

# Predicting Movie Genre Using Actor Co-Appearance Networks

Can network topology alone reveal genre?

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Social Networks Analysis — Fall 2025

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# The Question

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Can we predict a movie's genre  
using only actor collaborations?

No plot. No script. No text. No semantic features.

Just **who worked with whom**.

# Hypothesis

## Core Claim

Actor collaboration graphs exhibit strong **community structure**, and these communities correspond to **film genres** at rates significantly above random.

## Why might this work?

- Directors repeatedly cast the same actors
- Production companies specialize in genres
- Franchise ecosystems create dense clusters
- Horror circuits, rom-com ensembles, prestige drama pools

**Genre may be a network-emergent property.**

# Conceptual Framework

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## The Logic:

Actors specializing in similar film ecosystems tend to co-appear repeatedly. These recurring interactions create dense subgraphs that should map onto genre clusters if genre is a **socially emergent structure** within the film industry.

If communities correspond to genres, then **genre is recoverable from network structure alone.**

**We test this by:**

1. Constructing weighted co-appearance networks
2. Detecting communities via modularity optimization
3. Evaluating whether detected communities align with known genres

# Building the Network

**Graph Structure:**  $G = (V, E, w)$

- **Nodes**  $V = \{a_1, a_2, \dots, a_n\} = \text{Actors}$
- **Edges**  $E = \{(a_i, a_j) : \text{co-appear in film}\}$
- **Weights** = Genre-purity weighting

**Edge Weight Function:**

$$w(f) = \begin{cases} 1.00 & \text{single-genre film} \\ 0.25 & \text{dual-genre} \\ 0.05 & \text{triple-genre} \\ 0.01 & 4+ \text{ genres} \end{cases}$$

## Building the Network (continued)

Final edge weight between actors  $a_i$  and  $a_j$ :

$$W_{ij} = \sum_{f \in \mathcal{F}(a_i, a_j)} w(f)$$

where  $\mathcal{F}(a_i, a_j)$  is the set of films featuring both actors.

Intuition: A pure horror film is stronger evidence than Horror/Comedy/Romance.

# Edge Weight Rationale

## Why penalize multi-genre films?

### Step-function weighting:

- 1 genre: 1.00 (strong indicator)
- 2 genres: 0.25 (split signal)
- 3 genres: 0.05 (minimal)
- 4+ genres: 0.01 (nearly ignored)

### Rationale:

- Single-genre films strongly indicate genre affinity
- Multi-genre films dilute genre specificity
- We want to prioritize genre-pure collaborations

A collaboration in a pure horror film is **much stronger evidence** of “horror actor” than a collaboration in a film tagged Horror/Comedy/Romance/Drama.



# Why Community Detection?

**The central premise:** Genre is encoded in collaboration structure

## Key Insight

If actors cluster by genre, then:

- Actors within the same community share films more often than expected
- Each community should exhibit a dominant genre
- Community membership can serve as a genre **prediction**

**Without community detection, we have no way to partition the network and test whether partitions correspond to genres.**

# Community Detection: Louvain Algorithm

**Goal:** Find densely connected subgroups (communities)

**Modularity:**

$$Q = \frac{1}{2m} \sum_{i,j} \left[ A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j)$$

**Symbols:**

- $A_{ij}$  = edge weight
- $k_i$  = weighted degree
- $m$  = total edge weight
- $c_i$  = community of  $i$

**Interpretation:**

- $Q = 0$ : Random
- $Q \approx 0.3$ – $0.7$ : Significant
- $Q > 0.7$ : Strong

## Community Detection: Louvain Algorithm (continued)

### Louvain Process:

1. Each node greedily joins community maximizing  $\Delta Q$
2. Communities become super-nodes
3. Repeat until convergence

Two-phase algorithm: **Local optimization** then **aggregation**

# Why More Communities Than Genres?

The algorithm typically produces **more communities than the 5 macro-genres**

## Why?

- Sub-genre specialization  
(slasher vs. supernatural horror)
- Franchise isolation  
(MCU actors form own cluster)
- Niche production circuits  
(low-budget regional films)

