On Gravity and Quantum Gravity: A Brief Summary of Conclusions

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So, to review what we have learned about gravity and quantum gravity over the last few years.

Classical Gravity is incorrectly understood. It is actually a generalized gauge theory (G^2T), a mathematical object based on classical gauge theory—most precisely written down by Yang and Mills.

--Yang-Mills theory is determined by a base space and a group. From these objects various fibre bundles can be constructed and dynamical theories can be written down—most famously the Standard Model $SU(3) \times SU(2) \times U(1)$

--It was H. Weyl who conceived the most fundamental aspect of gauge theory (and through a most circuitous route involving a generalization of general relativity that was thought to be unphysical at the time). The remarkable idea was to stipulate that a theory based upon invariance of a group $\mathcal{G}$ should be invariant under transformations of $\mathcal{G}$ that differed from point to point.

--From this simple stipulation one can deduce the existence of a set of functions $\{A^a_\mu\}$ that reside alongside the 'mother' functions ψ on M (the base spaces) and play the role of compensating functions mathematically and force carriers physically. This remarkable structure has a wealth of experimental support provided:

1. The group $\mathcal{G}$ is chosen correctly (and it is not very complicated at all in the Standard Model).
2. Certain undetermined numbers appearing in the otherwise fairly well determined physical models are chosen so as to agree with experiment.
3. Certain representations of $\mathcal{G}$ are chosen rather than others.
4. Very simple dynamics are picked $\mathcal{L} \sim -\frac{1}{4}F^2$

--It is quite remarkable that so much physics resides in the kinematics of gauge theory, and this is reflected in the fact that so little else must be postulated in order to construct a viable dynamical theory.

--Since its inception gauge theory has been imagined as the correct conceptual and mathematical scheme for general relativity. The idea of "General relativity as a gauge theory" has sparked the imagination of several generations of physicists. The initial attempts to reproduce the physics of GR within the gauge theory rubric were only partially successful. In fact, all such attempts have had a fatal flaw.

--The fatal flaw is apparent without having to do any complicated calculations: One of the basic ingredients of gauge theory is a group $\mathcal{G}$. For a variety of fundamental reasons General Relativity's physics cannot be captured by any structure which relies on a group. The best that can be done if a group is insisted upon from the outset is to break up general relativity into a set of theories, each of which insists upon the metric being invariant under a certain isometry group at ∞. One can then use gauge theory to describe each of these bits.

--If one wants to create a gauge theory that contains the fundamental philosophical lessons of GR, one has to enrich the conceptual content of Gauge Theory.

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