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

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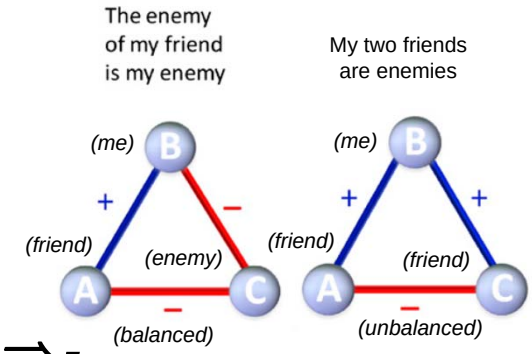
April 27, 2017

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*



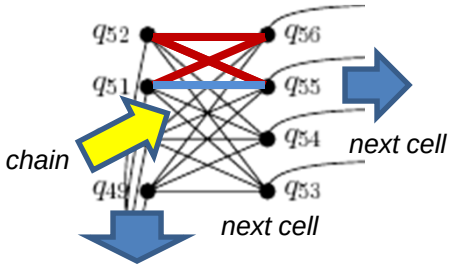
- There is an Ising model equivalent to this problem
  - $H = \sum_{i,j}\left(1 - J_{ij}s_i s_j\right) \ni J_{ij}, s_i \in \{-1,1\}$

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

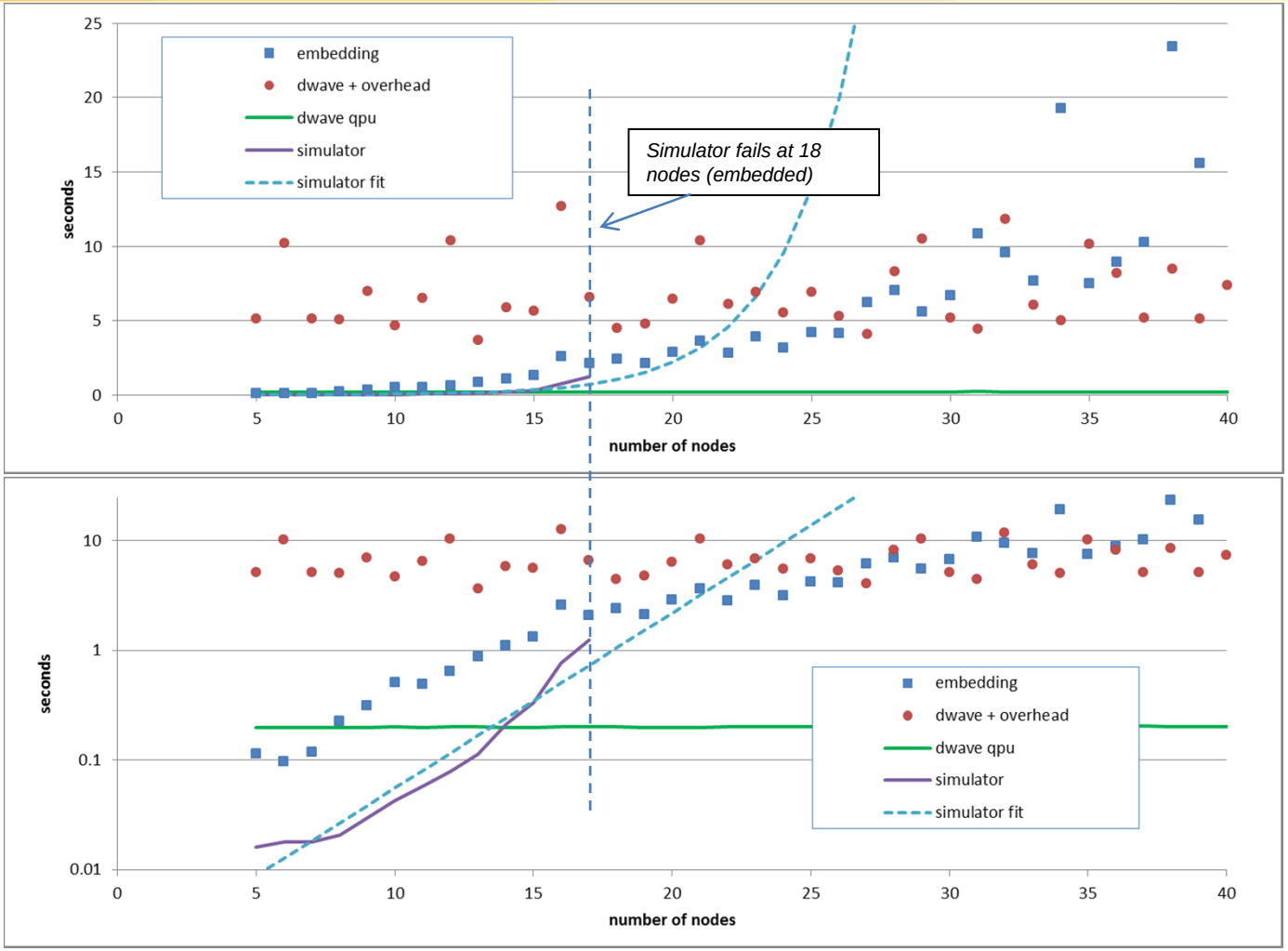
- We performed a series of experiments in calculating structural balance on signed-social networks, comparing D-Wave to a simulator on fully-connected graphs
- Challenges:
  - Arbitrary networks don't map to the D-Wave topology – even a triangle is hard