## This is informative!

- Algorithm discovers natural structure
- Multiple resolution levels
- Not preset—determined by modularity optimization

**The number of communities  $|\mathcal{C}|$  is determined by the data, not preset.**

# What Do Communities Contain?

Each community  $c \in \mathcal{C}$  is a set of actors:

$$c = \{a_{i_1}, a_{i_2}, \dots, a_{i_k}\}$$

**Genre Distribution:** Characterize each community by its genre mix

$$P_c(g) = \frac{\sum_{a \in c} \mathbb{I}[g^*(a) = g]}{|c|}$$

where  $g^*(a)$  is actor  $a$ 's dominant macro-genre.

This gives a probability distribution over genres for each community.

Pure communities have one dominant genre.

Mixed communities are spread across genres.

# Community Purity

## Single Community Purity:

$$\text{Purity}(c) = \max_g \frac{|\{a \in c : g^*(a) = g\}|}{|c|}$$

What fraction of a community shares the same dominant genre?

## Overall Purity (Weighted):

$$\text{Purity}_{\text{overall}} = \frac{1}{|V|} \sum_{c \in \mathcal{C}} |c| \cdot \text{Purity}(c)$$

Equivalent to unweighted accuracy when assigning each community its majority genre.

## Community Purity (continued)

### Interpretation:

- 0.20 = Random (5 genres)
- 0.40–0.50 = Weak clustering
- 0.60–0.70 = Moderate separation
- 0.80+ = Strong communities

**High purity** indicates that Louvain communities align with genre boundaries—the network *knows* about genre even though genre labels were never used.

# Purity vs. Accuracy

## Purity

- How homogeneous each community is
- Measures community-level consistency
- Equivalent to unweighted accuracy

## Accuracy

- How well community assignment predicts individual actors
- Can exceed purity with weighting
- PageRank-weighting amplifies signal

## Key Point

With PageRank-weighting, accuracy can exceed raw purity because **central actors** (who define the community) tend to have cleaner genre profiles than peripheral actors.



# Prediction Accuracy Metrics

## Three Voting Schemes:

### 1. Unweighted Accuracy:

$$\text{Acc}_{\text{unweighted}} = \frac{1}{|V|} \sum_{a \in V} \mathbb{I}[\hat{g}(c_a) = g^*(a)]$$

Each actor contributes equally

### 2. Degree-Weighted Accuracy:

$$\text{Acc}_{\text{degree}} = \frac{\sum_{a \in V} k_a \cdot \mathbb{I}[\hat{g}(c_a) = g^*(a)]}{\sum_{a \in V} k_a}$$

Weights by collaboration volume

### 3. PageRank-Weighted Accuracy:

$$ACC_{PR} = \frac{\sum_{a \in V} PR(a) \cdot \mathbb{I}[\hat{g}(c_a) = g^*(a)]}{\sum_{a \in V} PR(a)}$$

Weights by network influence

#### Rationale

Core actors (high PageRank) more reliably represent their community's genre identity than peripheral actors.

## PageRank: Finding Core Actors

$$\text{PR}(a_i) = \frac{1-d}{N} + d \sum_{a_j \in \mathcal{N}(a_i)} \frac{W_{ji}}{\sum_k W_{jk}} \cdot \text{PR}(a_j)$$

### Parameters:

- $d = 0.85$  (damping factor)
- $N$  = total actors
- $\mathcal{N}(a_i)$  = neighbors

### Intuition:

- Actor is important if they collaborate with important actors
- Weighted by strength of collaborations

### Key Insight

**Core actors** (high PageRank) define community identity.

**Peripheral actors** often appear in single cross-genre films.

# Gini Coefficient: Measuring Inequality

## Formula:

$$G = \frac{2 \sum_{i=1}^n i \cdot x_{(i)}}{n \sum_{i=1}^n x_{(i)}} - \frac{n+1}{n}$$

where  $x_{(i)}$  is the  $i$ -th smallest PageRank value.

