TOWARDS A COMPUTATIONAL THEORY OF HUMAN DAYDREAMING*

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ABSTRACT

This paper examines the phenomenon of *daydreaming:* spontaneously recalling or imagining personal or vicarious experiences in the past or future. The following important roles of daydreaming in human cognition are postulated: plan preparation and rehearsal, learning from failures and successes, support for processes of creativity, emotion regulation, and motivation.

A computational theory of daydreaming and its implementation as the program DAYDREAMER are presented. DAYDREAMER consists of 1) a scenario generator based on relaxed planning, 2) a dynamic episodic memory of experiences used by the scenario generator, 3) a collection of personal goals and control goals which guide the scenario generator, 4) an emotion component in which daydreams initiate, and are initiated by, emotional states arising from goal outcomes, and 5) domain knowledge of interpersonal relations and common everyday occurrences.

The role of emotions and control goals in daydreaming is discussed. Four control goals commonly used in guiding daydreaming are presented: rationalization, failure/success reversal, revenge, and preparation. The role of episodic memory in daydreaming is considered, including how daydreamed information is incorporated into memory and later used. An initial version of DAYDREAMER which produces several daydreams (in English) is currently running.

1. INTRODUCTION

Daydreaming is the spontaneous human activity of recalling or imagining personal or vicarious experiences in the past or future. Although sometimes viewed as a useless distraction from the task at hand, we postulate the following important roles of daydreaming in human cognition:**

- Daydreaming supports *planning for the future.* The anticipation of possible future situations allows the *formation of desirable responses* to those situations in advance and thus *improves efficiency.* By assessing the consequences of alternative courses of action in advance, daydreaming assists in *decision-making.* Future daydreaming also provides a *rehearsal* function to increase accessibility of responses and the skill with which they can be performed.
- Daydreaming supports *learning from successes and failures.* Examination of alternative actions in a success or failure experience allows one to *learn planning strategies* to be remembered for use in future similar situations. In addition, daydreaming allows the ongoing *reinterpretation of past experiences* in light of new information or if there was insufficient time to digest an experience when it occurred.
- Daydreaming supports processes of *creativity.* The *generation of fanciful possibilities* can lead to the discovery of new and useful solutions to a problem. While daydreaming about one thing, it is possible to stumble into a solution to another problem, i.e., *fortuitous recognition of analogies* among problems is possible. Daydreaming occurs in the context of an episodic memory which is constantly subject to *revision.* Each time a problem is examined, new information may be available that will enable a better, different, or more creative solution. Ideas generated while daydreaming often provide the initial *inspiration* for a creative work and further daydreaming, e.g., of success or praise from

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** See Mueller and Dyer (1985) for a more detailed discussion of the functions of daydreaming, both for humans and intelligent computer systems.

others, may increase the *motivation* to realize it.

- Daydreaming supports *emotion regulation*. For example, upon a failure experience, daydreaming enables one to *feel better* or *feel worse* depending on success or failure in rationalizing that experience. Fear associated with a future event may be reduced if one daydreams about effective plans to succeed in that event, or increased if daydreams of likely failure result.

1.1 Obtaining Daydreaming Protocols

Daydreaming is unlike most other human activities which artificial intelligence researchers attempt to model, since it is a behavior which is not manifested externally. The fact that there is no apparent "I/O" while a person is daydreaming presents several problems for us: How do we know when a person is daydreaming? Given that a person is daydreaming, how can we find out what that person is daydreaming about?

Several methods for gathering data about daydreaming have been used in the past. Varendonck (1921, pp. 215-216) used a form of *retrospective report* in which he first recalled the final portion of a daydream and then worked his way backward. Klinger (1971) and Pope (1978) used the technique of *thinking aloud* in which subjects would verbalize their stream of thought as it occurred. In the method of *thought sampling* used by Klinger (1978), subjects would carry a beeper with them. When the beeper sounded at a random time, subjects would fill out a questionnaire asking them to describe their most recent thoughts.

Retrospective reports are generated by recalling a memory trace of the stream of thought which is laid down in episodic memory (Tulving, 1972) during daydreaming. Although this memory trace fades with time, immediate transcription will produce fairly accurate recall. Ericsson and Simon (1984) argue that for cognitive processes of intermediate duration, retrospective reports will give the same information as thinking-aloud protocols, provided certain criteria are met. However, experiments conducted by Pope (1978) have suggested that thinking-aloud protocols of daydreaming may inhibit the subject or slow down and thus modify the stream of thought.

