Locating Hidden Groups in Communication Networks Using Hidden Markov Models

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Why?

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Need tools to detect groups that attempt to hide their communications within a communication network.

Identifying new emerging groups early

Resource allocation, etc.
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Communication Networks (eg. Newsgroups)

Individuals form groups.

Individuals communicate via an underlying communication medium.
We **know** the groups.

We **do not know** group membership.

We **only observe the communications**.

Infer group membership? (For example members of the same group are more likely to communicate).
Group membership may evolve.

Groups may appear/disappear.

Communications evolve according to group structure.
Above is an example of a **Broadcast** hidden group.

Hidden and regular communications are simultaneous.
Example

No Hidden Group

Communication Graph, t=1

Communication Graph, t=2

Communication Graph, t=3

Communication Graph, t=4

Communication Graph, t=5

Hidden Group

Communication Graph, t=1

Communication Graph, t=2

Communication Graph, t=3

Communication Graph, t=4

Communication Graph, t=5
Task

1. Determine whether there is a hidden group.

2. Who the hidden group members are.

Only using observed communications?

Intuition:

If the communications are not consistent with the observed groups (for example slightly more intense) then there may be a hidden group.

Consistent?
Slightly more intense?

\[
\text{\{probabilistic interpretations...\}
\]
Formal Problem Statement

Given:

Communications data.

Model for observed group dynamics and communication.

Model for hidden group dynamics and communication.

Determine:

Whether a hidden group is present.

Who the hidden group members are.
Simplified Example

Observed Group Model:

Dynamics: Static
Communication: mostly within group.

Hidden Group Model:

Dynamics: Static
Communication: mostly within group.
(emerging groups)
Broadcast
(abberent hidden group)
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Groups $F_1, \ldots, F_{N_g}$.

$F(t)$, is the **micro-state** matrix.

$$F_{ij}(t) = \begin{cases} 1 & \text{if node } x_i \text{ is in group } F_j, \\ 0 & \text{otherwise}. \end{cases}$$

The micro state is **hidden**.

The **communication graph** $C(t)$ is the **macro-state**,

$$C_{ij}(t) = \text{Intensity of } i-j \text{ communication.}$$

The macro-state is observed.
Micro-state evolves according to Markov process.

Macro-state is determined by micro state

Example

**F is static.**
(Special case of Markov process).

**C(t) is determined by a Poisson process.**

\[ P[C_{ij} = k] \]

has Poisson distribution with Poisson parameter proportional to number of groups \( i, j \) have in common.
Example – continued.

If there is a hidden group:

\[ C(t) = R(t) + H(t) \]

\( R(t) \) are regular Poisson communications.
\( H(t) \) is the hidden group broadcast communication.
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Maximum Likelihood Approach  
(No Hidden Group)

Given $F$ and the communication model,  

$$l(F) = \text{likelihood} = P[C|F, model]$$

Pick $F$ to maximize $l(F)$.  

$$l_0 = \max_F l(F)$$  
$$F_0 = \arg\max_F l(F)$$

(can also maximize w.r.t. model choice)
Maximum Likelihood Approach (Hidden Group)

Given $F$ and the hidden nodes ($v$) and the model,

$$l(F, v) = \text{likelihood} = P[C|F, v, \text{model}]$$

(Need to consider all possible decompositions of $C$.)

Pick $F_1, v_1$ to maximize $l$.

$$l_1 = \max_{F,v} l(F, v)$$

$$\{F_1, v_1\} = \arg\max_{F,v} l(F, v)$$

(can also maximize w.r.t. model choice)

$$l_0 > l_1 \implies \text{no hidden group}$$
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Experimental Setup

Small 9 node society.

Generate many societies
(with and without hidden group).

Montecarlo optimization with random perturbation

Obtain $l_0, l_1, F_0, F_1, v_1$.

$l_0 > l_1 \iff$ no hidden group

(identify hidden nodes, and group structure.)
Results

<table>
<thead>
<tr>
<th>True $H$</th>
<th>Predicted $H$</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.78</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.04</td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>

% correct = **89%**

% correct = % nodes identified correctly when $H=1$.

false negative is generally higher than false positive:

- hidden group is small,
- communications hard to detect.
Discussion

1. **Methodology is general**
   - given the model, can detect hidden group.
   - focused on simplified example.

2. **Proof of concept.**
   - develop optimization heuristics.
   - larger societies
   - real societies (eg. newsgroups).

3. **Where to get model from?**
   - social sciences.
   - learn it!
Thank You!

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