Body Time: A Physiologically Augmented Time Planning Interface

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ABSTRACT

The interfaces that humans commonly use to interact with time include watches, clocks and calendars. These present the concept of time as an abstract linearly incrementing quantity. The human body however maintains a completely independent sense of time, driven by an internal circadian pacemaker. This internal physiological time keeper governs many fluctuations in body characteristics including alertness and cognitive performance. The prevalence of linear time keeping devices tends to distance people from their internal or 'body' time. To bridge this gap, the author has developed a time-planning system for a personal digital assistant (PDA) that incorporates a sense of 'Body Time'. Mathematical models of the effects of sleep, and the circadian rhythm provide indicators of predicted alertness and sleep debt levels. This provides a tool for individuals to become aware of their personal physiology and maintain health and productivity especially under time-pressured work environments.

Keywords

Time, Scheduling, Circadian rhythm, Sleep, Alertness, Physiology, Models, PDA

1 INTRODUCTION

The human body is a dynamic physiological system. An important aspect of the body is the regular, time-varying fluctuation in almost all physiological processes. The most significant of these fluctuations is the daily, or circadian, change between the states of sleeping and waking. The transitions that we make between these states are not merely conscious decisions, but are in fact accompanied by deep changes in our physiology driven by an internal 'circadian pacemaker'. This circadian pacemaker acts as an internal clock that governs processes from core body temperature and heart rate, to cognitive performance and alertness. This internal clock acts to make us alert during the day and sleepy during the night.

However, given a mechanical sense of time when under pressure to maximize workplace performance or work irregular hours, individuals often place the natural functioning of their bodies as a secondary consideration. Furthermore when operating under high workload, the task at hand is often of primary attention, and it can be difficult to plan effectively so that both health and productivity are maintained in a sustainable manner. In essence, when under pressure it can be difficult to operate and plan using 'body time'.

Various time-management methods have been developed for organizing an individual's schedules to meet the requirements of their work and personal lives. Before electronic devices, these included notebooks, planners, and daily organizers. These methods have all been ported in into various electronic forms, such as Microsoft Outlook for Windows and DateBook for Palm. Programs such as these provide excellent interactive tools to schedule linear blocks of time, however none of them incorporate a human element into the process. When a user is presented with a representation of time as a linear sequence of blocks that can be allocated to different tasks, it encourages the assumption that all time is equal to the body. This is creates a misconception of time, and thus can lead to poor planning and decision making.

Presented in this paper is a new time-planning interface that that actively presents an individual with the state of their internal 'body clock', their alertness base-line level, and their sleep debt levels. It is an interactive activity scheduling and tracking tool to facilitate planning on 'body time'. With further refinement it has the potential to provide benefits in term of both health and productivity.

2 PHYSIOLOGICAL MODELLING

Research in the field of chronobiology, the study of time-varying biological processes, has provided significant insights into the nature of human circadian physiology. Detailed studies on sleep patterns, the effect of light on the circadian pacemaker[2], and variations in alertness have provided sufficient information to develop mathematical models[3]. In 1999 a ground-breaking paper from Harvard [4] presented an integrated mathematical model of the circadian pacemaker, and its effect on sleep, alertness, and cognitive performance. Calculation of the 'Body Time' of an individual is based on this model.

This physiological model consists of a set of differential equations that predicts alertness and cognitive performance based on the superposition of effects from three components

$$A = C + H + W \tag{1}$$

which are the circadian rhythm, sleep drive, and sleep inertia respectively. Each of these is described in detail below. Note that for brevity not all of the equation constants are given here, but they may be found in [4].

Circadian Pacemaker

The repeating twenty-four hour oscillation of the circadian pacemaker causes a corresponding fluctuation in alertness with the low point occurring at approximately 4 am. The circadian pacemaker itself is modelled as a self-regulating oscillator

$$\dot{x} = \frac{\pi}{12}\left[x_c + \mu\left(\frac{1}{3}x + \frac{4}{3}x^3 - \frac{256}{105}x^7\right) + B\right] \tag{2}$$

$$\dot{x_c} = \frac{\pi}{12}qBx_c - \left[\left(\frac{24}{\tau_x(0.99729)}\right) + kB\right]x \tag{3}$$

that is influenced by a driving force, (B), from exposure to ambient light. The driving input (B) is calculated by the logarithmic response (α) of the human eye to light:

$$\alpha = \alpha_0\left(\frac{I}{9500}\right)^p \tag{4}$$

where I is the ambient light intensity in units of Lux and

$$\dot{n} = 60[\alpha(1-n) - \beta n] \tag{5}$$

$$B = G\alpha(1-n)(1-mx)(1-mx_c). \tag{6}$$

The alertness component from the circadian pacemaker is finally

$$C = A_C(0.91x - 0.29x_c) \tag{7}$$

$$\tag{8}$$

Sleep Drive

The sleep drive or 'Homeostatic' drive describes the body's need for sleep. It is modelled as a process that decays while awake and restores itself while asleep. This element characterizes the effect of decreasing alertness after staying awake for extended periods of time. The decay while awake is given by the equation

$$\dot{H} = -\frac{t_w^2}{t_w + t_0}r_H(H - u_c) \tag{9}$$

and the recovery while asleep is

$$\dot{H} = r_H(u_H - H) \tag{10}$$

Sleep Inertia

Sleep inertia is an effect that models the initial 'grogginess' that is present immediately following awakening. During sleep it has a constant negative value

$$W = W_0 \tag{11}$$

and after awaking, it decays to zero according to

$$\dot{W} = -r_W W. \tag{12}$$

Implementation

Developing an efficient solver for these equations that can be programmed in C is a major focus of the development work. To achieve a balance between accuracy and computational efficiency, the models were linearized around their nominal values are implemented as a discrete-time state-space model with time step interval of 15 minutes.