1.2 Example Episode and Resulting Daydreams

In order to investigate the phenomenon of daydreaming, transcripts of daydreams have been obtained from a variety of sources. Wherever possible, we have sought immediate retrospective reports. The discussions which follow will refer to the episode below and resulting daydreams, which are an edited composite of several daydream transcripts:

NUART-EPISODE

Last night I went alone to the Nuart Theater to see a film. This actress whom I've always had a crush on also came alone and happened to sit down near me. I recognized her and started a conversation. We talked quite a while. At one point, she mentioned the obviously well-known director of the film we were about to see and I didn't know the name. I was embarrassed. I finally asked her if she'd like to go have a drink after the film. She said she had other plans. I was disappointed.

NUART-DAYDREAM1

I feel embarrassed for not knowing who the director was. I should've pretended to know who the director was. In the future I'll read up on the film before I go.

NUART-DAYDREAM2

I'm disappointed that she didn't want to go out with me. She might change her mind if I were to ask her out again. I would call her up, but I don't have her telephone number. I should've asked for her telephone number when I had the chance. I imagine that I asked for her telephone number and she gave it to me. Then later I call her up and she accepts my offer for a date. I regret not having asked for her number. But she's a movie star and out of my league. I feel better because no matter what I might have done, she wouldn't have gone out with me.

NUART-DAYDREAM3

I'm disappointed that she didn't want to go out with me. I imagine that she accepted my offer and we soon become a pair. I help her when she has to rehearse her lines. I go to the studio to watch her work. When she has to do a film in France, I drop my work and travel there with her. As we continue to travel, I begin to miss my work. I become unhappy and feel unfulfilled. She loses interest in me, because I have nothing to offer her. It's good that I didn't get involved with her, because it would've led to disaster. I feel less disappointed that she didn't accept my offer.

NUART-DAYDREAM4

I'm angry that she didn't accept my offer to go have a drink. I feel rejected. I imagine that I pursue an acting career and become a star even more famous than she is. She remembers

meeting me a long time ago in a movie theater and calls me up. I'm glad she admits she was wrong about me. I go out with her, but now she has to compete with many other women for my attention. I eventually dump her.

1.3 The DAYDREAMER Program

DAYDREAMER is a computer program designed to implement and test a computational theory of daydreaming. The program operates in two modes: *daydreaming mode* and *performance mode*. In daydreaming mode, the program daydreams continuously until interrupted. Performance mode allows the program to demonstrate that it has learned from daydreaming. DAYDREAMER takes as input simple situational descriptions, such as `accidentally meeting a movie star`, or `being fired from one's job`, and produces as output 1) actions that it would perform in the given situation, and 2) daydreams, all in English. DAYDREAMER learns as it daydreams by indexing daydreams, planning strategies, and future plans into memory for future use.

DAYDREAMER is composed of:

- **a scenario generator** consisting of a *planner* (Fikes & Nilsson, 1971; Meehan, 1976) and *relaxation rules*,
- **a dynamic episodic memory** (Tulving, 1972; Kolodner, 1984) of experiences used by the scenario generator,
- a collection of *personal goals* (Maslow, 1943; Schank & Abelson, 1977) and **control goals** which guide the scenario generator,
- **an emotion component** in which daydreams initiate, and are initiated by, emotional states arising from goal outcomes, and
- **domain knowledge** of interpersonal relations and common everyday occurrences.

In the sections which follow, we describe the above components. We should note that our theory is *not* intended to account for 1) mental imagery or the quasi-sensory experiences which are often a part of daydreaming (Singer & Antrobus, 1972; Singer, 1975), 2) the altered state of consciousness (called "fore-consciousness" by Varendonck, 1921) which often accompanies daydreaming, and 3) the subjective "feeling" of consciousness; see, for example, Nagel (1974) and Dennett (1978) for a discussion of the philosophical problems with such an endeavor.

2. THE ROLE OF EMOTIONS AND CONTROL GOALS IN DAYDREAMING

How and when are daydreams triggered? Given that many differing daydream sequences are possible at any given moment, what determines the way in which a daydream unfolds? We postulate a set of goals, called *control goals*, which are activated in part by emotions, and which both help trigger and direct daydreaming. Once a control goal is activated, the *scenario generator*, discussed in Section 3, generates a sequence of events according to that control goal. The purpose of control goals is generally to provide helpful modification of emotional state in the short run and to help achieve personal goals in the long run. Not all control goals serve both functions. Some in fact serve one function while ignoring or even harming the other.

The study of daydreaming is interrelated with the study of emotion. Previous work on simulation of human emotions has involved modeling the comprehension by a reader of the emotional reactions of story characters (Dyer, 1983b) or modeling emotional responses to real-world situations and the influence of emotional state on subsequent behavior (Pfeifer, 1982). However, a complete model of human emotions must not only account for the relationship between emotions and events in the external world, but also between emotions and *internal events*, i.e., imagined or expected outcomes (Abelson, 1981), or daydreams. Instead of simply modeling the single emotional response to an event, one must model the entire *sequence* of responses and daydreams resulting from an event, perhaps at last resting on a final emotion.

