David C. Wyld,
Dhinaharan Nagamalai (Eds)

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Volume Editors

David C. Wyld,
Southeastern Louisiana University, USA
E-mail: David.Wyld@selu.edu

Dhinaharan Nagamalai (Eds),
Wireilla Net Solutions, Australia
E-mail: dhinthia@yahoo.com

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Preface

The 2nd International Conference on Soft Computing, Artificial Intelligence and Machine Learning (SAIM 2021), July 10~11, 2021, Toronto, Canada, 9th International Conference of Advanced Computer Science & Information Technology (ACSIT 2021), 2nd International Conference on Semantic & Natural Language Processing (SNLP 2021), 9th International Conference on Information Technology in Education (ICITE 2021), 13th International Conference on Computer Networks & Communications (CoNeCo 2021), 9th International Conference of Information Technology, Control and Automation (ITCA 2021), 9th International Conference on Signal Image Processing and Multimedia (SIPM 2021) was collocated with 2nd International Conference on Soft Computing, Artificial Intelligence and Machine Learning (SAIM 2021). The conferences attracted many local and international delegates, presenting a balanced mixture of intellect from the East and from the West.

The goal of this conference series is to bring together researchers and practitioners from academia and industry to focus on understanding computer science and information technology and to establish new collaborations in these areas. Authors are invited to contribute to the conference by submitting articles that illustrate research results, projects, survey work and industrial experiences describing significant advances in all areas of computer science and information technology.

The SAIM 2021, ACSIT 2021, SNLP 2021, ICITE 2021, CoNeCo 2021, ITCA 2021 and SIPM 2021 Committees rigorously invited submissions for many months from researchers, scientists, engineers, students and practitioners related to the relevant themes and tracks of the workshop. This effort guaranteed submissions from an unparalleled number of internationally recognized top-level researchers. All the submissions underwent a strenuous peer review process which comprised expert reviewers. These reviewers were selected from a talented pool of Technical Committee members and external reviewers on the basis of their expertise. The papers were then reviewed based on their contributions, technical content, originality and clarity. The entire process, which includes the submission, review and acceptance processes, was done electronically.

In closing, SAIM 2021, ACSIT 2021, SNLP 2021, ICITE 2021, CoNeCo 2021, ITCA 2021 and SIPM 2021 brought together researchers, scientists, engineers, students and practitioners to exchange and share their experiences, new ideas and research results in all aspects of the main workshop themes and tracks, and to discuss the practical challenges encountered and the solutions adopted. The book is organized as a collection of papers from the SAIM 2021, ACSIT 2021, SNLP 2021, ICITE 2021, CoNeCo 2021, ITCA 2021 and SIPM 2021.

We would like to thank the General and Program Chairs, organization staff, the members of the Technical Program Committees and external reviewers for their excellent and tireless work. We sincerely wish that all attendees benefited scientifically from the conference and wish them every success in their research. It is the humble wish of the conference organizers that the professional dialogue among the researchers, scientists, engineers, students and educators continues beyond the event and that the friendships and collaborations forged will linger and prosper for many years to come.

David C. Wyld,
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A MODIFIED DRAKE EQUATION FOR ASSESSING ADVERSARIAL RISK TO MACHINE LEARNING MODELS

Josh Kalin[1, 2], David Noever[2], Matthew Ciolino[2] and Gerry Dozier[1]

[1]Department of Computer Science and Software Engineering,
Auburn University, Auburn, AL, USA
[2]PeopleTec, Inc, Huntsville, AL, USA

ABSTRACT

Machine learning models present a risk of adversarial attack when deployed in production. Quantifying the contributing factors and uncertainties using empirical measures could assist the industry with assessing the risk of downloading and deploying common model types. This work proposes modifying the traditional Drake Equation's formalism to estimate the number of potentially successful adversarial attacks on a deployed model. The Drake Equation is famously used for parameterizing uncertainties and it has been used in many research fields outside of its original intentions to estimate the number of radio-capable extra-terrestrial civilizations. While previous work has outlined methods for discovering vulnerabilities in public model architectures, the proposed equation seeks to provide a semi-quantitative benchmark for evaluating and estimating the potential risk factors for adversarial attacks.

KEYWORDS

Neural Networks, Machine Learning, Image Classification, Adversarial Attacks.

1. INTRODUCTION

This short note explores a simple version of a probabilistic equation for machine learning (ML), specifically to defend trained models from adversarial attacks. Probabilistic frameworks like the Drake Equation (predicting the number of alien civilizations [1-2]) offer a heuristic for traditional factor analysis, particularly helpful in the face of uncertainty. In that spirit, we adopt the basic formalism of its original population-based assessment by including both the leading factors and their corresponding loss fractions. The goal is less to provide a new ML risk model as much as to explore the practical factors needed to consider before fielding a new model [3]. Other work has detailed already much of the successes and failures in defending predictive models:

1) diversifying or augmenting training data [5]
2) ensembling and model voting [6]
3) obfuscating [7]
4) active learning[8]
5) protecting model descriptions or firewalling (e.g. nation-state security) [9]

All these strategies (plus many others not included here [3]) should appear in one or more proposed terms for this modified Drake Equation.

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2. MODIFYING THE DRAKE EQUATION

The format of the note is first to present the main factors for model defense, followed by an explanation and examples to support each included factor. We explore the interpretation of each factor where possible with an illustrative case mined from the AI Incidents database [4]. It is worth noting that other than these early efforts [4] to catalog adversarial attacks, less research has previously attempted to count or quantify systematically the failures of a given machine learning model in the wild. For example, should an adversarial attack be scored based on its frequency, severity, or difficulty to patch once a vulnerability gets discovered? This paucity of data further motivates the development of a modified Drake Equation, principally as a heuristic framework for understanding contributing factors and assessing their uncertainties. The structure of the note isolates each factor in reference to its more familiar population-based input, so for instance, the time that an attacker might probe a model's vulnerabilities maps to the original Drake Equation's reference to the time that a radio-aware civilization might broadcast its identity. An appealing aspect of the original format stems from its hierarchical factors from large to small fractional contributions as they change over time. One ultimately wants to understand the dependencies while solving for the machine learning model's attack surface, as measured by N, the number of successful adversarial attacks.

To defend a machine learning model, the number of successful adversarial attacks, N, is proportional to the model's size, R, as measured by its popularity (e.g. YOLO), sponsoring enterprise size (e.g. Microsoft, Google, Facebook), or monoculture of adoption (e.g. convolutional neural networks). The proposed modifications to the Drake Equation are described below:

$$N = R * f_p * n_e * f_l * f_i * f_c * L$$

N = *the number of successful adversarial attacks*
R = *average enterprise size*
f_p = *fraction of models published, named, open sourced or fielded in the wild*
n_e = *average number of* ***e****ngineered parameters* (*memory, billions of parameters*)
f_l = *fraction of* ***l****earning ratio, as training /test data or active hybrid feedback*
f_i = *fraction of* ***i****nput supervisory and quality control steps*
f_c = *fraction of* ***c****ompleted queries that return detectable or logged answers*
L = ***l****ength of time that attackers can query without consequences or timeouts*

2.1. R-Average Enterprise Size

In the original Drake Equation, this factor traditionally relates to a rate of new star formation. We generalize the rate of new ML models created, R, by an aggregate of overall enterprise size. This approach mirrors the literature on monoculture in computer operating systems (e.g. MS Windows) as a primary indicator to motivate cyber-attacks. The corresponding figure in defending ML models derives from a similar feature, namely that attacking large enterprise models like Google's Perspective API and OpenAI's Generative Pretrained Transformer (GPT-3) is more likely than probing or disabling a smaller, private, or novelty ML model.

One can hypothesize that the community's attraction to leader boards [4] and state-of-the-art (SOTA) competitions further drives the ML community to more singular ecosystems that may prove more difficult to defend from adversaries than a diversified one. As a figure of merit when

describing the cyber-risks for a monopoly in operating systems [10], the entire ecosystem may become unstable when the market share and global adoption reach 43% and more directed attacks garner hacker's attention. One ML-specific metric of whether a given type of neural network dominates its ecosystem can be approximated by search trend monitors. For example, by using Google Trends [11], the current popularity of three core approaches to modeling the neural architecture itself shows that convolutional networks (CNN) capture 72% market share, compared to graph neural networks (25%) and capsule networks (2%). An attacker that knows the unique weaknesses of CNNs (such as their inability to grasp long-range spatial relations. complex hierarchies, and symmetries [12-13]) may profitably attack those specific design elements, particularly given their monopoly as deployed models.

2.2. F_p- Fraction Published, Named, Open-Sourced, or Fielded in the Wild

In the original Drake Equation, this first factor in a hierarchical loss fraction stems from the number of stars with planets. In an adversarial attack, this factor similarly appears at the top of the hierarchy, namely how much is known about the model's origins. The literature spans model security from black-box (no knowledge) to white-box (full-knowledge), such that given a known or discoverable model structure, the attacker may also potentially know the weights and training dataset. This is most well-known in the release of GPT-2 versus GPT-3, where for some time the GPT-3 API was not available to researchers. When Open AI initially open-sourced its models, the company furthermore specifically withheld its larger one (1554M) to suppress the possibilities for abuse.

2.3. N_e - Average Number of Engineered Parameters

In the original Drake Equation, this second factor considers the number of planets capable of supporting life. In an adversarial attack, the relevant context would include model complexity, either as its memory, number of parameters, or layers of network architecture. A breakdown of computing n_e for a CNN could be as simple as a baseline of the number of parameters or number of layers. For object detectors, the relevant complexity often arises from the way the model searches for its characteristic anchor sizes and bounding boxes, whether multi-stage like a region-proposal network (R-CNN) or single-stage frameworks like YOLO.

2.4. F_l- Fraction of Learning Ratio

In the original Drake Equation, this third factor refers to planets that spawn life at some point. In an adversarial attack, this fraction includes losses for well-trained models that possess large and diverse data. Previous work has proposed using Akaike information criterion (AIC) and Bayesian information criterion (BIC) to evaluate model performance against dataset diversity and this style of metric may provide a baseline for this factor [14].

2.5. F_i- Fraction of Input Supervisory Guidance

In the original Drake Equation, this fourth factor addresses the rise of intelligent life from more primitive forms. In the machine learning context, this fraction includes the standard quality checks that separate a fieldable model from an experiment or lab bench demonstration. This factor corresponds to the breakpoint in many adversarial defenses, such that a prototype moves into production based on disciplined quality checks. Has the model seen out-of-vocabulary terms if a natural language processor? Is there a high fraction of augmented examples for each class? One traditional image approach augments training data with more diverse object types, usually including different lighting, viewing angles, or noise. Paleyes, et al. [15] describe 38 factors

attacking 15 systems that contribute to a failed productization of an ML model. At any one of these steps, ranging from data-collection to performance monitoring, there exist adversarial attacks that can poison the entire process. Wang et al. [16] define in detail the adversarial attack to each of these systems.

2.6. F_c- Fraction of Completed Queries that Return Detectable or Logged Answers

In the original Drake Equation, this fifth factor delineates the rise of technological capabilities such as radio transmission that travels at the speed of light and thus renders a distant galaxy observable. For adversarial attacks, this fraction defines the likelihood that an outside observer can understand the model type, its sensitivities, or its vulnerabilities. Particularly in the black-box approach where an attacker must launch a question-and-answer format to understand how the model works, this fraction restricts the obtainable universe of effective attacks. In experiments for text and image classifiers, Kalin, et. al [17] found that model architectures are easily discovered with strategic probing if the architecture is public. In this new equation, f_c is related proportionally to f_p factor.

