Attention, Please!

Alois Ferscha

In 1890, William James, a philosophy professor at Harvard University, wrote the following in The *Principles of Psychology*:[1]

> *Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization [and] concentration [of] consciousness are of its essence.*

James further derived that attention "implies withdrawal from some things in order to deal effectively with others and is a condition which has a real opposite in the confused, dazed, scatterbrained state [called] 'distraction' [or] 'Zerstreutheit.'"

Moving beyond this intuitive notion of attention, almost a century after James' foundational reference, Turing Award (1975) and Nobel Prize (1978) winner Herbert Simon studied rational decision making, identifying the inevitable limits of knowing all possible alternatives and consequences of a decision. Simon referred to human attention as a scarce commodity, saying that "in an information-rich world, the wealth of information means a dearth of something else: a scarcity of whatever it is that information consumes, (which is) the attention of its recipients."[2] He expresses attention as the limiting factor in the design of information systems, arguing that "a wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the overabundance of information sources that might consume it." Simon promoted system designs that excel in reducing and filtering out unimportant information to meet attention thresholds—rather than system designs that create more and more arbitrary information.

A few decades later, the concept of *attention economics* emerged from Thomas Davenport and John Beck's economic theory about attention scarcity. In *The Attention Economy: Understanding the New Currency of Business*, Davenport and Beck explain the devotion of attention as part of an (economic) act: "Attention is focused mental engagement on a particular item of information. Items come into our awareness, we attend to a particular item, and then we decide whether to act."[3]

Exploring attention scarcity and the relationship between attention and action is critical to designing today's pervasive computing systems. We need to build on attention research and the diverse theories and models it has produced to address issues of information and sensory overload. Ultimately, we must create a bridge between the fundamental results on specific attentional processes, created by research work in psychology and neuroscience, and the endeavors to apply these results to HCI in general and pervasive computing in particular.

ATTENTION THEORIES

At the core of many theories of attention is a question James asked: "To how many things can we attend at once?"[1] His own answer wasn't conclusive—the number is "indefinite, depending on the power of the individual intellect, on the form of the apprehension, and on what the things are," yet he further argues that however numerous the things, they can only be known in a single pulse of consciousness."

According to Dugald Stuart, this idea of "a single pulse of consciousness" exemplifies how the mind perceives points in a picture. In *Elements of the Philosophy of the Human Mind*, Stuart wrote the following [Quoted from *The Principles of Psychology*[1]]:

> *It is impossible for the mind to attend to more than one of these points at once; and as the perception of the figure implies a knowledge of the relative situation of the different points with respect to each other, we must conclude that the perception of figure by the eye is the result of a number of different acts of attention. These acts of attention, however, are performed with such rapidity, that the effect, with respect to us, is the same as if the perception were instantaneous.*

Today, this idea is more commonly known as the single channel theory (SCT).

Single Channel Theory

Kenneth Craik and especially Donald Broadbent investigated the competitive selection process that the mind seemingly undertakes when confronted

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with several sources of attraction.[4,5] They concluded from dichotic listening experiments that humans can orient their attention toward only a single channel of attraction at a time, employing filtering mechanisms that separate relevant from irrelevant information. According to SCT, additional attractions are always propagated through a single channel toward consciousness—that is, processed sequentially.

Early vs. Late Selection

Since the early 1960s, attention allocation has widely been seen as the process of selecting stimuli for processing, and research was concerned with the question of when and *how* stimuli are selected for processing. Broadbent argued that stimuli are filtered early (*early selection theory*), already at the perceptual level, so that irrelevant or unattended stimuli are not further processed.[5] Anne Treisman proposed a more flexible filter mechanism in her *Feature Integration Theory*,[6] in which disregarded stimuli are explained to be just attenuated—but not completely blocked as in Broadbent's model. James Deutsch and Diana Deutsch proposed an understanding where the actual filtering happens at a late processing stage and all input stimuli are processed equivalently (*late selection theory*).[7] Nilli Lavie combined both approaches by connecting the moment of selection to mental workload in her *Perceptual Load Theory*.[8] According to her findings, early selection is carried out in the case of high workload, but in cases of low workload, selection happens at a later stage.

Capacity Theory

In contrast to SCT, the Capacity Theory (CT) assumes that human attention is limited by an overall capacity of attentional resources, which are "shared" among different tasks. CT is based on the observation that tasks can be carried out simultaneously as long as they're sufficiently automated and don't require high mental effort. Various researchers have performed experiments to support the assumption that attention depends on the overall workload.

