storing plans in such a way that they can easily be found for future reference.

Although in real life there are always some constraints in doing errands, people mostly experience no real time pressure or only self-imposed pressures. Because doing errands is something most people do every day, it gives a very good impression of what kinds of strategies and representations people use and what cognitive limitations they experience.

The discussion about the real nature of what humans do when they plan is not settled, yet. In well-structured domains or domains where humans have a lot of experience the dominant approach is hierarchical. In ill-structured, highly dynamic, or new domains the strategy mostly resembles an opportunistic way. The discussion is also closely connected with how we represent problems - in production rules or in schemata - and with the function of memory structures. We come back to these issues in the section 5.

*Humans that plan organizational processes:* Planning is a phenomenon that occurs at multiple places in an organization. In its most abstract sense, all activities that involve the determination of the future of the organization are dealing with planning. This includes strategic considerations that determine “where the organization must stand” in 10 years, less abstract issues such as growth targets or product innovations, but also very concrete decisions such as who will work at what time next week, or the exact production times and machine allocations of the production for the following week (Smith & Lassila, 1994; Wilkins, 1990). It is the type of planning about concrete entities that we primarily focus upon. That kind of planning is about coordination of activities of organizational members and the allocation of resources (Myers, 1996). The types of activities and resources vary widely over organizations. A rough categorization that is based on the things that are planned is the distinction between production planning (machines, orders, machine operators), staff planning (shifts, personnel), and transportation planning (vehicles, routes, chauffeurs, shipments). A common ground for planning problems in organizations is that it basically concerns 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, Veloso, 1996; 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), 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. Most analyses are limited to task models, for example, McKay et al. (1995), Mietus (1994), Dorn (1993), 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’ discontent, to attribute the causes of poor organizational performance to the planning, or to analyze and design planning practices. For example, the cause of poor factory performance can be the mere impossibility of matching the requirements (e.g., there is not enough capacity available to meet the demands), the clumsiness of the organization of the planning, the inadequacy of the human planner to solve complex problems, the absence of specialized planning support in practice, or a combination of these factors.

In order to make generic statements about the planning task, it is important to know what the task performance depends upon (notice 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 on 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.

Jorna et al. (1996, p. 74) describe a number of organizational aspects of the planning that can be used to complement the description of a task as a collection of sub-tasks (the word “organizational” here refers to the organization of the task and therefore relates to the task strategy and not to the organization in which the planner works). A first distinction deals with the temporal relation between planning and execution. The planning horizon can be fixed or rolling, and both planning and plan execution can be organized in time buckets. A second distinction looks at the content of the planning. The planner can often use previously created (partial) plans as a starting point, and there can be patterns that the planner can use (e.g., fixed sequences of production, or fixed shift patterns in personnel planning).

Clearly, approaches of planning for yourself deal with other questions than approaches for organizational planning. In section 5, we will analyze in what way planning of organizations differs from planning of your own actions. First, however, we will look at planning by artificial agents.

Artificial agents ((simulated) robots; computers) that plan for themselves: Artificial agents that plan their own behavior needs (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 human and artificial agents, planning of artificial agents is very much related to the problem solving approaches as described in section 2. Techniques from Artificial Intelligence are used to let such agents function more or less independently in their environment, and react on unforeseen events (Sacerdoti, 1975; Curry & Tate, 1991; Beetz, 2000). Much of the planning research in Artificial Intelligence 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 & Nilson, 1971). Most Artificial Intelligence methods, whether they are called algorithms, procedures, or heuristics, are based on state space descriptions. An agent or actor finds himself in a state, in which it can
perform a limited number of actions. An action changes the state, after which it can again perform a number of actions (Meystel, 1987). The agent keeps on choosing and performing actions until the state it gets in somehow satisfies its goal. Planning is one way in which the agent can reach its goal. Other ways are, for example, trial and error or full search. To make a plan, an agent somehow anticipates the future by simulating the actions he will make. This requires the existence of (internal) representations. The original link to physical entities has been relinquished somewhat so planning agents are now often only computer programs that find a plan merely for the sake of research, and therefore not necessarily execute it. In this paradigm, planning is searching for a sequence of actions that will bring the agent from its current state in the goal state. Models of human problem solving, that were discussed in the previous subsection, have provided researchers in Artificial Intelligence with starting points for the planning functions of their artificial agents. Many examples are based on the initial General Problem Solver (GPS) of Newell & Simon, which constructs a proposed solution in general terms before working out the details, the opportunistic planning paradigm, and script-based planning. Here it becomes clear that models of human problem solving are closely related to the anticipation and planning of artificial agents.