2.7. L–Length of Time that Attackers Can Query without Consequence or Timeouts

In the original Drake Equation, this final factor introduces the notion of time, particularly how long a civilization might survive its technology before self-destructing or its evolutionary time to propagate signals to an outside observer. Like the numerical count of accepted API requests (f_c), the length of time to automate or web-scrape the API with new queries offers a secondary line of defense not in space (count) but in time. Despite a more mature field, software engineering for APIs still suffers from vulnerable code being written into production systems [18].

3. MISSING BUT NOT FORGOTTEN

This modification of the Drake Equation focuses on metrics that can be directly measured in a production environment. Missing elements in this heuristic might include additional pre-production factors for diversity, size, and quality of the input data, training lengths (epochs), and other historical elements that may or may not propagate usefully to the final model and its vulnerabilities. The collected metrics can then be used to refine the model performance against known benchmarks. For instance, common model types are easily discoverable via their input data and/or architecture [17].

4. AXIOMS

Axiom 1: Architecture and Dataset Metrics are related

The Learning Ratio, Parameters, and Guidance variables stem from the architectural design of the model. This equation is divided into two primary Adversarial fractional components: Architecture and Dataset. For teams to use the likelihood of successful adversarial attack assessment to improve their models, they will need to understand the contribution of architecture and dataset design to the overall adversarial risk. The first fraction defines the key parameters related to architecture and their overall contribution to adversarial risk:

$$Adversarial\ Fraction_{Architecture} = R * \frac{f_p * n_e * f_l}{N}$$

The second fraction defines the dataset metrics responsible for dataset contributions to adversarial risk:

$$Adversarial\ Fraction_{Dataset} = R * \frac{f_i * f_c * L}{N}$$

5. EXPERIMENTS

This framework is designed to work on large and small works. In the following experiments, the focus is on baselining the effective ranges of the factors, showing sample risk factors for common model architectures, and understanding the relative effect each factor has on itself and the risk factor.

5.1. Experimental Design

Each factor needs to be defined in terms of operating bounds to apply this new framework to current models. For the experiments, the following operating ranges for the variables were chosen to highlight the current capabilities that exist within the machine learning community today:

- ***R - Average Enterprise Size***
  - Range [0, n authors]
  - Enterprise Size is computed as the Number of Authors as it can be difficult to find the actual number of employees in a particular organization
- ***f_p- fraction published, named, open-sourced, or fielded in the wild***
  - Three values: Not Published 0.0, Published but not open source 0.5, Published and Open Source 1.0
  - For example, GPT-3 is fielded in the wild but is not open source: 0.5
- ***n_e - average number of engineered parameters***
  - Stepped Range [0,1] based on Number of Model Parameters
- ***f_l- fraction of learning ratio***
  - Stepped Range [0,1] as a relative factor to State of the Art (SOTA) performance
  - For example, the first benchmark in the model category is 0.1 and SOTA is 1
- ***f_i - fraction of input supervisory guidance***
  - Range [0,1]
  - Is training data sufficiently large and diverse?
- ***f_c - fraction of completed queries that return detectable or logged answers***
  - Range [0,1]
  - Estimated High Query Rate on the model
- ***L– Length of time that attackers can query without consequence or timeouts***
  - How long has the model been in public? Years [0, n]

As with the original formulation of the Drake Equation, each parameter represents an estimate of best guesses for factors in the wild. This modification to the Drake Equation will provide organizations the ability to benchmark, evaluate, and track the adversarial risk of their models in production. As a team observes the adversarial risk reduction on their model, there are factors within this equation that can directly be attributed to that reduced risk.

5.2. Empirical Results

Using the factor ranges described in the experiment design, six popular models were estimated as samples of how to apply this formulation. Figure 1 is sorted from top adversarial risk to lowest

risk. In the example of 'MyModel', the model is not deployed and therefore does not contain adversarial risk from outside actors.

Model	R	F_p	N_e	F_l	F_i	F_c	L	A_a	A_d	N
T5	9	1	0.8	1	1	1	2	0.50	1.25	14.40
VGG19	2	1	0.6	1	1	1	6	0.17	1.67	7.20
GPT3	31	0.5	1	1	0.75	0.5	1	2.67	2.00	5.81
BERT	4	1	0.6	0.75	1	1	2	0.50	2.22	3.60
FastText	4	1	0.1	0.7	1	1	4	0.25	14.29	1.12
MoibleNetV2	5	1	0.1	0.5	0.5	1	3	0.67	20.00	0.38
MyModel	1	0	0.2	0.75	0.2	0.05	1			0.00

Figure 1: Summary of Models Explored with Modified Drake Equation. Six Popular model architectures are benchmarked along with a custom model based on MobileNetV2's design. The table is sorted by estimated Adversarial Risk N in the last column.A_a/A_d represent the Adversarial Fraction for architecture and dataset respectively.

When exploring this formulation, it's incredible to see that newer, larger architectures are less vulnerable than older models. This is on purpose though as older models will have more vulnerabilities appear since they have been in circulation longer. There are further improvements that could be made to these experiments – for instance, the exploration of architectures could be split into text and computer vision. Each category of model architectures can have its boundary conditions. For instance, transformers technologies like BERT and GPT have revolutionized NLP problems over the last few years. Their properties may warrant a deeper exploration of parameter dependencies.

5.3. Correlation Analysis

The next experiment in this work is to understand the dependency of each factor on adversarial risk. Building a correlation matrix using the assumptions above, Figure 2 shows the relative importance of each factor to itself, the other factors, and to adversarial risk.

X-Correl	R	F_p	N_e	F_l	F_i	F_c	L	N
R	1.000	-0.061	0.619	0.305	0.049	-0.083	-0.439	0.116
F_p	-0.061	1.000	0.034	-0.063	0.788	1.000	0.606	0.406
N_e	0.619	0.034	1.000	0.848	0.428	0.018	-0.240	0.669
F_l	0.305	-0.063	0.848	1.000	0.439	-0.073	0.038	0.735
F_i	0.049	0.788	0.428	0.439	1.000	0.783	0.482	0.599
F_c	-0.083	1.000	0.018	-0.073	0.783	1.000	0.611	0.404
L	-0.439	0.606	-0.240	0.038	0.482	0.611	1.000	0.145
N	0.116	0.406	0.669	0.735	0.599	0.404	0.145	1.000

Figure 2: Cross-correlation of variables to the Modified Drake Equation including Adversarial Risk.

Within Figure 2, there are a few surprising things that come out of the correlation analysis. Here are the key observations:

- The most correlated variable when predicting adversarial risk is fraction of the learning ratio (0.735)
- The fraction of learning ratio is highly correlated to the number of parameters ($\rho(f_l, N_e)$ = 0.848)

- The fraction of input supervisory guidance is highly correlated to fraction published (0.788)
- The fraction completed queries is highly correlated to fraction published ($\rho(f_c, f_p)$ = 1.000)

Intuitively, the fraction of learning ratio being most correlated to adversarial risk represents that the most popular models have the most people trying to attack them. The goal is to track and reduce the adversarial risk to a model and this framework provides a starting benchmark.

6. SUMMARY AND FUTURE WORK

This work supports an established heuristic framework in analogy to the traditional Drake Equation. This simple formalism amounts to a summary of relevant factors. The basic equation has been modified elsewhere for detecting bio signatures in planet-hunting (Seager equation [19]), sociology (best choice problem [20]), infection risks [21], AI singularity [22], social justice [23], and other diverse probabilistic assessments [24]. Ultimately, its main purpose follows from assessing the multiple uncertainties that may vary by several orders of magnitude. For example, as ML builders consider whether to privatize or to open-source their models, they may intuitively favour one course over another given a perceived risk for model compromise. Is it true in practice that privatizing a model lowers the risk, or does it increase the attack surface because the model never gets hardened by peers? One would like to provide a framework for these important decisions and assist the ML community to identify the data needed for sensitivity analysis and the evaluation of consequences.

The biggest challenge in finding novel utility for this framework shares much in common with Drake's original notion. How to quantify each factor? What if the factors show strong correlations? How do the factors change with time, particularly if both the builders and attackers modify their behaviour? What are the appropriate units to assess ML risks, either as the number or severity of adversarial attacks? One informative output that previous technical papers often ignore in assessing model risk is the scale of the overall ecosystem (R). In the literature for cybersecurity, for example, the monoculture aspect for operating systems has proven most predictive of the next generation's attacks. In this view, the SOTA leader boards [4] might benefit from encouraging a more diverse model ecosystem, such that niche YOLO attacks cannot propagate throughout the whole ML community and its applications, particularly when a few fractional percentage improvements separate the field into universal adoption strategies. Future work should highlight the data sources for evaluating each factor. For instance, the publications dataset from Cornell's arXiv supports extensive topic analysis for extracting the popularity of ML models, their relevant attack methods, and promising defensive styles [26]. Classification methods for attack types [27] may also guide the practical counting or scoring for the universe of adversarial ML threats.

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AUTHORS

Josh Kalin is a physicist and data scientist focused on the intersections of robotics, data science, and machine learning. Josh holds degrees in Physics, Mechanical Engineering, and Computer Science.

David Noever has research experience with NASA and the Department of Defense in machine learning and data mining. He received his Ph.D. from Oxford University, as a Rhodes Scholar, in theoretical physics.

Matt Ciolino has experience in deep learning and computer vision. He received his bachelor's from Lehigh University in Mechanical Engineering.

Gerry Dozier is a pioneer in artificial intelligence, machine learning, genetic algorithms, and evolutionary computation. He is a professor of computer science and software engineering and is committed to keeping our information secure. He holds a Charles D. McCrary Endowed Chair in the Samuel Ginn College of Engineering at Auburn University.

SEASONAL HEAVY RAIN FORECASTING METHOD

Jaekwang KIM

School of Convergence / Convergence program for social innovation,
Sungkyunkwan University, Seoul 03063, South Korea

ABSTRACT

In this study, we study the technique for predicting heavy / non-rain rainfall after 6 hours from the present using the values of the weather attributes. Through this study, we investigated whether each attribute value is influenced by a specific pattern of weather maps representing heavy and non-heavy rains or seasonally when making heavy / non-heavy forecasts. For the experiment, a 20-year cumulative weather map was learned with Support Vector Machine (SVM) and tested using a set of correct answers for heavy rain and heavy rain. As a result of the experiment, it was found that the heavy rain prediction of SVM showed an accuracy rate of up to 70%, and that it was seasonal variation rather than a specific pattern that influenced the prediction.

KEYWORDS

Prediction Method, Forecasting, Machine learning, Feature extraction.

1. INTRODUCTION

Prediction of dangerous weather forecasts such as heavy rain and heavy snow is a very important research field because it has a profound effect on many people in various fields [1]. A typical method of predicting heavy rain today is to predict the weather using the situation at that time based on the past weather map similar to the current weather map. However, this method has a problem in that it is expensive to find a pattern similar to the current weather map in the vast amount of past weather maps. To this end, a data mining study that effectively analyzes past weather forecasts is needed [3]. In this study, based on past weather data, we learned whether heavy rain would occur or not after 6 hours, and predicted whether heavy rain would occur after 6 hours when current weather data was input. In addition, as an analytical study for this, we compared and analyzed whether each attribute representing weather is highly influenced by the feature pattern of weather map according to heavy / nonheavy weather or seasonally. Prediction of heavy / nonheavy rainfall after 6 hours through experiments showed accuracy of up to 70%, and it was confirmed that each property was more affected by the season. The rest of the paper is organized as follows: Section 2 includes an explanation of previous weather chart for forecasting. In Section 3, Heavy rain prediction experiments are shown to verify the proposed method. Section 4 presents a result of seasonal heavy rain situation prediction experiment. Finally, this paper is concluded in Section 5.

