Topological fingerprints of historical events in international relations networks

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In the last years, the study of signed networks has attracted considerable attention due to its applicability in ecological, biochemical, social and political contexts. Among the novel properties that signed networks display, structural balance [1] (the tendency of graphs to avoid cycles with an odd number of negative edges) is arguably one of the most influential. While empirical networks are rarely balanced, most of them exhibit properties reminiscent of balanced graphs. Because of this, several researchers have developed indices to measure the level of balance in such networks, like the Estrada-Benzi balance index [2]. However, an important question that has been overlooked is which nodes are contributing more significantly to the network's unbalance. This issue is particularly significant in international relations, as unbalanced nodes are often key players in international conflicts (figures 1a and 1b).

In this work [3], we address this question by developing a simple formula for the local balance κ_v of each node v in a signed graph with adjacency matrix A: $\kappa_v = (e^A)_{vv}/(e^{|A|})_{vv}$. This index captures the contribution of node v to the network's balance by comparing the number of positive and negative closed walks that pass through that node. We have proved several mathematical properties that make this index well-suited for understanding local balance. 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 (figure 1b). Moreover, we have compared this index to several other indices used by the signed graphs community, using both synthetic and empirical networks. This comparison showed that κ_v is the only index that adequately captures the level of balance at the level of individual nodes.

Equipped with this framework, we turned our attention to the network of international relations between 1814 and 2014. Using a historic database of alliances and conflicts [4], we constructed a signed network for every year and computed the local balance index of every country, obtaining a collection of local balance time series (figure 1c). After performing several statistical tests, we concluded that the drops in the local balance time series are significantly correlated with the appearance of violent conflicts in the analyzed countries, while increases in local balance are correlated with non-violent events like the signature of peace treaties or the creation of supranational alliances. Moreover, we also found that low levels of balance are indicative of systemic instabilities in a country and a high geopolitical risk.

In conclusion, in this work we propose a purely topological index, the local balance index κ_v, and find that it is able to capture geopolitical risk and the occurrence of major historical events. Our results highlight the role of the networked structure of international relations in the emergence of conflicts, and the regularities found provide strong evidence to the claim that "not everything in history is contingent and particular" [5].

References

[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, F., Bartesaghi, P., Estrada, E. (2023). arXiv preprint arXiv:2303.03774.

[4] Z. Maoz, P. K. Johnson, J. Kaplan, F. Ogunkoya, and A. P. Shreve. Journal of Conflict Resolution, 63.3, (2019): 811–835.

[5] P. Turchin, Nature, vol. 454, pp. 34–35, 2008.

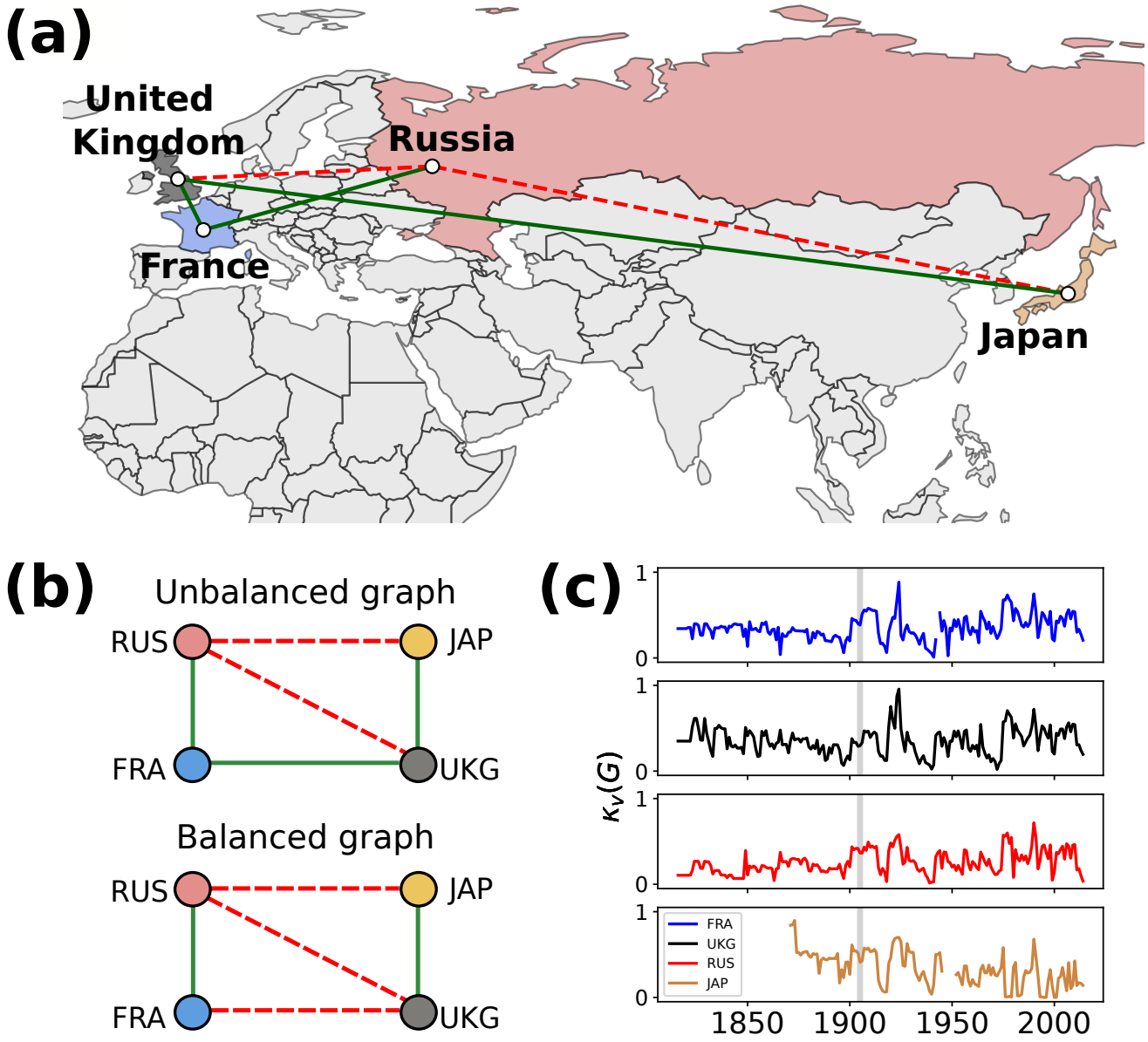


Figure 1: **Interplay between local balance and international conflicts in the Russo-Japanese war of 1904-1905.** (a) Map highlighting the international relations between Russia, the UK, France and Japan in 1904. (b) Schematic representation of the Russo-Japanese war. The analyzed subgraph contains cycles with an odd number of negative edges, so it is unbalanced. Moreover, France participates in more unbalanced cycles than Japan, indicating that it is contributing more to the network unbalance. Changing the sign of the edge between the UK and France would result in a balanced graph with two opposing factions. (c) Computing the local balance of every country and year, we obtain a collection of local balance time series, $\kappa_v(t)$. Drops in the balance time series correspond to violent historical events, while balance increases correspond to non-violent events. For example, the Russo-Japanese War causes a small drop in balance (grey area), while both World Wars cause deep valleys in the time series.