Machines (computers) that plan organizational processes: A lot of planning research deals with automatically finding (or generating) plans for future organizational processes. Usually, this 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 sciences: a problem space is set up and the aim is to find a state that satisfies all constraints and scores well 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).

Models exist for all kinds of processes such as routing of trucks, staff scheduling, job shop scheduling (Fox, 1983, Mckay et al. 1988), and flow shop scheduling. Some of the scientific fields that deal with this kind of research are Operations Research (e.g., linear programming, nonlinear programming, all kinds of heuristics), and Artificial Intelligence (constraint satisfaction programming, genetic algorithms). Although the approaches of course differ, they also possess common characteristics. They are based on an analysis of the entities that are scheduled. For example, to make an algorithm for a planning problem in a flow shop one must know the capacities of machines, setup- and cleaning times, the number and sizes of orders, the processing characteristics, etc. All these characteristics can be used to determine the best way to navigate through the problem space of possible solutions. An example of how such knowledge can be used in an algorithm is to start to plan on the bottleneck first, because it is often the sensible thing to do in order to avoid problems in a later stage of the planning process. Most techniques are somehow limited in the kinds of characteristics that they can handle. For example, a linear programming model cannot deal with nonlinear constraints, and temporal reasoning is tacky to implement in many mathematical techniques. Therefore, the domain analysis must be translated in the quantitative model, and the solution must be translated back to the application domain (Prietula et al. 1994).

Computer programs that create schedules are seldom used on their own. The fact that information is lost during abstraction and translation of the domain into the model is widely recognized. For that reason, mathematical solutions techniques are usually used in the context of decision support systems, where a planner can manipulate and change a plan manually so he is not bound to the solutions that is presented by an algorithm.
As with the distinction between humans that plan for themselves and humans that plan for organizational processes, the approaches that deal with computer programs that plan for their own actions differ from approaches that deal with computer programs that plan for organizational processes. The differences have to do with the characteristics of the actors and will be analyzed in the next section.

5. Analysis of the entities
We now have nearly all the ingredients available to make a reasonable comparison between the different perspectives on planning. The comparison is between the individual who is making a plan for himself and the individual who is making a plan in and for the organization, where the individual can be either natural or artificial. The goal of this comparison is to gain insight in the limitations that the approaches for the respective perspectives have and to see where those limitations come from. In the end, this should lead to a better understanding of the “planning” phenomenon, and perhaps the respective approaches can learn from each other.

The aspects that will be discussed in detail and that are used for comparisons are: a) closed versus open world assumptions; b) the information processing mechanism and its architectural components such as memory and attention; c) the representations; d) communication, meaning and interpretation; e) the characteristics of coordination; and f) aspects of execution of the plan.

"Closed world“ vs. “open world“: Looking from a generic perspective, the planning task itself can be called a synthetic or configuration task. It is well known that these kinds of tasks are very difficult to complete, by humans alone as well as with the support of software. From a task 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 combined with calculations. 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 and changes these in such a way that a solution is found. Formulated in other words, the phases of (1) initial state, (2) search, no solution and (3a) start again with a new 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, especially if humans have to make a planning. If the second phase does not give an optimal or satisfactory outcome given the constraints and goal functions, 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 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 or established fixed solution and (3b) adjustment of initial state according to the “fixed” solution reality. This sequence of activities is what human planners whether in the industry or doing errands frequently and with great success do, but formalizing such knowledge for use in a computer program or robot is very tricky.

Information processing mechanism and architectural components: An information processing mechanism operationalizes the way information is selected, combined,
created and deleted. The mechanism itself needs a physical or physiological carrier. Various possibilities are already present, such as the brain as our neurological apparatus, 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. 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 take place in the system. The cognitive system and the chip are internal, but they differ in the sense 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 reckoned with during planning. This is the case when a planner makes a plan that is executed by others.