2. PREVIOUS WEATHER CHART

For the past weather forecast, the weather forecast with ECMWF 1.5-degree resolution in 6-hour increments (00, 06, 12, 18 UTC) was used. Including UWND (East-West), VWND (North-South)

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with 6 properties and 4 isobar face layers of 850hPa, 700hPa, 500hPa, 200hPa for each property were used. The criterion for determining heavy rain is when the cumulative precipitation for over 6 hours rains more than 70 millimeters, and the criterion for determining heavy rain is defined as the cumulative precipitation for 6 hours is 5 millimeters or less. In addition, heavy / non-heavy rain days were extracted according to sequentially defined criteria among May, June, July, and September during which heavy rains are concentrated throughout the year. The total duration of the data used is 20 years from 1989 to 2009. The ECMWF 1.5- degree data consist of 60x31 grids representing East Asia. To predict the weather on the Korean Peninsula, it is unnecessary to observe the entire map of East Asia, and as shown in Figure 1, a 10x10 grid including the Korean Peninsula region and its surroundings was extracted and used.

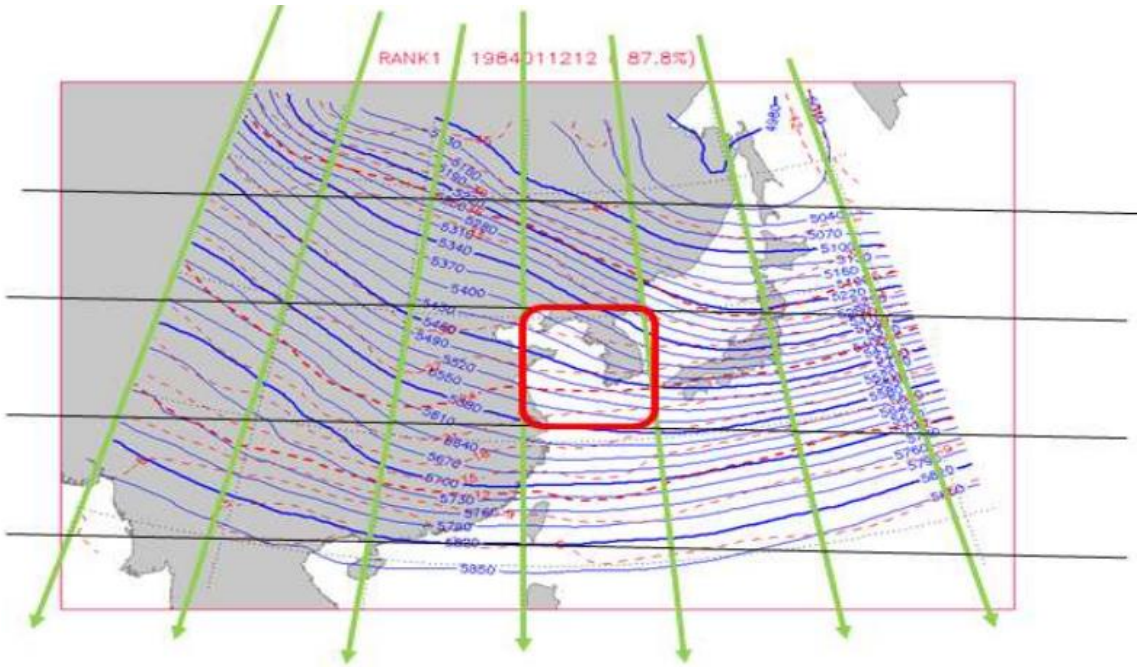

Figure 1. Extracting weather maps from the Korean Peninsula.

3. PROPOSED METHOD

3.1. Support Vector Machine: A Binary Classifier

SVM is one of the most widely used supervised learning techniques [5][6][7]. This model is similar to logistic regression in that it is driven by a linear function. One important point related to SVM is the use of the kernel trick [8]. Kernel trick allows many machine learning algorithms to be expressed only as inner product terms between samples.

Although the performance of SVM can vary greatly depending on the kernel function, there is a limitation in application that there is no theory on how to select an appropriate kernel function according to the data (Amari and Wu, 1999; Byun and Lee, 2002). . Therefore, it is necessary to go through the process of searching for parameters in order to select an appropriate kernel function according to the characteristics of the data. As such, parameter estimation is very important in using SVM as a prediction model. One thing to be aware of here is to set a parameter with a high degree of fit biased toward the learning data, which is called overfitting. That is, performance may be improved for previously used training data, but may decrease for new data. Therefore, in this study, the 10-Fold CV technique was used as a cross-validation (CV)

method to solve this problem. This is a method that randomly divides data (x, y) into 10 sets, uses one as validation data, and uses the rest as learning data. After modeling, the average error value is used to determine the Evaluate the model's performance.

3.2. Seasonal Heavy Rain Forecasting System

Figure 2 shows a conceptual diagram of our heavy rain prediction system. The system is composed with two man-parts: one is the training part and the other is the forecasting part. In the training part, two different conditions are input as a training data. The SVMs are trained with these inputs. In the forecasting part, weather data is input to the trained SVM model and the output shows that the input data is heavy rain or not.

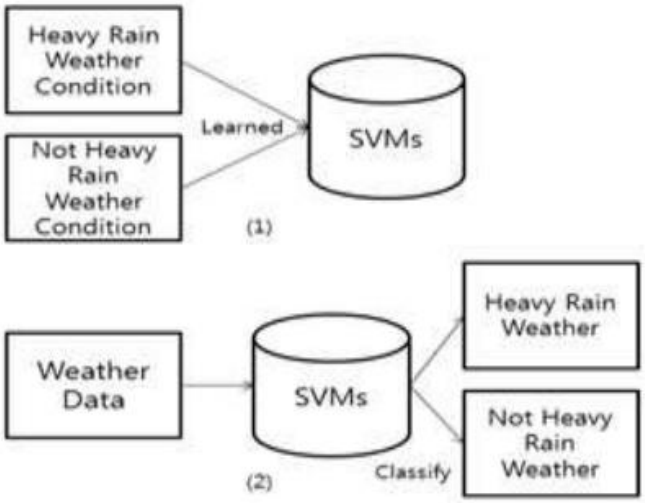

Figure 2. The Concept of the System.

4. HEAVY RAIN PREDICTION EXPERIMENT

For the prediction of heavy / non-heavy rainfall after 6 hours, a training set was constructed using a total of 200 dates of 100 heavy / non-heavy rains as defined above. The experiment was conducted with 5-fold cross validation consisting of 160 training data and 40 test data from the training set. Table 1 shows experimental results for each property and isobar. The attributes that showed the best results for each isostatic surface are shown in bold. The most predicted accuracy was 65-70% in most isostatic planes. Looking at the characteristics of the difference between isobars, GHGT and SHUM showed good results on all isobars, and TEMP also showed good results at low altitudes.

Table 1. Heavy / Non-Heavy Forecast Accuracy according to Each Feature.

hPa	GHGT	RHUM	SHUM	TEMP	UWND	UWNDxt
850	62.00	53.50	69.50	66.47	50.50	53.00
700	66.50	49.00	61.00	66.50	53.50	56.00
500	68.50	53.50	60.00	68.00	59.00	52.00
200	65.50	65.00	64.30	47.50	59.00	46.00

5. SEASONAL HEAVY RAIN SITUATION PREDICTION EXPERIMENT

For the prediction of the heavy rain situation according to the season, 100 rain and rain days meeting the criteria were selected in May and September based on the criteria defined above. 100 dates were selected for each of 50 dates. May, September, July, and August were grouped into two seasons, one summer and one summer. 5-fold cross validation was performed with 80 training data and 20 test data using 100 monthly dates consisting of a total of 4 sets. The experiment was conducted at 850hPa isostatic pressure. Accuracy, Precision, Recall, and F1 measures were used as indexes to evaluate the results. The results of experiments using dates classified in different seasons are much higher than the results obtained by using the data classified in the same season without distinction between heavy and non-heavy rains.

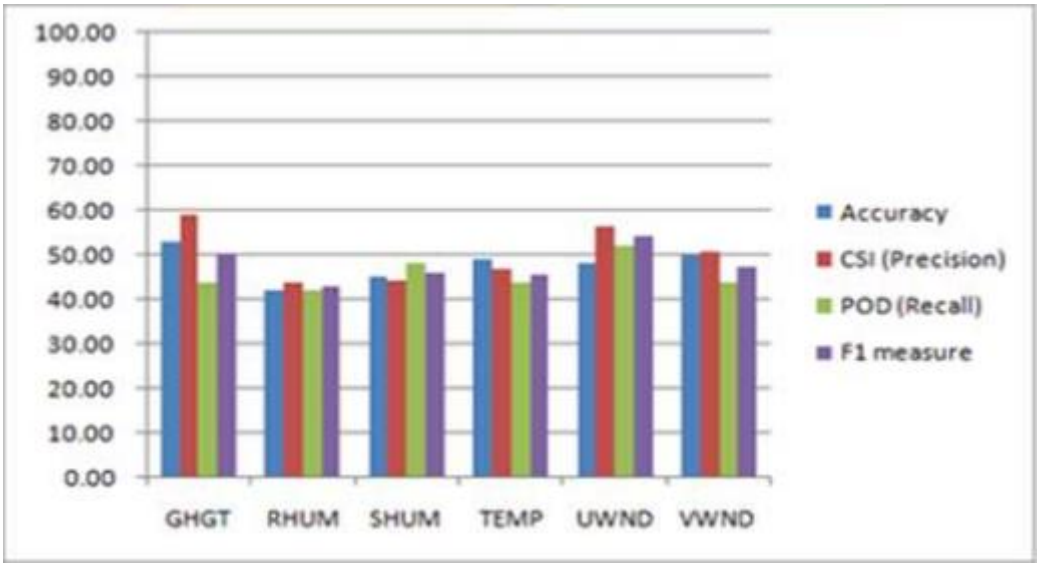

Figure 3. Seasonal heavy / non-rain rainfall forecast accuracy. (heavy rain 7, 8 vs. non-heavy rain 7, 8).

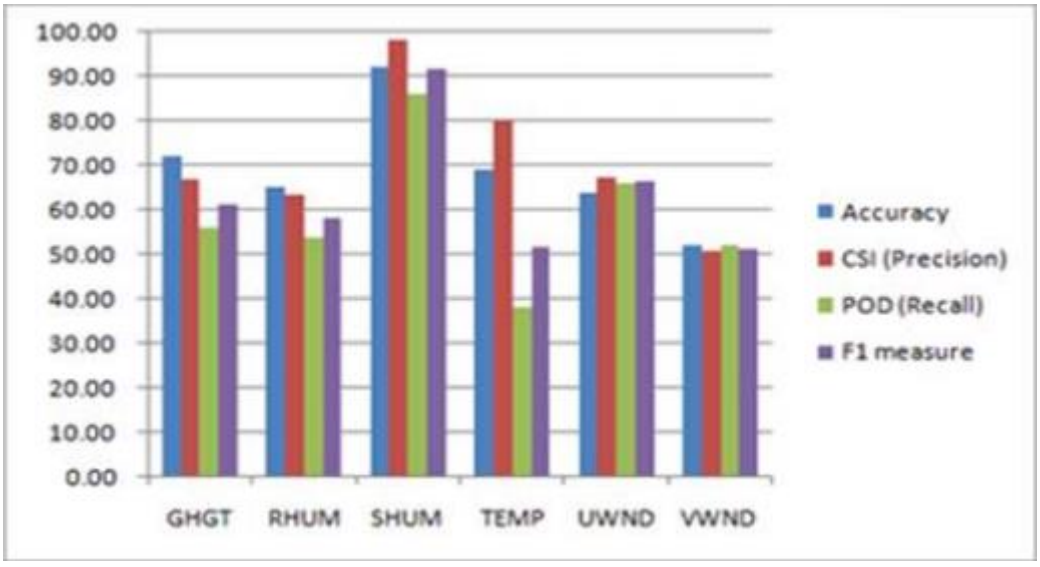

Figure 4. Seasonal heavy / non-rain rainfall forecast accuracy. (heavy rain 7, 8 vs. non-heavy rain 5, 9).