## Interpretation:

- $G \approx 0$ : Perfect equality
- $G \approx 0.2$ – $0.3$ : Weak hub structure
- $G \approx 0.5$ – $0.7$ : Power-law (realistic)
- $G \rightarrow 1$ : Extreme inequality

## What it tells us:

- Whether we have strong hubs
- How unequal actor importance is
- If network has realistic power-law shape
- If dataset is large enough to reveal structure

## Falsification Criteria

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The hypothesis is rejected if:

### Modularity

$Q < 0.3$  across all  
configurations

### Community Purity

No dominant genre per  
community

### Accuracy

Converges to random  
baseline  $\approx 0.20$

**None of these occurred.**

The hypothesis is strongly supported.

# Dataset

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**Source:** IMDb Non-Commercial Datasets

## Filters:

- Feature films only
- Runtime  $\geq$  59 min
- Released 1960+
- Top-3 billed cast
- Actors with  $\geq$  3 credits
- 18 canonical genres

## 5 Macro-Genres:

- **ACTION**: Action, Adventure, Thriller, Sci-Fi, War
- **DRAMA**: Drama, Romance, Biography
- **COMEDY**: Comedy, Music, Musical
- **DARK**: Crime, Mystery, Horror
- **FAMILY**: Family, Animation, Fantasy

**Sample Sizes:** 250, 1000, and 5000 films (top by popularity)

# Experimental Design

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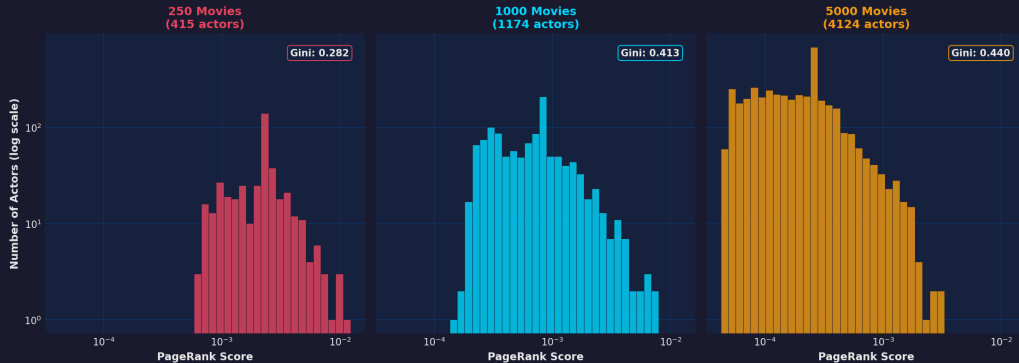
For each sample size  $N \in \{250, 1000, 5000\}$ :

1. Select top- $N$  films by popularity (vote count)
2. Construct weighted actor network
3. Vary genre count from 3 to 12
4. For each configuration:
  - Compute Louvain partition (weighted and unweighted)
  - Compute PageRank and Gini coefficient
  - Evaluate all three accuracy metrics
5. Generate diagnostic visualizations

**Total:** 3 sample sizes  $\times$  10 genre counts = 30 configurations

# Result 1: PageRank Distribution Evolution

PageRank Distribution Across Dataset Sizes  
(Log-log scale reveals power-law structure)