An architecture is a set of components of which the arrangement is governed by principles of form or function (Curry & Tate, 1991). A cognitive architecture consists of memory components, of attention processors, of sensory and motor components and of various kinds of central processors. The division is by function and the components are all implemented in neurological structures in the brain. Two other material structures for architectural layout are the chip and the constellation of a group of individuals. The same kind of components can be discerned for the computer, consisting of memory, sensory and motor components and central processors. For a group of individuals the architecture is different because the constituting elements are similar as for the individuals, but the roles and tasks are different. Again, the discussion about the character of the architecture boils down to a discussion about internally or externally defined. Internal is the cognitive architecture, whereas chips and groups of people can be dealt with externally.

(Internal) representations: 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, Dölling, 1998; Smolensky, 1988; Jorna, 1990). The basic idea 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. A system that internally symbolizes the environment is said to have representations at its disposal. 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. 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, for example because it cannot represent its environment or because it cannot manipulate its representation of the environment adequately. Furthermore, an entity that makes a plan for others can additionally have this problem with respect to the entities that must execute the plan. Representations are also immediately relevant for anticipation. A description of a future state in whatever symbol or sign system is the core of any discussion on anticipation.

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 restrictions on the kinds of symbols or signs that are used for the exchange. If we relate this to the before mentioned discussion about representations, the various kinds of signs have different consequences. Clearly, sign notations are more powerful, but also more restricted than sign systems, which in turn are more powerful than just sign sets (Goodman, 1968; Jorna, 1990; Jorna & van Heusden, 1998). Unambiguous communication requires sign notations, 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 less powerful - in terms of semantic requirements -, but more flexible sign systems. This means that computers can 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 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, various coordination mechanism can be found, such as a hierarchy, a meta-plan, mutual adjustment, a market structure, and many others (Thompson, 1967; 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 its outcomes in reality are valued differently in planning your own actions and in planning actions of others (i.e., organizational processes). The 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 errand tasks 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.

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<tr>
<th>Natural actor</th>
<th>Artificial actor</th>
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<td><strong>Close vs. open world</strong></td>
<td><strong>Organization planning</strong></td>
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<td>Self planning</td>
<td>Fixing the reality to the solution that is found; reformulate the starting-point</td>
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<td>Information processing mechanism</td>
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<th><strong>Information processing mechanism</strong></th>
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6. Conclusion
Planning and anticipation are closely connected. Anticipation is about the representation of goals, whereas planning implies representations and the (possible) actions that are required to reach the goal(s). We contend that every system that has and uses representations is an anticipatory system. However, a system with representations that does not undertake actions is a sterile system. Therefore, the discussion in this article is about actors that plan or planning systems. Making the step from anticipation to planning does not solve the problem of making clear what we are talking about. Planning is a much debated, highly controversial and multi-faceted issue. We stated that various kinds of actors can be discerned: natural, artificial and collective actors. We also discussed that there is no easy exchange between the various planning approaches. Management and organization, cognitive science, mathematics, artificial intelligence and economics, although all are discussing important issues in planning, do not start with the same problem formulation. We approached the issue of planning by looking especially at the entity that makes a plan for him/herself and for others. By looking at the kind of actor, their characteristics and the level of description of the entities and components involved, we stated that discussions about planning do not have to end in controversies and avowed misunderstandings. We have sketched the components and ingredients of planning actors and we showed that comparisons can be made and that positions can be clarified.

Are there good reasons to discuss planning issues in greater detail? We think there are two good reasons. The first is that any planning (or weaker: any anticipatory) system ultimately acts in an open world. There is nothing wrong with the closed world assumption, but in the end it is part of an open world. Switching between open and closed worlds is something human information processing can easily do, but it is difficult to get it realized for artificial (software) and collective systems (organizations). In the literature this is called the reformulation problem, and we discussed it in section 4. The second reason is that whether we like it or not, more and more of our fellow “intelligent” companions are software actors (agents) and we are interacting with them. Artificial and collective actors are also planning, but something seems to be different. This incompatibility cannot be solved by imposing one approach on all kinds of actors. It can
only be realized if we know what precisely natural actors do when they make plans. This perspective is also a way of anticipating the future.

References