  - 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

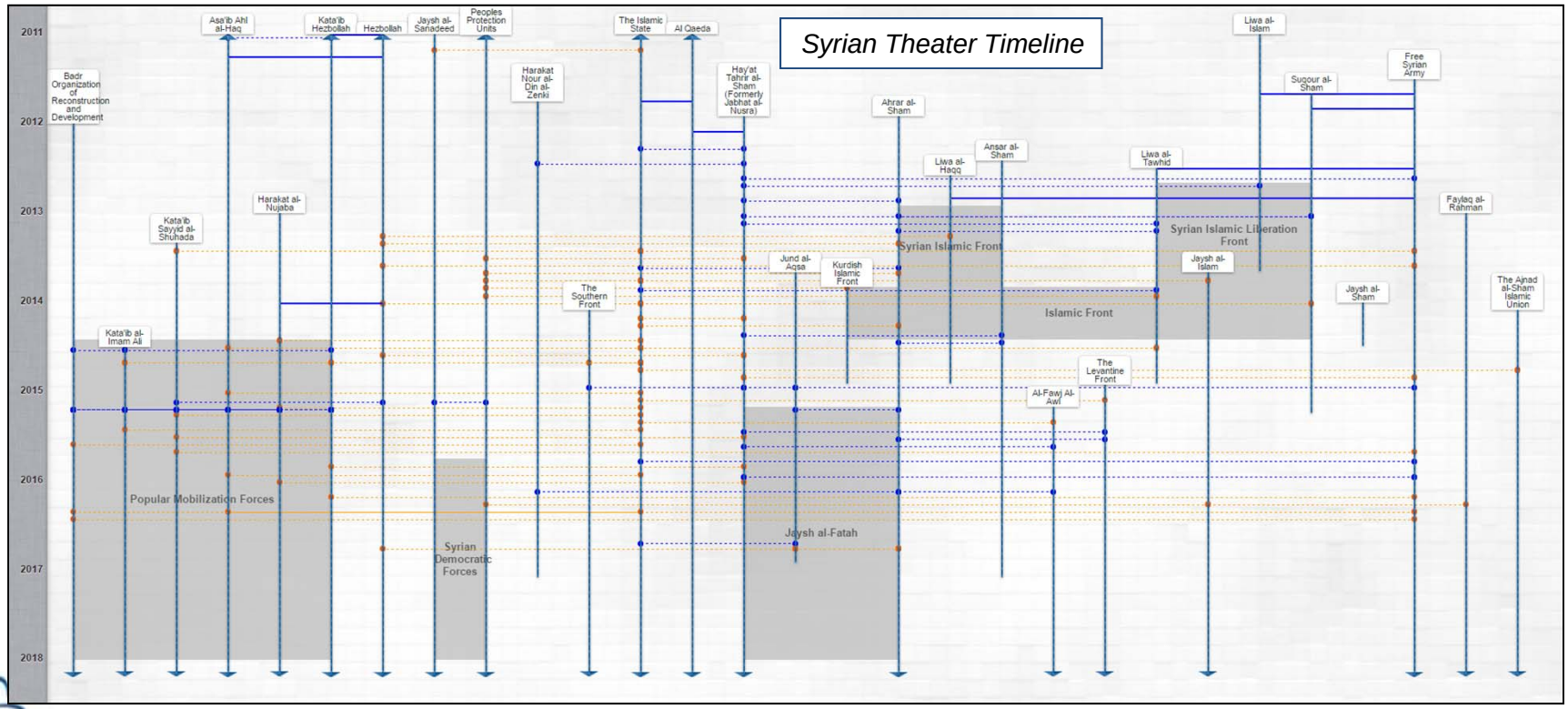
**Out of approximately 1152 q-bits*

D-Wave Performance on a Complete Graph

