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USING COGNITIVE MODELING TO STUDY BEHAVIOR MODERATORS: PRE-TASK APPRAISAL AND ANXIETY

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We present a cognitive model of a repeated serial subtraction arithmetic task in the ACT-R cognitive architecture (Anderson & Lebiere, 1998) that is modified to demonstrate how the influence of biobehavioral effects on cognition (sometimes called behavioral moderators) can be studied through a combination of cognitive modeling experimental psychology, and physiological psychology techniques.

We present a cognitive model of a serial subtraction task in the ACT-R cognitive architecture that is modified to demonstrate how the influence of biobehavioral effects on cognition (sometimes called behavior moderators) can be studied through a combination of cognitive modeling techniques and traditional empirical research. Two overlays, additions to the cognitive architecture changing parameters and knowledge, were created to include the effects of cognitive appraisal and math anxiety on task performance. The predictions of the model with one of the appraisal overlays matches fairly well the answer rate and percent correct for example data on a serial-subtraction task with and without stress (Tomaka, Blascovich, Kelsey, & Leitten, 1993). The math anxiety overlay, which is based on popular theories, produces further, novel predictions. Taken together, the model and overlay suggest that ACT-R's current default settings are too competent, and show how cognitive architectures can be used to explore the interactions between biopsychological processes and cognitive mechanisms.

The specific serial subtraction task that was modeled asks a participant to start with a 4-digit number and repeatedly subtract from it a specified 1- or 2- digit number. For example, the number 6,537 can be the starting number from which the number 7 should be subtracted repeatedly.

The specific behavioral moderator we chose to include in the serial subtraction model is task appraisal. Task appraisal is considered an internal moderator as it represents an individual's subjective evaluation of the situation. Task appraisals can be further specified as pre-task or post-task appraisals.

ACT-R

ACT-R is a cognitive architecture, specifically defined as: a theory for simulating and understanding human cognition. Researchers working with ACT-R are interested in understanding how people organize knowledge and produce intelligent behavior (Anderson, 2003). As research continues, ACT-R evolves towards a system that can perform the full range of human cognitive tasks: capturing in detail the way we perceive, think about, and act on the world.

Cognitive architectures are an approach to modeling behavior that assumes that there are two components to behavior, the architecture and knowledge. The architecture is composed of cognitive mechanisms that are fixed across tasks and basically fixed across individuals. These mechanisms typically include some form of perception and motor output, some sort of central processor, some working memory or activation of declarative memory, and some way to store and apply procedures. These mechanisms are used to apply task knowledge to generate behavior.

The ACT-R architecture is realized as a production system. ACT-R represents procedural knowledge in the form of if--then rules (productions) to process, store, and retrieve declarative memory, which is realized as a hybrid semantic network. ACT-R is also capable of compiling these productions to generate new procedural knowledge.

A diagram of this ACT-R architecture is shown in Figure 1. The diagram shows that specific areas of the brain can be associated with particular buffers in the architecture. As cognitive science and psychology discover new functionality in physiological areas of the brain, one can expect the ACT-R architecture to adapt accordingly.

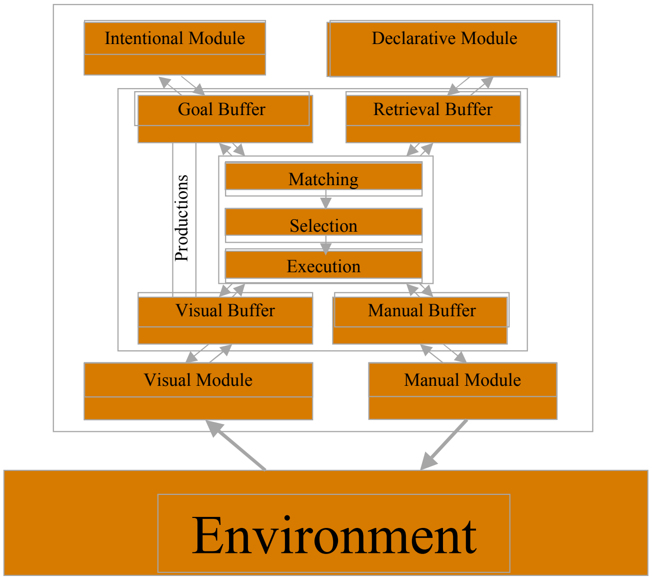


Figure 1. Schematic of the ACT-R 5 architecture.