In DAYDREAMER, emotions activate control goals which result in daydreaming. Daydreaming in turn results in modification of emotional state (in part as a result of the success or failure of control goals), directing the future course of daydreaming by causing the activation of other control goals. Thus we have a feedback loop in which 1) emotions trigger daydreams and 2) daydreams modify existing emotions and trigger new emotions, which trigger new daydreams, and so on. An important part of our research involves specifying an intuitive set of control goals and their interactions with scenario generation and emotion processes. In this section, we discuss four control goals which commonly appear in daydreaming:

- **Rationalisation:** generating reasons for why an outcome is satisfactory to the daydreamer in order to reduce negative emotions and maintain self esteem.
- **Revenge:** reducing negative emotions through imagined retaliations after a goal has been thwarted

by another.

- **Failure/Success Reversal:** altering reality by imagining scenarios in which failures were prevented or in which successes failed to come about in order to learn future planning strategies.
- **Preparation:** generating hypothetical future scenarios in order to learn planning strategies and/or specific actions to be used in possible future situations.

2.1 Rationalisation

In DAYDREAMER, recall of a goal success produces a positive emotion, while recall of a failure produces a negative emotion (Dyer, 1983b). Negative emotions resulting from recalled failures activate *rationalization* control goals. Rationalization, which involves finding a reason why a particular negative outcome is satisfactory, serves to reduce the intensity of a negative emotion associated with that outcome. In effect, failures result in a form of "cognitive dissonance" (Festinger, 1957) which must somehow be reduced. The scenario generator realizes a rationalization control goal through planning. There are many ways of rationalizing a failure.

In NUART-DAYDREAM3, the method for rationalization is to imagine that the goal in question succeeded instead of failed, and then imagine that this goal success in fact leads to a worse goal failure. Another method of rationalizing failures involves playing out the consequences of a goal failure and discovering that a more important goal success may be achieved.

Another method for rationalization is suggested by attribution theory (Heider, 1958; Weiner & Kukla, 1970). An *attribution* is the cause or causes that one attributes to a past success or failure. Attributions have an impact on emotional state. For failures, finding an *external attribution*, i.e., attributing the failure to another person, lack of luck, environmental factors, lack of ability, lack of effort, or fatigue, will often reduce a negative emotion resulting from blaming oneself for a failure. Thus external attribution is another possible plan for rationalization.

2.2 Revenge

The emotion of ANGER results when someone else causes DAYDREAMER a goal failure. The *revenge* control goal is activated upon presence of ANGER and serves the function of substituting a positive emotion for the negative emotion associated with the failure. An example is NUART-DAYDREAM4, where DAYDREAMER imagines that the actress now pursues him but he rejects her. Activation of control goals such as rationalization and revenge in response to an emotion, rather than to an abstract situation, is supported by experiments by Weiner (1980), which found that the presence of the emotion was required.

2.3 Failure/Success Reversal

Another control goal which is initiated upon a negative emotion resulting from a recalled failure is that of *failure reversal*, whose objective is to generate a means by which the failure could have been prevented and a success achieved. This control goal enables learning through the abstraction of generated alternatives to planning strategies for use in future similar situations.

In NUART-EPISODE, there are two failures: the failure of a social regard preservation goal resulting in the emotion of EMBARRASSMENT, and the failure of the goal to go out with the movie star resulting in emotions of DISAPPOINTMENT and REJECTION. Several failure reversal daydreams result. NUART-DAYDREAM1 involves having pretended to know the name of the director. NUART-DAYDREAM2 involves having asked the star for her telephone number and having received it.

Positive and negative emotional response to goal success and failure occur during imagined episodes just as during real episodes. Thus when DAYDREAMER imagines a way of avoiding a failure and achieving a success, a positive emotion results initially. However, it is often followed immediately by the renewal and intensification of the negative emotion associated with the failure. Thus failure reversal actually has a negative emotional function: for the sake of learning, it allows a negative emotion to be intensified. As a consequence, DAYDREAMER generates: "I regret not having asked for her number" in NUART-DAYDREAM2.

A *success reversal* control goal is sometimes pursued upon a recalled success. Why do people imagine failures as well as successes in their daydreams? It is well known that people learn from actual failures; see, for example: (Schank, 1982; Dyer, 1983a; Dolan and Dyer, 1985). It is reasonable to expect that it is possible to learn from imagined failures as well. By noting the causes of daydreamed failures in memory, one may avoid similar failures in the future.

2.4 Preparation

The *preparation* control goal is activated when thinking about a possible future situation or upcoming event which is emotionally charged. This control goal serves the following functions. First, it al-

lows one to be prepared, i.e., it increases the chances of success in the future event. Second, it serves to reduce negative emotions such as anxiousness if effective plans which lead to success are found. An example of plan preparation and rehearsal occurs in NUART-DAYDREAM2, where DAYDREAMER rehearses the plan of asking the actress out and spots the planning error of not having asked for her number.

