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A Functional Classification of Physical Principles, Illustrated by the Theory of Relativity

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Physical principles are statements pertaining to physical theories, the possibilities they represent, and what can be inferred from them. One can classify principles in many cross-cutting ways, but doing so according to the principles'scientific function can be particularly illuminating, illustrating the diversity of roles they can play, and how those roles can change over time. Using the theory of relativity (both special and general) as an example, I describe five functions: representational, axiomatic, law-like, inferential, and heuristic.

Representational principles delineate how mathematical structures in the models of a physical theory represent objects, properties, or relations. For instance, the "clock hypothesis"of relativity theory asserts that the length of any timelike curve represents the duration of a point-like process along that curve. Thus, if that curves traces the worldline of a particle, the lapse of a parameter tracking this duration serves as a dynamical parameter for the particle's equation of motion. Representational principles are especially important in what Einstein called constructive theories, where the mathematical models of the theory are given explicitly. In order for such models to play their theoretical role, they must be supplemented with representational principles.

Axiomatic principles, by contrast, serve at once to specify the theory itself and what possibilities the theory represents. In Einstein's original formulation of the special theory of relativity, the principle of (special) relativity allows one to generate possibilities by uniformly translating a coordinate system. Such principles are essential for what Einstein called principle theories, where the mathematical models are not given explicitly but must be found as those that provide models for the principles. Over different formulations of a theory, an axiomatic principle can become a representational one, as the principle of general covariance arguably has.

Law-like principles of constrain or reduce the possibilities that a theory—constructive or principle—would otherwise endorse. As the name suggests, they are sometimes expressed as physical laws, but often are deemed principles when they find expression across many different theories. In special relativity, energy conservation (i.e., that the energy-momentum tensor is divergence-free) expresses such a principle that is then subsumed under the Einstein Field Equation in general relativity. Energy conditions are also examples of law-like principles.

Focal principles draw out or emphasize a particular consequence of a theory for understanding, inference, or calculation. They do not provide extra constraints or meaning to mathematical models, but facilitate explanations and deductions. Action principles for deriving field equations are examples.

Heuristic principles suggest connections with or constraints on future theories. In this way, they are like aspiring axiomatic principles. For instance, the strong principle of equivalence suggests a procedure for taking a special relativistic matter theory and producing a corresponding general relativistic matter theory. The principle of background independence suggests constraints for future theories of quantum gravity.

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