Locating Hidden Groups in Communication Networks Using Hidden Markov Models

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June 2 2003

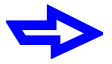
Why?

September 11, 2001

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

Identifying new emerging groups early

Resource allocation, etc.



INTRODUCTION

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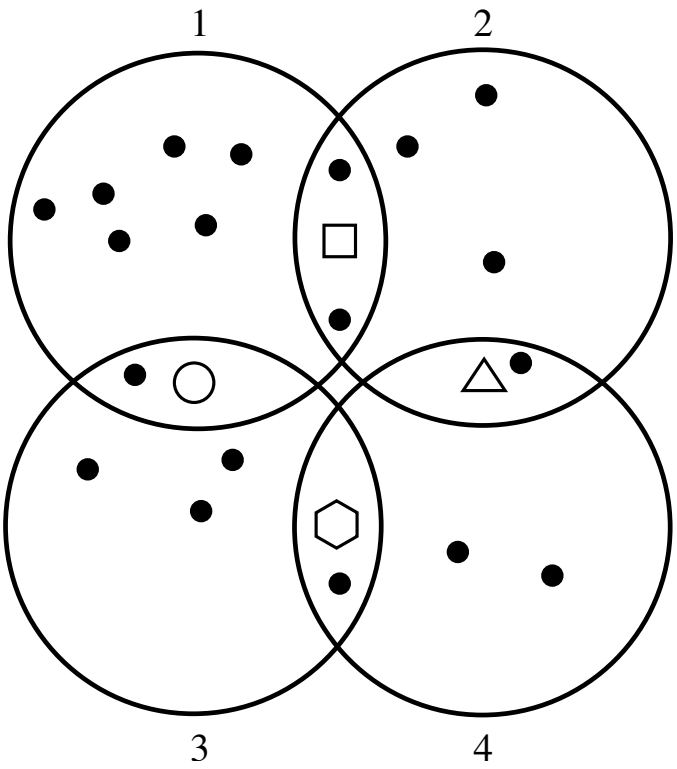
EXPERIMENTS

DISCUSSION

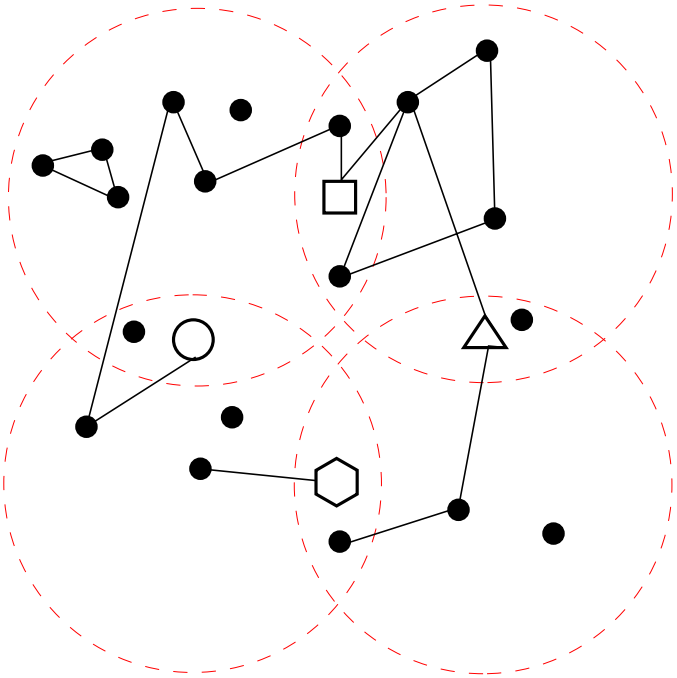
Communication Networks (eg. Newsgroups)



Individuals form groups.

Individuals communicate via an underlying communication medium.

Communication



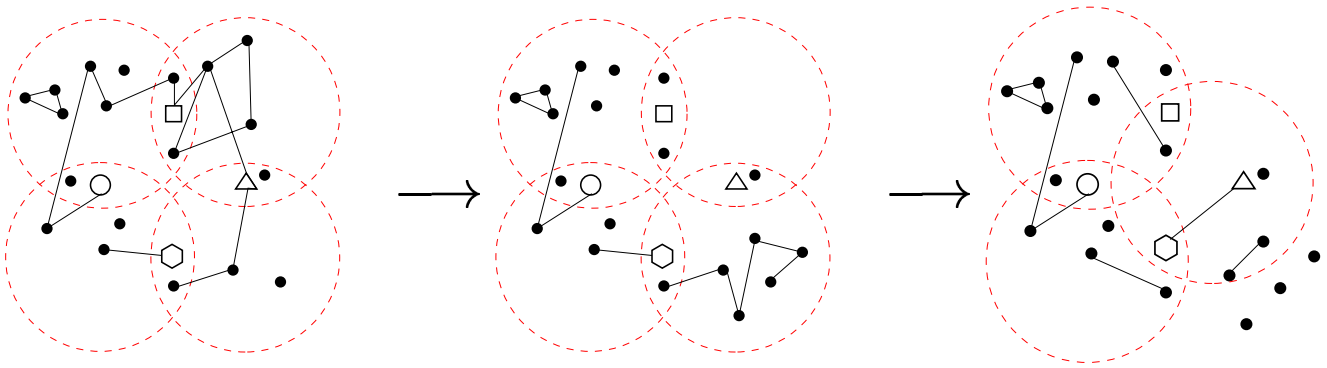
We **know** the groups.

