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ENTROPY-NORMALIZED MULTIDIMENSIONAL MODEL FOR USER ACTIVITY SEGMENTATION IN REDDIT

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Abstract. This paper proposes an entropy-normalized multidimensional framework for user activity segmentation in the Reddit social network. The relevance of the study is determined by the rapid growth of large-scale weakly structured behavioral data generated by modern digital platforms and online social systems. User engagement indicators such as likes and comments are shown to exhibit heavy-tailed statistical distributions characterized by strong variability, nonlinear interaction dynamics, and scale-free structural properties. Such characteristics significantly limit the applicability of classical statistical assumptions and motivate the development of scalable analytical approaches for intelligent behavioral modeling. To address this problem, we introduce a composite activity index integrating standardized engagement indicators with normalized Shannon entropy of temporal behavior. The proposed representation enables simultaneous analysis of interaction intensity and temporal regularity within a unified multidimensional behavioral framework. Temporal entropy is used to quantify uncertainty and

irregularity of user activity across hourly intervals, allowing the model to distinguish structurally different behavioral profiles even when engagement intensity remains similar. Heavy-tailed properties of engagement distributions are investigated using power-law analysis and complementary cumulative distribution function (CCDF) modeling in logarithmic coordinates. User segmentation is performed using the KMeans clustering algorithm, while clustering quality is evaluated using the silhouette coefficient. Experimental analysis confirms the existence of scale-free interaction dynamics in Reddit engagement data and demonstrates that entropy-normalized representations improve cluster separation and interpretability compared to raw-feature clustering approaches. The developed analytical pipeline is computationally scalable and suitable for large-scale digital platforms containing massive volumes of user-generated interactions. The proposed framework may be applied in intelligent analytics, recommendation systems, anomaly detection, behavioral profiling, and computational social science research. Furthermore, the obtained results indicate that entropy-aware multidimensional representations provide an effective foundation for future graph-based interaction analysis and machine learning approaches in complex online ecosystems.

Keywords: entropy-based modeling; power-law distributions; composite activity index; cluster analysis; scale-free systems; digital platform analytics

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REDDIT-ТЕ ПАЙДАЛАНУШЫ ӘРЕКЕТІН СЕГМЕНТТЕУГЕ АРНАЛҒАН ЭНТРОПИЯ-НОРМАЛДАНҒАН КӨП ӨЛШЕМДІ МОДЕЛЬ

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Аннотация. Бұл мақалада Reddit әлеуметтік желісіндегі пайдаланушы белсенділігін сегменттеу үшін энтропиямен нормаланған көп өлшемді құрылым ұсынылады. Зерттеудің өзектілігі заманауи цифрлық платформалар мен онлайн әлеуметтік жүйелер арқылы жасалған ірі көлемді әлсіз құрылымдалған мінез-құлық деректерінің тез өсуімен анықталады. Ұнату және пікірлер сияқты пайдаланушылардың қатысу көрсеткіштері күшті өзгергіштікпен, сызықтық емес өзара әрекеттесу динамикасымен және масштабталмайтын құрылымдық қасиеттермен сипатталатын ауыр құйрықты статистикалық үлестірімдерді көрсететіні сипатталды. Мұндай сипаттамалар классикалық статистикалық болжамдардың қолданылуын айтарлықтай шектейді және интеллектуалды мінез-құлықты модельдеу үшін масштабталатын аналитикалық тәсілдерді әзірлеуге түрткі болады. Бұл мәселені шешу үшін біз стандартталған қатысу көрсеткіштерін уақытша мінез-құлықтың нормаланған Шеннон энтропиясымен біріктіретін құрама белсенділік индексын енгіземіз. Ұсынылған көрініс бірыңғай көп өлшемді мінез-құлық шеңберінде өзара әрекеттесу қарқындылығы мен уақытша тұрақтылықты бір мезгілде талдауға мүмкіндік береді. Уақытша энтропия пайдаланушы белсенділігінің сағаттық аралықтағы белгісіздігі мен біркелкі еместігін сандық бағалау үшін қолданылады, бұл модельге қатысу қарқындылығы ұқсас болып қалса да, құрылымдық жағынан әртүрлі мінез-құлық профильдерін ажыратуға мүмкіндік береді. Қатысу үлестірімдерінің ауыр құйрықты қасиеттері логарифмдік координаттардағы дәрежелік заң талдауы және толықтырушы кумулятивтік үлестірім функциясын (CCDF) модельдеу арқылы зерттеледі. Пайдаланушы сегментациясы KMeans кластерлеу алгоритмін қолдану арқылы жүзеге асырылады, ал кластерлеу сапасы силуэт коэффициентін қолдану арқылы бағаланады. Эксперименттік талдау Reddit қатысу деректерінде масштабсыз өзара әрекеттесу динамикасының бар екенін растайды және энтропия бойынша нормаланған көріністер шикі ерекшеліктерді кластерлеу тәсілдерімен салыстырғанда кластерді бөлуді және түсіндіруді жақсартатынын көрсетеді. Өзірленген аналитикалық құбыр есептеу арқылы масштабталатын және пайдаланушы жасаған өзара әрекеттесулердің үлкен көлемін қамтитын ірі көлемді сандық платформаларға жарамды. Ұсынылған құрылым интеллектуалды аналитикада, ұсыныс жүйелерінде, аномалияны анықтауда, мінез-құлық профилінде және есептеу әлеуметтік ғылымдарын зерттеуде қолданылуы мүмкін. Сонымен қатар, алынған нәтижелер энтропияны ескеретін көп өлшемді көріністер күрделі онлайн экожүйелерде болашақ графикке негізделген өзара әрекеттесу талдауы және машиналық оқыту тәсілдері үшін тиімді негіз болатынын көрсетеді.