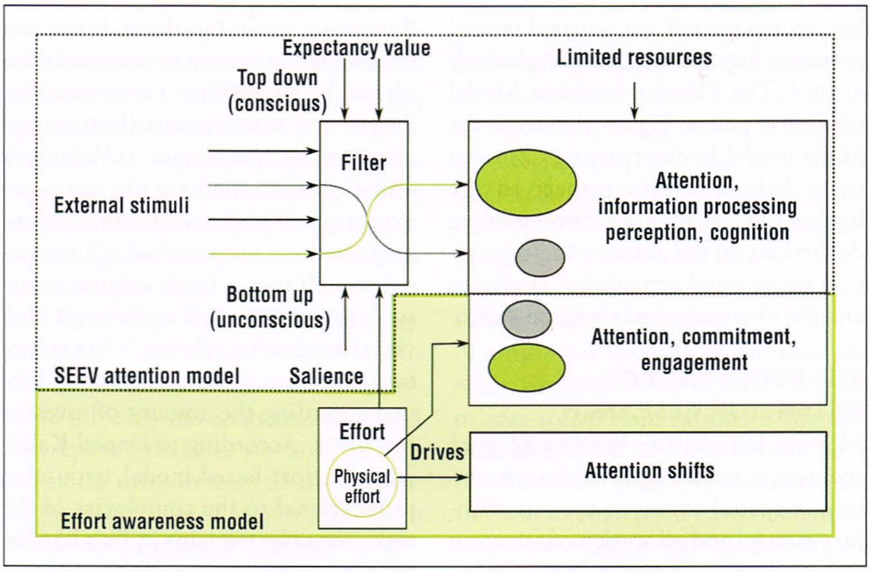

Figure 1. The Salience-Effort-Expectancy-Value (SEEV) attention model—extended with an effort awareness model.[11]

Mental Effort

Daniel Kahneman proposed a dynamic amount of attention capacity, depending on the individual's current level of arousal.[9] (Note that "arousal" is a physiological and psychological state of being awake or reactive to stimuli, and it's important in regulating consciousness, attention, and information processing.) He identified mental effort as the major control component of resource allocation, being directly proportional to the ability to manage mental resources. Martin Sarter described the link between effort and arousal as the "motivated activation of attentional systems."[10]

Multiple Resource Theory

SCT and CT cover different aspects of competitive selection, depending on the subject's task and situation. A more general class of attention models has evolved over the past few decades that integrates capacity, attentional resource allocation, and effort into a single model.

Christopher Wickens proposed the more integrated *Multiple Resource Theory* of attention, in which tasks can be carried out simultaneously as long as they differ in their type of resource demand—that is, nonoverlapping stimulus-response pairs.[11] He proposed a four-dimensional resource model, distinguishing between perceptual modalities, processing stages, perceptual channels, and processing codes. The model explains that simultaneous performance of a visual and an auditory task causes less interference of allocated resources than performing two visual tasks at the same time.

The Multiple Resource Theory includes findings from the CT and also implies single-channel phenomena for tasks with similar resource allocation. The concept of effort is considered as a factor affecting filtering and selection. An evidenced model of the Multiple Resource Theory is Wicken's Salience-Effort-Expectation-Value (SEEV) model of attention (see Figure 1). According to the SEEV model, incoming stimuli are filtered by top-down processes (or *endogeneous* processes, which guide attention to elements of the environment that are relevant for the current task) and bottom-up processes (or *exogeneous* processes, which guide attention to salient elements of the environment).

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Succeeding stimuli are assigned mental resources according to their level of relevance. The Effort-Awareness Model (the lower part of Figure 1) extends the SEEV model by interpreting observed overt behavior with respect to the invested physical effort, thus enabling deductions on the amount and orientation of invested attentional resources and the observation of attention shifts.

THE EVOLUTION OF ATTENTION RESEARCH

Moving beyond the borders of pure theoretical models to investigate attention in spatial contexts, the (in)voluntary control and allocation of attention is a major area of interest. In particular, the aspects of voluntary vs. involuntary attention control and overt vs. covert attention are important in analyzing attention and engagement with signals of attraction in the real world.

Types of Attention

Several types of attention have been identified in the evolution of attentional research. *Focused attention* resembles a short time engagement of an individual with full commitment toward a single stimulus—for example, reaction-time tasks (think of the goalie during a penalty kick). *Sustained attention* covers constant mental activities over long time periods—(think of a rally car driver). *Selective attention* describes the competitive selection process of stimuli to which attentional resources are assigned in contrast to stimuli that remain unattended. *Divided attention* represents the actual parallel processing of stimuli as attention is divided between different tasks. Finally, *switched attention* examines the actual process of shifting the attentional focus between areas or topics of interest.

