Using the D-Wave 2X Quantum Computer to Explore the Formation of Global Terrorist Networks

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Abstract

Social networks with signed edges (+/-) play an important role in an area of social network theory called structural balance. In these networks, edges represent relationships that are labeled as either friendly (+) or hostile (-). A signed social network is balanced only if all cycles of three or more nodes in the graph have an odd number of hostile edges. A fundamental property of a balanced network is that it can be cleanly divided into 2 factions, where all relationships within each faction are friendly, and all relationships between members of different factions are hostile. The more unbalanced a network is, the more edges will fail to adhere to this rule, making factions more ambiguous. Social theory suggests unbalanced networks should be unstable, a finding that has been supported by research on gangs, which shows that unbalanced relationships are associated with greater violence, possibly due to this increased ambiguity about factional allegiances (Nakamura et al).

One way to estimate the imbalance in a network, if only edge relationships are known, is to assign nodes to factions that minimize the number of violations of the edge rule described above. This problem is known to be computationally NP-hard. However, Facchetti et al. have pointed out that it is equivalent to an Ising model with a Hamiltonian that effectively counts the number of edge rule violations. Therefore, finding the assignment of factions that minimizes energy of the equivalent Ising system yields an estimate of the imbalance in the network.

Based on the Ising model equivalence of the signed-social network balance problem, we have used the D-Wave 2X quantum annealing computer to explore some aspects of signed social networks. Because connectivity in the D-Wave computer is limited to its particular native topology, arbitrary networks cannot be represented directly. Rather, they must be "embedded" using a technique in which multiple qubits are chained together with special weights to simulate a collection of nodes with the required connectivity. This limits the size of a fully connected network in the D-Wave to about 50 simulated nodes, using all of the approximately 1150 qubits in the machine.

In order to keep within this limitation, while exploring a problem of potential social relevance, we constructed time series of historical network snapshots from Stanford's Mapping Militants Project, where nodes represent militant organizations, and edges represent either alliances or rivalries between organizations. We constructed two series from different theaters – Iraq and Syria – spanning timelines from about 2000 to 2016, each with networks whose maximum size was in the 20-30 node range.

Computationally, our experience suggests D-Wave technology is promising, providing fast, nearly constant scaling of computational effort in the main part of the calculation that relies on the quantum annealing cycle. However, the cost of embedding an arbitrary network of interest in the D-Wave native topology scales poorly. If the embedding cost can be amortized relative to the annealing cycle, it may be possible to gain a substantial advantage over classical computing methods, provided a large enough network can be accommodated by partitioning into subnetworks or some similar strategy.

In terms of our application to networks of militant organizations, we found a rise in network imbalance in the Syrian theater that appears to correspond roughly with the entrance of the Islamic State into a milieu already populated with other groups, a phenomenon we plan to explore in more detail. In these very preliminary results, we also noticed that during at least one period where both the size and imbalance of the network increased substantially, the imbalance per edge seemed to remain fairly steady. This may suggest some adaptive behavior among the participating factions, which may also warrant further exploration.

Kiminori Nakamura, George Tita, David Krackhardt , “Violence in the ‘Balance’: A Structural Analysis of How Rivals, Allies, and Third-Parties Shape Inter-Gang Violence”, Heinz College Research, Research Showcase @CMU, http://repository.cmu.edu/cgi/viewcontent.cgi?article=1411&context=heinzworks, (2011).

Giuseppe Facchetti, Giovanni Iacono, and Claudio Altafini, “Computing global structural balance in large-scale signed social networks”, PNAS , 108, no. 52, 20953–20958 (2011).

Mapping Militant Organizations, http://web.stanford.edu/group/mappingmilitants.