Түйін сөздер: энтропиялық модельдеу; дәрежелік таралулар; интегралдық белсенділік индексі; кластерлік талдау; масштабқа тәуелсіз жүйелер

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ЭНТРОПИЙНО-НОРМАЛИЗОВАННАЯ МНОГОМЕРНАЯ МОДЕЛЬ ДЛЯ СЕГМЕНТАЦИИ АКТИВНОСТИ ПОЛЬЗОВАТЕЛЕЙ В REDDIT

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Аннотация. *Актуальность.* В статье предлагается энтропийно-нормализованная многомерная структура для сегментации активности пользователей социальной сети Reddit. Актуальность исследования обусловлена быстрым ростом объемов слабоструктурированных поведенческих данных, генерируемых современными цифровыми платформами и онлайн-социальными системами. Показатели вовлеченности пользователей, такие как лайки и комментарии, демонстрируют статистические распределения с тяжелыми хвостами, характеризующиеся высокой изменчивостью, нелинейной динамикой взаимодействия и масштабно-инвариантными структурными свойствами. Такие особенности ограничивают применимость классических статистических предположений и требуют разработки масштабируемых аналитических подходов для интеллектуального моделирования поведения пользователей. *Цель.* Разработать многомерную энтропийно-нормализованную модель для сегментации активности пользователей Reddit, позволяющую учитывать как интенсивность взаимодействия, так и временную регулярность пользовательского поведения. *Методы.* Для решения поставленной задачи введен

составной индекс активности, интегрирующий стандартизированные показатели вовлеченности с нормализованной энтропией Шеннона временного поведения. Предложенное представление позволяет одновременно анализировать интенсивность взаимодействия и временную регулярность в рамках единой многомерной поведенческой структуры. Временная энтропия используется для количественной оценки неопределенности и нерегулярности активности пользователей в течение часовых интервалов, что позволяет модели различать структурно разные поведенческие профили даже при сходной интенсивности вовлеченности. Свойства распределений пользовательской активности с тяжелыми хвостами исследованы с применением степенного анализа и моделирования дополнительной кумулятивной функции распределения (CCDF) в логарифмических координатах. Сегментация пользователей выполнена с помощью алгоритма кластеризации KMeans, а качество кластеризации оценено с использованием коэффициента силуэта. *Результаты и выводы.* Экспериментальный анализ подтвердил наличие безмасштабной динамики взаимодействия в данных об активности пользователей Reddit. Установлено, что энтропийно-нормализованные представления улучшают разделение кластеров и повышают интерпретируемость результатов по сравнению с подходами кластеризации на основе исходных признаков. Разработанный аналитический конвейер является вычислительно масштабируемым и может использоваться для анализа крупных цифровых платформ, содержащих значительные объемы пользовательских взаимодействий. Предложенная структура применима в интеллектуальной аналитике, рекомендательных системах, обнаружении аномалий, поведенческом профилировании и вычислительных исследованиях в области социальных наук. Полученные результаты показывают, что многомерные представления с учетом энтропии могут служить эффективной основой для дальнейшего анализа взаимодействий на основе графов и методов машинного обучения в сложных онлайн-экосистемах.

