# AdS/CFT and the Littlest Higgs

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## 1 Overview

The AdS/CFT correspondence provides us with unique insight into strongly-coupled quasi-CFTs [1]. The dual description in terms of a modified RS1 model [2] allows us to not only consistently introduce gravity into a 4D CFT, but to also understand the non-trivial bound states of the CFT in terms of simple boundary conditions on the "TeV-brane". Because the AdS picture is weakly coupled, we can do perturbative calculations that are often intractable in the CFT picture. Therefore, we can meaningfully construct Standard Model extensions involving a strongly-coupled quasi-CFT that confines at some scale greater than a TeV; all we need to do is construct a 5D action in AdS space involving some combination of gauge bosons, fermions, and scalars with interesting boundary conditions at the Planck- and TeV-branes.

These ideas are further motivated by noting that the RS1 model gives a natural way of solving the hierarchy problem. The weakness of gravity on the TeV-brane is explained by the exponential warp-factor and the fact that the zero-mode graviton is localized near the Planck-brane. In CFT language, the cut-off of the Standard Model really is at a TeV, where strong-dynamics take over. So if the Higgs boson really were a CFT bound state, then a Higgs mass of, say, 100 GeV would require only 10% fine-tuning.

In fact, we can do much better than this. From QCD, we know that it is completely natural to find light scalars below $\Lambda_{\text{QCD}}$. These are the pions, the pseudo-Goldstone bosons arising from spontaneous breaking (via $SU(3)_C$ confinement) of the approximate chiral $SU(2) \times SU(2)$ symmetry that rotates the up and down quarks. If the chiral symmetry were not broken by quark mass terms, then the pions would be exactly massless at tree-level. Because the pions transform under $U(1)_{EM}$, the charged pions pick up a power divergent mass from a gauge boson loop, $m \sim g\Lambda_{\text{QCD}}/4\pi$, and for small enough gauge coupling, this yields a natural explanation for why the pions are so light.

We can imagine carrying over the pion logic to treat the Higgs boson as some pseudo-Goldstone boson. This line of thinking has been taken to an extreme in the Littlest Higgs model [3], where the cutoff can be pushed to 10 TeV while still maintaining a naturally light Higgs by implementing collective breaking. In particular, the interactions of the theory are manufactured in pairs such that the Higgs is an exact Goldstone boson when *either* of the paired coupling constants is zero. Thus, *both* coupling constants are needed to generate a Higgs mass, which means that the Higgs mass is protected from power divergences up to two loops.

What the Littlest Higgs model needs, however, is a UV completion, and the AdS/CFT correspondence is ideally suited to provide such a completion. An example of this reasoning is shown in [4], where the Higgs arises from the strong dynamics of a quasi-CFT dual to a modified RS1 model. On the CFT side, this model has a global $SU(3)_L \times U(1)_X$ symmetry with a weakly gauged $SU(2)_L \times U(1)_Y$ subgroup. Through the strong dynamics of the quasi-CFT, the global symmetry is spontaneously broken to the gauged symmetry, and the Higgs is the pseduo-Goldstone boson from this breaking. While such a model naturally provides the right size negative mass squared for the resulting Higgs boson, it cannot easily produce the large quartic self-coupling of the Higgs necessary for triggering electroweak symmetry breaking.

In our imagined CFT-extension of the Littlest Higgs, the CFT has a $SU(5)$ global symmetry that is broken through strong dynamics to $SO(5)$. An $SU(2)_A \times SU(2)_B \times U(1)$ subgroup of $SU(5)$ is weakly gauged, and is spontaneously broken to a diagonal $SU(2)_L \times U(1)_Y$ by the strong dynamics. In this model, the large quartic self-coupling of the Higgs *is* generated naturally. Furthermore, the $\Lambda_{CFT}$ is roughly 10 TeV, and such a large Standard Model cutoff seems favored by precision electroweak tests. In this way, the Littlest Higgs — or at the very least, the gauge sector of the Littlest Higgs — is ideally suited for an AdS/CFT description.

Our goal then, is to explicitly realize the RS1 model for the Littlest Higgs, with a Planck-brane, a 10-TeV-brane, and appropriate gauge bosons and fermions to generate the Standard Model at low energies. By the AdS/CFT correspondence, we are guaranteed that this model is dual to some CFT, but we will use the AdS picture to carry out perturbative calculations. Because the Littlest Higgs model requires specific fermion interactions, we will have to do a bit of work to come up with the correct 5D AdS model. The payoff is that at the end of the day, we will have a UV complete, technically natural, and phenomenologically viable theory.

## References

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[4] R. Contino, Y. Nomura, A. Pomarol. *Higgs as a Holographic Pseudo-Goldstone Boson.* `hep-ph/0306259`