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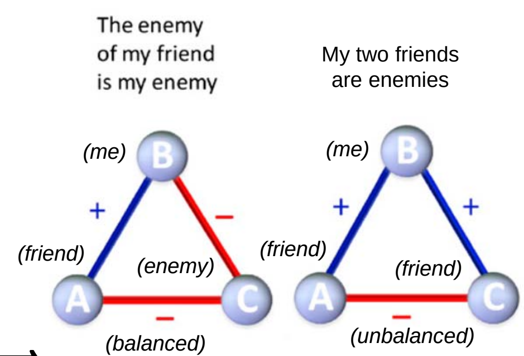
April 27, 2017

Using the D-Wave 2X to Explore Structural Balance Sensitivity in Radical Social Networks

- The D-Wave is a quantum annealing machine
- There is an area in the study of social networks called *structural balance*
  - Social network with signed edges
    - Bipartite nodes, labeled by cohort (+, -)
    - Signed edges: + for friendly, - for hostile
    - ***Edge rule: same cohort ⇒ +; different ⇒ -***
    - Given the edge signs, what is the best cohort assignment to nodes that tries to follow the edge rule? → *NP-Hard problem*



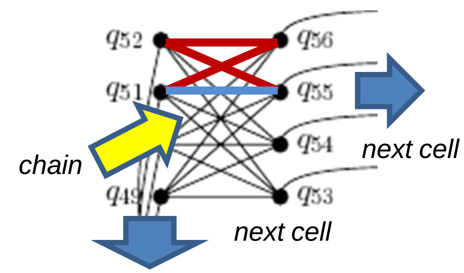
- There is an Ising model equivalent to this problem
  - $H = \sum_{i,j}(1 - J_{ij} s_i s_j) \ni J_{ij}, s_i \in \{-1,1\}$

Effectively measures the number of edge rule violations

PNAS / December 27, 2011 / vol. 108 / no. 52 / 20953–20958

Exploring Signed Social Networks with D-Wave

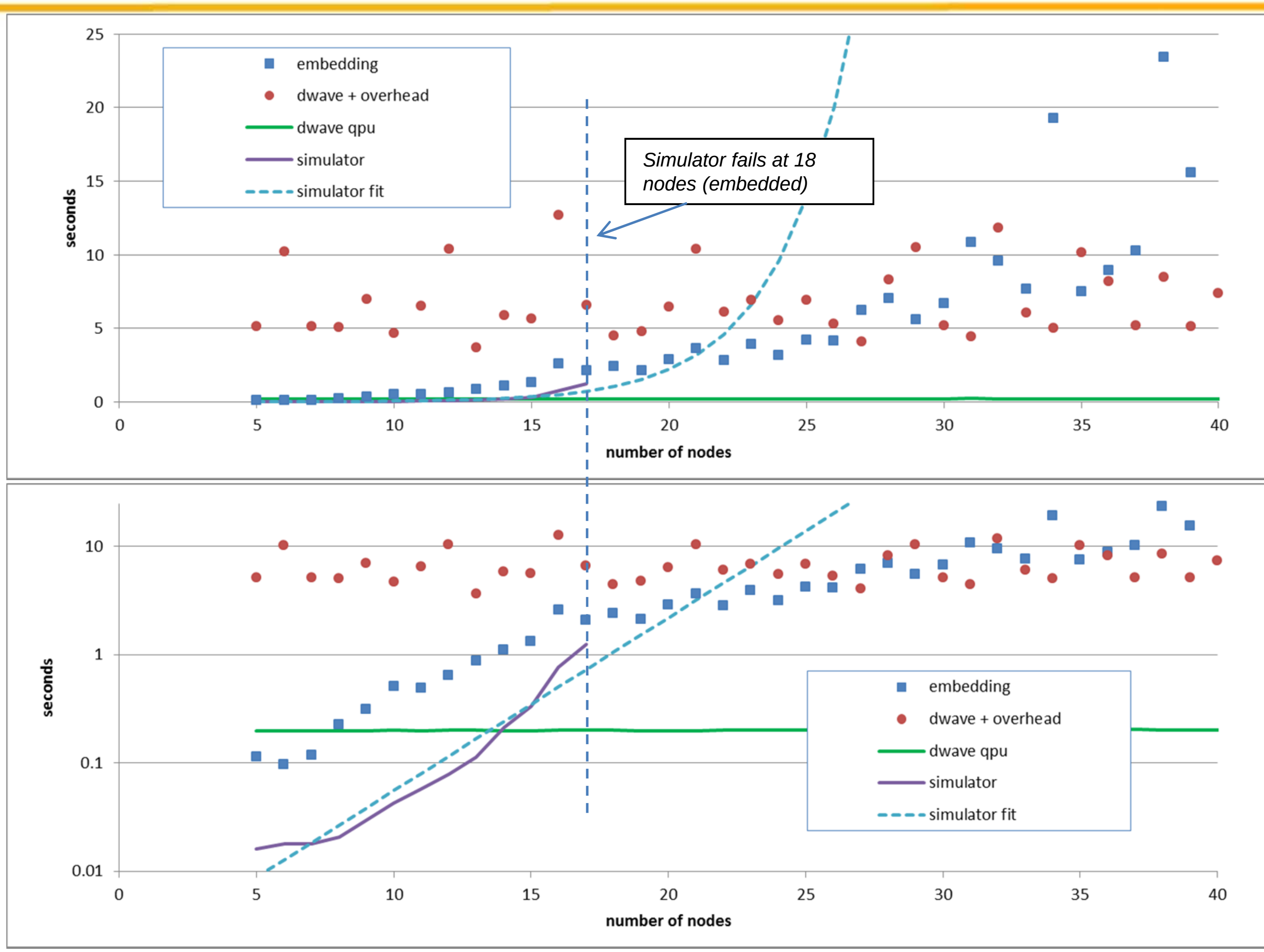
- We performed a series of experiments in calculating structural balance on signed-social networks, comparing D-Wave to a simulator on fully-connected graphs
- Challenges:
  - Arbitrary networks don't map to the D-Wave topology – even a triangle is hard