Ключевые слова: энтропийное моделирование, степенные распределения, интегральный индекс активности, кластерный анализ, масштабно-инвариантные системы, Reddit, KMeans, поведенческая аналитика

Introduction. In the modern digital ecosystem, social networks generate large-scale weakly structured data reflecting user behavior and interaction dynamics. Understanding engagement patterns has become an important research direction in data mining, computational social science, and intelligent analytics (Aggarwal, 2015). Reddit represents a structurally organized platform composed of thematic communities known as subreddits, which makes it particularly suitable for modeling heterogeneous engagement behavior. However, engagement indicators such as likes and comments typically exhibit heavy-tailed statistical distributions and strong variability, limiting the applicability of classical statistical assumptions (Clauset et al., 2009).

This study proposes an entropy-normalized multidimensional model for user activity segmentation. The key contribution lies in constructing a composite activity index integrating engagement intensity and temporal regularity of user behavior.

Main Contributions. The main contributions of this study are summarized as follows:

- An entropy-normalized multidimensional representation of user activity is proposed for behavioral segmentation in online social platforms.
- A composite activity index integrating engagement intensity and temporal regularity is developed.
- Heavy-tailed properties of Reddit engagement distributions are empirically validated using power-law analysis.
- Comparative clustering experiments demonstrate that entropy-aware representations improve cluster separation and interpretability.
- A computationally scalable analytical pipeline suitable for large-scale digital platforms is constructed.

Unlike traditional engagement-based clustering approaches that rely primarily on interaction magnitude, the proposed framework integrates entropy-aware temporal regularity into a unified multidimensional representation. This allows the model to distinguish structurally different behavioral patterns even when engagement intensity is similar.

The novelty of the proposed approach lies in combining heavy-tailed engagement modeling, entropy-based temporal analysis, and multidimensional behavioral embedding within a computationally scalable clustering framework for online social systems.

Modern online platforms produce extremely heterogeneous interaction environments where user activity evolves dynamically under the influence of collective attention, information diffusion, and temporal behavioral cycles. Such environments generate massive volumes of weakly structured behavioral data characterized by nonlinear dependencies, scale-free interaction patterns, and substantial statistical variability.

Traditional statistical models often assume approximately Gaussian distributions and homogeneous behavioral structures. However, empirical observations demonstrate that social media engagement metrics frequently violate these assumptions due to the presence of highly active outliers and long-tail interaction dynamics. As a consequence, scalable analytical approaches capable of capturing heavy-tailed statistical properties become critically important for modern behavioral analytics.

In recent years, entropy-aware representations and multidimensional behavioral embeddings have become increasingly important in computational social science and intelligent digital analytics. Such approaches enable simultaneous analysis of interaction intensity, temporal uncertainty, and structural heterogeneity within large-scale online systems.

Literature Review. Heavy-Tailed Behavior in Online Social Networks

The study of user activity in online social networks is closely connected to the theory of complex networks and scale-free systems. Barabási and Albert (1999), in their seminal work *Emergence of Scaling in Random Networks*, introduced the preferential attachment mechanism to explain the emergence of power-law degree distributions in complex networks. Later, Clauset, Shalizi, and Newman (2009) proposed rigorous statistical procedures for identifying and validating power-law distributions in empirical data, providing a methodological foundation for heavy-tailed analysis in social systems.

Newman (2005) further demonstrated that power-law, Pareto, and Zipf distributions frequently arise in natural and social phenomena, including online communication networks. In the context of social media, Vosoughi, Roy, and Aral (2018) showed that information diffusion processes exhibit strong heterogeneity and scale-free characteristics. Similarly, Cinelli, Quattrociocchi, and Galeazzi (2021) investigated echo-chamber effects and highlighted the role of collective attention in shaping online engagement dynamics.

Behavioral Analytics and Post Segmentation.

The rapid growth of user-generated content has stimulated extensive research in computational social science. Lazer et al. (2009) emphasized the importance of large-scale behavioral data analysis for understanding social dynamics in digital environments. Aggarwal (2015), in *Data Mining: The Textbook*, and Tan, Steinbach, and Kumar (2019), in *Introduction to Data Mining*, presented comprehensive frameworks for clustering and behavioral analysis that remain widely used in posts segmentation tasks.

Zhou, Liu, and Wang (2022) reviewed machine-learning approaches for user behavior modeling in online social networks and demonstrated the effectiveness of clustering-based segmentation techniques. Zhao and Karypis (2022) further reported that multidimensional user representations improve clustering quality and behavioral interpretability in online social systems.

Temporal Dynamics and Entropy-Based Modeling.

Temporal behavior has become an increasingly important aspect of social network analytics. Ribeiro, Perra, and Baronchelli (2021) quantified temporal regularity in online user activity and demonstrated the existence of strong daily and weekly behavioral cycles. Yang and Leskovec (2022) analyzed temporal variation in online media and showed that engagement dynamics evolve according to complex time-dependent processes.

