Symmetry of STRUCTURE

an interdisciplinary Symposium

Abstracts

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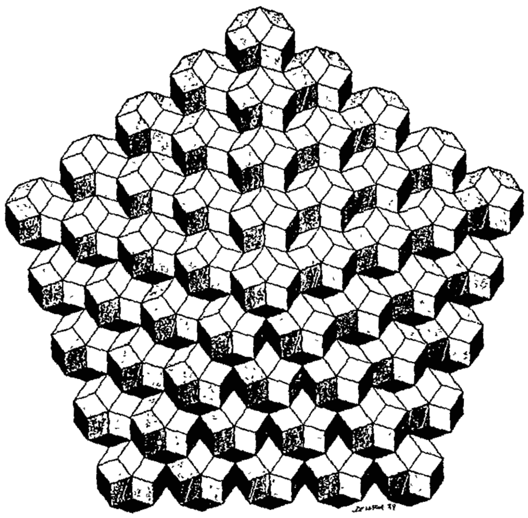

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SYMMETRY IN THE STRUCTURE OF SCIENCE

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Abstract

It is shown that reproducibility and predictability, forming the dual cornerstones of the structure of science, are kinds of symmetry.

Introduction

The structure of science rests firmly upon the dual cornerstones of reproducibility and predictability. Reproducibility is the repeatability of experiments by the same and by other investigators, giving data of objective value. That makes science a common human endeavor. Predictability means that order can be found among the phenomena investigated, from which laws can be formulated, predicting the results of new experiments. (Then theories might be developed to explain the laws.) Predictability makes science our means both to understand and to exploit nature. (Thus nature's irreproducible or unpredictable aspects, whatever they may be, lie outside the domain of concern of science.)

It is well known that symmetry holds an eminent position in science. Examples: spatial symmetry of crystal lattices, temporal symmetry of periodic processes, Poincaré symmetry of relativistic theories, gauge symmetry of elementary particle theories. However, symmetry is of crucial importance in the structure of science itself. Indeed, I will show that both reproducibility and predictability are kinds of symmetry.

Symmetry

In everyday speech symmetry usually means a balance, a repetition of parts, a regularity of form. More precisely and generally symmetry can be said to be invariance under transformation, i.e. the situation is symmetric if there are one or more changes that can be made that nevertheless leave some aspect of the situation unchanged. Consider, for example, a uniform metal equilateral triangle and imagine rotating it by 120° or 240° about its center within its plane. Although a transformation, a change, has been made, the result looks the same and has the same physical properties as the original. Thus our piece of metal possesses symmetry under these rotations with respect to external appearance and physical properties. If the triangle were not uniform or had a corner chopped off, it would not possess this symmetry.

Actually, a system that might possess symmetry may in general be concrete or abstract. The transformations involved need not be geometric, but may involve any concrete or abstract aspect of the system, as may the invariant aspect be concrete or abstract and does not have to be appearance or physical property. But the very least we need for symmetry is the possibility of making a change and some aspect that is immune to this change.

Reproducibility as symmetry

Putting things in terms of experiments and their results, reproducibility is commonly defined by the statement that the same experiment always gives the same result. But what does "same" mean here? No two experiments or results are identical; they will always differ at least in time (repeating the experiment in the same laboratory) or in location (duplicating the experiment in another laboratory) and will differ in other respects as well. So by "same" we must mean "equivalent" in some sense. We cannot even begin to think about reproducibility without permitting ourselves to overlook certain differences involving time, location, and various other aspects of experiments.

Let the difference between two experiments be expressed as a transformation, the change that must be imposed on one experiment to make it into the other. Such a transformation might involve temporal displacement and/or spatial displacement and/or rotation. It might involve putting into motion or bending the apparatus. Or we might change the experiment to measure temperature rather than pressure, for instance. And so on and on.

But not all possible transformations are associated with reproducibility. Let us see which are. Temporal and spatial displacement are obviously included. And the motion of the Earth requires us to add rotations and velocity transformations. To be able to use different sets of apparatus, we need replacement by other materials, other atoms, other elementary particles. Due to unavoidably limited experimental precision we must include small changes in the conditions. And we also need changes in certain other aspects of experimental setups, over which we have no control in practice or in principle.

So we define reproducibility: Consider an experiment and its result, consider the experiment obtained by transforming the original one by any transformation belonging to the above set of reproducibility-associated transformations, and consider the result obtained by transforming the original result by the same transformation. If this transformed result is what is actually obtained by performing the transformed experiment, and if this relation holds for all transformations belonging to the set, we have reproducibility. This is symmetry, as can be seen as follows: Consider a reproducible experiment and its result. Transform it and its result together by any transformation belonging to the set of transformations we associate with reproducibility. The pair (transformed experiment, transformed result) is, of course, different from the pair (original experiment, original result), but there is an aspect of the pairs that does not change under the transformation. This is that the result is what is actually obtained by performing the experiment. Said in other words, this symmetry is that for any reproducible experiment and its result, the experiment and result obtained from them by any transformation belonging to the above set are also an experiment and its actual result.

Predictability as symmetry

Again expressing things in terms of experiments and their results, predictability is that it is possible to predict the results of new experiments. Of course, that does not come about through pure inspiration, but is attained by performing experiments, studying their results, finding order, and formulating laws. So imagine we have an experimental setup and run a series of n experiments on it, with inputs inp_1, inp_2, ..., inp_n, respectively, and corresponding results res_1, res_2, ..., res_n. We then study these data, apply experience, insight and intuition, perhaps plot them in various ways, and, maybe with a bit of luck, discover order among them. Suppose we find that all the data obey a certain relation, R, according to which all the results are related to their respective inputs in the same way. Using function notation, we find that $res_i = R(inp_i)$ for $i=1, ..., n$. This relation is a candidate for a law, res = R(inp), predicting the result res for <u>any</u> input inp. Imagine further that this is indeed the correct law for our experimental setup. Then additional experiments will confirm it, and we will find that $res_i = R(inp_i)$ also for $i = n+1, ...$ as predicted. Predictability is the existence of such relations for experiments and their results.

That predictability is a symmetry is seen as follows: For a given experimental setup consider all the different input-result pairs (inp, res) that have been, will be or could be obtained by performing the experiment. Transform any one of these into any other simply by replacing it. The transformed pair is different from the original one, but the pairs possess an aspect that is not changed by the transformation. This is that <u>inp and res obey the same relation for all pairs</u>, namely the relation res = R(inp). Put in different words, this symmetry is that for any predictable experiment and its result, the experiment and its result obtained by changing the experimental input obey the same relation as the original experiment and result.

Conclusion

Following the definition of symmetry as invariance under transformation, it is shown that both reproducibility and predictability are kinds of symmetry by showing for each the changes that can be made and the aspect that is immune to these changes. For reproducibility any experiment-result pair can be transformed by any of the set of reproducibility-associated transformations. The invariant aspect is that the result is what is actually obtained by performing the experiment. For predictability any input-result pair can be transformed by replacing it with any other pair for the same experimental setup. What is invariant is the relation between experimental input and result. Since reproducibility and predictability are the two most fundamental cornerstones of science, we see that symmetry not only serves within science, but is actually intrinsically involved in its structure and is thus inherent to the very existence of science.

Bibliography

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