  - Chaining nodes together to make the topology you want – a process called embedding – is also NP-hard
  - Given the current D-Wave machine topology, and the number of q-bits available, the maximum number of fully-connected, *simulated* nodes* is about 49 on a perfectly fabricated machine
  - Much of the overhead in executing a job on the D-Wave is communication and initialization, which can be many times more than D-Wave annealing time of 20 microseconds

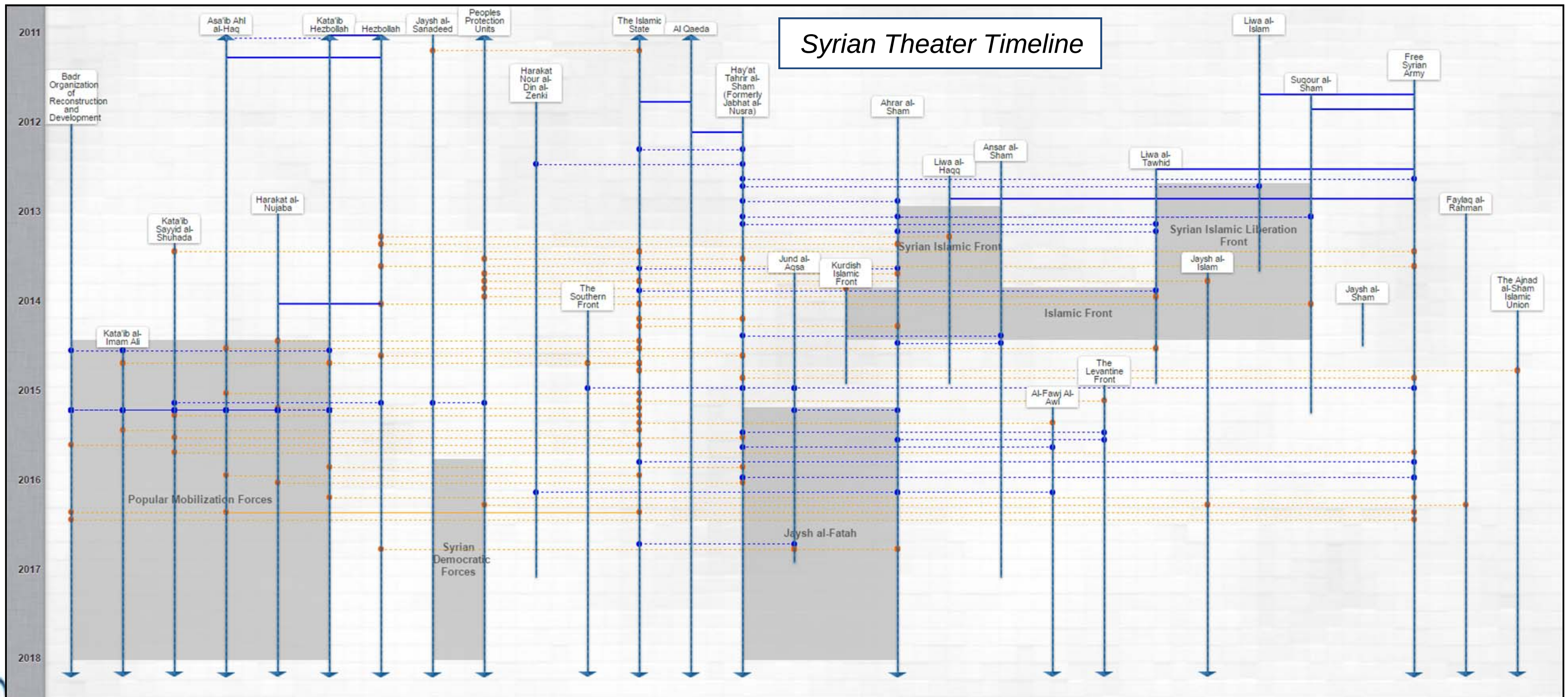
**Out of approximately 1152 q-bits*

D-Wave Performance on a Complete Graph



Real World: Stanford Mapping Militants Project

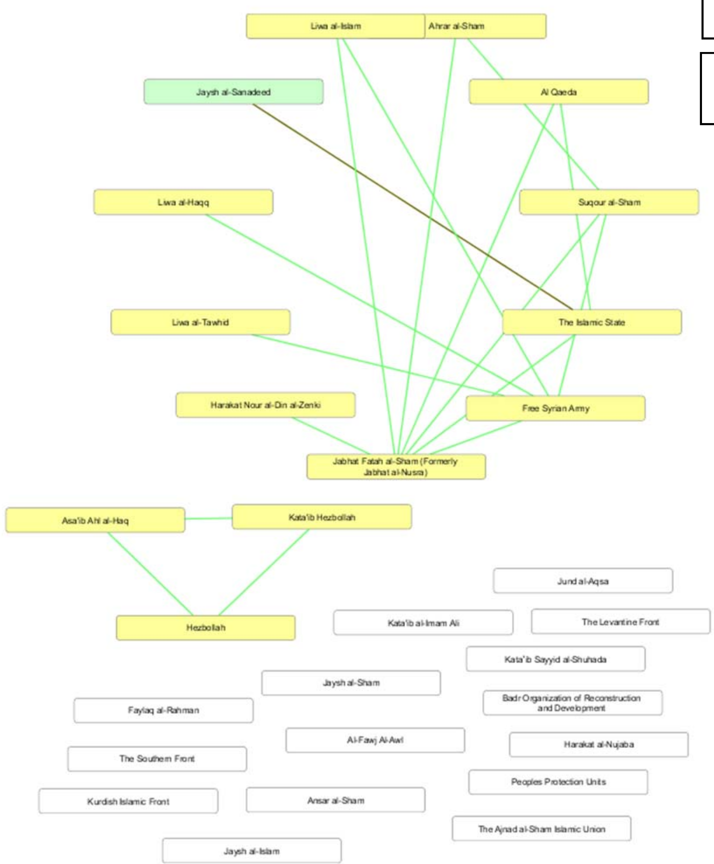
- Project identifies patterns in the evolution of militant organizations, in specified conflict theatres, and provides interactive visual representations (http://web.stanford.edu/group/mappingmilitants/)