Entropy-based approaches provide a natural framework for quantifying behavioral uncertainty and temporal variability. Shannon (1948), in his seminal work *A Mathematical Theory of Communication*, introduced entropy as a fundamental measure of information uncertainty. Since then, entropy has been widely applied in information theory, communication systems, complex networks, and behavioral analytics. In the context of online social systems, entropy enables the quantification of temporal regularity and activity diversity, providing an interpretable measure

of behavioral variability. Recent studies have demonstrated that entropy-aware representations can improve user profiling, behavioral segmentation, and the analysis of interaction dynamics in large-scale digital platforms.

Network Science and Advanced Behavioral Representations.

Modern behavioral analytics increasingly combines network science, machine learning, and temporal modeling. Fortunato and Hric (2016) reviewed community-detection techniques and emphasized their importance in identifying structural patterns within complex networks. Rosvall et al. (2014) demonstrated that memory effects in network flows significantly influence community formation and information propagation processes.

Holme and Saramäki (2012) introduced the concept of temporal networks, providing a theoretical framework for analyzing dynamic interactions over time. Furthermore, Hofmann, Schölkopf, and Smola (2008) demonstrated the effectiveness of kernel-based machine-learning methods for constructing multidimensional behavioral representations.

Despite substantial progress in computational social science, relatively few studies integrate heavy-tailed engagement modeling, entropy-based temporal analysis, and multidimensional clustering within a unified analytical framework. The present study addresses this gap by combining scale-free interaction analysis with entropy-normalized behavioral representations for Reddit user activity segmentation.

Methods. Problem Formulation. Let each user u_i be characterized by engagement metrics:

$$\begin{aligned} L_i &= \text{average number of likes;} \\ C_i &= \text{average number of comments.} \end{aligned}$$

Additionally, let $a_{i,h}$ denote the number of user actions during hour h , where $h = 1, \dots, 24$. The objective is to construct a multidimensional representation of user activity that:

1. Accounts for heavy-tailed engagement distributions;
2. Incorporates temporal behavioral patterns;
3. Enables interpretable segmentation;
4. Improves clustering quality.

Recent advances in machine learning and network science further emphasize the importance of multidimensional behavioral representations in large-scale online systems. Modern analytical frameworks increasingly combine statistical modeling, temporal analysis, graph representations, and scalable clustering algorithms in order to capture complex interaction dynamics emerging in digital ecosystems. Several recent studies demonstrate that entropy-aware representations improve robustness and interpretability of user segmentation models, particularly in environments characterized by high variability and nonlinear interaction structures. Such approaches are especially relevant for Reddit-like platforms where collective attention processes and information cascades strongly influence engagement dynamics.

Dataset Description.

The dataset was collected using the official Reddit API during the period from January 2024 to March 2025. Data aggregation was performed across several thematic communities related to technology, science, gaming, and education. The final dataset contains approximately 12,438 users, 84,210 posts, and more than 310,000 user interactions, including likes and comments. For each user, engagement statistics and temporal activity distributions were extracted.

Preprocessing included duplicate removal, inactive-user filtering, elimination of bot-like activity using heuristic thresholds, and normalization of engagement indicators. Missing values were removed during preprocessing to ensure statistical consistency of the dataset. Temporal activity was aggregated across 24 hourly intervals in order to analyze behavioral regularity and daily interaction patterns.

Dataset statistics. Basic descriptive statistics of the engagement metrics are presented in Table 1.

Table 1 — Descriptive statistics of engagement metrics

Metric	Mean	Std	Min	Max
Likes	18.7	24.5	0	214
Comments	9.2	16.3	0	205
Posts per user	3.1	2.4	1	18
Entropy H^*	0.63	0.17	0.21	0.94

The statistics confirm strong variability of engagement metrics, which is typical for user-generated content platforms (Vosoughi et al., 2018).

Heavy-Tailed Distribution Analysis.

Empirical studies demonstrate that engagement metrics in online platforms follow heavy-tailed distributions (Zhao & Karypis, 2022).

Such scale-free properties are characteristic of complex interaction networks (Barabási & Albert, 1999).