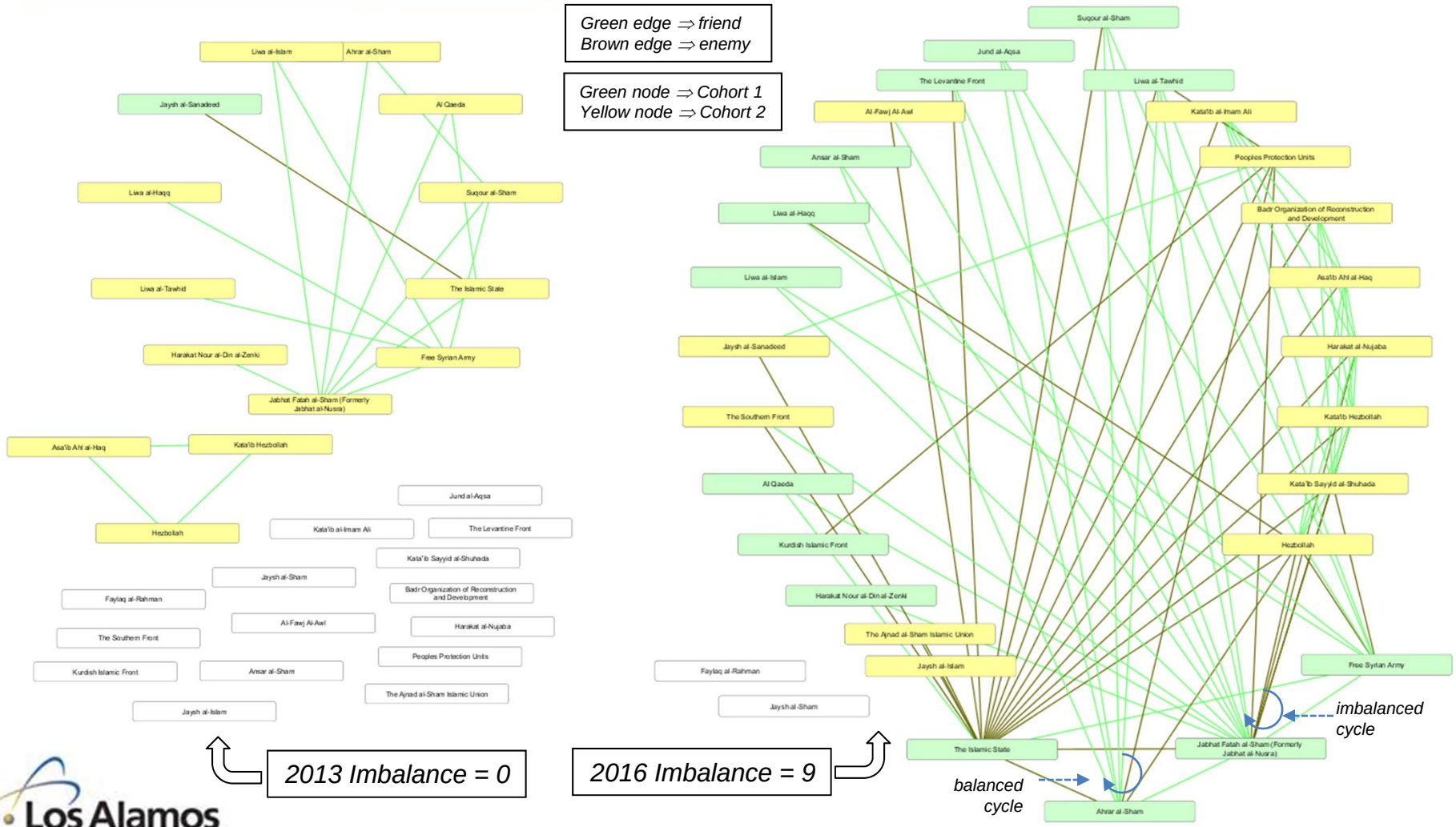


Real World: Stanford Mapping Militants Project

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

