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A graph representation for the distribution of dark matter halos

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Dark matter halos, produced during cosmic structure formation, organize themselves under gravity in an expanding background. We show that some novel features of their distributions can be understood in the framework of network theory by using a preferential attachment mechanism. For the subhalos sitting inside their least massive hosts, we create links based on their spatial extensions and construct a tree-like graph for each host halo. We use public state-of-the-art cosmological simulations to show that the degree distributions of these graphs are power-law with an index close to minus two. We show that the linear accretion rate in minor mergers corresponds to an asymptotic regime of linear preferential attachment, based on which we construct a simple network model that gives rise to the same power exponent. With the effects of major mergers and tidal evolution incorporated, our model can be used to efficiently generate the subhalo abundance and the hierarchical structure of subhalo distribution using a graph representation. These generated graphs give rise to similar graph metrics to the ones constructed from cosmological simulations. The topological and structural information encoded in the graph metrics can be exploited to quantify the recent accretion history of a halo or to probe some novel scale-dependent non-gravitational dynamics.

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