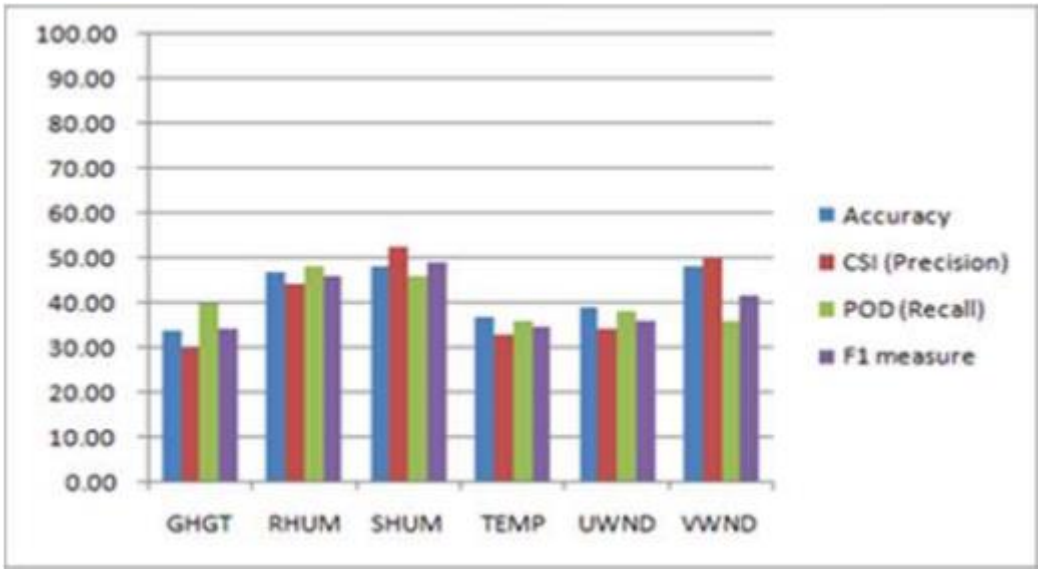

Figure 5. Seasonal heavy / non-rain rainfall forecast accuracy. (heavy rain 5, 9 vs. non-heavy rain 5, 9).

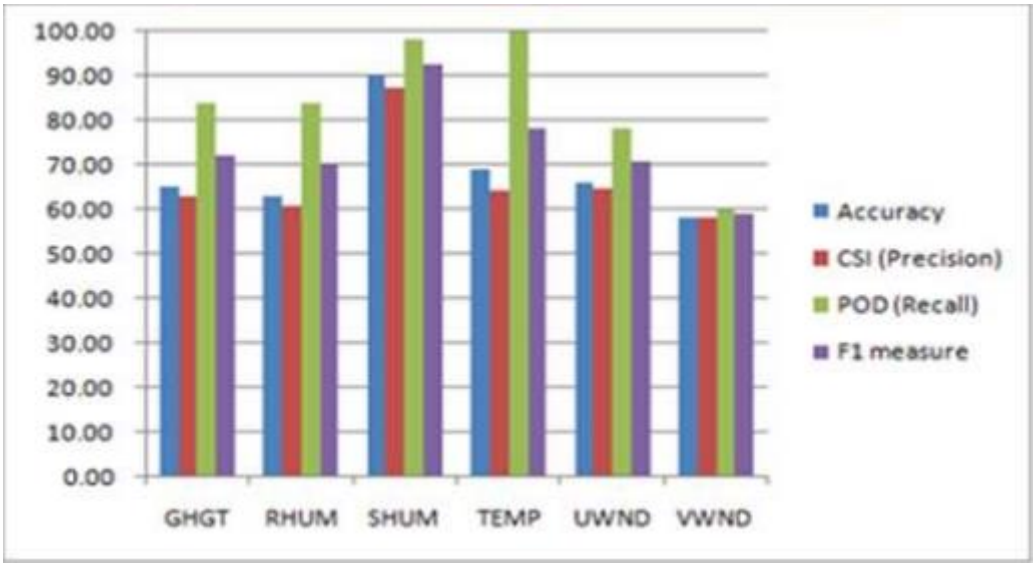

Figure 6. Seasonal heavy / non-rain rainfall forecast accuracy. (heavy rain 7, 8 vs. heavy rain 5, 9).

6. CONCLUSIONS

In this paper, we study the technique for predicting heavy / non-rain rainfall after 6 hours from the present using the values of the weather attributes. We investigated whether each attribute value is influenced by a specific pattern of weather maps representing heavy and non-heavy rains or seasonally when making heavy / non-heavy forecasts. In the experiments, a 20-year cumulative weather map was learned with Support Vector Machine (SVM) and tested using a set of correct answers for heavy rain and heavy rain. By considering the experiment results, it was found that the heavy rain prediction of SVM showed an accuracy rate of up to 70%, and that it was seasonal variation rather than a specific pattern that influenced the prediction. In the future, combining our proposed method with the latest research related to recommendation systems or knowledge processing, we expect to be able to expand expressions efficiently [9][10].

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AUTHOR

Jaekwang KIM

He was born in Seoul, South Korea, in 1980. He received the B.S., M.S., and Ph.D. degrees from Sungkyunkwan University (SKKU), Suwon, South Korea, in 2004, 2006 and 2014, respectively, where he is a currently an assistant professor with the College of Convergence and Convergence program for social innovation. His research interests include networks, security, medical health, education based on various machine intelligent algorithms. He received the Best Presentation Paper Award at ICUIMC, Suwon, in January 2009, and was elected as a Bronze Medal Superior Student from the Brain Korea 21 Enterprise Department, Sungkyunkwan University.

MANUFACTURERS, AI MODELS AND MACHINE LEARNING, VALUE CHAINS, AND 5TH GENERATION WIRELESS NETWORKS

Robert B. Cohen

Economic Strategy Institute, Washington, D.C, USA

ABSTRACT

When AI models and machine learning are fully interconnected in factories with cabling-free 5G wireless networks, firms become "fully digital". This analysis argues that it is not the initial efficiencies gained by optimizing a plant's operations but rather a firm's ability to build a collection of knowledge about each step of its operations, what we call "knowledge synthesis". This is information about how each product is produced, how the process to produce it is managed and optimized, and the software and systems required. This knowledge is important because it permits firms to exploit network effects based upon connecting plants together or sharing expertise with partners. This greatly expands the potential for economic benefits from the use of AI and 5G. This review explores cases from firms with smart factories that have adopted AI and 5G communications including Moderna, Sanofi, Mercedes, Ford, and VW. It examines how these firms have benefitted from the move to smart factories with 5G communications networks. It also explores how firms have improved their value chains by building smart factories that connect nearly all manufacturing processes to machine learning and AI models that analyze machine and process data rapidly. Next, they take advantage of network effects – due to "knowledge synthesis" that permits early smart factories with 5G networks --to derive even larger benefits inside their production operations and in their supply chains. In both phases, the adoption of 5th Generation wireless in plants ramps up firms' abilities to interconnect their digital systems. Once the interconnected systems exist, firms exploit network effects to create "knowledge synthesis" or knowledge platforms to consolidate insights gained from optimizing many machines and processes. Using "knowledge synthesis", firms can also transfer knowledge from one group of equipment to another that is not optimized even when the equipment is in different facilities. This makes firms far more flexible, interoperable, and scalable.

KEYWORDS

"Fully Digital"Firms, Smart Factories, Knowledge Synthesis, Manufacturing Processes,Value Chains.

1. "FULLY DIGITAL" FIRMS

"Fully digital" firms create an integrated networking infrastructure in their plants and make analytics, using AI models and machine learning techniques, central to their plants' operations. Firms achieve this status while they also pass through two phases to change their value chains. In phase one, they build smart factories and connect nearly all manufacturing processes to machine learning and AI models that analyze data rapidly.[1] In phase two, they take advantage of *network effects that have even larger benefits inside firms and for supply chains*. In this phase, firms exploit the benefits of a fully digital ecosystem of factories that is often global in scope. Here too, they take advantage of network effects to reshape their value chains.

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In adopting a "fully digital" infrastructure, a firm integrates three steps. First, it deploys a digital networking infrastructure that links together all machines. Second, it prioritizes the analysis of equipment performance and how to optimize and change related operations. This is much easier to achieve following the deployment of 5G communications within factories. Third, it constructs an ecosystem of insights from these analytics. This lets firms evaluate and optimize machines' performance within a plant and across plants.

Sanofi's new Continuous Biologics Manufacturing Facility [2] exemplifies what firms can accomplish in phase one. It is a digitally enabled, continuous manufacturing facility, where Sanofi takes advantage of AI analysis to evaluate process data in nearly real-time. In this factory, AI models' results are transmitted quickly to workers' iPads and displayed on large video screens. With this capability, Sanofi's employees can quickly fine-tune any processes.

Once firms complete this initial phase, they: 1) make more efficient use of capital in optimized processes; and 2) continuously update and refine the machine learning models that help define how AI models analyze processes. Firms can add additional variables and conditions to improve their analysis of such processes.

In phase two, "fully digital" firms take advantage of network effects that have even larger benefits inside firms and in their supply chains. In this phase, firms begin to understand that a *fully digital ecosystem* can take advantage of network effects that have the potential for *unprecedented* impacts on how they reshape their value chains. The World Economic Forum and McKinsey have argued that the main benefit of adopting AI is the dramatic change in cash flow that "frontrunners", adopters of AI in the first 5 to 7 years of its commercial use, obtain by 2025. This is due to the efficiencies that early adopters of AI can achieve. See [3, Fig. 1]

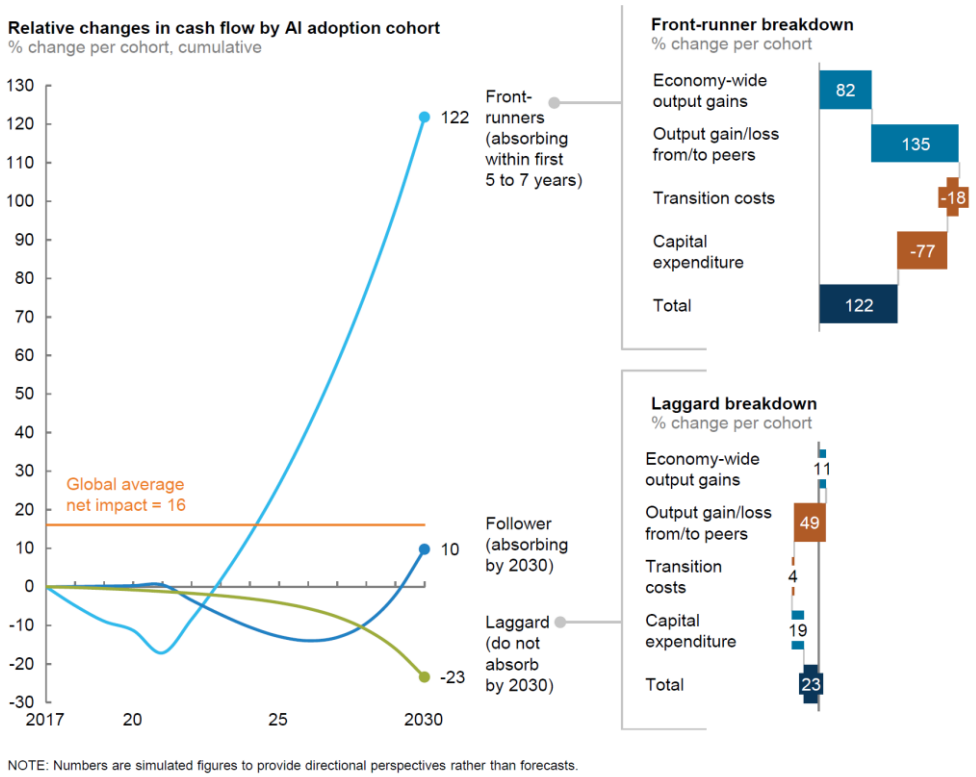

Figure 1. Faster adoption and absorption by front runners can create larger economic gains for these companies.