Syrian Theater Networks

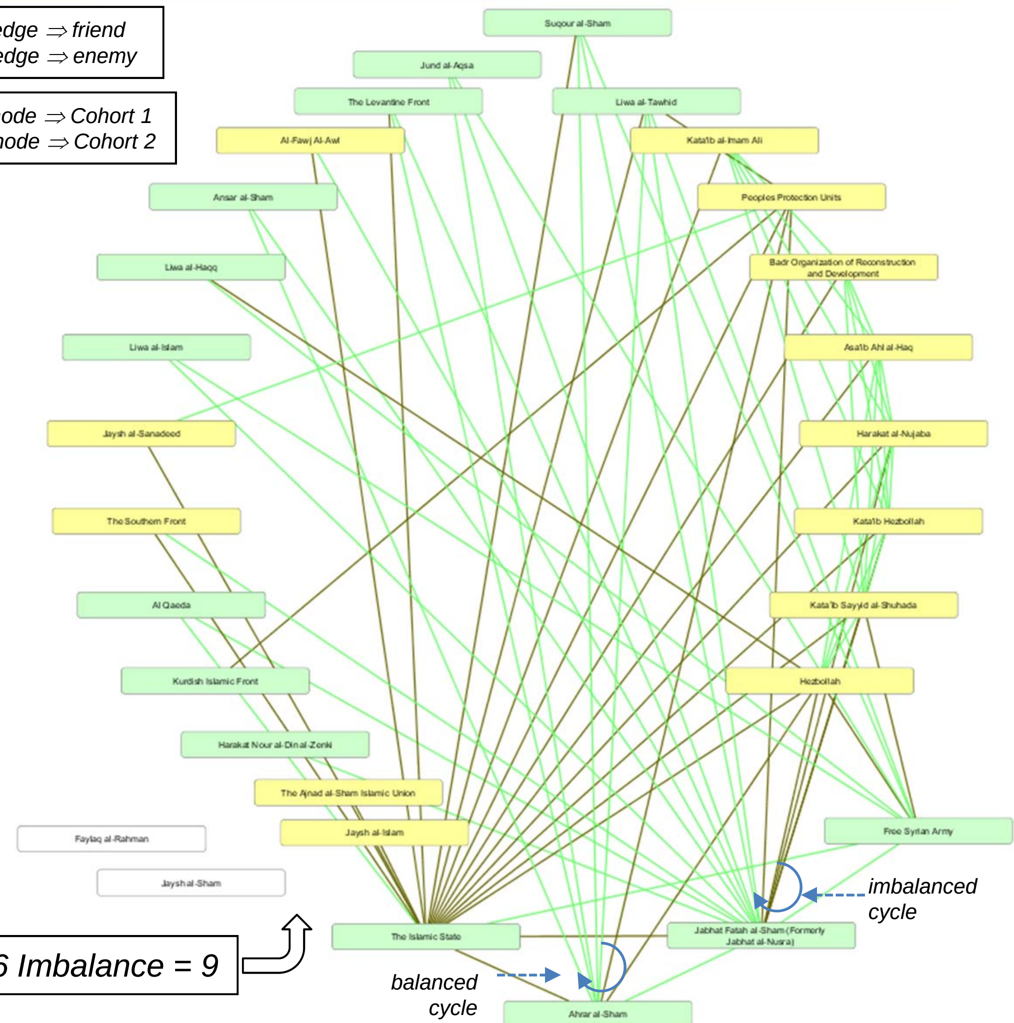
Green edge ⇒ friend
Brown edge ⇒ enemy

Green node ⇒ Cohort 1
Yellow node ⇒ Cohort 2



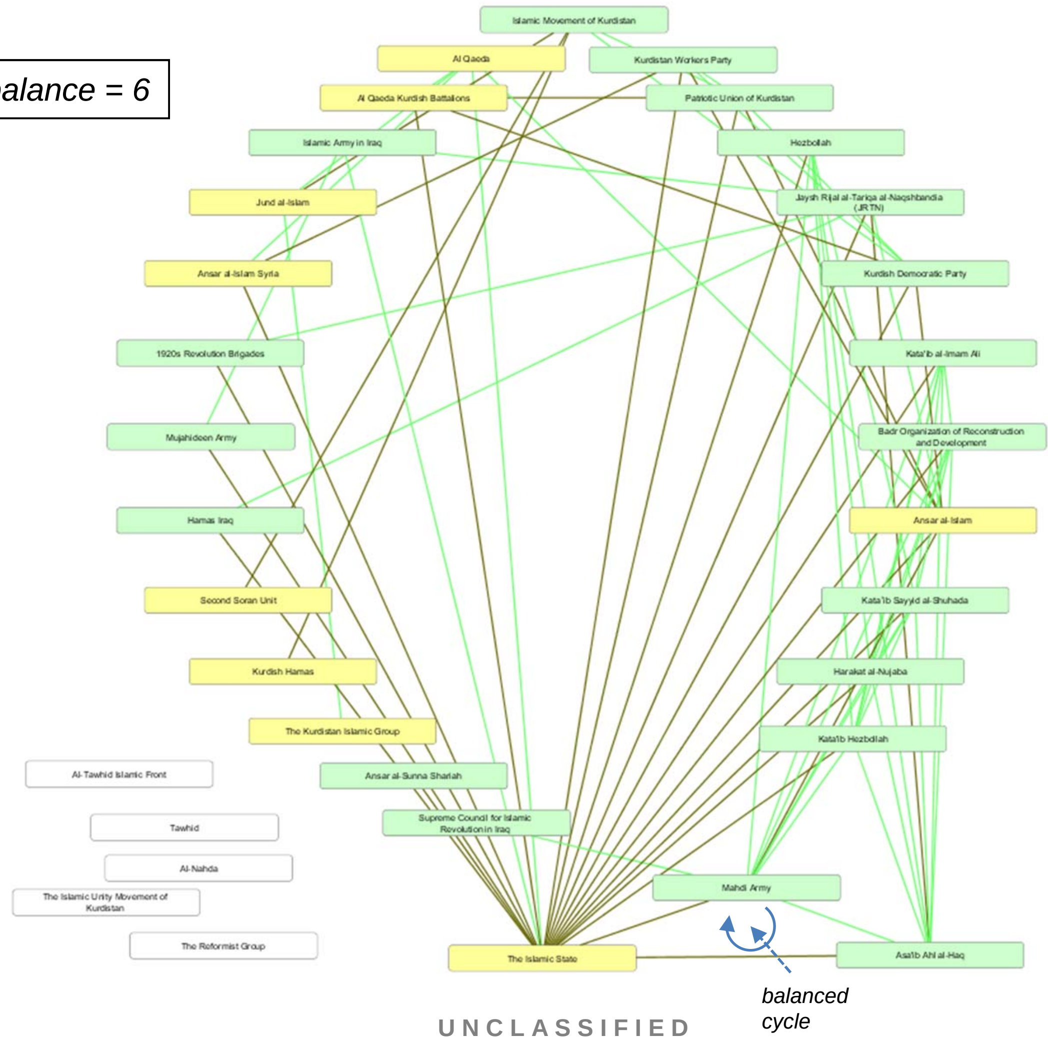