A striking example of the plan rehearsal aspect of daydreaming occurred in a case where a friend (F) of the second author was stung by a bee, whereupon F experienced a strong allergic reaction to the bee venom. F was rushed to the hospital and treated in time to avoid anaphylactic shock. F stated that, for an entire year after this experience, F would spontaneously daydream about being stung. These daydreams were not repetitions of the original event, but began by imagining being stung in various situations, e.g., by a pool, at the beach, while at a party, while biking, while alone at home, etc. Each daydream consisted of imagining what F would do in case F's bee sting kit was inaccessible, in case the phone was out of order, in case the car broke down, and so on. F claims now to have rehearsed plans for a large number of hypothetical circumstances, e.g., using ice from the refrigerator, knowing where a hospital is and driving at breakneck speed to a hospital before collapsing, etc. This case is rather dramatic because the original goal threat was to a very high-priority goal, i.e., a health preservation goal. The function of daydreaming in this case was to rehearse and examine plans in imagined situations. Clearly, daydreaming here provides an advantage over planning systems which only initiate planning when posed with the actual occurrence of a goal threat or goal failure. Preparation-based daydreams tend to be triggered by emotions of fear. Thus, generating this class of daydreams involves specifying a process model of what might be called "worrying" when observed in people.

3. REALIZING A DAYDREAM THROUGH SCENARIO GENERATION

How are the various imaginative sequences of events which make up daydreaming generated? In DAYDREAMER, the *scenario generator* generates daydreams in response to and under the guidance of control goals. We propose that the basic mechanism for scenario generation is *planning* (Fikes & Nilsson, 1971; Sacerdoti, 1974; Meehan, 1976), i.e., generating a sequence of actions necessary to achieve a goal. However, the scenario generator differs from traditional planning mechanisms in several fundamental ways. First, instead of relentlessly pursuing a given goal, the scenario generator operates as an ongoing process under numerous, often conflicting, personal goals. It is possible to start planning for one goal only to abandon that goal in pursuit of another. Second, the scenario generator incorporates relaxations which enable it to generate scenarios which are fanciful, i.e., non-realistic solutions to problems. Third, the scenario generator incorporates an episodic memory of experiences which influences the planning process 1) by providing the experiences which are the subject matter of daydreaming and which trigger activities such as attempting to learn from a failure or rationalization, and 2) by providing a source of knowledge for use by the scenario generator in generating possible events or sequences of events. In this section, we discuss the first two above aspects of the scenario generator. The third aspect, the role of episodic memory, is discussed in Section 4.

3.1 Daydreaming Is Influenced by Multiple Personal Goals

In a wish-fulfillment daydream (Freud, 1908; Varendonck, 1921), the course that a daydream takes is determined by a wish of the daydreamer. Where do wishes come from? In addition to control goals, DAYDREAMER has a large number of *personal goals*, including: health, food, sex, friendship, love, possessions, self esteem, social esteem, enjoyment, and achievement. How does the scenario generator choose which goals or wishes to focus upon at any given point? Minsky (1977) espoused a computational theory of the mind as a society of intercommunicating and conflicting entities. He described a child playing blocks: Internally, the WRECKER in the child wants to destroy the tower being built by the BUILDER. Meanwhile, the I'M-GETTING-HUNGRY entity is growing in strength. As the control of the BUILDER weakens, the child destroys the tower and gets up to go home and eat. Schank and Abelson (1977) constructed an elaborate taxonomy of goal states and interactions while Wilensky (1978) showed how knowledge of goal competition and goal conflict is needed to understand stories involving multiple, interacting narrative characters.

In DAYDREAMER, goals are organized into a *goal tree* (Carbonell, 1980) which specifies the relative importance of each of the goals at any point in time. When confronted with several competing goals, the scenario generator pursues a course of action which leads to the satisfaction of the more important goal. For instance, in NUART-DAYDREAM3, DAYDREAMER imagines that success in the relationship leads to loss of his job. Suppose, however, that he were beginning to grow tired of his job. In this case, daydreaming that he goes to France might more likely lead to imagining that he finds a better job and begins an entirely new career.

3.2 Relaxation of Constraints

A collection of relaxation rules allow the generation of fanciful scenarios. In particular, the following constraints may be relaxed in planning:

- **Behavior of others:** DAYDREAMER imagines that the movie star accepts his offer in NUART-DAYDREAM3.
- **Self attributes:** one might imagine being an olympic athlete or being a famous movie star.
- **Physical constraints:** one might imagine being invisible or being able to fly.
- **Social constraints:** one might imagine starting a food fight at a fancy restaurant.