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 Dynamics

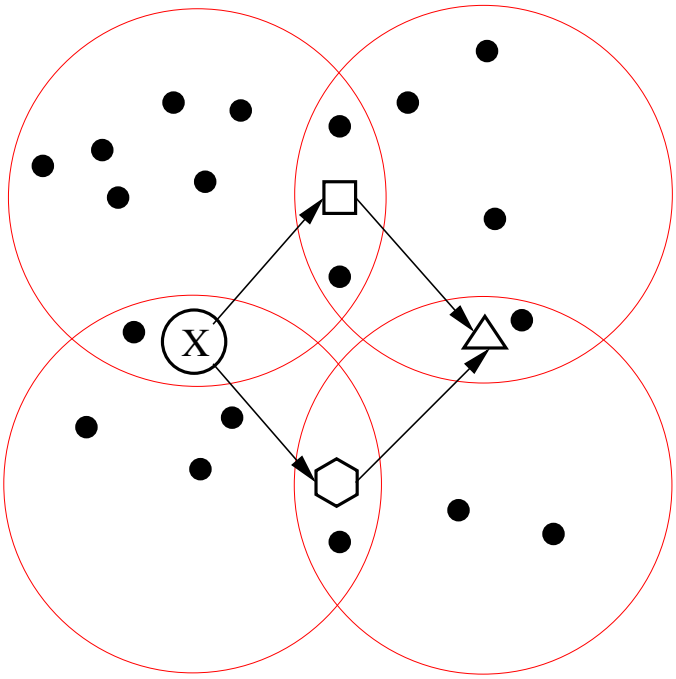


Group membership may evolve.

Groups may appear/disappear.

Communications evolve according to group structure.

Hidden Groups



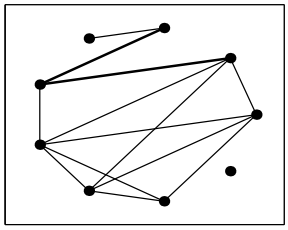
Above is an example of a **Broadcast** hidden group.

Hidden and regular communications are simultaneous.

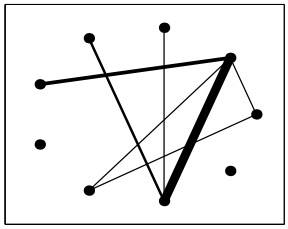
Example

No Hidden Group

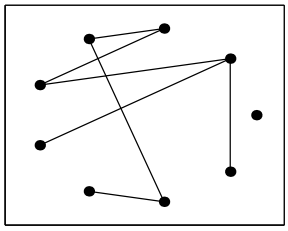
Communication Graph, t=1



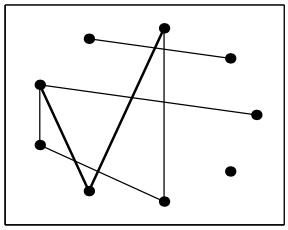
Communication Graph, t=2



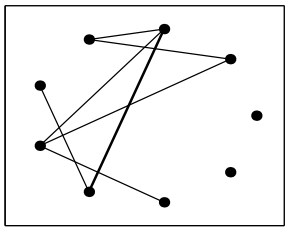
Communication Graph, t=3



Communication Graph, t=4

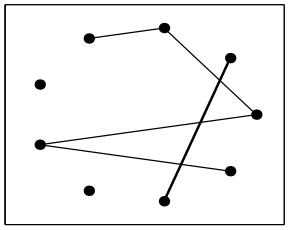


Communication Graph, t=5

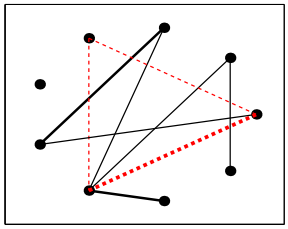


Hidden Group

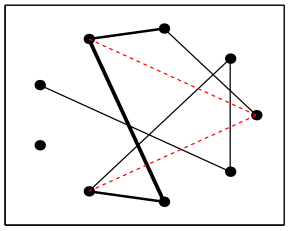
Communication Graph, t=1



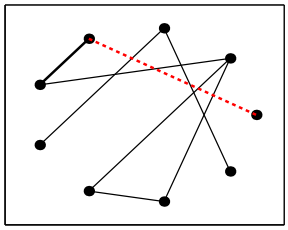
Communication Graph, t=2



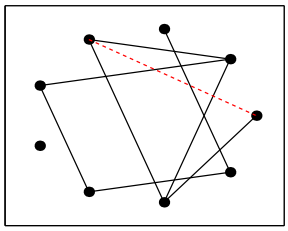
Communication Graph, t=3



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? } 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)

✓ INTRODUCTION

⇨ **POBABILISTIC SETUP**

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Micro/Macro-State

Groups $F_1, \ldots, F_{N_g}$.