Control Mechanisms and Behaviors

In addition to attention types, a major aspect of understanding attentional processes is identifying attention control mechanisms and the corresponding behaviors.

Bottom-up versus top-down. Influences on the filtering process for external stimuli can be divided into conscious (top-down) and unconscious (bottom-up) components (see Figure 1).Voluntary attention control covers the conscious execution of tasks, whereas involuntary attention is connected with external stimuli that actively capture a person's attention—such as through high visual or acoustic saliency.[12] Yet voluntary attention control is severely limited regarding the amount of invested resources. According to Daniel Kahneman's effort-based model, arousal is proportional to the complexity of the task—or as he explains it, "it's hard to try hard on an easy task, but easy to try hard on a hard task."[13]

Overt versus covert attention. The distinction between overt and covert attention by Michael Posner is directed at distinguishing between observable, extrinsic behavior—such as head turning or eye movements toward selected stimuli—from covert processes, which describe inward activities.[14] Posner found a "striking tendency of attention to move to the target prior to an eye movement."

Experiments carried out by Amelia Hunt and Alan Kingstone indicate that in the case of bottom-up controlled, reflexive processes, overt and covert attention are strongly related, whereas for top-down controlled processes, inferring backward from eye gaze alone to overt attention is error-prone.[15] A typical example of the ambiguity of overt and covert attention for top-down-controlled processes is the blank stare, a phenomenon in which a person will look at a destination without any perception (his or her mind is elsewhere).

Understanding Goals and Plans

Human behavior is motivated by plans and goals. Plans refer to conscious intentions, while goals can exist at both levels of consciousness. Furthermore, plans and goals are equipped with a priority attribute, which indicates how targeted the fulfillment of this goal will be pursued and how easily people can be distracted. Ap Dijksterhuis and his colleagues assume that goals are major top-down components that drive attention.[16] Goals and intents aren't necessarily connected to awareness. They state that, "goals guide behavior through attention, and this guidance can occur outside of a person's awareness."[16] The fact that goals can be imposed unconsciously is supported by experiments of Karin Bongers and her colleagues,[17] additionally indicating a negative influence on perceived self-esteem in case of failure, even on unconsciously activated goals.

Emotions and instincts represent abstract forms of built-in goals and plans that are only directed at unconscious and automated processing. Margaret Bradley concentrated on the most fundamental motivational system, which is survival instinct, and identified mechanisms that affect orientation of attention and behavior.[18]

In her extensive review about the effects of emotion on attention, Jenny Yiend stated that there's no general *pop-out effect* of negative information, but the visual search for negative or threatening information runs much faster.[19] This supports assumptions from capacity-based attention models in which additional resources can be allocated in case of states of high arousal. Elizabeth Phelps and her colleagues found evidence that emotion facilitates early vision, and vision is improved in the presence of emotional stimuli.[20] Ray Dolan describes how emotion influences decision-making processes by relating emotions from past decisions to future determinations, thus also connecting learned experiences to future decision making and behavior.[21]

ATTENTION METRICS

Attention can't be measured—at best, it can be estimated based on inferred indicators. The usual approaches in psychology for attention measurement use tests in which the performance of a subject on a task is recorded, whereas the task design depends on the respective attention element to be evaluated. Moreover, studies have shown that there are also somatic indicators, which can be used to infer mental activities. Specifically for the estimation of the visual focus of attention, approaches that trace somatic indicators have been followed.

Performance Tests and Interviews

There are numerous tests for attention performance. Lloyd Beck and his colleagues developed the Continuous Performance Test (CPT) to measure sustained and selective attention.[22] This test has been improved several times, resulting in, for example, the Test of Variables of Attention and the Integrated Visual and Auditory CPT, which are used in commercially available systems. In Beck's original CPT, correct detection, reaction times, omission errors, and commission errors are used as test scores.

Cynthia Riccio and her colleagues evaluated the CPT concerning its expressiveness of attention performance.[23] They found that the CPT is suitable for reliably detecting attentional disorders, such as attention deficit hyperactivity disorder and schizophrenia, but that no general analysis of brain structures can be achieved by applying only a CPT test.

A different test, directed at surveying selective attention mechanisms, is the d2 test by Rolf Brickenkamp.[24] d2 is designed to "measure processing speed, rule compliance, and quality of performance, allowing for a neuropsychological estimation of individual attention and concentration performance."

