Detecting Communities in K-Partite K-Uniform Hypernetworks

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Introduction

Given a k-partite k-uniform (hyper)network, where each (hyper)edge is a k-tuple composed of nodes of k different types, how can we automatically detect communities for nodes of different types?

2-partite 2-uniform network:
- author-paper bipartite network
- actor-movie bipartite network
- consumer-product bipartite

3-partite 3-uniform network:
- user-tag-resource hypernetwork (Social Tagging Systems)

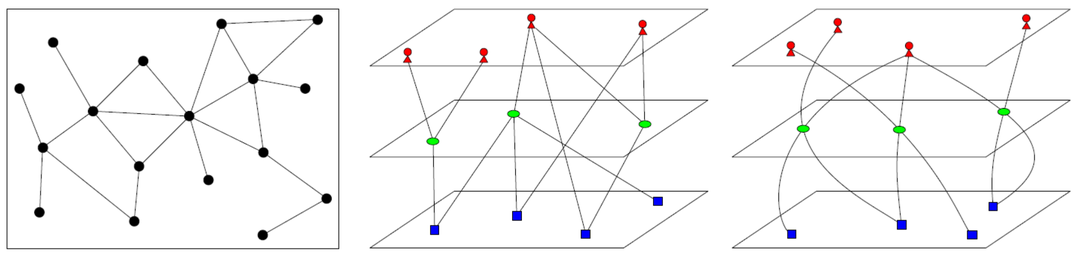

Fig. 1. Illustrations of unipartite network, k-partite network, k-partite k-uniform hypernetwork

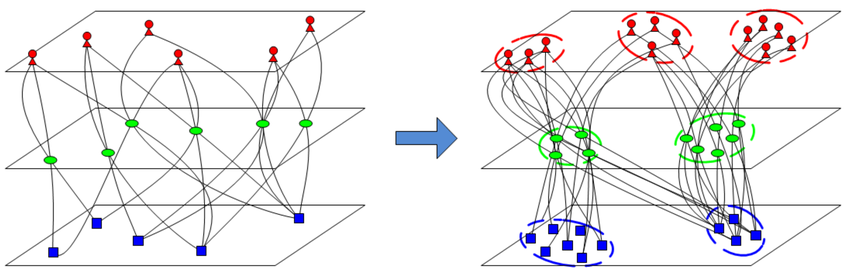

Fig. 2. Community detection in 3-partite 3-uniform hypernetworks. The three-way hyperedges are represented as curved lines.

Methods

Convert the community detection to a problem of finding an efficient compression of the (hyper)network's structure

1. **Based on the Minimum Description Length (MDL) Principle, we define a quality function for measuring the goodness of partitions of a k-partite k-uniform (hyper)network into communities:**

$$Q(\mathscr{C}) = \sum_{t=1}^{k} n_t \log c_t + \log(m+1)\prod_{t=1}^{k} c_t + \sum_{\alpha_1=1}^{c_1}\sum_{\alpha_2=1}^{c_2}\cdots\sum_{\alpha_k=1}^{c_k} \log\left(\frac{|S_1^{\alpha_1}||S_2^{\alpha_2}|\ldots|S_k^{\alpha_k}|}{\sum_{v_1^{i_1}\in S_1^{\alpha_1}}\sum_{v_2^{i_2}\in S_2^{\alpha_2}}\cdots\sum_{v_k^{i_k}\in S_k^{\alpha_k}} A_{i_1 i_2 \ldots i_k}} \right)$$

2. **We develop a fast algorithm for optimizing the quality function:**

Algorithm 1: Detecting communities in a (hyper)network $\boldsymbol{H}$ by minimizing quality function Q

Input: Connectivity array $\mathbf{A}$ of $\boldsymbol{H}$
Output: Partition of $\boldsymbol{H}$ into communities

```
begin
    // Phase 1
    assign each node in H a unique label;
    repeat
        update each node's label;
    until a local minimum of Q
    repeat
        // Phase 2
        build a reduced ⟨ℜ, ℜ⟩-(hyper)network H′;
        assign each node in H′ a unique label;
        repeat
            update each node's label;
        until a local minimum of Q
        // Phase 1
        retrieve labels in H from the corresponding labels in H′;
        repeat
            update each node's label;
        until a local minimum of Q
    until no change in Q
    identity communities as groups of nodes bearing the same labels;
end
```