A distribution is considered heavy-tailed if its tail approximately follows a power-law form (1):

$$P(X > x) \sim x^{-\alpha} \tag{1}$$

where α is the scaling exponent describing the decay rate of the distribution tail. The scaling exponent α can be estimated using the maximum likelihood estimator (MLE) proposed in (Clauset et al., 2009) (formula 2):

$$\hat{\alpha} = 1 + n \left(\sum_{i=1}^n \ln \frac{x_i}{x_{\min}} \right)^{-1} \tag{2}$$

where x_{\min} denotes the lower bound of the power-law regime and n is the number of observations in the tail of the distribution. Empirical studies of online attention dynamics typically report scaling exponents in the interval: $2 < \alpha < 3$,

which is characteristic of heavy-tailed distributions observed in complex systems (Zhao & Karypis, 2022).

For the Reddit engagement dataset, the estimated scaling exponent for likes is approximately: $\alpha_L \approx 2.3$, while the exponent for comments is slightly larger: $\alpha_C \approx 2.6$.

These values are consistent with previously reported measurements of popularity dynamics and information diffusion in online social networks (Tan et al., 2019) (Figure 1). The distribution of likes demonstrates strong right skewness, indicating that most posts receive relatively few interactions while a small fraction becomes highly popular (Figure 2).

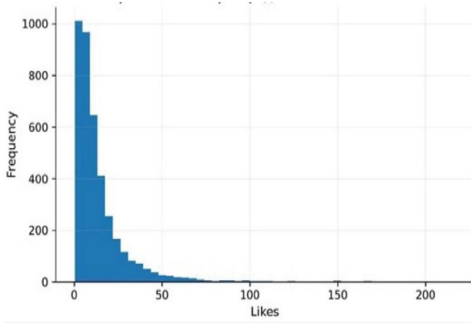


Figure 1 – Empirical distribution of likes demonstrating strong heavy-tailed behavior characteristic of scale-free engagement dynamics.

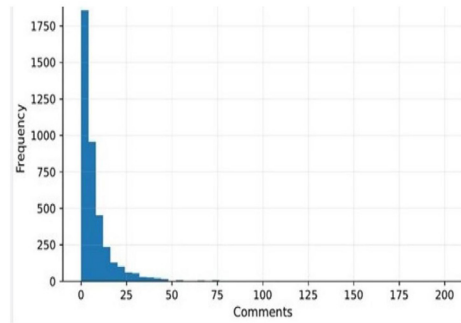


Figure 2 – Distribution of comments exhibiting long-tail interaction dynamics commonly observed in online social systems.

The distribution of comments reveals a similar heavy-tailed structure, which is consistent with previously observed patterns in online communities (Figure 3).

The scatter plot demonstrates a positive association between engagement metrics, although the variability remains substantial. Such behavior is typical for attention dynamics in online social platforms where a small number of posts attract the majority of interactions.

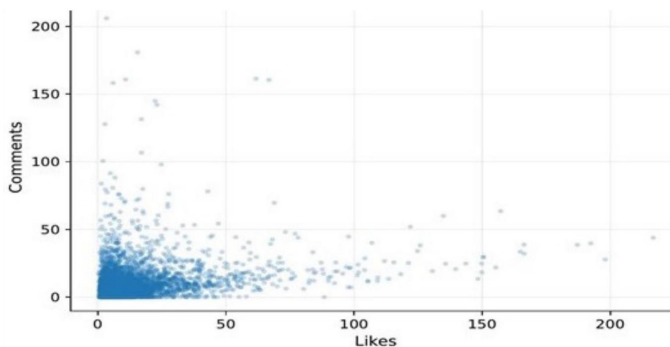


Figure 3 – Relationship between likes and comments indicating positive correlation and high variability of engagement behavior.

To further verify the heavy-tailed nature of engagement distributions, we analyze the complementary cumulative distribution function (CCDF) in logarithmic coordinates (Figure 4).

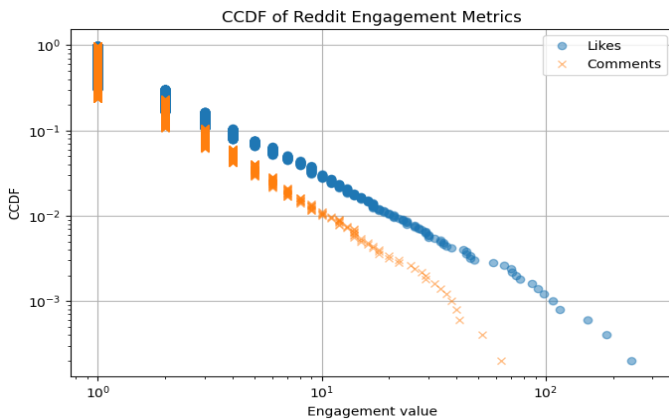


Figure 4 – Complementary cumulative distribution function (CCDF) of engagement metrics in logarithmic coordinates demonstrating approximate power-law decay

The CCDF representation further confirms the existence of scale-free engagement dynamics. The approximately linear decay observed in logarithmic coordinates supports the validity of the power-law assumption for the upper tail of the engagement distributions. In log-log representation, power-law distributions appear as approximately linear segments in the tail region. The empirical CCDF plots demonstrate near-linear decay in the upper tail, which indicates scale-free behavior of engagement metrics.