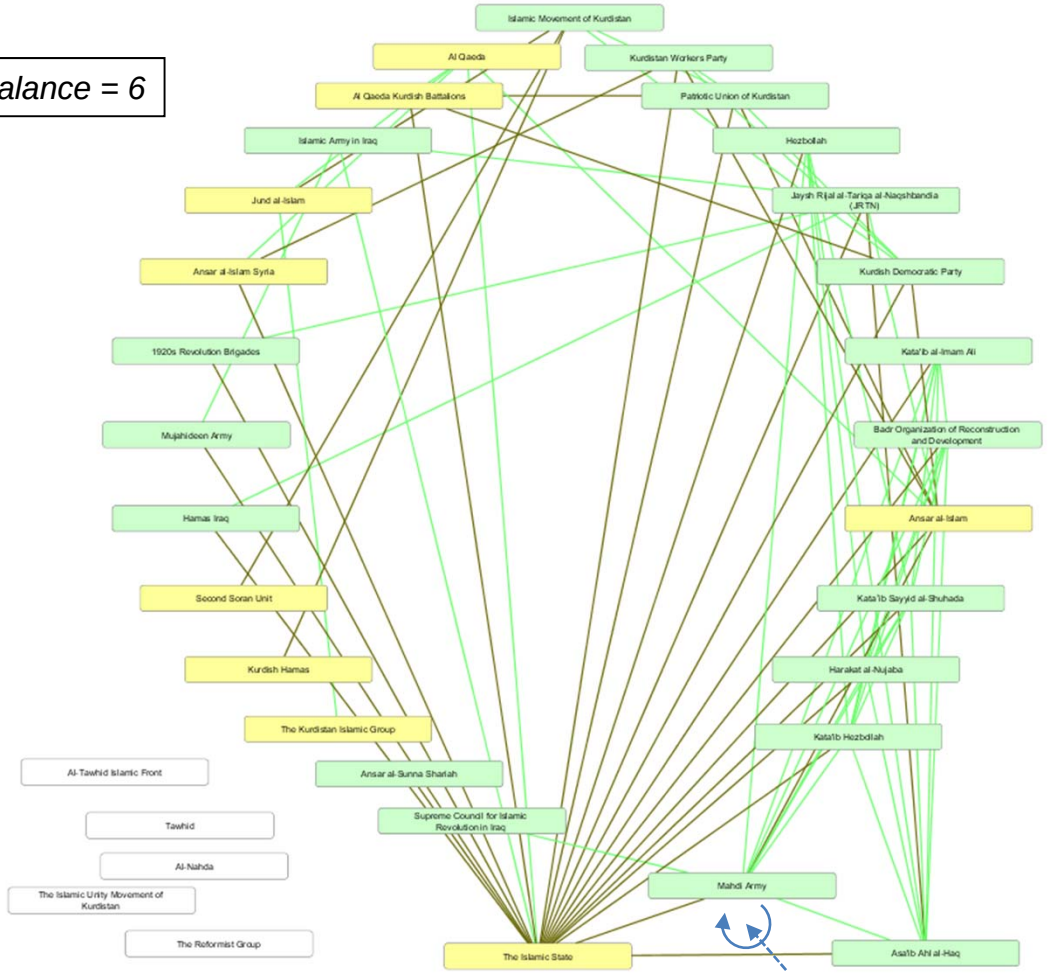


Syrian Theater Networks



Iraq Theater Network

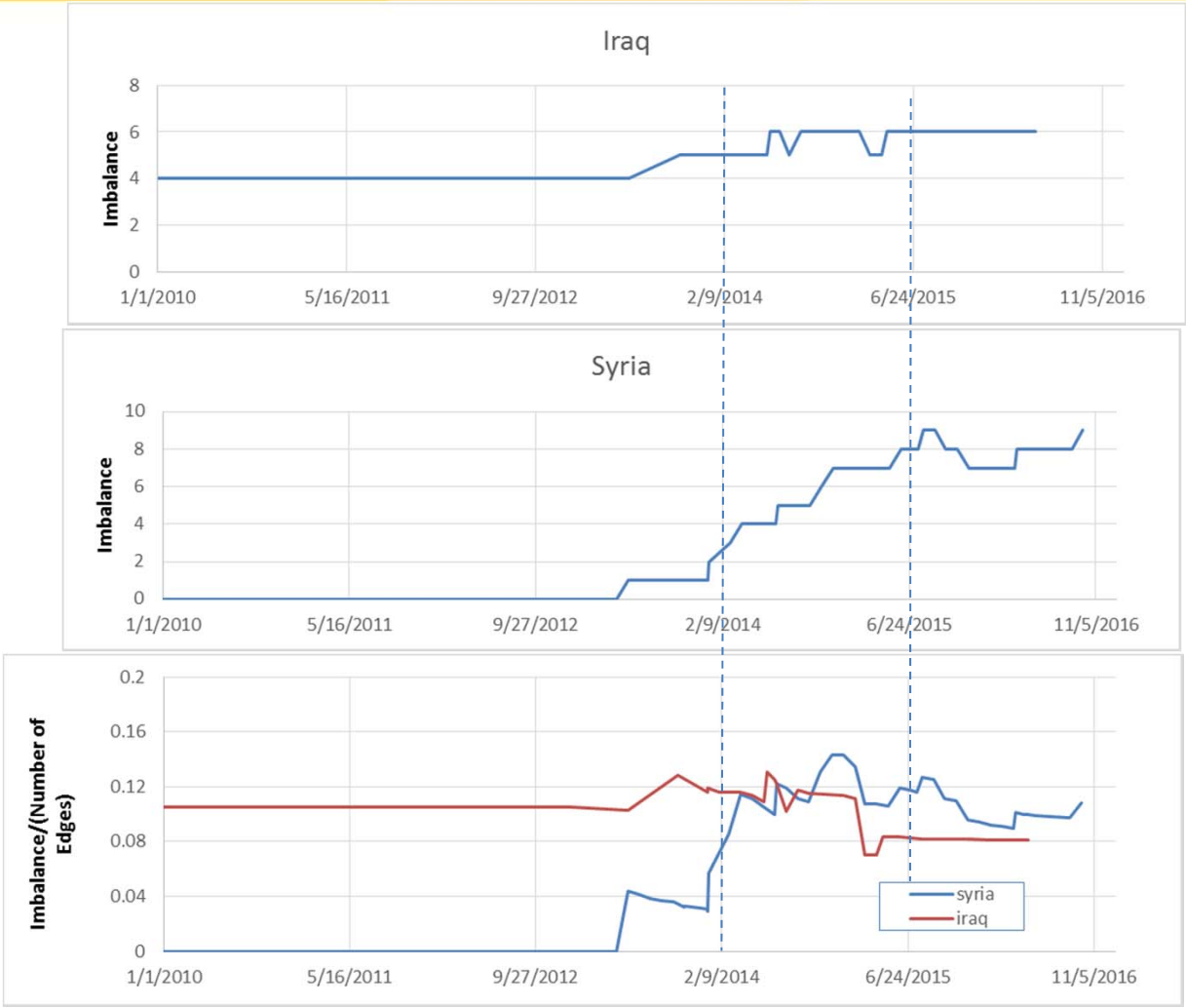
2016 Imbalance = 6



balanced cycle

