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p-Values
What are they? Who do we Ask?

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Abstract

p-values are everywhere, from the daily newspapers to the most serious scientific publications. But what are they, and who might we ask? We give a brief overview and then outline some current directions towards a resolution.

Introduction

Humans have always been curious, even avid in seeking verification of suggestions and appearances. Pure thought provides one route and leads to philosophy. A more hands-on approach leads to investigations, to science, and to statistics. While many steps have preceded it, the emergence of the test of significance represented the first more formal approach: there would be some hypothesis of interest; the search then for an appropriate variable that would examine suspected departures from what might be expected under the hypothesis; the collection of data for that variable; and then an assessment of whether the data were possible or realistic under the hypothesis. An example in Fisher concerned the hypothesis that stars were uniformly and randomly distributed on the celestial sphere; and then took as data some measure of the congestion of stars in the Pleiades constellation [1]. A more prominent example concerns whether light is bent from a straight-line trajectory by a large mass such as the sun; an opportunity arose with an eclipse of the sun in 1919; the data came from a view of a bright star close in line to the eclipsed sun; the particular variable was the position of the star relative to neighboring bright stars when its light passed very close to the sun. The resulting data confirmed a departure thus giving some confirmation to Einstein's theory.

Accept-reject

A more formal approach was proposed by Neyman & Pearson [2]. They considered a model for the behaviour of the variable in an investigation and recommended an Accept or Reject based on the observed value of that variable, and then proposed a procedure that would Reject under the Hypothesis at most 5% of the time yet would have a maximum possible probability under the Alternatives to the Hypothesis. This Accept-Reject approach with its 5% rate or sometimes an rate was widely supported and still has many direct and indirect supporters. The approach then became widely used for making an Accept-Reject of articles for publication in scientific journals; but Sterling [3] offered a detailed discussion to show that it provided just a way to a wealth of publications with incorrect results. One sociology journal more recently then declined to consider submitted papers that used p-values, specifically those of the Accept-Reject form. The American Statistical Association considered the issues; also a recent group of statisticians has suggested the 5% threshold be changed to 0.5%. This latter proposal over-looked the reality that the problem was really the use of decisions, loose decisions, to assert validity of hypotheses. A more insightful proposal recommends the presentation of the actual probability position of the data point relative to the various values of the relevant parameter say θ for the variable being examined, leaving potential action to the judgement of the investigator [4].

Statistical position of data

More recently, approximation theory has allowed the use of much more general models and the use of available highly accurate approximations coming from saddle point theory [5]. As a result exponential models can be used as an approximation for a very broad range of models; and in addition the models can be expressed in terms of simple statistical quantities such as maximum likelihoods estimates and information functions. This bypasses the familiar concepts of sufficiency and ancillarity conventionally used in many assessments. For some recent discussion, see Fraser [4] and Fraser [6]. For example with the simple statistical model $f(y-\theta)$ together with observed data y^0 say the p-value function,

$$p(\theta) = F(y^0 - \theta) = \int^{y^0} f(y-\theta)\,dy$$

gives the %-age position of the data relative to possible values of the parameter θ, in effect telling the full statistical story about the data with model. This shifts the decisive step from being an Accept-Reject step to one of judgment of the statistical position of data, this later then resting entirely with

the particular scientist, where it belongs. And the calculation of the p -value function is widely available, with accuracy and uniqueness coming from the continuity typically present with most models. Thus a sociologist might pursue further investigation when the p-value function was less than say 5% while a high energy physicist might use say 1 in 3×10^5 to assert publicly that he had found a new fundamental particle.

Discussion

We have provided a very short overview of the process from informal assessment, through an attempt to mechanize the acquisition of knowledge by an Accept-Reject approach, to a form of judgment coming from the statistical position of acquired data.

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