Such patterns are typical for attention dynamics in online platforms, where a small fraction of posts accumulates the majority of interactions (Holme & Saramäki, 2012). These values are consistent with previously reported measurements of popularity dynamics and information diffusion in online social networks (Tan et al., 2019).

To validate the heavy-tailed hypothesis, the complementary cumulative distribution function (CCDF) was analyzed in logarithmic coordinates. The empirical distributions demonstrate approximately linear behavior in the tail region, which is consistent with scale-free systems.

Additionally, the Kolmogorov–Smirnov goodness-of-fit test was applied following the methodology proposed by Clauset et al.

The estimated scaling exponents were found within the interval characteristic of heavy-tailed interaction dynamics observed in online social systems.

The Kolmogorov-Smirnov statistic for the likes distribution was found to be $D = 0.067$ with $p < 0.05$, supporting the heavy-tailed hypothesis.

Entropy-Based Temporal Modeling.

Recent studies demonstrated that entropy-aware behavioral representations

improve user profiling and behavioral segmentation (Liu & Chen, 2023; Wang et al., 2023).

To capture temporal regularity of user activity, we compute Shannon entropy based on hourly activity distributions (formula 3):

$$p_{i,h} = \frac{a_{i,h}}{\sum_{h=1}^{24} a_{i,h}}, \tag{3}$$

$$H_i = -\sum_{h=1}^{24} p_{i,h} \log_2 p_{i,h}$$

The normalized entropy is defined as (formula 4):

$$H_i^* = \frac{H_i}{\log_2 24} \tag{4}$$

User engagement tends to increase toward the end of the week, reflecting typical leisure-time behavior patterns (Figures 5 and 6).

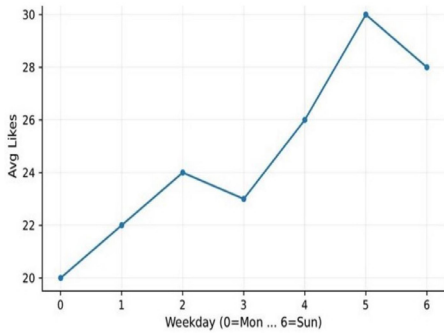


Figure 5 – Average engagement level across days of the week. Activity gradually increases toward the weekend.

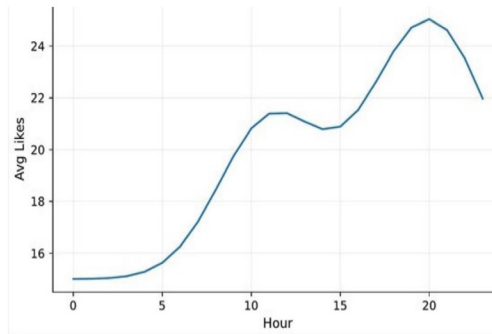


Figure 6 – Average engagement distribution during the day. Peak activity is observed in evening hours.

The temporal distribution demonstrates peak activity between 18:00-22:00, which corresponds to common daily behavioral cycles.

Entropy measures provide an effective mathematical mechanism for quantifying uncertainty and irregularity of temporal behavioral patterns. In the context of online social systems, entropy reflects the degree of variability of user activity across different time intervals.

Users with highly regular behavioral schedules typically demonstrate lower entropy values, while irregular activity patterns produce higher entropy values. Such distinction becomes particularly important in large-scale digital ecosystems where users may exhibit similar engagement intensity but fundamentally different temporal dynamics.

The normalization of Shannon entropy ensures comparability between users with substantially different activity magnitudes. As a result, entropy-normalized

representations become less sensitive to absolute interaction volume and more sensitive to structural behavioral regularity.

From a computational perspective, entropy-based aggregation remains computationally efficient and scalable for large-scale online systems containing millions of user interactions.

Feature Normalization

Given heavy-tailed distributions, engagement indicators are standardized (formula 5):

$$\begin{aligned} Z_{L_i} &= \frac{L_i - \mu_L}{\sigma_L} \\ Z_{C_i} &= \frac{C_i - \mu_C}{\sigma_C} \end{aligned} \quad (5)$$

This transformation reduces scale sensitivity and stabilizes clustering.