$\mathbf{F}(t)$, is the **micro-state** matrix.

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

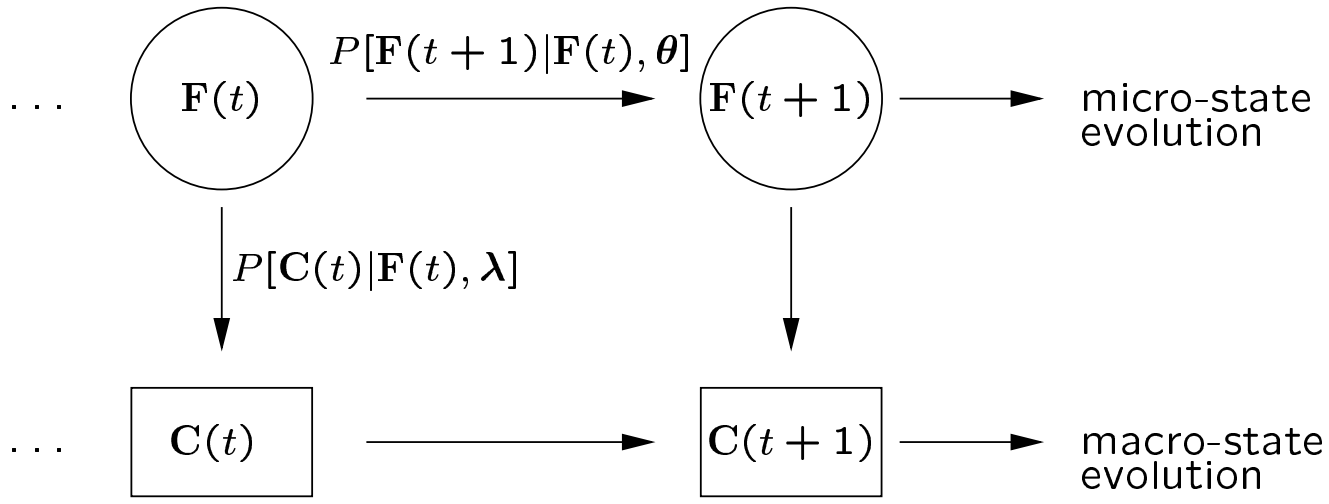
The micro state is **hidden**.

The **communication graph** $\mathbf{C}(t)$ is the **macro-state,**

$$\mathbf{C}_{ij}(t) = \text{Intensity of i–j communication.}$$

The macro-state is observed.

Hidden Markov Model



Micro-state evolves according to Markov process.

Macro-state is determined by micro state

– **Hidden Markov Process**.

Example

$\mathbf{F}$ is **static**.

(Special case of Markov process).

$\mathbf{C}(t)$ is determined by a **Poisson process**.

$$P[\mathbf{C}_{ij} = k]$$

has Poisson distribution with Poisson parameter proportional to number of groups i, j have in common.

Example – continued.

If there is a hidden group:

$$\boxed{\mathbf{C}(t) = \mathbf{R}(t) + \mathbf{H}(t)}$$

$\mathbf{R}(t)$ are regular Poisson communications.

$\mathbf{H}(t)$ is the hidden group broadcast communication.

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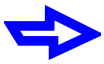

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Maximum Likelihood Approach
(No Hidden Group)

Given $\mathbf{F}$ and the communication model,

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

Pick $\mathbf{F}$ to **maximize** $l(\mathbf{F})$.

$$\begin{aligned} l_0 &= \max_{\mathbf{F}} \ l(\mathbf{F}) \\ \mathbf{F}_0 &= \operatorname*{argmax}_{\mathbf{F}} \ l(\mathbf{F}) \end{aligned}$$

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

Maximum Likelihood Approach (Hidden Group)

Given $\mathbf{F}$ **and the hidden nodes** ($\mathbf{v}$) and the model,

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

(Need to consider all possible decompositions of $\mathbf{C}$.)

Pick $\mathbf{F}_1, \mathbf{v}_1$ to **maximize** l.

$$\begin{aligned} l_1 &= \max_{\mathbf{F},\mathbf{v}} l(\mathbf{F}, \mathbf{v}) \\ \{\mathbf{F}_1, \mathbf{v}_1\} &= \operatorname*{argmax}_{\mathbf{F},\mathbf{v}} l(\mathbf{F}, \mathbf{v}) \end{aligned}$$

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

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

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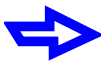

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Experimental Setup

Small 9 node society.

Generate **many societies**
(with and without hidden group).

Montecarlo optimization with random perturbation

Obtain $l_0, l_1, \mathbf{F}_0, \mathbf{F}_1, \mathbf{v}_1$.

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

(identify hidden nodes, and group structure.)

Results

20 time steps

True H	Predicted H 1	0
1	0.78	**0.28**
0	**0.04**	0.96

% correct =**89%**

50 time steps

True H	Predicted H 1	0
1	0.88	**0.12**
0	**0.03**	0.97

% correct=**94%**

% 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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