2013 Imbalance = 0

2016 Imbalance = 9



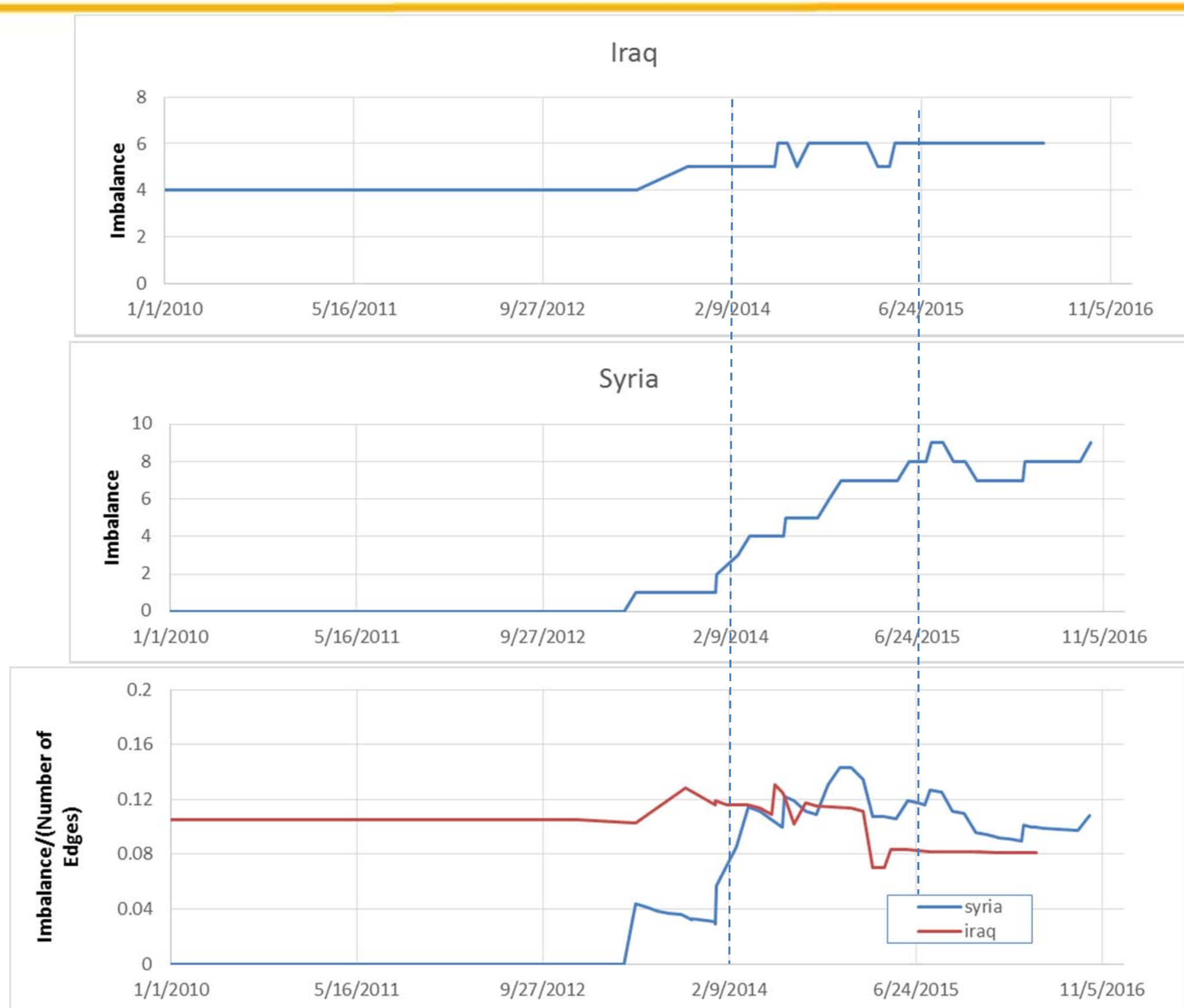
Iraq Theater Network

2016 Imbalance = 6



Balance Over Time

- In the time window shown, the imbalance in Syria has increased by 4 times, but the imbalance per edge is nearly constant
- What does it mean?
- Are inter-group relationships adaptive to local imbalances?



