

Jelena Tešić: Research Impact and Plan

Unstructured data encompasses diverse data types and formats, such as video data, electronic health data records, surveys, experimental readings, sensor data, social platform content data, genomics data, and purchase reviews. The arching quest of my research is to **identify** analytics tasks where unstructured data or task at hand do not adhere to underlying assumptions of state-of-art algorithms and to **provide** efficient, effective, intuitive, and responsible algorithms for addressing the challenges of extensive unstructured data collections in the wild. The research impact and plan Dr. Tešić lead in the Data Lab @ TXST (DataLab12.github.io) is grouped by the tasks it solves in the following sections.

1 Scaling Signed Graph Tasks through Fundamental Cycle Basis

In network science, signed graph representation of relations provides more information than unsigned graph networks. Spectral pollution, computational complexity, inherent bias, and training requirements are the main hurdles that have slowed the adoption of the signed network as data representation and signed graph algorithms for modern data analysis. This project drew inspiration from mathematical sociology and focused on balance theory to solve the signed network tasks at scale. First, the research has expanded the balance theory to signed social network graph analysis. Dr. Tešić w Dr. Rusnak proposed a frustration cloud view of the signed graph where the vertices and edges are quantified in frustration cloud statistics and validated this new social network graphs analysis approach for multiple real social benchmark networks [32] [pdf]. Dr. Tešić initialized the development of an algorithm to efficiently compute the fundamental cycle basis in large, unstructured graphs. This collaborative approach does not require training data and avoids spectral pollution to scale the frustration cloud computation [11][pdf]. There has been no benchmark to evaluate state-of-the-art tasks on signed graphs derived from real networks. Dr. Tešić has led the effort to compare and contrast state-of-art community discovery on actual signed graphs in [18] [pdf]. Methods are compared assumption-free in terms of efficacy, efficiency, scalability, and reproducibility of existing methods. As a follow-up, the team has proposed the frustration cloud-based approach for cluster boosting for high modular signed graphs [19] [pdf]. Two master and five undergraduate students contributed to this research project. Mr. Shebaro, Ph.D. student, and Dr. Tešić are expanding the use of efficient fundamental cycle basis processing and developing algorithms for other NP-hard tasks [26] [pdf]. They have already proposed algorithms to solve the task of computing frustration and the balanced state of the graph at scale [28] [pdf] and the task of finding the largest balanced subgraph in any network [27] [pdf] for graphs with millions of nodes and edges. Next, they are working on the scalable community discovery algorithm, extending the analysis using a fundamental cycle basis to the recommendation and anomaly detection tasks and applying the algorithms to sensor and agent networks and signed gene networks.

2 Modeling Social Network Relations

The multifaceted interconnectivity of users and content on Twitter through user connections, replies, quotes, hashtags, and shared content makes it an exciting medium for research on the effectiveness of the representation and methods used. Ms. Nogueira’s master thesis, supervised by Dr. Tešić, introduced a scalable end-to-end Twitter network data management pipeline that gathers, stores, and models rich relationships from Twitter networks [16] [pdf]. Then, the research work compared and contrasted the analysis results of millions of Twitter data using multiple graph construction processing approaches [17] [pdf]. How well the tweet content can be classified based on modeling relationships from interactions alone, and how well can community classification predict the label of the content? The community-based modeling (tweet is classified

not on the content but on the retweets, replies, quotes, hashtags, and the author) yields precision, recall, and accuracy comparable to lexical classifiers [25] [pdf]. The project proposes new multi-modal approaches that consistently deliver the most robust outcomes and exhibit the highest performance measures for network graphs constructed based on Twitter interactions related to the COVID-19 pandemic [1] [pdf] and [25] [pdf]. The next step is to extend relationship modeling to signed and weighted graphs as proposed in Section 1 and to explore network representations to provide an assumption-free and bias-free baseline for evaluating graphical neural network performance for network science tasks.

3 Vision Tasks for Large Variable Video Data

Video analytics tasks are not limited to consumer or side camera data. In this project, Dr. Tešić addresses classification and its efficiency, anomaly detection, indexing, search, and deduplication tasks for large high-variable video datasets. The high variability of content in the overhead imagery stems from the terrestrial region captured, the high variability of acquisition conditions, and the number and size of objects in aerial imagery that are very different than in the consumer data. State-of-art fails due to the high variability of the domain and the low availability of training data. The project has proposed multiple domain adaptation approaches to alleviate the degradation of object identification in previously unseen overhead datasets with significant domain gaps and dominant small objects [5] [pdf] and [29] [pdf]. Next, the work focuses on developing new algorithms for overhead videos to detect anomalous activities [10] [pdf] and [33]. Five undergraduates, two masters, and three Ph.D. students participated in this project sponsored by NAVAIR. Mr. Biswas (Ph.D. student) and Dr. Tešić proposed multiple innovative and efficient contrastive learning algorithms to improve object classification in previously unseen highly variable overhead datasets utilizing contrastive learning, object detection difficulty and the context in [6] [pdf] and [7] [pdf]. The research is now introducing progressive domain adaptation to produce domain-invariant features across aerial datasets using local and global components for domain adaptation and object classification for the task in [9][pdf], [8] [pdf] and [21] [pdf]. Next, the study will improve scene understanding in highly variable videos.