ARCHITECTURAL OVERLAYS

We introduce the idea of an architectural overlay, an addition to all models in the architecture by modifying the architecture or its parameters. Overlays offer a new way of working with cognitive architectures that we will need to explore as a way of including global effects of moderators on cognition. Overlays have been suggested for implementation in a number of cognitive architectures. Specifically JACK, ACT-R, Soar and Cogent have all been suggested as viable architectures for studying overlays (Ritter & Avraamides, 2000). The general purpose and implementations of overlays should be similar across architectures, despite their differences. Overlays in various architectures seek to modify the behavior of models within an architecture in a generalized, global manner. There are numerous psychologically plausible reasons for wanting to affect a model in a generalized manner. Specifically, behavioral moderators such as fatigue and appraisals of tasks as threatening or challenging appear to affect behavior in a global way (Kelsey et al., 2000). The use of interpreted programming languages to create these architectures also helps support adding overlays.

If the goal of cognitive models is to accurately model aspects of human behavior (Gray & Pew, 2004), then theories of specific behavioral moderators should be developed and tested. In our attempt to create a defendable theory of behavioral moderators we offer an exemplar architectural overlay for ACT-R.

Our cognitive appraisal overlay models the effects of challenging and threatening appraisals by modifying the amount of noise in the procedural knowledge selection process. The math anxiety overlay provides a rule that simulates active worry as a distracting thought. The predictions of the model with these overlays are shown in Table 1. The model with the appraisal overlay matches fairly well published data on this task, also shown in Table 1, for answer rate and percent correct (Tomaka et al., 1993). While not a perfect correspondence, the correspondence suggests that the overlay provides a plausible explanation for decreased performance on this task as a function of appraisal or worry.

Table 1. Comparison of the 4.0 model's behavior with and without the overlays to human data taken from Tomaka et al. (1993). The per minute rate has been multiplied to give the totals per 4-minute block. Standard deviations of the model's performance are shown in parentheses. > denotes significant difference between means at [symbol: α]=.01

Cognitive Appraisal Overlay

		Threat (EGN=1)		Challenge (EGN=0.1)		Neutral (ACT-R Default) (EGN=0)
Model	Attempts	46.8 (3.6)	<	54.5 (3.5)	<	70.9 (1.3)
(N=100)	Correct	42.5 (5.1)	<	50.2 (5.1)	<	70.9 (1.3)
	% correct	91%		92%		100%
Model with math anxiety	Attempts	36.8 (2.6)	<	40.6 (2.6)	<	58.8 (1.0)
(N=100)	Correct	32.2 (4.3)	<	36.0 (4.2)	<	58.8 (1.0)
	% correct	88%		88%		100%

		Threat	Challenge
Human data	Attempts	46	61
(N=22)	Correct	42	56
	% correct	91%	92%

The math anxiety overlay, which is based on popular theories of math anxiety (Ashcraft & Kirk, 2001), produces novel predictions, that are also shown in Table 1. These predictions suggest that participants who actively worry perform fewer subtractions, and may represent a sub-population of Tomaka et al.'s data. Taken together, the model and overlay suggest that ACT-R's current default settings are too competent, show how cognitive architectures can be used to explore the interactions between biopsychological processes and cognitive mechanisms, and illustrate how a general theory of how cognition is affected by behavioral moderators can be implemented as a cognitive architecture overlay. The next steps for us are to gather more detailed data on serial subtraction as well as performance on other tasks at the same time that we measure working memory capacity, processing speed, and further physiological effects of task appraisal and other moderators such as caffeine.

The model utilized in this study was implemented in ACT-R 4.0. We are developing a similar version in ACT-R 5.0. Aside from our focus on behavioral moderators there are a number of other interesting research questions that are posed when attempting to modify a model to work in an upgraded architecture. Cognitive models have received criticism for not being properly tested in multiple versions of a particular architecture (Cooper & Shallice, 1995).

While still in the process of developing the model in ACT-R 5.0 we discovered at least one reason that models are typically not compared across versions of an architecture. Specifically, we found changes in the architecture do not always support a model's information processing strategies across versions. Given this problem, comparison of models across versions can be more informal than one might want.