Somatic Indicators of Attention

In addition to performance tests and interviews, which both force subjects into an explicit test situation (which can interfere with natural attention), there are investigations into somatic signs that indicate attention levels. Estimation of gaze direction and eye tracking is a popular and simple approach for estimating the focus of visual attention. In laboratory settings, tracking eye movements is a reliable indicator for detecting observed objects; however, because only overt attention mechanisms are analyzed, conclusions regarding covertly perceived information are difficult.

Additionally, in real-world use cases, eye-gaze tracking must be both unobtrusive (to preserve the natural behavior of subjects) and accurate, a technical discrepancy that has yet to be solved. An actual measurement of arousal that might be considered as proportional to attention is eye pupil dilation. Kahneman reported that rhythmic contractions and dilations of the pupil cease during performance, requiring mental effort.[9] Furthermore, he mentions the increase of galvanic skin conductance as another possible, but less reliable, indicator for mental activity. Stephen Fairclough investigated the influence of mental activity on heart rate and blood glucose levels.[25] He showed that the cardiovascular measure correlates with time-on-task variables. In conclusion, somatic markers show promising results indicating mental activity, but still can't provide reliable assessments of allocated attention.

Visual Focus of Attention

A common approach in technical attention research is based on visual focus, involving tracking technology (such as gaze and pose tracking) to capture indicators of attention. Stylianos Asteriadis and his colleagues built a system for estimating the user's attention when using e-learning applications.[26] They employed a neurofuzzy inference system to classify six different attention states—frustrated/struggling to read, distracted, tired/sleepy, not paying attention, attentive, or full of interest—using overt, somatic features.

Visual focus of attention in HCI scenarios has been extensively investigated based on the interpretation of head poses and eye gazes. The attention indicators are deduced from the statistical analysis of head movements and object fixations. Sustained attention and distractability are the main concern of interest here, and attention-aware systems as well as attentive user interfaces the goal.

Public Space Scenarios

A major problem in exploiting the early findings of attention research in real-world applications is the fact that almost all of these results have been derived from experiments carried out in controlled environments—where the conditions under which subjects act and work are well known. Researchers have started to experiment in settings where there's little or no control over the conditions under which subjects work, a prominent case being the assessment of the attention of individuals in public places, like passers-by in train stations or airports. Here the question is often how to interpret overt behavior in public areas, describing competitive selection and switched attention processes.

Kevin Smith and his colleagues created a head tracking application in an out-of-home advertisement scenario and included a simple attention analysis consisting of a focused state and an unfocused state.[27] Subjects were evaluated as focused if their gaze were directed at the display for a certain number of consecutive frames.

In general, surveillance camera footage to estimate the area and direction of interest of pedestrians, taking head pose, upper body pose, body orientation, and direction of movement as features, appear promising for attention estimation in the public. For example, Yasunori Yakiyama and his colleagues estimate a person's attention level toward a target object using a laser sensor and the computed distance, basic orientation, and movement speed.[28] Francis Quek and his colleagues analyze the position of the subject's feet and their

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Figure 2. Different kinds of behavior in a mall scenario when passing a pervasive display: Passersby might not perceive the display at all and show no reaction (shown in white), they might, for example, turn their head toward the screen but continue their way (shown in yellow), or they might even stop and take time to perceive the presented information (shown in green).

movement orientation to estimate visual focus.[29]

Effort-Based Attention Estimation

A recent approach to estimate attention takes directed effort—for example, turning one's head after passing the attractor, or moving a few steps in that direction. For example, I've worked with Benedikt Gollan to propose a system that carries out an on-the-fly behavior analysis of passers-by to a pervasive display by analyzing movement and orientation patterns (see Figure 2).[30]

Our estimation architecture builds on an integrated attention model, covering the path from the perception of signals of attraction and the filtering stimuli to the alteration of the motivation chain and allocation of attention resources to the execution of related plans to satisfy underlying motivations (see Figure 3). We build on the hypothesis that behavior change is an indication of effort, and directed effort is an indication of attention allocated toward a source of attraction.

Currently, in media-rich environments and spaces, where thousands of people are continuously flooded with signals of attraction and messages at all levels of modalities (visual, auditory, tactile, olfactory) and perception, it has become difficult for individuals to allocate attention to the right things at the right time. Recently, many researchers have started studying how attention is allocated, how information is perceived and shared, and how this leads to "informed decisions" and behavioral change. Specifically, the dynamics of individual attention and the emergence of collective attention appear to be among the most demanding challenges of today's information society. Many are interested in understanding how spontaneous, local, individual attention to novel information items occurs, propagates, and eventually fades among large populations.

