

Woodwardian Causality in Eyetracking

- A Case Study - *

Section: Philosophy of the cognitive sciences

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Recently, the investigation of overt visual attention has moved into the center of interest in vision research. Allowing direct measurements of shifts of attention, eye-tracking is a widely used technique. By recording subjects eye-movements in cautiously designed studies, it is not only possible to investigate saccadic behavior, but also to differentiate between different hypotheses of visual attention.

Eyetracking enables scientists to measure many different properties of visual behavior including fixation positions and durations, saccade directions and distances, blinking frequency and the diameter of the pupils. In short, eyetracking enables us to know which information enters the visual system and allows for a more detailed answer to the question of why it is selected. Having detailed knowledge in this area is an important milestone in our understanding of the visual system and attentional mechanisms. Although our understanding of visual attention has made considerable progress, some fundamental problems remain to be solved. For instance, it is known that stimulus features as well as different tasks can alter viewing behavior in a systematic way. Still, the means by which these changes are accomplished have yet to be clarified.

The idea of philosophical notions of causal explanations is to provide a clear description of what counts as a valid explanation and what does not. As a result, causal explanations should not only provide guidelines for valid experimental designs, but they also have to prove their validity in the light of scientific practice. Over the last years, Woodward (2005) has developed a non-reductive manipulationist account as an alternative to more traditional approaches and is purported to be particularly close to scientific practice. According to his approach, relationships are causal and explanatory if they are potentially exploitable for purposes of manipulation and control. X directly causes Y if changing X would change Y or the probability distribution of Y when all other variables are held fixed. X is a contributing cause, if there is a directed path of direct causes between X and Y . How changes in X should be performed is defined by the notion of an intervention. I is a proper intervention if I is the only cause of X and if I influences Y only through X . Also, I should be independent from a Z that either causes Y or lies within the causal chain between X and Y .

From a general point of view, there are manifold reasons why a manipulationist account of causal explanations is adequate with regard to experimental practice. First and foremost, changing experimental conditions by intervening on the independent variables and relating a notion of causality on changes in

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the dependent variable is close to the common principles of experimental design. Put differently, it is comfortable and close to experimental thinking to view causal reasoning and experimental findings as referring to what if things had been different questions that can be answered. Also, causal claims established this way do not rely on the doubtful definition and presence of a natural law. In the following, Woodward's claim of being close to scientific practice will be investigated in more detail by relating his ideas of adequate experimental designs and interventions to an eyetracking case-study.

This study by Betz et al. (submitted), was designed to differentiate between different mechanisms of task-dependent viewing behavior. Subjects were given tasks of different complexity according to which they had to examine webpages. One theory suggests that changes in viewing behavior are achieved by changes in weights of stimulus features (weak top-down). An opposing view is that fixations are altered by an independent top-down module. For the current discussion, two types of calculations have to be described in more detail. Fixation Density Maps (FDMs), which are most often created by averaging viewing behavior of different subjects, provide a measure of fixatedness of different regions of a stimulus. Using FDMs, it is possible to statistically evaluate whether fixation behavior is equal or different. A second important measure is based on the area under curve (AUC) of receiver operator characteristics. Put simply, this measure described the relative importance of visual features (such as color contrast, edges, saturation or luminance) at fixated regions by providing a measure on how good actual fixations can be differentiated from control fixations. AUC is therefore directly related to stimulus (bottom-up) dependent influences on visual attention. Changes in viewing behavior induced by different tasks are classified as top-down, because they are stimulus independent. The idea of the study was as follows: If it is possible to observe differing viewing behavior in different tasks (as shown through differential FDMs), then a close observation of feature values at fixation points should reveal whether the difference resulted from changes in feature-weights or not (for instance, it would be thinkable that the task influences viewing behavior by emphasizing the red color channel). The experimental question was whether top-down influences cause differential viewing behavior via a causal route through changes in bottom-up features or whether they have to be seen as a direct and independent cause.

Woodward's definition of a surgical intervention requires, among others, that the intervention acts as switch for all the other variables that cause X. Moreover, Woodward's approach demands that all background variables have to be held constant during the intervention.

For many eyetracking experiments, these requirements causes two problems. First, it is known that both bottom-up stimulus features as well as top-down task processes can alter viewing behavior. This means that for an experimental design and intervention on the task-variable, changes in the stimulus features have to be kept stable. This way, changing viewing behavior could directly be ascribed to changes in the task (strong top-down). However, it is simply not possible to control the positions of the subjects fixations and the experimental design necessarily violates Woodward's requirements. A solution to this problem can be given by the following idea: If the variable cannot be fixed, the question is whether a mere inspection of the variable, as in the case of AUC, suffices. If an investigation of the complete state of the variable is possible and it remains fixed without external control, then there seems to be no argument against the

validity of this procedure. In the end, the values of the variable are fixed and the way of accomplishing this is of minor importance. In theory, an observation of a stable variable should thus suffice to fulfill the requirement of being fixed. Clearly, the bottleneck of the description lies in the full observability.

The second problem is directly related to Woodward's definition of a proper intervention according to which, among others, the intervention on the top-down variable has to act as a switch for all the other variables that cause X . This requires that all top-down influences, apart from the task, are kept stable. However, because of memory-effects, it is not possible to show the same stimulus twice to one subject. The standard solution to this is to show every stimulus only once per subject and later perform an across-subject analysis. This solves the memory-effect, but results in the problem that many top-down effects such as prior knowledge, etc. are no more guaranteed to be equal in the different conditions (across subjects). Although this violates Woodward's definition of a proper intervention, it is generally assumed that a random assignment of subjects to different conditions renders the groups equivalent with regard to external (uncontrollable) influences.

Concerning across-subject designs it is important to note that no direct correspondence of viewing behavior and task can be established because no subject is presented with the same stimulus under the influence of different tasks. Although the stronger claim of an individual change is not supported, finding an effect across subjects shows that, in the mean, fixation behavior changes. This claim is widely regarded as equally valid.

Woodward's theory was developed to be a tool for scientists and to be close to experimental practice. The current work provided an interpretation of parts of his theory with regard to the standard practice of experimental design in psychophysics and eyetracking. It was shown that, although Woodward's approach towards causal explanations seems to be very well equipped to actually cover the scientific practice, there are some issues with his definition of a proper experimental setup and intervention. As noted above, feature-values at fixation points cannot be controlled. As a solution, it was suggested that close observations of stable variables suffice for it to be considered as fixed. Although the general approach of across-subject designs seems to violate Woodward's ideas of ideal experiments, it is assumed that external (hidden) effects equal out by randomly assigning subjects to different experimental conditions. Although across-subject design and randomization do not fix the stimulus and external variables in the original sense, they can still be interpreted as being stable across the overall group and are therefore in line with the definition of a proper intervention.

References

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