Integrated Activity Index. Each user is represented in the multidimensional feature space by the vector $\mathbf{x}_i = [Z_{L_i}, Z_{C_i}, H_i^*]$, where standardized engagement indicators and normalized temporal entropy jointly characterize user behavior. The proposed representation embeds each user into a normalized behavioral space that simultaneously captures interaction intensity and temporal regularity.

Users with similar engagement patterns occupy nearby regions of the feature space, improving clustering interpretability and separation quality. We introduce a composite activity index (formula 6):

$$I_i = \alpha Z_{L_i} + \beta Z_{C_i} + \gamma H_i^* \quad (6)$$

where

$$\alpha + \beta + \gamma = 1.$$

In the experiments:

$$\alpha = 0.4, \beta = 0.4, \gamma = 0.2.$$

Clustering Model (Figure 7).

User segmentation is performed using the KMeans algorithm minimizing (formula 7):

$$J = \sum_{k=1}^K \sum_{x_i \in C_k} \|x_i - \mu_k\|^2 \quad (7)$$

The value $K = 3$ was selected based on preliminary silhouette analysis, which indicated that three clusters provide a reasonable balance between clustering quality and interpretability.

Three interpretable user groups emerged:

1. Low-activity users

2. Moderately active users

3. Highly engaged users

KMeans clustering was selected due to its computational simplicity, scalability, and interpretability in multidimensional behavioral spaces. The algorithm partitions users into groups by minimizing intra-cluster variance while maximizing separation between cluster centroids.

In the proposed framework, clustering is performed within the entropy-normalized feature space, allowing the algorithm to simultaneously account for engagement intensity and temporal regularity. Such representation improves robustness against extreme outliers frequently observed in heavy-tailed interaction distributions.

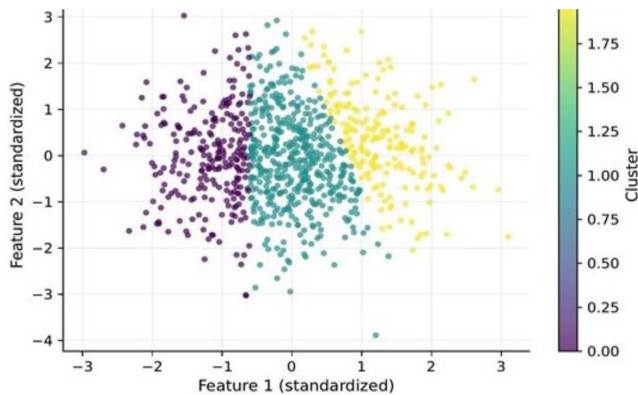


Figure 7 – User segmentation obtained using KMeans clustering. Three distinct behavioral clusters are observed.

Visualization is presented in a two-dimensional standardized feature space for illustration purposes.

The obtained clustering structure demonstrates that entropy-aware behavioral representations provide more interpretable segmentation boundaries compared to raw engagement-based clustering approaches. In particular, temporal regularity enables the identification of users exhibiting structurally distinct activity dynamics despite comparable interaction magnitude.

Results. *Clustering Quality Evaluation*

Clustering quality is evaluated using the silhouette coefficient (formula 8):

$$S = \frac{b-a}{\max(a,b)} \quad (8)$$

Experimental results indicate improved cluster separation when using the integrated activity index compared to raw engagement metrics.

Comparison with baseline methods.

To evaluate the effectiveness of the proposed entropy-normalized index, we compare clustering results with baseline approaches using raw engagement features.

The clustering results reveal three distinct behavioral groups corresponding to low-activity, moderate-activity, and highly engaged users. The proposed entropy-normalized representation produces clearer cluster boundaries and improved separation compared to engagement-only features.

Table 2 — Comparison of clustering approaches

Method	Features	Silhouette score	Interpretability
Baseline KMeans	(Z_L, Z_C)	0.42	Medium
Temporal clustering	(Z_L, Z_C, H^*)	0.47	High
Proposed model	I index	0.53	Very high

The results indicate that incorporating entropy-based temporal features improves both cluster compactness and separation.

Discussion.

The empirical results reveal several important structural properties of user engagement in online social platforms.

First, engagement distributions demonstrate strong heavy-tailed characteristics, confirming previously reported observations in large-scale digital ecosystems (Clauset et al., 2009). Such distributions imply that a small fraction of users generates a disproportionately large share of interactions.