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?



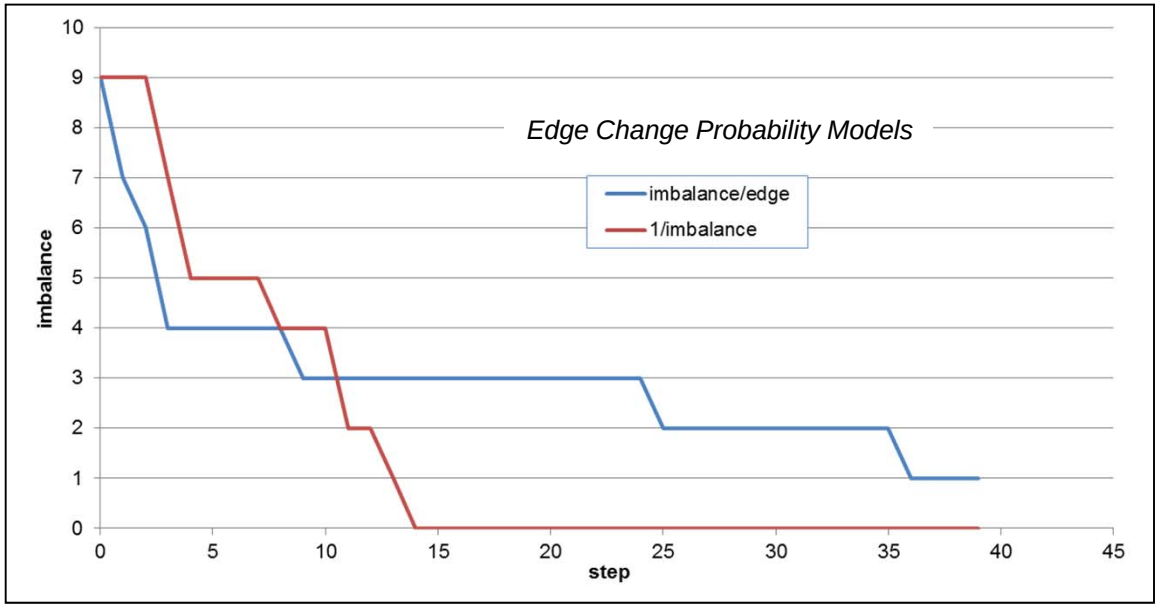
Dynamic Relaxation of Network Imbalance

- 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