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Medical Affective Computing: Medical Informatics Meets Affective Computing

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Abstract

> "The need to cope with a changing and partly unpredictable world makes it very likely that any intelligent system with multiple motives and limited powers will have emotions." [1]

From advisory systems that understand emotional attitudes toward medical outcomes, to wearable computers that compensate for communication disability, to computer simulations of emotions and their disorders, the research agendas of medical informatics and affective computing—how and why to create computers that detect, convey, and even have emotions—increasingly overlap. Some psychiatric and neurological researchers state their theories in terms of actual or hypothetical computer programs. Adaptive intelligent systems will increasingly rely on emotions to compensate for their own conflicting goals and limited resources—emotional reactions about which psychiatrists and neurologists have special insights. DEP2 (Depression Emulation Program 2) is a computer simulation of adaptive depression—learning from explainable patterns of failure in autobiographical memory—that simulates many depressive behaviors. In the terminology of fault-tolerant computing, adaptive depression involves fault detection (triggered by failure), fault location (strategic retreat and failure diagnosis), and fault recovery (return to on-line operation). DEP2 relies on subsystems whose structures and behaviors are based on popular hypotheses about left and right brain hemispheric function during depression and emotion. DEP2 and its predecessors, DEP and DEPlanner, are relevant to psychiatric and neurological informatics, and to the design of adaptive autonomous robots and software agents.

Keywords

Affective computing; Medical Informatics; Depression; Psychiatry; Neurology; Simulation.

Introduction: Affective Computing

At the MEDINFO'95 conference Patel, Kaufman, Arocha and Kushniruk [2] argued for more interaction between cognitive science and medical informatics. The themes sounded were new alliances and common goals. Suggested areas of cooperation included medical education, knowledge representation, interface evaluation, and decision support. Three years later, as affective computing and medical informatics increasingly overlap, yet more opportunities for synergy between cognitive science and medical informatics are occurring.

Thirty years ago, Herbert Simon suggested that emotions function like operating system interrupts that prompt one processing activity to be replaced by another of higher priority [3]. Today, affective computing research is beginning to create computers that detect, convey, and even simulate emotions [4,5]. For example, fear and anger redirect attention toward saving ourselves and punishing others in useful ways, so useful that eventually many intelligent systems will also simulate fear and anger. Adaptive depression is an especially useful form of emotional intelligence [6] that forcefully redirects attention away from immediate environmental opportunity and threat, and toward occasionally necessary explanation of past failure and rehearsal of new, more adaptive behavior.

Computer models of adaptive depression include DEP [7], DEPlanner [7], and DEP2 [8]. DEP used connectionist techniques. When failures built up in memory, DEP retreated from its environment, rehearsed and retrained new behaviors, and then more successfully re-engaged its environment. DEPlanner relied on three kinds of memory: declarative, procedural, and autobiographical. Together, DEP and DEPlanner simulated ten phenomena of depression (Table 1, items 1-10).

DEP and DEPlanner focussed on psychological—not neurological—evidence and hypotheses. DEP2 is a new simulation of adaptive depression whose design is influenced by popular hypotheses about the structure and function of human left and right brain hemispheres.

This kind of research sits at an intellectual crossroad between medical informatics and affective computing, because emotional computers will find applications in medicine, and what psychiatrists and neurologists know about normal and abnormal emotion can guide their construction.

None of the DEP models explicitly simulate clinical depression. They simulate the mild, beneficial depression that conserves resources and changes behavior during environmental adversity. Many evolutionary psychiatrists and psychologists have suggested that such an adaptive depression does indeed exist [9,10]. Just as an adequate theory of heart failure cannot exist without a model of normal heart function, a model of normal depression is relevant to adequate theories of clinical depression.

Materials and Methods: Computer Simulation

DEP was a connectionist model that paired a network, capable of fast sequential actions (implemented by one-at-a-time activation of connectionist units, L1, L2, Ln in Figure 1), with a network that stored and monitored the outcomes of previous actions (implemented by a parallel array of connectionist units, R1, R2,...Rn in Figure 1). When the latter network detected a pattern of failed actions, it pulled the former network off-line and slowly retrained its sequential behaviors. After retraining, both networks returned to their acting and monitoring functions, until another pattern of failures built up again.

The DEPlanner simulation relied on older, more traditional artificial intelligence planning and machine learning methods to model three kinds of human memory: general declarative, fast procedural, and autobiographical. DEPlanner did not have two subsystems, but it did problem solve and learn in a popular virtual environment. Blocksworld consists of a few virtual blocks strewn about a virtual surface. DEPlanner's goal was to successfully build towers as quickly as possible in order to achieve as high a lifetime score as possible. Patterns of failure caused DEPlanner to retreat from its world, revise its assumptions, rehearse new behaviors, and re-enter its world—after adapting to and learning from its failures.