The scenario generator does not always employ relaxation rules. The level of relaxation can be varied depending on what control goals are currently active. For example, if the daydreamer is pursuing a failure-reversal control goal whose objective is to generate realistic ways of having prevented a failure (e.g., NUART-DAYDREAM1), then the relaxation level is set on LOW. If, however, DAYDREAMER is pursuing a revenge control goal whose objective is to generate a fanciful retaliation (e.g., NUART-DAYDREAM4), then the relaxation level is set on HIGH. It is also important to *assess* the level of relaxation which led to a given scenario in order to avoid raising expectations, since raised and failed expectations lead to negative emotions. The result of such assessment can be seen in NUART-DAYDREAM2, where DAYDREAMER imagines "But she's a movie star and out of my league ... no matter what I might have done, she wouldn't have gone out with me."

In standard planning systems such as ABSTRIPS (Sacerdoti, 1974), relaxation of operator preconditions is employed to reduce the amount of searching needed to solve a problem. However, in daydreaming, relaxation rules may actually *increase* the amount of searching that is done, since such rules enable the generation of numerous imaginative situations which are not realistic methods of achieving current personal goals. Still, such explorations may prove useful in the future, may enable the fortuitous discovery of realistic solutions, or may simply serve some other function such as emotion regulation.

4. THE ROLE OF EPISODIC MEMORY IN DAYDREAMING

After a daydream, what remains in memory? How is information which is incorporated into memory during daydreaming used in the future? That is, how does one *learn* from daydreaming? First of all, one may be skeptical of the ability for humans to remember their daydreams and thus doubt that it is truly possible to learn from them. However, the mere fact that it is possible to obtain transcripts of daydreams from people proves that some daydreams are remembered, at least for a short while. Moreover, many subjects have reported, long after the fact, daydreams that they remember having had (Singer & Antrobus, 1972). Varendonck (1921, p. 327) reports near complete recall of his daydreams during writing: "when I am composing letters I often afterwards write them almost exactly as I worded them in my phantasy." Even subtle memory modifications may occur during daydreaming. Neisser's (1982) analysis of the testimony of John Dean shows that he often remembered conversations in terms of his own fantasy about how those conversations *should* have been, rather than how they actually were.

The *dynamic episodic memory* (Tulving, 1972; Schank, 1982) of DAYDREAMER is its long-term memory of personal or vicarious experiences and daydreams. This memory is called *dynamic* because it is constantly being modified during daydreaming. Thus not only are actual experiences available for use at any point, but so are previously daydreamed ones. This gives rise to a dynamic behavior dependent on previous external *and internal* experiences.

DAYDREAMER incorporates the following information into memory as it daydreams:

- entire daydreams,
- future plans or actions formed during daydreaming, and
- planning strategies formed during daydreaming.

How is information indexed in episodic memory so that it is available at an appropriate time in the future? Once information is retrieved, how is it applied to the current situation? Our work on mechanisms for storage, organization, retrieval, generalization, and application of experiences in episodic memory builds on previous work by Kolodner (1984), Schank (1982), and Anderson (1983). Episodes (both daydreams and personal or vicarious experiences) are organized in and retrieved from dynamic episodic memory according to surface-level similarities as well as Plot Units (Lehnert, 1982), emotions and abstract themes (Dyer, 1983a). The decision to organize episodes by emotions is also partly supported by the work of Varendonck (1921, p. 192) and Bower and Cohen (1983).

4.1 Indexing Entire Daydreams in Episodic Memory

How are entire daydreams indexed in memory for later use? Suppose that at some point in the past, DAYDREAMER had been interviewed for a job he wanted, was turned down, and had the following daydream:

JOB-DAYDREAM

I'm angry at the interviewer for not hiring me. I imagine that years from now I am president of a large company. The interviewer has lost his job and comes to me for employment. I tell him that he doesn't have the necessary qualifications.

In order to recall this daydream in the future, DAYDREAMER indexes it under the RETALIATION Plot Unit,* which represents the abstract situation of a person A achieving a positive outcome by causing a negative outcome for B, where B had originally caused a negative outcome for A. DAYDREAMER also indexes the daydream under REJECTION, which is a negative emotion of a person A resulting from the failure of A's goal to activate a positive relationship R with a person (or group) B, where that failure is caused by B.

4.2 Recalling and Using Recalled Episodes

Daydreams have a certain amount of coherence to them. We believe that this coherence is partially provided by abstract knowledge structures such as Plot Units. Once a control goal is activated, the scenario generator must select and execute a plan to achieve it. Plans for achieving control goals may often be captured by Plot Units, e.g., one plan for the revenge control goal is RETALIATION. Realization of plans for achieving control goals expressed as Plot Units may be simplified through reminding of appropriate episodes indexed by those Plot Units.