3 TIME PLANNING INTERFACE

The concept for the time planning interface is to augment a regular time-planner application with the information provided by the models. A Palm Pilot is used as the target device for this application as it affords regular interaction to monitor and track activities.

A basic activity recording system is developed as the foundation for the augmented version. It consists of a horizontal bar representing a single 24-hour period. Activities are recorded by filling in the bar with one of three activity classifications

- Sleep
- Awake and Working
- Awake and Non-Working

Activity entry is performed through intuitive selection of an activity button followed by highlighting of a region on the time bar.

Three different applications are developed on top of this basic frame to isolate the separate interface aspects and test one physiologically augmented version.

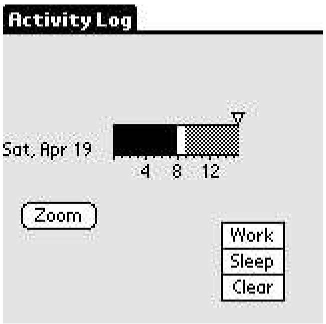

Figure 1: Activity log

Activity Recording
The Activity Recording interface only records past activities. No future planning is enabled as the time bar only extends up to the present time. In Figure 1 the solid colour indicates sleep, the grey colour indicates awake and working, and the clear indicates awake and non-working. A triangular marker indicates to the current time.

Activity Recording and Planning
The Activity Recording and Planning interface allows recording of past activities and planning future activities. As the planned events move into the past, they can be modified to reflect what actually occurred. This interface is identical to the previous one except that time bar extends for the full length of the day. Two different scenarios are shown in Figure 2.

Activity Recording and Planning with Body Time
The Activity Planning with Body Time interface presents information about physiological alertness and sleepiness in conjunction with the ability to record past activities and plan future activities.

The first step in implementing this is to program solutions to the differential equation models described in Section 2. This is done through a C-code algorithm and the reduction of the equations to discrete-time state space equations.

Given physiological predictions, the time bar is then augmented with the alertness and sleep information in two ways:

1. The height of the bar while awake indicates the alertness level as predicted by the physiological models.
2. The height of a sleep section indicates the total restoration of the sleep drive provided by that sleep episode.

The intention of these modifications are to encourage optimal scheduling of work times and sleep times. Two sample scenarios are shown in Figure 3. A comparison to Figure 2 illustrates the additional information that is provided by the variable height bar. A graphic sense of diminishing returns on labour nearing the end of a long work session is provided.

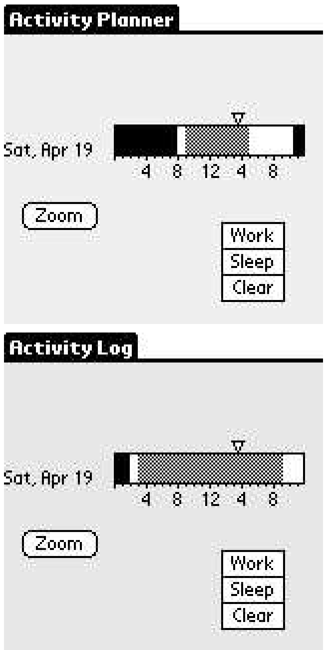

Figure 2: Activity planner without physiological augmentation. Typical schedule above, extended work schedule below.

4 EVALUATION

Evaluation of this system was performed through a user trial. Participants with a Palm Pilot were given each of the three applications and were asked to evaluate them sequentially for a number of days. Since one aspect of the application deals with interactions that occur over a time span of weeks, no quantitative metrics were attempted to be measured given the time constraints. To determine qualitative measures of success of the interface implementation a questionnaire was used. The questionnaire elicited answers in the following categories

- What are you typical activity patterns?
- To what degree did accurately record your activities?
- What features were of value to you?
- After using this program have you learned anything about your body?

5 RESULTS

Results of the evaluations indicated that individuals who often work long or irregular hours perceived value

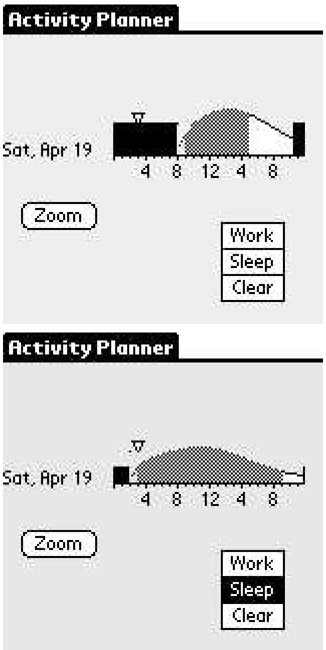

Figure 3: Activity planner augmented with physiological models. Typical schedule above, extended work schedule below.

in understanding their physiological systems to help better plan future work habits. The ability to test different future scenarios in the physiologically augmented version was an attractive feature.

Individuals who keep highly regular schedules however perceived marginal value to this program. There was a preliminary interest in analyzing the physiological predictions related to their current behaviour pattern, but with no significant variance on a day to day basis there would be little motivation to use on a continuing basis.

The current interface shows only a single day, but users suggested that allow observation of daily historical trends would add significant value and encourage regular use. This would provide another level of understanding about their behaviour.

And finally, users of current day timers indicated that they would not want to maintain two separate time tracking systems. The work related task tracking features in existing programs are an important feature.

6 CONCLUSION

The physiologically augmented time planner developed here presents a solution to integrating 'clock' time and 'body' time. The implementation of human physiological models into an interactive electronic scheduler on a common personal computing platform is a significant step towards a practical application. Given further refinement, it has the potential to encourage maintenance of good work habits and health. One possible direction for this is to combine features from this system into the existing Palm DateBook program.

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