**250 films**

Thin distribution

No heavy tail

**1,000 films**

Heavy tail starts

Power-law forming

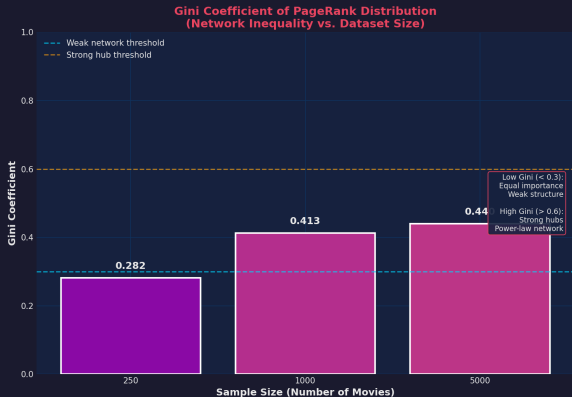
**5,000 films**

Clear power-law

Strong hubs



## Result 1 (cont.): Network Inequality Scales with Size

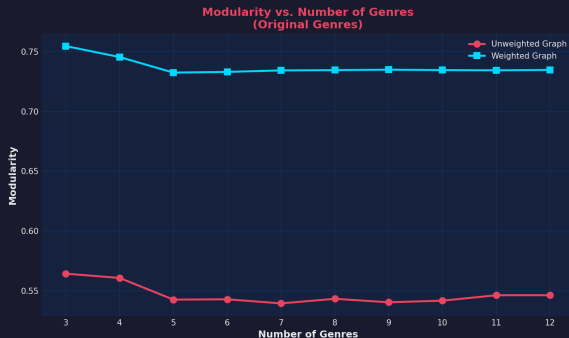


Films	Actors	Gini
250	415	0.282
1,000	1,174	0.413
5,000	4,124	0.440

### Finding:

Larger datasets →  
more realistic hub structure  
(rich-get-richer)

## Result 2: Strong Community Structure



Films	Peak $Q$
250	<b>0.919</b>
1,000	<b>0.845</b>
5,000	<b>0.755</b>

### Finding:

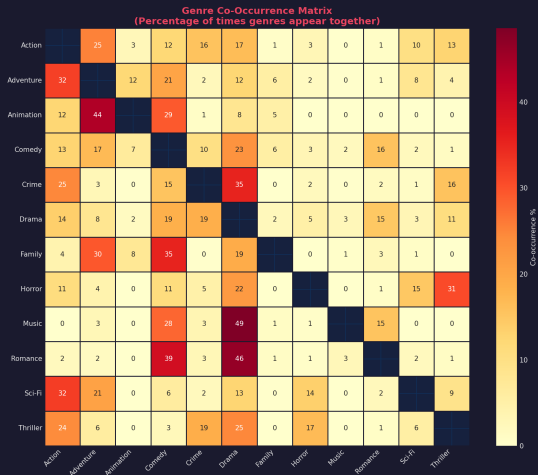
$Q > 0.7$  at all scales

Actor networks are  
**highly modular**

# Result 3: Genre Separation



## Result 4: Genre Co-Occurrence Explains Overlaps

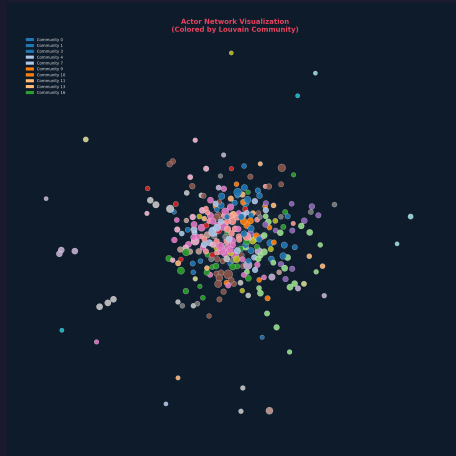


### Key Structures:

- Action–Adventure–Thriller triad
- Family–Animation cluster
- Comedy avoids Dark
- Drama connects everything

Multi-genre films create cross-community bridges.

## Result 5: Network Visualization



5,000 films. Node color = community. Node size = degree.