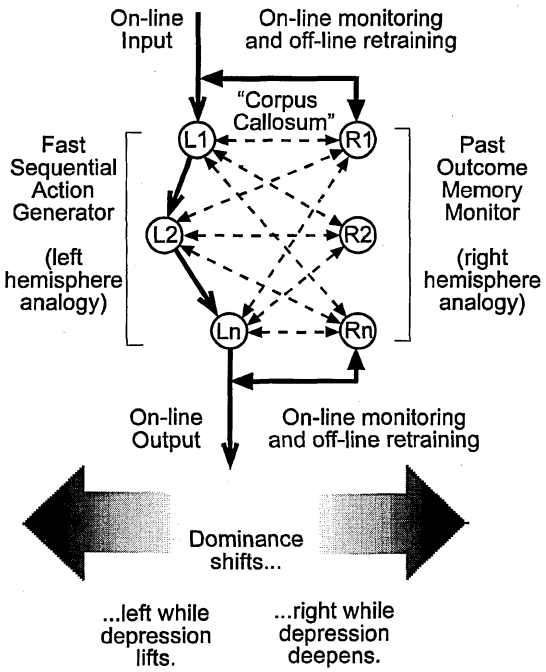

Figure 1 - Depression Emulation Program (DEP)

Physician and neuroscientist, Ramachandran proposes a theory of interaction between left and right hemispheres based on research with brain-damaged patients [11]. He argues that the left hemisphere is like a stubborn theorist, while the right monitors inconsistencies that occasionally build to such a level the left hemisphere is forced to revise its theories (resembling occasional shifts from old to new scientific frameworks in response to accumulating anomalies).

DEP's structure did not intentionally model neurological aspects of depression, but, while Ramachandran did not develop his theory to explain depression, DEP's subprograms correspond well to Ramachandran's model of left and right hemisphere operation and communication.

Results: DEP2's Structure and Behavior

In contrast to DEP and DEPlanner, DEP2 also addresses neurological evidence and hypotheses. Like DEPlanner, DEP2 operates in Blocksworld and simulates most of the same depressive phenomena as DEP and DEPlanner (for details see [7]), but also simulates sequential versus parallel operation [12], acting versus monitoring function [13], and local versus diffuse representation in left and right brain hemispheres [14].

The most convenient way to display the results of the DEP2 simulation is to compare its features to the previous simulations (Table 1, items 1-17).

Failure does not trigger depression; its explanation does. Globally (1) important failures due to stable (2) causes for which the individual is culpable (3), are more likely to trigger depression. In all of the DEP simulations, including DEP2, failure-processing (4) correlates with important (of global significance), reoccurring (due to stable causes), but avoidable (through retreat, revision, and rehearsal) failure.

Depressive realism (5) occurs in all simulations, including DEP2, because previously ignored errors finally begin to influence behavior.

All three of the Depression Emulation Program simulations generalize (6) about failure by comparing features of each failure to find a parsimonious explanation.

In their non-depressed states, none of the programs learn, except in the sense that they add material to autobiographical memory from which something might be learned later. During depression, past failures that have been ignored begin to drive learning – a cognitive change (7) leading to higher performance.

Behavior directed toward their external environment slows (8) because each program spends more time in off-line search.

DEPlanner calculated self-esteem (9) and self-efficacy (10) according to ratios of successful versus unsuccessful goals in autobiographical memory. Since DEPlanner was a goal-based planner, these statistics were easy to obtain. Self-esteem and self-efficacy have less obvious analogies in connectionist simulations than speed and generalization.

Bradshaw and Nettleton [12] assert that the left hemisphere specializes in sequential behavior while the right operates in a parallel, pattern-matching mode [11,12]. DEP2's left hemisphere sequentially searches toward goal states. Its right hemisphere operates in parallel to compare problem states, guide search, and detect similarity between failures.

Table 1 - Explicit Models of the Psychology and Neurology of Depression (LH=Left Hemisphere, RH=Right Hemisphere)

	DEP	DEPlanner	DEP2
Psychological			
1 ↑ Global explanation	yes	yes	yes
2 ↑ Stable explanation	yes	yes	yes
3 ↑ Internal explanat'n	yes	yes	yes
4 ↑ Failure rumination	yes	yes	yes
5 ↑ Realism	yes	yes	yes
6 ↑ Generalization	yes	yes	yes
7 ↑ Cognitive change	yes	yes	yes
8 ↓ Speed	yes	yes	yes
9 ↓ Self-esteem	no	yes	no
10 ↓ Self-efficacy	no	yes	no
Neurological			
11 LH Sequential	no	no	yes
12 RH Parallel	no	no	yes
13 LH Acting	no	no	yes
14 RH Monitoring	no	no	yes
15 LH More vulnerable	no	no	yes
16 RH More diffuse	no	no	yes
17 LH→RH Shift	no	no	yes

Tucker and Williamson [13] contend that the left hemisphere tends to act (such as guide the right hand) while the right hemisphere tends to monitor (such as recognize faces and their emotions) (13, 14). DEP2's left hemisphere is responsible for behavior directed at its external environment. It acts. DEP2's right hemisphere records the results and occasionally participates in off-line retraining of DEP2's left hemisphere. It monitors.