In this phase, firms begin to employ "knowledge synthesis", insights obtained by optimizing many machines that are part of a process -- for instance, assembly and stamping in an auto plant or producing printed circuit boards in an electronics plant -- to create a template or knowledge platform that indicates how the firm should optimize all the machines and software needed to produce a product. Firms utilize this knowledge inside a single factory or can share it among a group of "sister" factories.

To become completely digital, firms adopted digital technologies as well as new communications technologies, such as 5G private networks, and integrated them with AI and machine learning. DXC Technology defines this shift to data analysis-based interconnected machines and equipment as "industrialized AI". It believes that the definition includes automating, scaling, and operationalizing "siloed analytics capabilities". [4]

There are three ways [5] that firms create digital landscapes. These features are likely to emerge as the new enterprise architecture for data analytics, including AI and ML, and for rapid adjustment of business processes. The emergence of this architecture involves several steps.
First, firms integrate digital production with cloud computing and data analysis. A step beyond this integration is refining applications so that they are easier to analyze using the compute power that is available at the Edge that is usually far more limited than the computing capabilities in the cloud. For instance, two German auto firms have adopted paint inspection technology that Durr, a robotics manufacturer, created. Durr, reworked "its DXQ equipment analytics program with Software AG to record, analyze, and eliminate faults in the painting process." The process measures "230 different signals from each [robot], at any one point in time – out of 100,000 data points we are collecting" [5] to stop any paint jobs that have gone awry. The software innovation means that 230 data points are sufficient to identify live painting errors, not 100,000. If there is a problem, the software stops the line at once, identifies the painting error and flags the fault in the machine.

A fully digital firm with extensive sensor networks, AI models and 5G communications acts as a flexible matrix. It can rapidly collect data and information about how the firm operates. This flexible matrix structure moves beyond Industry 4.0 because its data analytics originate in sensor networks, that, due to 5G communications can send information rapidly to the Edge of networks and get it returned almost in real time. This feedback structure lets workers visualize performance and correct how processes are operating. It also connects to an extensive collection of cloud services.

Second, digital firms focus on the "knowledge synthesis" created from the analysis they have performed. This allows them to optimize design and development processes as well as many manufacturing processes. The result is not only cost reductions, but also the application of "lessons learned" in one section of a business to other operations.

We defined this concept after noting automakers' intentions to connect many of their smart factories with 5G private networks. For instance, Jorg Burzer, a Member of the Divisional Board of Management of Mercedes-Benz Cars has noted that "with the installation of a local 5G network, the networking of all production systems and machines in the Mercedes-Benz Cars factories will become even smarter and more efficient in the future. This opens up completely new production opportunities." [6] We also considered Volkswagen's plan to build 5G mobile networks in 122 factories in Germany in 2020 and "develop an 'industrial cloud' to combine the data of all machines, plants and systems from all 122 facilities of the Volkswagen Group and …. [possibly include its] global supply chain linking 1,500 suppliers and partners across 30,000 locations" [7] including those in China.

Volkswagen plans to achieve a 30 percent increase in system-wide productivity between 2018 and 2025 by making such changes in its factory ecosystem. It believes its "biggest optimization potential lie[s] in the production structures and processes, considered to be far too complicated in many places." "And there is also room for improvement in standardizing our global production network…that is why we are now introducing uniform structures at all factories along with uniform and comparable key performance indicators." [8] By comparison, the Nokia Oulu, Finland factory achieved more than a 30 percent increase in productivity in one year. It leverages a 5G private network as well as "IoT analytics running on Edge cloud, and a real-time digital twin of operations data." [9]

Volkswagen's shift moves the firm's focus from a "product to a process orientation". [10] Here, we develop new thinking about how factories will operate in the future extending our thinking to the future focus on processes.

"Knowledge synthesis" shortens the time to transfer knowledge from one set of processes to another. Firms support transferring insights from one part of their business to another. This reduces the time required to deploy new machines, software, and processes in one plant or in a related "sister" plant that produces similar products. This is largely thanks to connectivity 5G networks offer to global businesses. Moderna's rapid development of a coronavirus vaccine was possible by using "knowledge synthesizing", drawing on its own previous model of vaccine development.

After these steps, firms turn using AI into a process innovation strategy. They transform processes and develop innovative ways to create new or different types of products. They build digital architectures and processes that are based upon a digital twin infrastructure. Aerospace and auto firms have employed digital twins – virtual models of components – to model and test key parts of a product, such as its engines. Rolls-Royce and other engine manufacturers do this to speed testing and for the C-130 and F-35. The digital twin infrastructure is the foundation for moving to an all-digital-software analytics infrastructure over the next 2-3 years.

Morgan Stanley's and Wells Fargo's use of AI analytics to determine their banks' exposure to liquidity risk is a good example of how AI and ML have become central to a firm's performance. Using critical analysis based upon ML and AI models gave these banks predictions of their risk exposure. These proved to be far more accurate than calculating risk exposure with traditional regression models. Consequently, these banks migrated many of their most important assessments of risk to AI and ML models.

We have constructed a conceptual model of how applications and services change in moving to smart factories with 5G communications [11, Fig. 2]. We believe this model characterizes how smart factories and firms will use 5G communications and AI. We think it may be possible that other technologies could arise that would help firms transfer insights about processes between plants more rapidly. Perhaps this could happen after innovations that provide new ways to transfer exceptionally large files between specific locations.

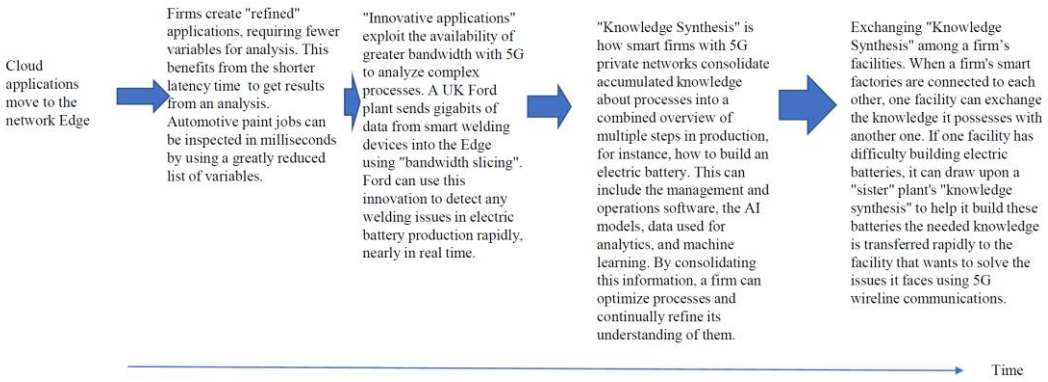

Figure 2. The Evolution of applications in smart factories and interconnected smart factories

2. FULLY DIGITAL FIRMS, NETWORK EFFECTS AND CHANGES IN VALUE CHAINS

Which firms have already become “fully digital”? Those that have integrated communications across a factory with 5G communications. As a result of this shift, firms operate in a paperless environment where data-analytics operations integrate AI and machine learning.

In September of 2020, these firms were present in four industries. In automobiles, “fully digital” firms included Volkswagen’s Industrial Cloud and Digital Production Platform (DPP), in Wolfsburg, Germany, and its engine plants in Chemnitz, Germany and Polkowice, Poland. VW’s DPP will also be installed in Porsche’s plants – Porsche is part of the VW group -- in Leipzig and Zuffenhausen, Germany, in 2020. Also included in this group is the BMW Group i8 Factory in Leipzig, Germany, and its Regensburg, Germany, “sister” plant. At Daimler Benz, the Smart factory, “Factory 56”, in Sindelfingen, Germany and Daimler’s Full-Flex Plant for Mercedes’ compact A-series cars in Kecskemet, Hungary are “fully digital”. We also include Toyota’s Tsusho Canada plant in Ontario, Canada, Ford’s 5GEM plant in Dunton, UK, Subaru’s Indiana Automotive plant, and the Bosch smart factory for auto parts in Celaya, Mexico.

The digital firms in pharmaceuticals include Moderna’s plant that led the rapid development of a coronavirus vaccine in Norwood, MA, and Sanofi Genzyme’s Continuous Biologics Manufacturing Capability, or digitally enabled, continuous manufacturing facility, in Framingham, MA. We also expect that similar Sanofi Genzyme plants in Toronto, Canada, Waterford, Ireland, Sisteron, France, Brazil, and China[12] are “fully digital” as is the Lonza Specialty Ingredients pharma plant in Visp, Switzerland, and Eli Lilly’s Small Volume Continuous Facility in Kinsale, County Cork, Ireland.

In electronics and sensors, we find “fully digital” plants at Schneider Electric’s smart factories in Amberg, Germany, and Le Vaudreuil, France. Schneider is expected to fully digitize plants in Lexington, Kentucky, Wuhan, China, Hyderabad, India, and Batam, Indonesia. We have identified “fully digital” plants at ABB (ASEA Brown Boveri) factories in Shanghai, China, and Heidelberg, Germany. Similar plants include the factories at JUMO GmbH & Co. in Fulda, Germany, that produce high technology sensors and Ericsson’s plants in Louisville, Kentucky, Texas, Kista, Sweden, and Nanjing, China.

The sole “fully digital” firm we have discovered producing industrial tools is Sandvik Cormorant’s factory in Gitmo, Sweden.

Although today's number of "fully digital" firms is small, many of them plan to convert nearly alltheir facilities into smart factories using 5G networks. This is likely to begin a major transformation of manufacturing and the modern corporation. In the future, it is likely that the corporation will be defined by how it uses AI and machine learning as well as 5G communications, Edge computing, and more extensive sensor networks that are part of the Internet of Things.

In today's environment of extremely rapid changes in technology, especially software to operate and analyze the operations of modern corporations, Peter Drucker's thoughts about management may need to be redefined. Where Drucker finds that organizations integrate specialized knowledge in a common task, [13] today's firm appears to operate more by capturing knowledge about processes where individuals, rather than managers, often decide how to implement new approaches and develop new software. This non-hierarchical management approach has more in common with a decentralization of power and creativity in the smart factory with 5G communications.

Firms are no longer "rules-based" but "efficiency-focused" [14]. Our definition of "efficiency focused" does not mean minimizing transaction costs. Instead, efficiency is due to how firms have made AI models and cloud computing central to their operations.

