Uncovering the Useful Structures of Complex Networks in a Socially-Rich and Dynamic Environment

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A complex network (CN) is applicable in many fields
- Internet, food web, metabolic networks, and social networks
- CN in socially-rich and dynamic environments

Three challenging areas
- Graph model
- Uncovering a useful structure
- Distributed and localized solutions

Different communities
- Graph theory, distributed systems (e.g., ICDCS), distributed computing (e.g., PODC), and social networks
Graph Model

- Dynamics of CN: node connections change over time, e.g., DTN

**Which graph model is suitable for representing a CN?**

- Intersection graphs: unit disk graphs and interval graphs

![Graph Diagram]

- Challenges
  - Hyperedge (ACD in above): a link connecting > 2 vertices
  - Interval hypergraphs and multiple interval graphs?
  - Edge density distributions in online social networks?

ICDCS 2017
Graph Model (cont’d)

- **Time-evolving graph** (EG) in (discrete) time and space

- EG extends to temporal with new notion of connectivity
  - Path to *journey* (a path over time)
  - Diameter to *dynamic diameter* (flooding time)
  - Earliest completion path, fastest path, minimum hop path

- Challenges
  - Macro-level vs. micro-level (probabilistic contact, edge-Markovian)
  - Granularity control: expressiveness vs. decision power

ICDCS 2017
Uncovering Useful Structure

- **Structural trimming**: trim “useless” nodes and links
  - Static vs. dynamic, e.g., connected dominating set (CDS)

- **Challenges**
  - Dynamic trimming in EG with probabilistic contacts
    - Optimal routing, e.g., multi-bus riding

- **Forwarding set (FS)**
  - A single-copy message is forwarded to a new contact if it belongs to the FS.

**How can we design a methodology to derive an FS?**

- If message utility is time-sensitive, FS is time-varying.
- In a multi-message deliver application, FS is copy-varying.
Uncovering Useful Structure (cont’d)

- **Structural layering**
  - **Scale-free (SF):** node degree distribution follows power-law
  - **Nested SF:** SF hierarchy is done by peeling off lowest degree nodes. All subsequent subgraphs are SF and “similar.”

Can we uncover more inherently layered structures, not only in the space dimension, but also in time-and-space?

*e.g., small-world behavior of the real world in time-and-space*
Uncovering Useful Structure (cont’d)

- **Structural remapping**: representation
  - Geographic routing: *conformal mapping* using Ricci flow
  - Greedy routing without being stuck at a local minimum

- Mapping from one representation to another: Euclidean space to non-Euclidean space

*Can we remap a problem from one domain to another?*
Uncovering Useful Structure (cont’d)

- **Structural remapping: domain**
  - Converting a routing in a highly mobile and unstructured contact space in DTN to one in a static and structured feature space

**How can we uncover the influence that social relationships have on the structure of an underlying network?**

*Multi-scale and multi-layer CNs*
Distributed/Localized Solutions

- **Static labels**: each node is labeled a small number of times
  - E.g., clustering, maximum independent set (MIS), CDS
- **Nested SF (single root) vs. regular SF (multiple roots)**

![Diagram showing node degree and nested node degree](image)

Up-and-down routing
Dynamic labels: a labeling process where nodes are labeled a large number of times

- E.g., Bellmen-Ford algorithm, Page Rank, and HITS

Link reversal (LR): labels associated with nodes as height

- Maintaining a destination-oriented DAG upon link failures

Special LR with labels associated with links, still $O(n^2)$
Type of solutions

- Distributed solution (DS): a node’s interaction with others in a restricted vicinity, say k-hop; maintaining and propagating labels
- Localized solution (LS): DS without information propagation

Challenges:

How can we deal with the complexity of building a structure along with a change of topology?

View consistency: SDN (central) vs. MANET (distributed)

How do we handle the long convergence time usually occurred in the dynamic label in a distributed solution?
Distributed/Localized Solutions (cont’d)

- Hybrid of distributed and localized
  - E.g., Fault-tolerant routing and broadcasting in hypercubes

- Safety levels: special coded labels
  - Unlike LR, safety level is decided, at most, once. Overall, $O(\log n)$
Conclusions

Several key issues in complex networks

- **Graph model**
  - Intersection graphs: unit disk graph and interval graph
  - Time-evolving graphs

- **Building a useful structure**
  - Trimming, layering, and remapping

- **Challenges in designing distributed/localized solutions**
  - Static labels and dynamic labels
  - Hybrid of distributed and localized