

# Local balance reveals major historical events in signed networks of international relations

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Structural balance [1], the tendency of graphs to avoid conflictual situations (modelled as cycles with negative parity), is widely regarded as the most important property of signed networks. Although real-world networks are rarely perfectly balanced, their deviation from balance significantly impacts their structural and dynamical properties. As such, researchers have developed indices, such as the Estrada-Benzi balance index [2], to measure the level of balance in such networks. However, an important question that has been overlooked is which nodes contribute more to the network's unbalance. This issue is particularly significant in international relations, as unbalanced nodes are often key players in international conflicts.

In this work [3], we address this question by developing a local balanced index  $\kappa_v$  for each node  $v$  of a signed graph with adjacency matrix  $A$ :  $\kappa_v = (e^A)_{vv} / (e^{|A|})_{vv}$ . This index is well-suited for understanding the role of nodes in network unbalance due to its connection with the statistical mechanics of network ensembles and its mathematical properties. For instance, it has bounds  $0 < \kappa_v \leq 1$ , and  $\kappa_v = 1$  for every node  $v$  if and only if the network is perfectly balanced.

Equipped with this statistical-mechanical framework, we turn our attention to the network of international relations between the years 1814 and 2014 and analyze the time series of the local balance index of each country. We find that the drops in the local balance time series are strongly correlated not only with armed conflicts between countries, but also with systemic instabilities within a country, even in the absence of war (figure 1). This is the case of the revolutionary wave of 1848, where several European countries suddenly reduce their local balance despite the absence of interstate conflict between them.

This index not only identifies unbalanced nodes in a network, but also sheds light on the structural causes of geopolitical instability. For example, we find that cliques made up of negative edges significantly reduce the balance of all nearby nodes, even those not directly connected to the clique. We observe the existence of these negative cliques in various regions during periods of deep crises, such as Europe in 1941, Yugoslavia through the 1990s, and the Middle East in 1961 (figure 2).

Overall, our work highlights how unbalanced subgraphs are at the core of many geopolitical conflicts. Moreover, it emphasizes the role of the networked structure of international relations in the emergence of conflicts.

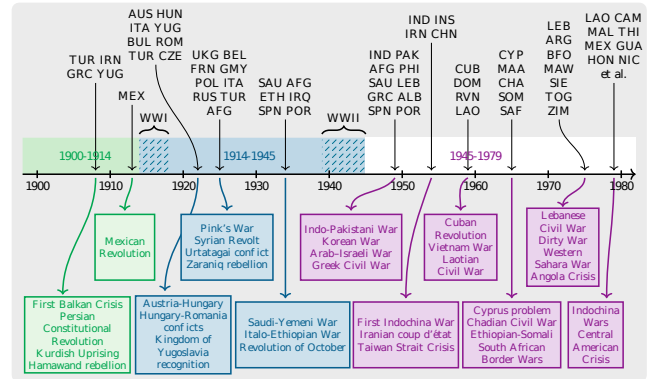


Fig. 1. Timeline of significant local balance drops. The upper half indicates the affected countries. Most balance drops correspond to important historical events (wars, revolutions, political and economic crises...).

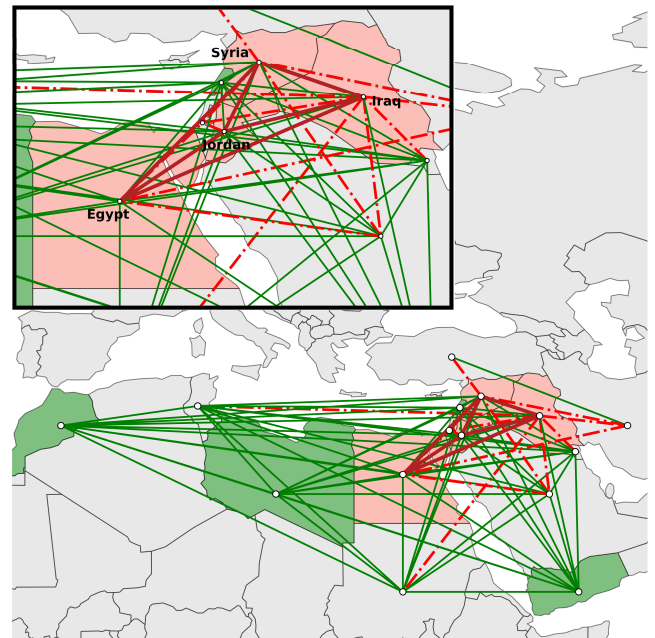


Fig. 2. Signed network depicting the international relations in the Middle East in 1961. Despite the abundance of positive links, the involved countries show a low balance index due to the presence of a negative clique, indicating that the region is highly unstable.

[1] Cartwright, Dorwin, and Frank Harary. Psychological review 63.5 (1956): 277.

[2] Estrada, Ernesto, and Michele Benzi. Physical Review E 90.4 (2014): 042802.

[3] Diaz-Diaz, Fernando, Paolo Bartesaghi, and Ernesto Estrada. "Network theory meets history. Local balance in global international relations." arXiv preprint arXiv:2303.03774 (2023).