Both VW and BMW have invested in fully digital factories that provide high value for assembly processes. Network effects, or what I call "knowledge synthesis" is the second driver that changes value chains. Both VW and BMW expect to benefit from network effects by linking together similar processes within a single factory and, later, by interconnecting many plants linked through the cloud and 5G communications. This will join processes within different plants that use the same machines or employ the same manufacturing processes.

Value chains are likely to change in two ways in the auto and biopharma sectors. First, firms will rely upon AI models and machine learning to analyze processes. With machine learning models, it is possible to get a more sophisticated analysis of key stages in the assembly process. With auto firms, this level of information improves operations.

Second, with "knowledge synthesis", these firms transfer information about how one stage in the assembly process was optimized to other processes. Since "knowledge synthesis" lets firms take knowledge gained in one place and apply it to machines in another, it reduces the cost of experimenting with new processes. It also transfers insights about how to optimize a process at a low cost.

Moderna [15] has employed "knowledge synthesis" to accelerate the development of its new coronavirus vaccine. Moderna's messenger RNA-based framework builds on its previous research on streptococcal pneumonia and personal cancer vaccines, including algorithms and designs for testing. By applying previous genomic designs and frameworks, Moderna reduced the time to design, produce, test, and prepare the coronavirus vaccine to just 42 days.

Moderna's digitization is a central feature of its new facility outside Boston. Once digitized, every step on the factory floor and all the testing and development work in a lab is recorded electronically. The reasons to digitize include [16]: 1) the fact that all of its drug targets were based on messenger RNA -- since messenger RNA's structure includes DNA's four basic human genome chemicals, it could be easily described in an computerized data base; 2) similar data was being used in the previous drugs it was developing because they used variants of messenger RNA; and 3) Moderna wanted to work on multiple drugs that had different treatment approaches at the same time; if it considered working with a traditional pharmaceutical firm's structure and

overlaying it with digital capabilities this would not be possible. The only way to achieve this type of flexibility would be to connect "hundreds of thousands" [17] of applications at an astronomical cost.

On the shop floor, Moderna optimized processes just as Volkswagen did. It reported a decrease in manual exceptions by 85%, shift labor by 40%, and batch review from 3 days to 3 hours [18]. Moderna also focused on ways to optimize laboratory instruments. In this area, sensor data from different instruments provides usage information as well as failure frequencies. Moderna used this to drive needed capital investments and set up usage-based calibrations for instruments.

Improvements in factory-level performance drive a fundamental restructuring of value chains, often due to operational enhancements. In the auto industry, these value chain benefits are focused not only on the assembly line and its stamping shop but also in engine and drive train production. These changes introduce a high level of new technology in specific parts of the value chain and spur firms to improve the technological sophistication of their supply chains.

The initial digitization at auto firms focused on the highest value-added parts of auto manufacturing. In Volkswagen's case, they supported a "step change" in productivity.

Both VW and BMW focused on the stamping shop to address quality issues. This is one of the earliest, high value stages in auto assembly. Mistakes in this stage carry over into other stages. By reducing errors and imperfections here, auto firms increase the value they create.

Volkswagen's Digital Production Platform (DPP) has also focused on engines. Volkswagen's goal is to "to standardize and network all production-level machinery, equipment and systems, which currently use different software programs. Therefore, the Volkswagen Industrial Cloud could use application programming interfaces [19] to simplify data." [20]

"Knowledge synthesis" also alters the value chain. It exploits what economists call network effects[21], where a good's value or benefit increases as the number of users grows. The Internet is an excellent example; as more people used it, its value increased. The greater the spread of new efficiencies, the greater the return. With digital analytics, firms take advantage of "knowledge synthesis" by building insights and knowledge they gain when they optimize and adjust, or even redesign, a single process. Firms apply this framework or knowledge platform – insights and "learnings" -- to different products that are part of their operations.

"Knowledge synthesis" is only possible once a factory is fully digital. It acts as a driver behind a firm's construction of highly connected 5G private networks within plants and between plants. It also drives manufacturers' efforts to connect their analytic and optimization systems with their suppliers. These networking impacts result in substantial improvements in productivity and innovation.

In the coming decade, this process is likely to transform suppliers that have traditionally performed lower value-added operations for auto firms. Lower-level suppliers, so-called Tier 2 and 3 suppliers, traditionally are more labor intensive and they produce less technologically advanced parts and components. They can shift to higher value-added tasks because using AI and machine learning would result in tighter control over processes. As these suppliers employ quicker modeling of the changes a firm makes when it shifts manufacturing from one product to another, they can rapidly modify the way they manufacture an existing product.

This unlocks an opportunity for auto producers or similar final product producers to remake their supply chains. In auto production, especially for assembly and key subsystems, such as drive

trains, final assemblers need to refashion tighter connections between their assembly plants and their supply chain's subsystem manufacturers. This ensures that smart technologies will reach external suppliers, raising their technical competence. It also provides a way for automakers to obtain supplier data that helps model changes in an area like brake design and to evaluate how a different design for brakes will perform in a product like an electric car. Conversely, large suppliers can use their own data centers and edge computing to evaluate the components, such as electronic batteries that they ship to automakers.

These cases illustrate how network effects might have an extraordinary impact on value chains as more firms adopt AI and machine learning.

3. 5TH GENERATION WIRELESS TECHNOLOGY IN MANUFACTURING FIRMS; EXAMPLES FROM MERCEDES AND VOLKSWAGEN

Fifth generation (5G) wireless communications permits factories to communicate almost instantaneously with computing power and applications at the Edge of computer networks. Factories benefit from 5G's ability to analyze operations with low latency and high bandwidth. This section enumerates the early benefits of adopting 5G private networks.

Auto firms have faced a difficult issue analyzing the quality of welding. When a weld has flaws, the welded part is useless. Ford has contracted with Vodafone to create a factory of the future for electric battery production in Essex, UK. Welding is critical to producing high quality batteries. To ensure high quality, the Ford plant's 5G private network transmits large quantities of data requiring lots of bandwidth, nearly half a million bits of data every minute, from intelligent battery welding tools. Over a thousand of these tools make welds on each battery. Ford's welding operations are managed by AI models at the end of the network, or its Edge, that rely upon rapid, high-bandwidth data capture. This is a new feature of 5G communications called bandwidth "slicing".

Another benefit of 5G communications in AI-connected factories is "personalization at scale" or customization. Mercedes Benz's newest factory at Sindelfingen, Germany, includes intelligent workstations where employees create tailor-made vehicles. Among the innovations that 5G makes possible is the use of autonomous guided vehicles that bring required parts to these workstations. At Sindelfingen, the "TecLine" intelligent workstations install engines, braking systems, drive trains, and body trim. They are a stationary workplace that replaces a moving assembly line. The "TecLine" draws its inputs from elsewhere in the factory. It is called a "cycle operation" [22].

This works in the following way. At the beginning of the trim line, Mercedes redefines the tracks for the driverless transport systems. This shifts production from a moving assembly line to a cycle, or static, operation. In the latter, a "vehicle remains in position and is not continuously moved along the line[23]. This makes sense for automated activities …when installing a glass roof. In addition, …the driverless transport systems [make it possible to expand] individual assembly units …without interfering in the building's structure"[24].

Mercedes' Sindelfingen, Germany, factory networks together machines and computer systems. Different "assembly facilities and materials-handling technology are "Internet of Things"-ready."[25] In this plant, "Factory 56", the assembly stations or intelligent workstations receive all the materials required for assembly. Mercedes calls this a "pick zone", or "TecLine" that employs intelligent picking systems. Mercedes supports these workstations with Big Data

technology that collects and evaluates the information required to optimize operations and improve existing production processes.

Ericsson and Telefonica Germany are partnering to connect Mercedes' production systems and machines in "Factory 56". They are installing secure 5G communications with gigabit data rates and almost real-time latency – less than a few milliseconds – to complete the analysis of large amounts of data. This 5G network will "boost flexibility, production precision, and efficiency"[26]. It will also support data linking or product tracking on the assembly line, making all processes more robust and optimized. The assembly line or "pick zone" can change at short notice to address new market demands.

5G private networks and their connections to applications and services at the Edge of networks promote significant gains in productivity when they optimize operations.

Volkswagen is one of the pioneers in these efforts. It has linked production to analytic functions on a cloud computing platform. First, VW connected different machines to an Internet of Things (IOT) platform that sends performance results to a data model. Analytic tools analyzed and presented the results very quickly to staff and management.

The "fully digital" system at VW measures the operational equipment effectiveness (OEE) [27] of each machine. There is a *teamtafel*, a team dashboard, that displays the OEE score for different machines on the shop floor. VW is refining this calculation by creating services to augment the Amazon Web Services' estimates of OEE. VW is applying this architecture in its production system, not only its auto assembly plants, but also facilities that produce major components such as drive trains.

These changes allow Volkswagen to improve processes on the shop floor. It created a platform with "use cases", i.e., applications, developed with Amazon that improve process management. With AI and visualization in place, mangers no longer run the shop floor with paper-based reports. VW can use new technologies like AI to evaluate important processes, including the stamping process, to see whether defective parts exist among those pieces that have already been pressed. If they do, managers can eliminate parts with pressing defects before they are incorporated into vehicles further down the assembly line. There, they could disrupt production.

Workers on the shop floor benefit from machine learning and AI models. These tools evaluate performance data and send the results back to teams that can adjust machines' performance. Thanks to 5G communications and computing and analytics at the Edge of networks, factories benefit from the increased speed in obtaining performance information and results of analysis. This is a major advance over previous systems where information took a slow route to the core of cloud computing systems and back to the factory. The results from earlier analytic models took much longer to obtain and could not usually be used to make rapid adjustments. For more details, the reader is referred to [28, Table 1].

Table 1. How Volkswagen manages the shop floor

Structural changes	**How it works using the Internet of Things and 5G Communications**
1. VW has organized work on the shop floor in process steps.	1. An Internet of Things platform connects all of the heterogenous machines in every process step.
2. A single Production Logic Controller (PLC) controls all of the machines in a specific process.	2. Data from each step as well as all the operations is sent to a unified data model.
	3. The results of data analysis are displayed on two different screens
	a. A "team display" gives employees a view of process steps and machine performance.
	b. A management display of machine efficiency and the performance of each process.

The Digital Shop Floor Management system (DSFM) allows Volkswagen to control critical parts of its value chain [29]. It enhances problem solving since it retrieves data and delivers reports automatically. It improves machine availability because it transparently tracks activity and shares knowledge across plants. It also optimizes throughput times by focusing on bottlenecks, the value stream and reliable delivery. In sum, it increases productivity by uncovering data that describes production losses and revealing the factors that cause them.

The initial reason for implementing AI and machine learning is their role in optimizing “high-frequency, complex production processes”[30]. This was Volkswagen’s focus during 2019, when it concentrated on high value processes where improvements help it produce cars more efficiently. One focus is the metal stamping process. Defects in the stamped metal products, be they fenders or doors, reduce the value achieved on the factory floor. This requires visualization, AI, and machine learning. The reader is referred to [31, Table 2].

