All-loop singularities of scattering amplitudes in massless planar theories

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Consider a Feynman-parametrized Feynman integral,

\[
\int \prod_{r=1}^{L} d^{D} l_r \int_{\alpha_i \geq 0} d^{\nu} \alpha \delta \left( 1 - \sum_{i=1}^{\nu} \alpha_i \right) \frac{\mathcal{N}(l_{r}^{\mu}, p_{i}^{\mu}, \ldots)}{D^{\nu}}
\]

Integrated expression will develop singularities when a set of Landau equations is satisfied,

\[
\sum_{i \in \text{loop}} \alpha_i q_i^{\mu} = 0 \text{ for each loop, and } \alpha_i(q_i^2 - m_i^2) = 0 \text{ for each } i
\]

corresponding to a pinching of integration contour by 'colliding poles' of the integrand,
Graph Operations

The content of (massless) Landau equations is preserved by electrical circuit - inspired graph moves
Using the theorem on $n$-terminal $Y - \Delta$ reduction (Gitler, 1991), planar Landau graphs of arbitrary complexity are reduced to 'ziggurat' graphs.
Conclusions

- The first-type Landau singularities of an n-particle scattering amplitude in any massless planar field theory are a subset of those of the n-particle ziggurat graph.
- In the special case of planar $\mathcal{N} = 4$ super Yang-Mills theory, technology that can verify whether singularities are spurious exists (amplituhedron, on-shell diagrams).
- We find that perturbative amplitudes in planar $\mathcal{N} = 4$ super Yang-Mills theory exhibit singularities on all possible first-type singularity loci.
Thank You!