Results

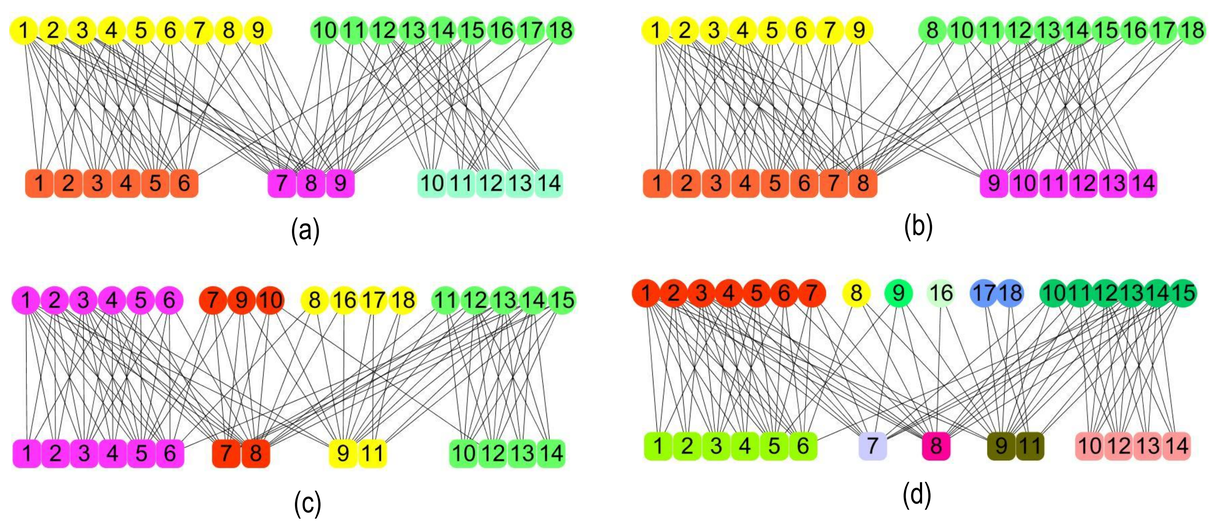

Fig. 3. Partitions of the Southern women bipartite network obtained by (a) our method, (b) the extended modularity optimization approach advanced by Guimerà, (c) the extended modularity optimization approach presented by Barber, (d) the extended modularity optimization approach brought forward by Suzuki.

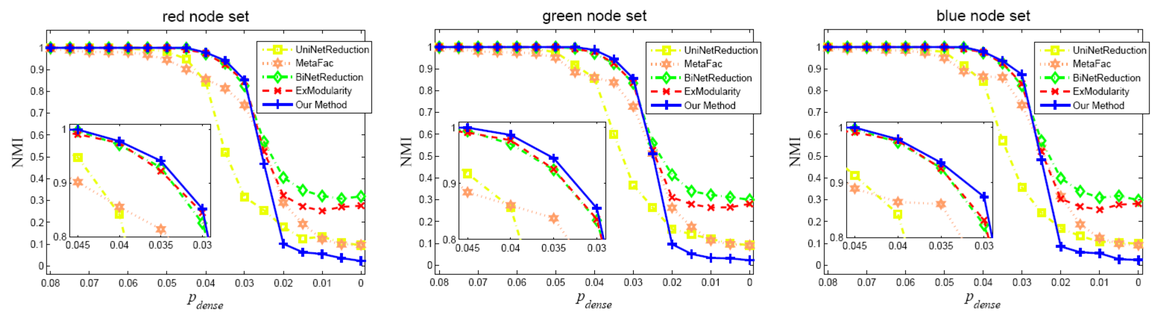

Fig. 4. Performances of various methods in the synthetic 3-partite 3-uniform hypernetworks with built in communities of one-to-one correspondence.

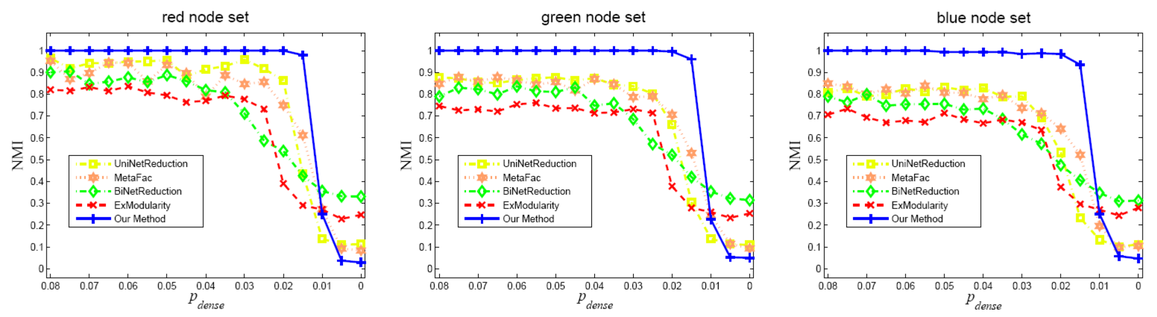

Fig. 5. Performances of various methods in the synthetic 3-partite 3-uniform hypernetworks with built in communities of many-to-many correspondence.

Conclusion

Our method overcomes limitations of previous approaches and has the following key properties:

- **Comprehensive: able to handle broad families of k-partite k-uniform (hyper)networks.**
- **Adaptive: competent for both communities with one-to-one correspondence and many-to-many correspondence.**
- **Parameter-free: automatically detect communities in different node sets, without any prior knowledge like the numbers of communities.**
- **Accurate: more accurate than previous approaches.**
- **Scalable: fast and scalable to large-scale (hyper)networks.**

References

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More relevant information is available at www.ai.cs.titech.ac.jp