Semmes [14] argues that left hemisphere behaviors are more easily disrupted because they are more focally represented than in the right hemisphere and therefore more vulnerable to damage (15,16). DEP2 uses what neural network researchers refer to as "coarse coding" in its right hemisphere. Each problem state, represented by only one unit in DEP2's left hemisphere, is distributed across three units in its right hemisphere. Since these units participate not in on-line action, only in off-line monitoring and retraining, disabling a right hemisphere unit does not immediately affect on-line behavior. In contrast, damage to DEP2's left hemisphere (simulated by randomly disabling a unit) dramatically disturbs DEP2's ability to generate sequential behaviors directed at external opportunities, as occurs in humans where left hemisphere stroke more likely disrupts such sequential cognitive processes as language.

Goldberg, Podell, and Lovell [15] believe that the left hemisphere is responsible for routine behavior, while the right is responsible for novel behavior. Learning a new task activity shifts hemispheric dominance from left to right, then gradually back. During depression hemispheric dominance also shifts right [16]. Adaptive depression is a kind of learning, and, consistent with this, control of DEP2's processing shifts from left to right as depression deepens, and then back as depression lifts (17).

Thus, DEP2 simulates most of the psychological behaviors that DEP and DEPlanner simulated (except for self-esteem and self-efficacy), but also uses design constraints drawn from neurological and neuropsychological research.

Discussion: Adaptive Intelligent Systems

The DEP family of computer simulations of adaptive depression are relevant to practical problems in medical informatics. In particular, they are prototypes in the class of adaptive intelligent systems, proposed by Hayes-Roth, who developed Guardian, an intensive-care monitoring agent that adapts intelligently and in real-time [17]. Hayes-Roth proposes five forms of adaptation, which I paraphrase here and apply to computer modeling of adaptive depression.

1. Adapt perceptual strategies to changing information requirements and resource limitations: In its non-depressed state, DEP2 ignores failure and reacts to opportunity. In its depressed state DEP2 ignores opportunity and searches for failure.
2. Adapt to changing goals and uncertainties: When DEP2's implicit goal is to act, it suppresses depression. When its goal is to learn from past failures, DEP2 allows adaptive depression to ensue, but strategically retreats to reduce risk of further failure.
3. Adapt to changing trade-offs between local and global goals: DEP2 is designed to attempt to maximize lifetime performance. Therefore DEP2 tolerates short-term decrease to obtain long-term increase in performance.
4. Adapt reasoning methods to available information and changing performance criteria: Not just any failure triggers DEP2's switch from fast, opportunistic behavior to slow, failure-related processing. The cause of failure must be important (have global significance), lasting (due to stable causes), but remediable (due to internal causes). Sometimes not enough information to make this decision is available and the simulation follows a conservative strategy of continuing in its non-depressed state until more informative failures occur.
5. Adapt adaptation, itself: All of the DEP simulations are hardwired to react to patterns of failure in memory. More sophisticated models of adaptive depression should not just learn from depression, they should also learn when and how much to get depressed. This generation of computer models will surely be relevant to understanding why psychotherapy—particularly cognitive therapy—can so successfully teach people to better man-

age their depressions.

Conclusion: Insights Gained

DEP, DEPlanner, and now DEP2 are qualitative simulations that—only approximately—model depressive behaviors and brain structures. Their designs resemble, in philosophy, animates, the artificial animals created and studied by artificial life researchers. But, storing and releasing change is a general problem for adaptive intelligent systems. Simpler adaptive systems can sometimes reveal insights that apply to more complex ones. DEP, DEPlanner, and DEP2 are simple systems, relative to mind and brain, but they coherently connect a greater number of previously disparate behaviors, structures, and hypotheses about depression, than have ever been connected before.

Computational theories of abnormal emotion, such as clinical depression, require computational models of normal emotion. For example: How might a computer model of adaptive depression be modified to simulate depression that is too long? Too intense? Too easily triggered?

Furthermore, adaptively intelligent robots, intended to operate with minimal or no human supervision (such as robots that explore distant planets), will need emotions to more independently manage multiple goals and limited resources in changing and partially unpredictable worlds. Perhaps a future robot sent to Mars will become occasionally and appropriately depressed—because it will be designed to do so.

Computer models of adaptive depression straddle medical informatics and affective computing research arenas. The confluence of medical informatics and affective computing will continue, and might reasonably be called Medical Affective Computing.

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