Plans for achieving the rationalization control goal may also be expressed in terms of Plot Units. One plan is expressed by the MIXED BLESSING Plot Unit, employed in NUART-DAYDREAM3, which represents the abstract situation of a goal success leading to the failure of another goal. Here the MIXED BLESSING Plot Unit is realized as a fantasy in which dating the actress leads to eventual failure of the relationship and DAYDREAMER's career. Another plan for rationalization is captured by the SUCCESS BORN OF ADVERSITY Plot Unit, which represents the abstract situation of a goal failure leading inadvertently to the success of another goal. Here we could imagine a daydream in which, as a result of being turned down, DAYDREAMER imagines drowning his sorrows at a bar and by chance meeting a more beautiful actress.

Once JOB-DAYDREAM is indexed in memory, when might it later be recalled? Consider the situation of NUART-EPISODE in which DAYDREAMER feels REJECTION and ANGER toward the movie star. The ANGER activates a revenge control goal. Next, the scenario generator will activate the RETALIATION Plot Unit in attempting to realize this control goal. JOB-DAYDREAM, which is indexed under RETALIATION and REJECTION, will then be recalled. The scenario generator now adapts this daydream to the situation of NUART-EPISODE in order to achieve the active revenge control goal and the following daydream is produced:

NUART-DAYDREAM5

I'm angry that the actress didn't want to go out with me. I imagine that years from now I am an influential director. The actress is having trouble finding work and comes to read for a part in my next film. I tell her that I can't use her.

A recalled experience or daydream is adapted to the current situation through *analogy*. The major correspondences which make up the analogy may be identified by the abstract structures used to recall the episode. In our example, the interviewer may be seen to be analogous to the actress, since they occupy the same roles in their respective REJECTION and RETALIATION structures. Similarly, the EMPLOYER-EMPLOYEE relationship of JOB-DAYDREAM can be seen to be analogous to the FRIENDS relationship of NUART-EPISODE. The scenario generator must now complete a scenario analogous to JOB-DAYDREAM in the NUART-EPISODE context. Analogous details are filled in using the same planning knowledge that the scenario generator would need to generate NUART-DAYDREAM5 from scratch. However, in this case, less effort is required (Carbonell, 1983).

The use of recalled episodes is not limited to the generation of entire daydream sequences. Episodic memory is also useful for suggesting possible continuations, or next events, of an ongoing scenario. For example, when DAYDREAMER imagines he is going out with a movie star in NUART-DAYDREAM3, he is reminded of the time he helped an actor friend rehearse for a play. By analogy DAYDREAMER produces the following scenario event in NUART-DAYDREAM3: "I help her when she has to rehearse her lines." Similarly, a reminding of a recent magazine article about an actress going to France to shoot a film leads DAYDREAMER to imagine: "When she has to do a film in France, I drop my work and travel there with her."

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* Plot Units were developed by Lehnert (1982) to represent narrative plots. Plot Units consist of abstract configurations of positive and negative outcomes linked to mental states by initiation, termination and coreference links. By combining Plot Units, larger plot structures can be created dynamically.

5. CURRENT STATUS

An initial version of the DAYDREAMER program has been constructed using GATE (Mueller & Zernik, 1984), an integrated set of graphical artificial intelligence development tools for the T language (Rees, Adams, & Meehan, 1984), a dialect of Scheme running on Apollo Domain workstations. GATE includes a graphical knowledge representation system, a demon-based programming language, and a logic programming system.

DAYDREAMER currently 1) participates in NUART-EPISODE by receiving and performing actions in response to input phrases such as `You are near Debra Winger` and `She tells you that she does not want her and you to go out on a date`, 2) indexes the episode into memory under the DENIED REQUEST Plot Unit, 3) generates versions of NUART-DAYDREAM2, NUART-DAYDREAM3, and NUART-DAYDREAM4 in English produced by a simple recursive descent generator, indexing the daydreams into memory via Plot Units and emotions, and indexing into memory the planning strategy formed during NUART-DAYDREAM2, i.e., not to forget to ask for someone's telephone number, and 4) participates in another episode in which it demonstrates that it has learned the above planning strategy. An abbreviated trace of DAYDREAMER as of June 1985 is provided in Appendix A.

6. FUTURE WORK AND CONCLUSIONS

DAYDREAMER is being extended to enable it to 1) participate in a larger variety of input episodes, 2) generate more daydreams and possible scenarios in response to each episode, 3) incorporate many daydreams, planning strategies, and future plans into memory, and 4) demonstrate the use of recalled daydreams, planning strategies, and future plans in future internal (daydreaming) and external behavior. The use of analogy and episodic memory in scenario generation and learning of planning strategies will be investigated in greater detail. We intend for DAYDREAMER to be able to daydream continuously, stopping only to receive new experiences.

Numerous problems and issues have faced us in the ongoing implementation and design of DAYDREAMER. These include:

(1) The representation of knowledge in the interpersonal domain, e.g., representing conceptualizations for: "having a crush" on someone, "rehearsing lines", "getting involved with someone", "admitting being wrong" about someone, and so on.