Table 2. How Volkswagen brings intelligence to the shop floor

Volkswagen's Digital Production Platform Includes 3 digital production services	**Applications and analysis in the cloud**	**Applications and analysis at the Edge of networks**	**Use cases**
1. Digital shop floor management	1. Initial deployment in the cloud means that calculations take longer to complete the round trip from a factory to the center of the cloud and back to the factory.	1. Later deployment of applications at the network Edge relies upon a 5G private network in a factory linked to AI models.	1. Efficiency of the press shop or other parts of the production line.
2. Pressing stage optimization	2. This means the latency between the time to collect the data and receive the results of analysis takes about 200 milliseconds; this is considered too slow to respond to changes in performance data on the shop floor.	2. This speeds up analysis. The latency or time to send and recive the results of AI models at the Edge that receive data and perform analysis takes milliseconds. This provides results in nearly real time. It is easy to adjust processes with the AI models' results.	2. Reducing scrap in processes with great potential for errors, such as painting and welding.
3. Part localization	3. The amount of data that can be sent to the center of the cloud is limited by the size of the bandwidth available in the network connecting to the firm. This makes evaluating more complex operations difficult.	3. There is more bandwidth to send far greater amounts of data to the Edge for analysis. In addition, techniques such as "bandwidth slicing" lets firms evaluate gigabits of data far more rapidly at the Edge than at the center of the Cloud.	3. Part localization benefits greatly from 5G communications inside the plant. This makes customization possible at intelligent workstations in the plant.

Volkswagen’s architecture is described in the following table [32, Table 3]. It describes how data moves from production equipment to the “industrial edge” where data is gathered before it is sent for analysis. The Edge is often the initial location for analysis, including the use of machine learning. In Table 3 below, this is the “enterprise cloud” and it supports the Digital Production Platform (DPP) Enterprise Cloud which includes applications and services.

VW’s plant in Wolfsburg and Porsche’s plants in Zuffenhausen and Leipzig have implemented DPP. Volkswagen designated these plants as centers for future innovation and the development of new business models. [33]

Table 3. How Volkswagen's digital production platform (DPP) coordinates manufacturing

Equipment Tier	**Connects to the Enterprise Cloud Through**	**The DPP Enterprise Cloud**
1. The production equipment tier	1. Operational technology - information technology gateway	1. DPP application landing zones
2. The industrial Edge tier	2. An Edge gateway	2. DPP Use Case Application Framework
3. Plant cloud tier	3. Amazon Web Services outposts, DPP plant/Edge services, and on-premises applications	3. Managed Landing Zones

4. CONCLUSIONS

Interconnecting machine learning and AI models with the help of 5th Generation wireless communications will change how businesses operate. It will place analytics at the core of the modern corporation and make the management of processes, not products central to the way firms operate. As a result, firms in several industries are changing their factory floors to incorporate much greater levels of intelligence. This means that highly capitalized and critical operations in firms' value chains, such as welding in the auto industry, can be managed much more efficiently. In addition, once firms compile the insights and skills needed to optimize processes that these new systems provide, they can synthesize this knowledge, what we call "knowledge synthesis", and employ it to optimize similar operations in the same factory or in a "sister" plant. This makes firms more productive and contributes to innovation.

It also opens the path for more extensive customization based upon the use of AI models, rapid data analysis and timely acquisition of parts needed for assembly. This has the potential to shift a large part of production from more automated production lines to intelligent workstations that assemble products that customers want customized. This "personalization at scale" may be one result of focusing analytics on processes. Thus, AI in manufacturing has the potential to support firms as they reorganize production. This could lead to new types of jobs with new work skills, not the displacement of employees by machines that perform workers' traditional tasks.

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AUTHOR

Short Biography

Robert Cohen is an economist and senior fellow at the Economic Strategy Institute. He directs a study of the impact of cloud computing, machine learning, AI, smart factories and 5G on the U.S. economy. He developed the first technology strategy for New York State and chaired the state's High Technology Council. With two co-founders, he created NYSERNet, New York's part of the U.S. Internet.

Dr Cohen has been Associate Professor of International Business and Finance at New York University Business School, Associate Professor of Finance and Economics at York College of the City University of New York, and Senior International Economist at the Futures Group. Dr Cohen served as executive director for the TM Forum's Enterprise Cloud Leadership Council. He is a past president of the Forecasters Club of New York.

He holds an M.A. and Ph.D. in economics from the New School for Social Research and a B.A. from Swarthmore College. He is an author, co-author, or editor of four books, including: Changing the Face of the Internet. Virtual Worlds and the Information Economy; Nontariff Barriers to High-Technology Trade; The Multinational Corporation: A Radical Approach – Papers of Stephen H. Hymer; and The New North American Order.

A DEVELOPMENT FRAMEWORK FOR A CONVERSATIONAL AGENT TO EXPLORE MACHINE LEARNING CONCEPTS

Ayse Kok Arslan

Oxford Alumni of Northern California, Santa Clara, USA

ABSTRACT

This study aims to introduce a discussion platform and curriculum designed to help people understand how machines learn. Research shows how to train an agent through dialogue and understand how information is represented using visualization. This paper starts by providing a comprehensive definition of AI literacy based on existing research and integrates a wide range of different subject documents into a set of key AI literacy skills to develop a user-centered AI. This functionality and structural considerations are organized into a conceptual framework based on the literature. Contributions to this paper can be used to initiate discussion and guide future research on AI learning within the computer science community.

KEYWORDS

Machine learning, visual editing, construction, neural nets, artificial intelligence.

1. INTRODUCTION

There is a need to add research that investigates what new skills will be needed in the future as AI transforms the way people communicate, work, and live with each other and technically. It is seen as a technological innovation to transform our society, economy and jobs in the digital community, let alone its accelerated outcome during the Covid phase. Some of the most well-known examples of AI non-driving vehicles, voice assistants, online search engines, robotic vendors, etc. Despite the destructive AI myth represented in films like Terminator or I, Robot, the fact is that nowadays clever algorithms contain a series of simple rules applied to a great series of numbers, and the result is called AI.

This study examines the use of a chat agent with four consecutive AI modules, as well as testing machine learning and information representation. This study provides a design framework for a program related to training content. While previous knowledge of chat agents and other factors can affect a user's ability to understand, the basic assumption is that all users can benefit greatly from the interaction with the agent and chat. Within this context, the following ideas are based on:

1. Collaborating with the agent helps to increase participation in the whole process.
2. Agent recognition and training content lead to user learning and understanding of how machines learn.

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2. RELATED WORK

Historically, computer use refers to mainframe computers for editing and writing hidden lines of text code that can be made. Learning a low-level programming language, such as BASIC established in 1964, meant remembering instructions and working in a solid text environment without feedback or help. That learning to think like a software engineer can be made easier and more playable is proved by Papert, who had the original idea of the Logo program in 1967 and made a line for Scratch's continued success [1].

When it comes to integrating CS into the curriculum, today's efforts largely incorporate the use of ML-based language-enabled language through platforms such as the Mechanized Learning for Kids [4] website and the Cognimates project [12 involving blocks that provide easy access of various cloud AI services. This does not explicitly provide a plan for building neural networks - connectors dealing with the programs they offer for training and using neural networks only.

To give some examples, Google's Teachable Machine [4] provides a web page where users can train the image classification system while TensorFlow provides a playground to collaborate, train, and test an in-depth neural learning net.

- *Learning with AI:* While most AI educational programs are the latest in a long line of ideas, the idea of introducing people to AI ideas began to work with Seymour Papert and Cynthia Solomon using the LOGO program and the Turtle robot [3, 5, 7, 9]. It has served as the basis for much of the current work. Many platforms teach AI by having an individual program in block-based languages including Cognimates [23], Machine Learning for Kids [29, 17] and eCraft2Learn [27]. Other platforms introduce AI within the context of robots, such as Popbots [19, 21], as well as performance enhancements [3] and MIT App Inventor AI Extensions [13, 17, 19].

- *Learning with Conversational Agents*: Conversation agents are also used for learning, often as intelligent educators and learning friends [5]. The structure of these communication systems varies greatly, from incorporations and results based on the text [6] to integrated agents that can express emotions [7].

Researchers exploring how to engage younger students in design activities involving AI [4] identified five "major ideas" of AI to guide the development of standards:

1) "Computers detect the earth using sensors";
2) "Agents maintain models / representation of land and use it for consultation";
3) "Computers can learn from data";
4) “Making social media agents is a major challenge for AI engineers”; and
5) "AI applications can affect society in both positive and negative ways" [13]].

The model development starts with the following questions about AI:

What is AI?

Explaining what AI can confuse even experts [16,12], as the term has changed over the years. Nilson describes AI as "that work dedicated to making machines smarter ... [where] intelligence is the quality that makes a business more efficient and foresight" [10]. However, Schank notes that the definitions of intelligence may vary depending on the investigator and their approach to understanding AI [16]. He suggests that there are two main objectives of AI research - "building a smart machine" and "finding a kind of intelligence" [16]. He then proposed a set of features that

included common "intelligence" - communication, knowledge of the world, internal knowledge, purpose, and art - emphasizing that the ability to read is the most important factor in intelligence [16].

What Can AI Do?

While AI has been able to find patterns in the amount of data, perform repetitive tasks, and make decisions in controlled environments, people now live better in many tasks that require art, emotion, information transfer, and social interaction.

How does AI work?

A better understanding of how AI works can help people build more sensible types of programs they work with. For this and other reasons, much of the research available on AI education in university and K-12 environments focuses on informing how AI works.

Cognitive Systems

Cognitive systems - or AI systems are rated after ideas about the human mind [4] - are used in a variety of application domains, including WordNet, IBM's Watson, expert systems, and cognitive educators. Most comprehension program messages cover topics related to information representation, planning, decision making, problem solving and learning.

Cognitive systems use many techniques for planning, decision-making, problem-solving and learning. Users may not need to understand all of these strategies in detail, but a higher understanding of how computers make decisions can help in interpreting and understanding the algorithms [29].

Machine Learning

Many students think that computers think like humans and want to make connections between human perceptions of understanding and machine learning [12]. Students are also often surprised that ML requires human decision-making and is not self-inflicted.

Research suggests that one of the ways to eliminate students' misconceptions about ML is to get involved in integrated integration. Sulmont et al. while others suggest that students develop physical algorithms to understand them in a practical way [4,6,12]. This technique has also been used in CS education [2]. In general, AI manual testing has been used as a means of implementing a variety of AI education programs (e.g. [4]), including projects where students can train ML models to analyze their movements and gestures [4,14].

Robotics

Understanding that AI agents can physically act on and react to the world is an important prerequisite for understanding robotics. Learning about sensors and their capabilities (one of the “big ideas” of AI [13]) can also aid in understanding how AI devices gather data and interface with the world.

This study provides the development of a platform and curriculum around the three “Great Ideas” in AI, as it directs ideas that have a major impact on making people understand about AI [3]. At the same time, these ideas also allow people to explore the use of a visual chat interface. The three ideas are:

• *Representation and Consultation:* People are expected to understand how the agent learns and represents new information. The agent generates two different visuals to indicate the representation of the information.

• *Conceptualization:* The agent also demonstrates the concept of how machines classify ideas. Individuals witness instances when the agent might succeed or fail in its learning and make attempts to correct it.

• *Social Impact:* The curriculum emphasizes the moral and social impact of the AI community through structured dialogue and reflection on the impacts of larger image environments.

Agent platform is a visual web connector that can be linked to a web browser and people engage with the agent in a chat in a small setting led by a personal facilitator.

3. PROPOSED MODEL

This study examines the use of a chat agent with four consecutive AI modules, as well as testing machine learning and information representation.

3.1. Overview of AI Modules

The AI curriculum consists of four modules: "Do You Know the Agent?", "Teaching a Lawyer", "Machine Witnessing", and "AI and Ethics". Before entering the first module, individuals learn to communicate with the agent through an introduction, where the agent greets and talks with them.

Part 1, “What Does the Agent Know?” introduces people to represent information and consultation using mind maps. The representation method used is a mind map or “mind map”, which people can analyse to find relevant attributes. Positive attributes (existing) are shown as blue circles, and negative (missing) circles are shown as red circles. Users can also analyze the corpus given by the agent to create mind maps, and thus draw connections between natural language sentences and related mind map details.