More than two decades of pervasive and ubiquitous computing research has changed how we view the "computer." It's no longer a single device or network of devices but rather the entirety of all services originating in a digital world (a globe-spanning, dynamic, complex infrastructure), perceived through the physical world (technology-rich spaces and objects of everyday use). In this emerging symbiosis of the digital and the physical world, human attention is a crucial and fundamental resource. Thus, the development of a body of formal methods and computational models for attention, together with the respective design and operational principles of "attention-aware" pervasive systems, represent a foundational research challenge for novel, "human friendly" ICTs. Future generation ICTs will have to be grounded in reliable models and mechanisms of human attention but also in other individual cognitive capacities, including expectation, belief, meaning, trust, experience, forgiveness, and empathy.

While the history of attention research has manifested a body of descriptive and operational models of selected aspects of human attention

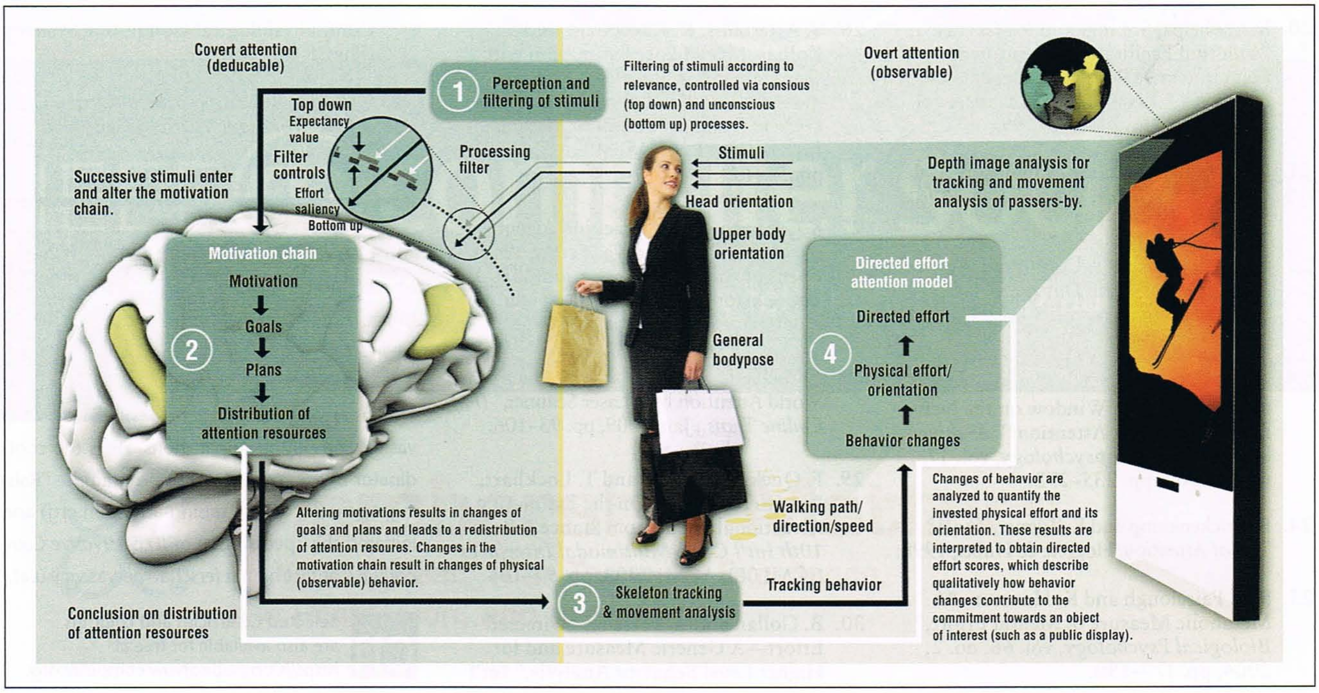

Figure 3. A directed-effort-based attention model for pervasive displays:[30] (1) Incoming stimuli are filtered according to top-down and bottom-up processes (as in the Salience-Effort-Expectation-Value model); (2) succeeding stimuli enter and alter the motivation chain and influence the distribution of attention resources; (3) a realization of plans are expressed in observable behavior; and (4) behavior changes can be tracked, quantified, and interpreted.

(such as the single- and multitasking capability, cognitive load thresholds, and sensor-motor coupling), we still don't have in place a "holistic theory of attention"[31] that bridges research work in psychology and cognitive neuroscience with pervasive and ubiquitous computing research. ▪

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