(2) The interaction of processes of scenario generation, relaxed planning, emotional triggers, control goal activation, Plot Unit selection, and episodic memory remindings.

(3) The separation of personal episodes experienced by DAYDREAMER, from vicarious episodes, from imagined episodes already daydreamed and stored in episodic memory.

How and to what extent is reality separated from imagination? Mentally healthy individuals rarely confuse what they have imagined from what they have experienced. How easy is it for our daydreams and imaginings to subtly alter our interpretation of past events? This issue will become all the more pressing as DAYDREAMER's memory of input and daydreamed experiences grow and as we try to make DAYDREAMER's dreams available to systems concerned with such creative tasks as conversation, invention, and story invention.

Through the continuing design and implementation of DAYDREAMER we have been exploring a computational theory underlying daydreaming. This theory is based on a process model which specifies how emotions, scenario generation, planning, plot structures, themes, personal goals, control goals, episodic memory, and analogy processes interact with one another. We have argued that, far from being a useless epiphenomenon, daydreaming serves an important cognitive function in plan preparation and rehearsal, learning from failures and successes, support for processes of creativity, emotion regulation, and motivation. Truly intelligent computers should not be left in a "diddle loop" or turned off when unused, but engaged in daydreaming like ourselves.

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APPENDIX A: ABBREVIATED TRACE OF CURRENT DAYDREAMER

Below is an abbreviated trace of DAYDREAMER producing fragments of NUART-DAYDREAM2, NUART-DAYDREAM3, and NUART-DAYDREAM4. The entire trace showing all goals, subgoals, preconditions, plans, relaxations, control goals, and emotions, is over 16 pages long, so only a suggestive segment with much information removed can be shown here.

```
-----------------------------------------
DAYDREAMER [GATE/T/Apollo of 6/8/85] ...
Input? You are near Debra Winger.
Input?
Mode? performance
I tell Debra that I want her and me to
go out on a date.
Input? She tells you that she does not
Input? want her and you to go out on a
Input? date.
Input?
Mode? daydreaming
I fail at going out with Debra.
TERMINATE PLANNING FOR [^WEB.1631: GOAL FAILED ME (IPT-LOVERS)]
-----------------------------------
 IF   self goal failure
 THEN activate negative affect
-----------------------------------
ADD TO WM [^WEB.1632: AFFECT NEG ME]
I feel displeased.
EPISODE INDEX: Plot Unit [^WEB.1633: PU-DENIED-REQUEST DEBRA ME]
-------------------------------------------------
 IF   negative emotion associated with failure
 THEN activate control goal to rationalize failure
-------------------------------------------------
ADD TO WM [^WEB.1635: GOAL ACTIVE (RATIONALIZATION) ME CONTROL]
I want to rationalize failing at going
out with Debra.
START PLANNING FOR [^WEB.1635: GOAL ACTIVE (RATIONALIZATION) ME]
GOAL [^WEB.1635: GOAL ACTIVE (RATIONALIZATION) ME CONTROL]
 INTENDS PLAN [^WEB.1674: PLAN ME]
ADD TO WM [^WEB.1674: PLAN ACTIVE ME]
EXECUTE CODED PLAN [^WEB.1674: PLAN ACTIVE ME]
ADD TO WM [^WEB.1677: GOAL SUCCEEDED (IPT-LOVERS) ME DELTA]
I succeed at going out with Debra.
ADD TO WM [^WEB.1500: IPT-LOVERS DEBRA ME]
-------------------------------------------------
 IF   active indices match episode indices
 THEN retrieve episode and analogize to current situation
-------------------------------------------------
ADD TO WM [^WEB.118: EPISODE JODIE]
ADD TO WM [^WEB.1678: M-ACT DEBRA]
The time Jodie Foster the actress acted
in Paris.  Debra acts in Paris.
PROVE ALL (#AND# [^WEB.780: IPT-LOVERS ME] ...) [^WEB.782: #PROX#]
PROVED (#AND# [^WEB.780: IPT-LOVERS ME] ...) 1 WAY(S)
PROVED [^WEB.782: #PROX#] 1 WAY(S)
-------------------------------------------------
 IF   positive interpersonal thema with person and
      requirement violated
 THEN activate preservation goal
      on the interpersonal thema
-------------------------------------------------