MODELS

Model – Version 1

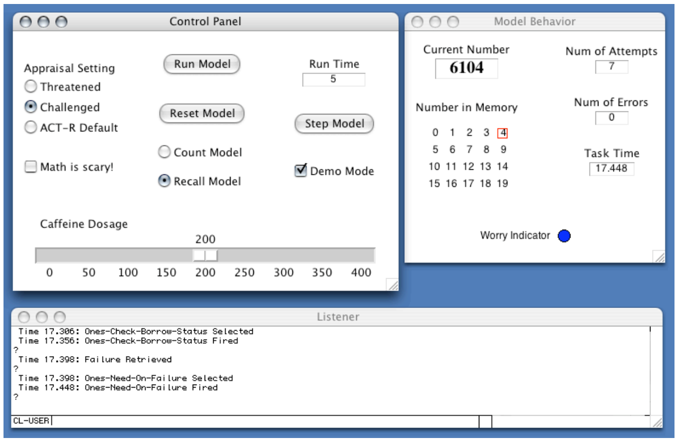
The ACTR-4.0 model that we initially used to study behavioral moderators performs a serial subtraction task implemented in a similar manner as the actual human participants in the Tomaka et al study (1993). The model's declarative knowledge consists of arithmetic facts and goal-related information. The model also possesses procedural knowledge, in the form of production rules, that allow for retrieval of subtraction and comparison facts necessary to produce an appropriate answer.

This model performs subtractions by attempting to recall the appropriate declarative memory chunk to produce a subtraction answer. This model's behaviour is modified by an overlay representing the effects of task-appraisal. The validity of this behavioral moderator has been demonstrated by previous empirical research demonstrating a correlation between task appraisal (i.e., threatening vs. challenging) and performance on arithmetic tasks. Specifically, appraisals of the task as threatening have been associated with fewer responses and more errors whereas challenging appraisals have been associated with more attempts and better performance then a neutral appraisal (Kelsey et al., 2000; Tomaka et al., 1993).

Model – Version 2

Our ACT-R-5.0 model implements two different theories of subtraction. One theory of subtraction utilizes a recall technique where the model attempts to recall the correct memory chunk in order to obtain the correct answer. The other theory of subtraction that we implemented in our model was a counting backwards technique whereby the model simple counts backwards until the desired answer is achieved. A partial trace and the interface for this model can be seen in Figure 2.

When implementing the same overlay with the 5.0 model we found different predictions. This could be due to a number of reasons including, irreconcilable changes in the architectures and or different programming approaches to the model. Although preliminary analyses of the new model's performance and a comparison of the models are promising any conclusions without further work would be conjecture.



Appraisal Setting
○ Threatened
● Challenged
○ ACT-R Default

☐ Math is scary!

○ Count Model
● Recall Model

☑ Demo Mode

Run Time: 5

Caffeine Dosage: 200

Current Number: 6104

Num of Attempts: 7

Num of Errors: 0

Task Time: 17.448

Number in Memory

0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19

```
 Time 17.306: Ones-Check-Borrow-Status Selected
 Time 17.356: Ones-Check-Borrow-Status Fired
?
 Time 17.398: Failure Retrieved
?
 Time 17.398: Ones-Need-On-Failure Selected
 Time 17.448: Ones-Need-On-Failure Fired
?
CL-USER
```

Figure 2. Running Model and Observational Interface

CONCLUSIONS

It appears that there is evidence indicating that overlays accounting for behavioral moderators are worthy of further research by cognitive modelers (Ritter, Avraamides, & Council, 2002; Ritter et al., 2003). Because the modifications to the model that created the desired behavioral effects were implemented at the architectural level, the initial overlay should be capable of similarly affecting other models of the same architecture.

When testing our hypothesis with the developing version, pilot data indicated that our original overlay may need to be revised in order to create an overlay representative of a task-appraisal behavioral moderator in the current ACT-R architecture. Initial work translating this model suggests that it would be helpful to have a standardized technique for updating models between architectural versions, lest we fall prey to the problems noted previously (Cooper & Shallice, 1995). An exemplar implementation of this is the update function available between Soar4 to Soar5. This function made the differences between the versions clear, and did support the approach of moving models between versions. This would allow for more accurate generalization and overlay testing.

When comparing the existing model and the developing model there are a number of interesting tertiary research areas that could be examined. Successful implementation in 5.0 will provide a better understanding of implementing behavioral moderator overlays and the interaction of overlays and the ACT-R architecture.

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