## Result 6: Genre Co-Occurrence Chord Diagram



### Visualization:

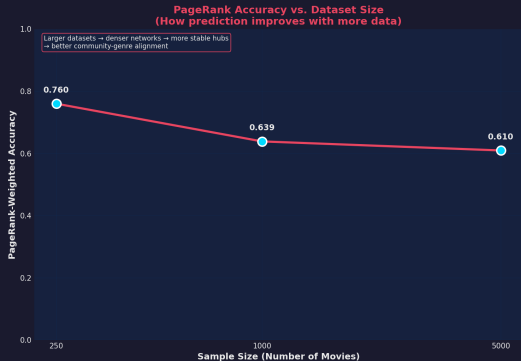
- Genres around circle
- Arcs = co-occurrence
- Thickness = frequency

### Key insight:

Thick arcs → frequent  
co-occurrence → natural genre  
clusters

Example: Action–Adventure–Thriller  
triad

# The Central Result: Prediction Accuracy



Films	Accuracy	Lift
250	76.0%	3.8×
1,000	63.9%	3.2×
5,000	61.0%	3.1×

Random baseline: 20%

**3× better than random  
using only topology!**

## Accuracy Comparison: All Methods

Films	Unweighted	Degree	PageRank	Random
250	0.720	0.696	<b>0.760</b>	0.200
1,000	0.608	0.502	<b>0.639</b>	0.200
5,000	0.524	0.553	<b>0.610</b>	0.200

### Key Findings:

1. PageRank-weighted accuracy is consistently highest across all sample sizes
2. Accuracy exceeds 3× the random baseline even at largest scale
3. Central actors encode genre identity more reliably than peripheral actors
4. The network knows about genre despite never being given genre labels



# Why Does Genre Emerge from Network Structure?

The film industry operates through collaboration microcultures:

- Recurring casts (e.g., Christopher Nolan's ensemble)
- Director-actor partnerships
- Franchise ecosystems (MCU, horror sequels)
- Genre-bound production companies
- Low-budget horror circuits
- Rom-com ensembles
- Prestige drama clusters
- Animation voice actor pools

These **institutional structures** manifest as high-modularity subgraphs aligned with recognizable genres.

# Why Does Accuracy Decline with Scale?

## Larger datasets introduce noise:

- Multi-genre actors  
Blur community boundaries
- Cross-genre franchises  
Create inter-community bridges
- High-degree bridge actors  
Reduce modularity
- DRAMA as umbrella genre  
Connects disparate clusters
- More genre mixing  
Dilutes cluster purity

**However, accuracy never approaches random—**  
genre signal persists at all scales.

# Why PageRank-Weighting Wins

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## The Problem

Peripheral actors appear in single cross-genre films.

They add **noise** to community genre assignment.

## The Solution

PageRank identifies **core actors** who define the community.

These actors have consistent genre profiles.

PageRank weighting = amplify signal, suppress noise

# Summary of Findings

## Network Properties:

- **Modularity:**  $Q > 0.73$  at all scales
- **Gini coefficient:** Increases with scale
- **PageRank accuracy:**  $3\times$  random baseline
- **Community purity:** Majority-genre assignment succeeds

## Key Results:

- Strong community structure at every scale
- Realistic hub formation with larger datasets
- Clear genre clusters in network visualization
- PageRank-weighting consistently best method

Actor co-appearance networks contain **substantial intrinsic genre information**, recoverable without textual, plot, or semantic features.

**61% accuracy**

on a 5-class problem

(random = 20%)

**Using only network structure**

No text. No plot. No semantics.

Even at the largest and noisiest scale (5,000 films), the model achieves **61.0% accuracy** using only network structure—over three times the random baseline of 20%.

## Conclusion (continued)

### Theoretical Implications

Genre is not merely a content-based label. It is a **network-emergent pattern** shaped by:

- Collaboration structure
- Institutional clustering
- Recurring partnerships
- Production company specialization

**Genre, fundamentally, is a pattern of relationships.**

*“Genre, fundamentally,  
is a pattern of relationships.”*

[github.com/avih7531/social\\_networks\\_final](https://github.com/avih7531/social_networks_final)