Searching for unseen objects in extensive visual archives is challenging, demanding efficient indexing methods supporting meaningful similarity retrievals. Mr. Rahman (Ph.D. student) and Dr. Tešić introduced new indexing and search algorithm for deep descriptor databases that have up to four times lower memory usage and higher effectiveness than state-of-art [22] [pdf] and [23] [pdf] on millions of deep descriptors. Current work focuses on how efficient indexing can improve the performance and the storage of the crowd-sensing image and video applications at scale [21] [pdf]. The next step is to improve the indexing footprint while keeping the search effectiveness by proposing a new stratified graph approach [24] [pdf], and to extend the findings to multi-modal indexing, combining feature with GIS attributes for spatial and shape indexing.

4 Semantic Segmentation Task in The Wild

Semantic image segmentation is the task of assigning a label to each pixel in an image. Dr. Tešić's contribution to semantic segmentation focuses on pavement distress detection for transportation and road maintenance and NASA spaceflight sample images. The project has quantified the main influencing factors that affect the performance of deep learning models in pavement distress detection pipelines and proposed a semantic segmentation algorithm that significantly improves the accuracy of localizing pavement cracks [12] [pdf]. Current research led by Ms. Tani (Ph.D. student) explores the domain adaptation approaches from Section 3 to improve the algorithmic performance for specialized fields and how pixel-wise segmentation can improve the

explainability of the model. In parallel, the project focuses on a semantic segmentation pipeline to automatically classify Bacterial Adhesion and Corrosion from images obtained in the NASA SpaceX-21 experiment. The inability to control microbial biofilms during spaceflight poses a severe health risk to astronauts. Automatically identifying corrosion in tens of thousands of images of samples flown into space will help researchers streamline the samples' data collection and help them reach conclusions faster on what countermeasures will work in space. Two undergraduate and two master's students also contributed to the project.

5 Predictive Modeling of Noisy Tabular Data

Tabular data in the wild are difficult to model due to the uneven distribution of attributes, missing, overlapping, noisy values, a mix of categorical and numerical data attributes, data imbalance, and a long tail of sparse values. For her master thesis, Ms. Yu has developed an intentional data science pipeline that can automatically uncover important attributes, reduce feature space, and model prediction in a robust manner from multi-source tabular data in [14][pdf]. Dr. Tešić's team has designed the multi-feature importance analysis algorithm and applied it to large-scale analysis of public data from the National Center for Education Statistics (NCES) to provide data-driven insights into teacher attrition challenges. The study discovered that the race and sex of the principal, the type of school, and the school's location impact teacher retention rates the most and that modeling historical data resulted in a predicted attrition rate of over 10%, aligning closely with the current prevalent attrition rates in the USA [15] [pdf]. The project has developed an interpretable data-driven scoring fusion to discover the most critical factors from an extensive collection of heterogeneous public data sources on learning loss during the COVID-19 pandemic in Texas public schools. Our robust approach found that the number of students on school campuses in the Fall of 2020 and in the Spring of 2021 was the most resilient and most impactful predictor of how the students would perform on the standardized test in mathematics and reading in the Spring of 2021 in Texas [4] [pdf]. The work has been extended to include the latest educational data for multi-year learning recovery predictions as part of Mr. Payan's undergraduate honor's thesis [3]. The work introduced new cascade enhancement to ensure effectiveness and the prediction coverage of our modeling pipeline to predict long COVID in N3C data [20] [pdf]. The project is a seed to Ms. Elizondo's Ph.D. thesis work [20] [pdf]. Current work focuses on improving the loss function in the gradient boosting approach using contextual contrastive learning to handle the sparsity, relevance, and hierarchical values in the tabular N3C data more effectively.

Summary

Algorithms for unstructured data are driven by the data type, format, acquisition, size, and intended task. My research focuses on providing new algorithms based on mathematics, computer science, and statistics theory while considering the specifications (efficiency, scalability, usability, interpretability) of the task at hand, data characteristics, and domain applicability. To this end, Dr. Tešić has collaborated with other Labs at our department and proposed data-driven solutions for their specific challenges: (1) optimizing cyber alert allocation using deep learning [30] [pdf]; (2) improving the efficiency of architecture instruction prediction using machine learning [2][pdf]; (3) Improving Diagnosis through Data Integration [13][pdf]; and (4) Small sample ensemble deep learning for fall detection[31][pdf]. Dr. Tešić is currently looking into developing implicit neural representations to encode large climate models and to continue to invent new algorithms and methods for solving challenging analytics tasks stemming from the nature and size of unstructured data that do not adhere to common assumptions.

* *author* - names of the student authors are in *italic*

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