the relevant structure is the cognitive coordinate system in which three-dimensional visual stimuli are interpreted. The x, y, and z axes that exist in the mind of the viewer may or may not correspond to the intrinsic axes of the objects itself or to the axis of rotation. Friedman's research demonstrated that these kinds of correspondences have profound influences on the effects of stimulus complexity, mental rotation strategy, and spatial ability. The manipulations involved in this research hold promise of disentangling the confusing and sometimes contradictory literature on these problems.

Roc Walley discussed the mental operations involved in visual word recognition. His use of the priming paradigm also involves the interaction of cognitive representations with basic visual information processing operations: Priming depends on the existing semantic relationship between words and the effect of that relationship on the process of recognizing words. Walley focussed on the possibility that the pattern of excitation and facilitation previous researchers had found in priming studies may be essentially a case of lateral inhibition. This proposal would unify an important result in cognitive psychology by elucidating a fundamental mechanism involved in neural information processing. However, this proposal makes predictions about the nature of priming at short temporal intervals that have seldom been obtained in the past. Walley presented data indicating that the predicted effects do occur when careful attention is paid to the relationship between the prime and the target words and to the presentation duration of the stimuli.

Will Hill's talk took a broad perspective on information processing and its relationship to artificial intelligence. Hill challenged the traditional view of the goal of artificial intelligence as the creation of computer programs and systems that behave intelligently. Instead, he proposed that artificial intelligence was in the business of creating new technologies that people could use as expressive media. In this view, the work in this area lies on a continuum with other technological innovations such as the printing press and cinema. The term "artificial intelligence" is anachronistic in the same way that "horseless carriage" and "wireless telegraph" are. Hill's proposal has dramatic implications for the interrelationship between cognitive psychology and artificial intelligence. He presented an impressive glimpse of what is on the horizon with regard to the human interface with this technology.

In conclusion, the attendees to this year's BASICS were presented with a broad spectrum of exciting ideas in cognitive psychology and cognitive science. Next year, as in past years, the Eighth BASICS will be held in the early part of May 1989 in Banff. Inquiries may be directed to either of us.

A RESEARCH FRAMEWORK FOR INVESTIGATING INFORMATION ACQUISITION AND LOSS[1]

GEOFFREY R. LOFTUS
University of Washington

Much of human cognition consists of information acquisition from the environment (learning) and information loss from the cognitive system (forgetting). My concern here is with developing a framework for characterizing the effects of certain independent variables (hereafter, *focal variables*) on information acquisition and loss. In the following four sections, I discuss (1) the *monotonicity assumption* which is the theory data link, (2) general models of focal variable effects, (3) applications of the framework, and (4) problems with the framework.

The Monotonicity Assumption

Linking observed performance to underlying theory requires the assumption that performance (e.g., probability correct or d') is monotonically related to some important underlying theoretical construct (e.g., "amount of information" or "memory strength"). This is the monotonicity assumption.

Additive and Multiplicative Effects

If one wishes to study information acquisition or loss, one performs an experiment in which one varies *time:* either acquisition time (e.g., exposure duration of some stimulus) or forgetting time (delay interval between learning and testing). A plot of some memory measure against time, $P(t)$, then constitutes a performance curve. If one is interested in the *effect* of some focal variable (e.g., in the effect of stimulus

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luminance) then one compares performance curves for multiple levels of the focal variable (e.g., for dim and bright stimuli). In particular, one can test whether the focal variable's effect is additive or multiplicative.

Additive effects. Consider two levels, i and j, of some focal variable that yield two performance curves, $P_i(t)$ and $P_j(t)$. An *additive effect* of the focal variable is implied if the times required to achieve equal performance in the two levels differ by a constant amount for level j relative to level i. The equation relating two additive performance curves is,

$$P_j(t) = P_j(t + k)$$

where k is a constant in units of time.

Additive performance curves are *horizontally parallel.* The interpretation of an additive effect is that being in level i of the focal variable is equivalent to having an additional k ms relative to being in level j. To illustrate, in collaboration with Johnson and Shimamura, I presented unmasked and masked pictures for varying durations, and found that memory performance for a d-ms unmasked picture (i.e., a d-ms picture followed by an icon) was equal to performance for a (d+100)-ms masked picture (i.e., a [d+100]-ms picture not followed by an icon). This constitutes an additive effect of masking. Having an icon is equivalent to having an additional 100 ms of physical exposure duration.

Multiplicative effects. A *multiplicative effect* of the focal variable is implied if the times required to achieve equal performance in the two levels differ by a constant ratio for level j relative to level i. The equation relating two multiplicative performance curves is,

$$P_j(t) = P_j(ct)$$

where c is a dimensionless constant.

Multiplicative performance curves are *constant-ratio diverging.* The interpretation of a multiplicative effect is that in level i of the focal variable processing speed is increased by a factor of c relative to level j. To illustrate, I presented bright and dim pictures for varying durations, and found that memory performance for a d-ms bright picture was equal to performance for a (1.4d)-ms dim picture. This constitutes a multiplicative effect. Processing of bright pictures is faster by a factor of 1.4 than processing of dim pictures.

On conclusions about underlying theory. Any conclusions about the horizontal relation between performance curves (such as that they imply additive or multiplicative effects) can be extended to any variable that is monotonically related to observed performance. Given the monotonicity assumption, such conclusions can be extended to interesting underlying theoretical constructs (e.g., such that "amount of extracted information," not just performance is additively or multiplicatively affected by some focal variable).

Other Applications

Several focal variables have been tested for additive and multiplicative effects. In collaboration with Truax and Nelson I have found *observer age* to produce a multiplicative information-acquisition effect; older observers acquired information about 67% as fast as younger observers. Reinitz, Wright and I found *stimulus priming* to produce a multiplicative information-acquisition effect for pictures of simple objects, but an additive effect for complex scenes. I have rejected an additive forgetting effect of amount of original learning, and infer from this that forgetting rate depends on degree of original learning (see also work by Slamecka, and Slamecka and McElree).

Two Problems with the Framework

The two most salient problems concern the validity of the monotonicity assumption and the statistical analyses.

Validity of the monotonicity assumption. If the monotonicity assumption is incorrect, testing of additive or multiplicative models does not make sense. Neither does the testing of any other specific, quantitative model, such as those implied by ANOVA. Bamber has provided a very useful discussion of this issue.

Statistical analyses. Ordinarily, memory experiments are designed such that time (exposure or forgetting time) is the independent variable, and performance is the dependent variable. Standard ANOVA is designed to assess vertical relations among curves, e.g., to test the hypothesis of no vertical interaction. However, the hypotheses that are tested in the proposed framework demand horizontal comparisons of curves, and thus cannot be tested by standard ANOVA.

There are two current solutions to this problem. The first is to collect data with sufficient power that statistical analyses are unnecessary. The second is to design experiments in which time to achieve prespecified performance levels can be measured for different focal variable levels. Obviously, there are experiments for which neither of these solutions is feasible. Other solutions are presently under investigation.