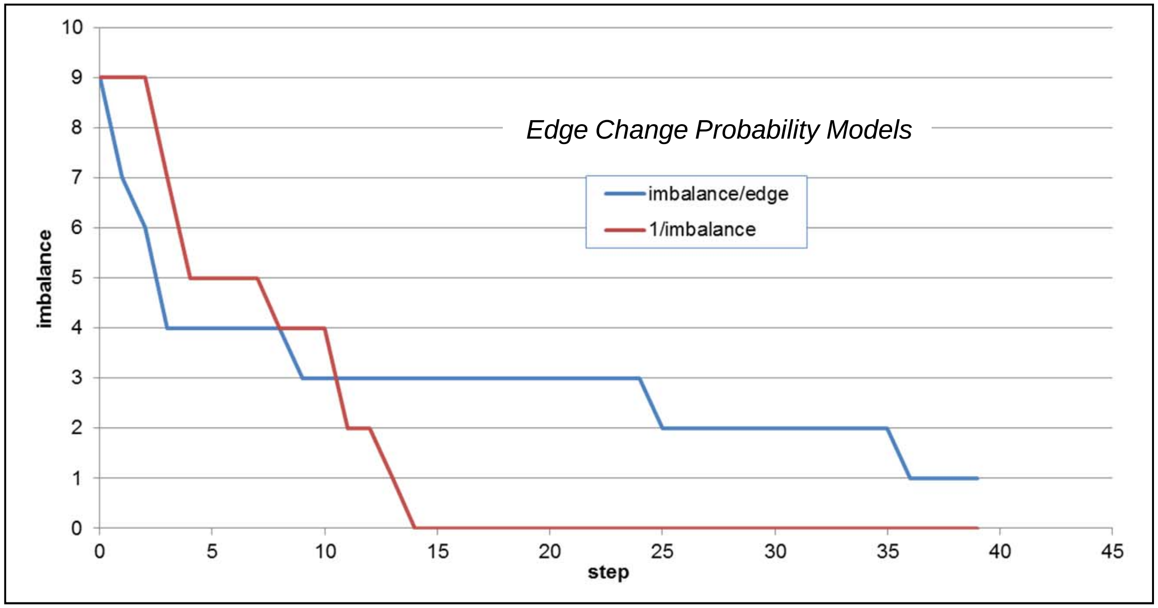
Dynamic Relaxation of Network Imbalance

- We use the D-Wave as an accelerator chip in a dynamic relaxation simulation $\Rightarrow$ only need to embed the problem once

1. Given a social network with only edges assigned $\{J_{ij}\}$
2. Find the node assignment $\{s_i\}$ and net imbalance (H) in the ground state using the D-Wave (quantum step)
3. Perturb the edge assignments, based on local edge rule violations (classical step) based on the probability that an improperly assigned edge changes sign. Two cases:
   a) The probability is proportional to the imbalance/(number of edges)
   b) The probability is proportion to 1/(the imbalance)
4. Return to (2)

Relaxation Over Time

- Each time an edge violating the rule is changed, a new global solution is obtained
- It is nonetheless curious that these curves are monotone



Summary Experience

- We have used the D-Wave to explore some aspects of signed social networks
- We have encountered several challenges – some expected and some not
  - The number of nodes that can be accommodated is relatively small (~49 out of 1152)
  - Embedding is a costly computation that doesn't scale well
  - Surprisingly large communications and initialization overhead
- Perhaps a "domain-iterative" method, with a pre-embedded scaffold on each sub-network domain, would allow a D-Wave-accelerated computation on very large networks

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- We have chosen to explore applications that will fit within our D-Wave machine without using multiple domains, specifically for *estimating the structural imbalance in mappings of terrorist groups and their interrelations*
- In these very preliminary results, we have noticed that, for an extended period in one instance, the *imbalance per edge seems to remain fairly constant while the size and imbalance in the network increase*
- We have also contrived a "dynamical" model that requires no re-embedding – the relaxation of an imbalanced network – based on the notion that problematic relationships (those that violate the edge rule) may spontaneously change sign with some given probability
- *Curiously, although these spontaneous changes intended to reduce imbalance are local, the global imbalance appears to decrease monotonically*

Interpretations and Thoughts of Future Work

- Sociological research shows unbalanced networks may be associated with greater levels of violence (Nakamura et al. 2011)
- A balanced network can be cleanly divided into 2 factions
- Research on gangs suggests unbalanced relationships are associated with greater violence between rival gangs, possibly due to increased ambiguity about factional allegiances
- Hypothesis: increased imbalance in Syria network in 2013-2014 is due to conflicts among rebel groups that arose at this time due to entry of ISIS into the conflict
- This might be demonstrated through sensitivity studies
- Caveat: Initial rise in imbalance could be artifact of data collection
- Correlation with violence could be established using validated casualty data, if available