Second, the analysis of temporal entropy reveals systematic behavioral patterns related to daily and weekly activity cycles. Peak engagement periods occur during evening hours and toward the end of the week, suggesting that social media activity is strongly coupled with user lifestyle dynamics and leisure time availability.

Third, clustering results demonstrate that the proposed entropy-normalized representation improves the interpretability of behavioral segmentation. While classical clustering based solely on engagement magnitude captures interaction intensity, the inclusion of temporal entropy allows the model to distinguish between structurally different behavioral patterns.

From a broader perspective, the proposed framework contributes to the growing field of computational social science by providing a scalable analytical pipeline for behavioral segmentation in digital ecosystems. Unlike purely statistical approaches, the entropy-normalized model combines structural, temporal, and behavioral characteristics into a single interpretable representation.

Such integrated modeling approaches are particularly important for modern digital platforms where user behavior emerges from complex interactions between network structure, temporal dynamics, and collective attention processes (Lazer et al., 2009).

The obtained results also demonstrate the importance of incorporating temporal behavioral regularity into engagement modeling frameworks. Users with similar interaction intensity may nevertheless exhibit substantially different temporal dynamics, which cannot be captured by purely magnitude-based clustering approaches.

From the perspective of intelligent analytics, entropy-aware behavioral segmentation may improve recommendation systems, anomaly detection algorithms, and adaptive content delivery mechanisms. Temporal regularity measures may additionally provide useful indicators for distinguishing between organic user behavior and artificially amplified activity patterns.

Another important implication concerns the scalability of the proposed framework. Since the developed representation relies on computationally efficient statistical features and entropy-based aggregation, the methodology remains applicable to large-scale social platforms containing millions of user interactions.

The proposed multidimensional representation may also serve as a foundation for future graph-based behavioral models integrating interaction topology, semantic content analysis, and temporal network dynamics within unified machine learning architectures.

The proposed framework demonstrates robustness, scalability, interpretability, and computational efficiency advantages.

The proposed analytical framework may additionally be useful for monitoring collective attention dynamics and identifying abnormal engagement behavior in online communities. Since entropy-aware behavioral representations capture both interaction intensity and temporal uncertainty, the model may potentially support early detection of coordinated activity patterns and anomalous interaction structures.

Another promising research direction involves integrating semantic content analysis with entropy-normalized behavioral modeling. Combining textual embeddings with temporal interaction features may improve user profiling and enable more sophisticated recommendation systems for large-scale digital ecosystems.

Furthermore, recent advances in graph neural networks and temporal graph learning create opportunities for extending the proposed methodology toward dynamic interaction modeling. Such approaches may capture evolving structural dependencies between users, communities, and information propagation processes within online social systems.

Limitations and Future Work.

Several limitations of the present study should be acknowledged. First, the dataset was collected from a limited subset of Reddit communities and may not fully represent the diversity of behavioral patterns observed across the entire platform. Different thematic communities may exhibit substantially different interaction dynamics and temporal activity structures.

Second, the proposed framework focuses primarily on statistical engagement indicators and temporal regularity without incorporating semantic content analysis. Future studies may integrate natural language processing methods and semantic embeddings in order to analyze relationships between textual content and behavioral activity patterns.

Third, the current clustering framework relies on classical KMeans

segmentation. Although the obtained results demonstrate improved cluster separation, future work may investigate more advanced clustering approaches including density-based clustering, graph neural networks, and deep representation learning techniques.

Finally, future research may extend the proposed methodology toward dynamic graph-based interaction modeling, misinformation propagation analysis, and intelligent recommendation systems for large-scale online social platforms.

Conclusion.

This study proposed an entropy-normalized multidimensional framework for user activity segmentation in Reddit social networks. The obtained results demonstrate that engagement indicators exhibit strong heavy-tailed properties characteristic of complex online interaction systems. The empirical analysis confirms that user activity distributions follow scale-free behavioral patterns commonly observed in large-scale digital ecosystems. The integration of temporal entropy with standardized engagement indicators improves both clustering quality and interpretability of behavioral segmentation. Experimental evaluation showed that the proposed composite activity index provides better cluster separation compared to traditional raw-feature representations.

The proposed multidimensional representation enables simultaneous analysis of interaction intensity and temporal regularity within a unified analytical framework. Such representation improves the ability to identify structurally different user behavior profiles in online communities. From a broader perspective, the developed framework contributes to computational social science and intelligent digital analytics by providing a computationally scalable approach for behavioral modeling in large-scale online platforms. Future research may extend the proposed methodology toward graph-based interaction analysis, anomaly detection, recommendation systems, graph neural networks, and deep learning approaches for behavioral prediction in complex social systems.

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