ADD TO WM [^WEB.1855: GOAL ACTIVE (IPT-LOVERS) ME PRESERVATION]
I want to continue to be going out with
Debra.
START PLANNING FOR [^WEB.1855: GOAL ACTIVE (IPT-LOVERS) ME]
GOAL [^WEB.1855: GOAL ACTIVE (IPT-LOVERS) ME PRESERVATION]
 INTENDS PLAN [^WEB.1861: PLAN ME]
ADD TO WM [^WEB.1861: PLAN ACTIVE ME]
PERFORM ACTION [^WEB.1862: PTRANS ME (POLITY)]
ADD TO WM [^WEB.1862: PTRANS ME (POLITY)]
I go to Paris.
ADD TO WM [^WEB.1856: IPT-LOVERS DEBRA ME]
TERMINATE PLANNING FOR [^WEB.1867: GOAL SUCCEEDED ME (IPT-LOVERS)]
PROVE (#AND# [^WEB.828: M-JOB ME] ...)
PROVED (#AND# [^WEB.828: M-JOB ME] ...) 1 WAY(S)
-----------------------------------
 IF   have a job and requirement violated
 THEN activate preservation goal on the job
-----------------------------------
ADD TO WM [^WEB.1868: GOAL ACTIVE (M-JOB) ME PRESERVATION]
I want to continue to have a job.
START PLANNING FOR [^WEB.1868: GOAL ACTIVE (M-JOB) ME PRESERVATION]
GOAL [^WEB.1868: GOAL ACTIVE (M-JOB) ME PRESERVATION]
 INTENDS PLAN [^WEB.1874: PLAN ME]
ADD TO WM [^WEB.1874: PLAN ACTIVE ME]
CHECKING PLAN PRECONDITIONS [^WEB.1874: PLAN ACTIVE ME]
-------------------------------------------------
 IF   working on a goal causes a p-goal to be activated
 THEN resolve conflict
-------------------------------------------------
ADD TO WM [^WEB.1876: GOAL FAILED PRESERVATION ME (M-JOB)]
I fail at having a job.
-----------------------------------------
 IF   failure of goal G and success of G leads
      to major goal failure G1
 THEN failure of goal G is rationalized
-----------------------------------------
EPISODE INDEX: Plot Unit [^WEB.1877: PU-MIXED-BLESSING ME]
ADD TO WM [^WEB.1879: RATIONALIZATION]
I rationalize failing at going out with
Debra by the fact that succeeding at
going out with her leads to failing at
having a job.
-------------------------------------------------
 IF   control goal to rationalize goal failure succeeds
 THEN reduce scale of affect associated with goal failure
-------------------------------------------------
REPLENISH ACTIVATION OF [^WEB.1632: AFFECT LESS-THAN-NORM NEG ME]
I feel a bit displeased.
ACTIVATION FALLS BELOW LIMIT [^DEBRA: PERSON RT-ACTOR FEMALE]
REMOVE FROM WM [^DEBRA: PERSON RT-ACTOR FEMALE]
ACTIVATION FALLS BELOW LIMIT [^WEB.1497: PTRANS ME (ORGANIZATION)
REMOVE FROM WM [^WEB.1497: PTRANS ME (ORGANIZATION)]
-----------------------------------
 IF   person caused a self goal failure
 THEN activate anger toward person
-----------------------------------
ADD TO WM [^WEB.1882: AFFECT DEBRA NEG ME]
I am angry at Debra.
-----------------------------------------
 IF   negative affect directed toward person
 THEN activate control goal to gain revenge
-----------------------------------------
ADD TO WM [^WEB.1883: GOAL ACTIVE (REVENGE) ME CONTROL]
I want to gain revenge for Debra tel-
ling me that she does not want her and
me to go out on a date. I want Debra to
like me. I study to be an actor. I tell
Debra that I do not want her and me to
go out on a date.  I feel pleased.
-----------------------------------------
 IF   recalled goal failure
      and negative emotion not strong
 THEN activate control goal to reverse failure
-----------------------------------------
ADD TO WM [^WEB.2305: GOAL ACTIVE (FAILURE-REVERSAL) ME CONTROL]
I want to reverse failing at going out
with Debra. I want to be going out with
Debra. I want Debra and me to be in
touch. I want to know Debra's telephone
number. I want Debra and me to be in
touch.
START PLANNING FOR [^WEB.2249: GOAL ACTIVE (VPROX) ME]
GOAL FAILURE [^WEB.2249: GOAL ACTIVE (VPROX) ME]. PLANNING LOOP
ADD TO WM [^WEB.2252: GOAL FAILED ME (VPROX)]
TERMINATE PLANNING FOR [^WEB.2260: GOAL FAILED ME (IPT-LOVERS)]
-----------------------------------------
 IF   top-level goal failure from planning loop
 THEN index new conditional plan precondition
-----------------------------------------
INDEXING UNDER GOAL [^WEB.1284: GOAL (IPT-LOVERS) ACTIVE DELTA]
 PLAN [^WEB.1286: PLAN]
 CONDITION [^WEB.2261: VPROX]
 PRECONDITION [^WEB.2262: KNOW (PHONENUMBER)]
INTERRUPT...
Input?  You are near Debra Winger.
Input?
Mode? performance
I tell Debra that I want to know her
telephone number.
Input?
-----------------------------------------
```