In the next module, Module 2, "Teaching Agent", individuals are assigned the task of providing the agent with data on selected subjects. People can give the agent any information about a topic they would like to find. This enables them to put AI learning experience into their knowledge and interests. Agent works as an AI with minimal knowledgeable information, and users help an agent create mind maps on each topic. The concept map concept is presented in Module 1 and is based on the following modules.

Module 3: "Machine learning", is where users look at the learning process and the agent's thinking. They ask the agent to make a guess based on a previously taught concept and the agent calculates the similarity of the words in each concept by using words that represent the words representing the agent ideas and showing these schools using a bar graph. It is important for users to understand why and why the agent may be incorrectly guessing by drawing a link between similarities within Module 2 mind maps and Module 3 scores, and how to use this link.

In the final module, Module 4, "AI and Ethics", facilitators lead a discussion on how data negotiating agents and data-learning agents are used in society with both positive and negative outcomes. These discussion questions are divided into the Learning Resources section. Users can think of situations where the agent makes mistakes, and then be asked questions such as, "Will the agent know if what we are teaching is right or not?" and “How would you feel if an agent

found out something wrong with you?". The purpose of this section is to empower users with AI design tools with ethical principles. The study also aims to test users on the social consequences of mistakes made by AI, and how they can reduce injuries (Payne 2019).

3.2. System Design

The system is designed to be easy to use. It can be used using any browser anywhere you have internet access. The main features of the program are (1) a speech synthesizer, (2) a speech identifier, (3) a semantic parser, (4) a word map classifier, and (5) a website visualizer, as follows:

1. Speech amplifier: This section includes the voice of the agent using the Web Speech API. It should be noted that a particular word from the visual interface of speech recognition should be chosen so that it is not as gender neutral as possible. (A common advice is to refer to the agent as "it" instead of "he" or "she".)

2. Speech identifier: This section converts user speech to text using the Web Speech API.

3. Semantic parser: This section performs natural language processing using NLTK [29, 32, 17, 18] and CoreNLP tools (Manning et al. 2014). The NLTK toolkit works with words, while the CoreNLP toolkit renders parts of speech [30] and processes sentences obtained from speech recognition. The adjective performs the following three functions used in each function.

> *a) Name identification:* As a job introduction, the agent asks people for their name and location. The relay conveys the input received after each query, removing all nouns, proper nouns, and foreign names. The specified name or location is the appropriate last name seen.
>
> *b) Subject Identification*: In the first module, the tester identifies which user the question is asking. Since the number of ideas that the agent is aware of is limited, the examiner searches for these ideas. When a familiar concept is found, the parser retrieves the identified concept and a pre-programmed mind map is displayed to users. These mind maps are created offline using a third-party explorer capability.
>
> *c) Mind Map Builder:* In Modules 1 and 2, the agent demonstrates his / her knowledge of ideas and words on mind maps that are generated according to sentence structure and speech components. An adjective identifies a field of concept for the interaction between descriptive words and a topic (e.g., a negative interaction between water and desert), and then sends this information to a web browser.

4. Classifier: This section classifies the word by comparing word representation using NLTK's Wordline Interface (Loper and Bird 2002; Fellbaum 1998). In each sense, all the descriptive words are compared to each other. Once the similarity between all pairs has been calculated, the overall similarity between a concept and topic is its weighted average similarity score. The classifier returns a normalized score for each topic, denoting the topic with the highest similarity score to be the topic that the concept relates to.

5. Visualizer: This section creates mind maps and histograms based on pre-defined sentences and user-defined sentences using D3.js [15, 25].

To show how the parts fit together, in the introduction, the system prompts the user to speak; sends a user voice response to a browser-based speech recognition, which converts the response into text; stores text response to user location session data; sends a text response to a server-based

server, processing the text for important details; returns the processed information to a browser-based speech compiler, which causes the agent to speak, causing the user to speak again; and repeats the process until it ends the conversation.

Figure 1. includes a view of the histogram, which shows similarities between the concept and the sentence of the title.

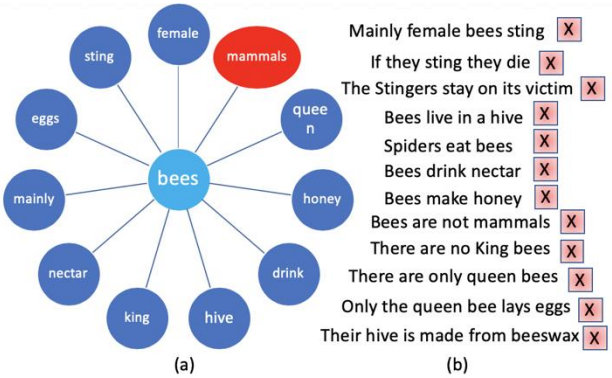

Figure 1: (a) Mind map composed of sentences in (b). This is shown in Module 2 on the agent's website. (b) Users of sentences have informed the agent during the study.

4. RESULTS AND DISCUSSION

To measure system performance, a small pilot study can be done to determine if people understand the visual representations. Once hired people can hear about the three different perspectives on information representation (Modules 1 and 2) and the three different machine learning perspectives (Module 3) shown in Figure 2.

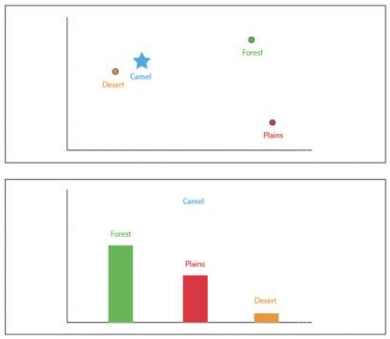

Figure 2: As shown in the orange bar in this histogram view, the agent can guess which concept will affect it.

Testing can also be done even if the knowledge of the learning platform and the content of the training improves people's understanding of how machines represent information and learn. Specifically, the level of user engagement can be assessed by measuring the number of sentences used in the conversation with the agent, and whether it corresponds to their level of understanding.

A consistent test protocol can be followed at different times. The size of the session can be from one to four, each with a facilitator. First, researchers can randomly test participants' information

on voice assistants such as Siri and Alexa via icebreaker. After this, they can conduct a pre-follow-up test for the agent (Figure 3). Modules 1 to 4 must then be completed respectively. All work will last ~60-80 minutes depending on the length of the conversation. People should do all the tests individually on paper and without the slightest distraction from the investigators. In addition to the measurement data from the test, researchers can also perform video recordings of the time, participants in log sentences contribute and record users' responses to test questions.

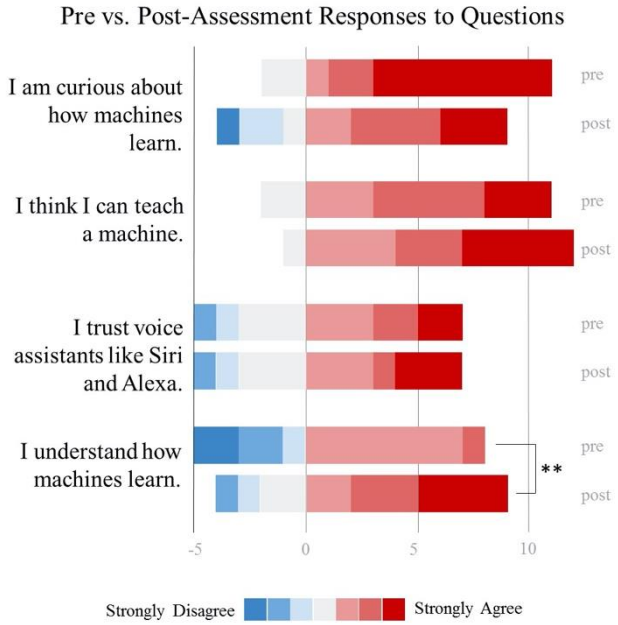

Figure 3: Sample responses to pre- vs. post-examination

Assessments

To answer the idea that people can learn effectively and to understand how machines learn, the following questions can be asked for assessment purposes:

1. What sentences can you say to the facilitator to create the following mind map in Figure 1? (This tests their understanding of how information is represented.)

2. What can you tell the agent about a particular name so that he can correctly guess the related topic? (This tests their understanding of how the agent reads.)

3. Why would an agent find it difficult to match another word to a particular topic even if he knows everything that needs to be known about them? (This is an open-ended questionnaire for examining potential mistakes an agent may make.)

4. Have you ever tried to mention the name ‘agent’ to the agent? If not, ask your tutor if you can try. Does the agent recognize its own name? If not, why not? Can you think of another name the agent would not see? (This is an open question in the agent's internal language management.)

These pre- and post-test assessments can also be used to assess individual self-awareness as an engineer and motivation to learn. People can be asked to rate how much they agree or disagree with the various statements on a scale of 1 to 5.

1. I want to know how a machine learns.
2. I think I can teach it to the machine.
3. I trust voice assistants like Siri and Alexa.
4. I understand how the machine learns.
5. The activities we have done today have been helpful in learning how machines learn. (Post-test only.)
6. The mind map of each concept and topic helped me think about the agent's brain. (Post-test only.)
7. The histogram helped me to understand how the agent made decisions. (Post-test only.)

5. CONCLUSION AND FUTURE SCOPE

This work introduces a development framework for a conversational agency that educates individuals about the representation of information and machine learning.

By training an agent, recognizing his mistakes, and retraining an agent, individuals can make sense of the intelligence of a representative. In the future, the content of the agent training should be expanded to address more topics in AI. Hopefully, this work will promote more AI training content using conversational agents and viewing tools to help individuals understand the AI algorithms.

The current framework of research has some limitations. First, it includes a small number of participants. Further testing may reinforce the claim that the agent is operating. Also, there is a need to create a future iteration of this study in which researchers can compare the performance of the visual interface of another chat agent.

Computer scientists usually rely on statistical tools to demonstrate that a particular underlying factor had a "causal" effect on the outcome of interest. While in the natural sciences, causal effects are measured using lab experiments that can isolate the consequences of variations in physical conditions on the effect of interest, more often than not, social life (including education through means of AI) do not permit lab-like conditions that allow the effects of changes in the human condition to be precisely ascertained and measured. This would merely provide evidence on *one* of the causes, which may not even be one of the more important factors. In a quest for statistical "identification" of a causal effect, scientists might often have to resort to techniques that answer either a narrower or a somewhat different version of the question that motivated the research. So, research can rarely substitute for more complete works of synthesis, which consider a multitude of causes, weigh likely effects, and address spatial and temporal variation of causal mechanisms.

For this study to be conducted, there is a need to control how participants interact with the agent by reducing their knowledge required for participants to be able to train the agent in real time.
Last, but not least, the skills and design considerations outlined in this paper will need to be expanded to keep pace with new discoveries, technologies, and rapidly changing social norms. Researchers and educators of AI, and related technology and education communities should be encouraged to both participate in intimate discussions and design considerations in this paper and use them to lead and promote artistic and future research on AI learning.

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AUTHORS

Ayse received her MSc in Internet Studies in University of Oxford in 2006. She participated in various research projects for UN, Nato and the EU regarding HCI (human-computer interaction). She completed her doctorate degree in user experience design in Oxford while working as an adjunct faculty member at Bogazici University in her home town Istanbul. Ayse has also a degree in Tech Policy from Cambridge University. Currently, Ayse lives in Silicon Valley where she works as a visiting scholar for Google on human-computer interaction design.

AN OBJECT DETECTION NAVIGATOR TO ASSIST THE VISUALLY IMPAIRED USING ARTIFICIAL INTELLIGENCE AND COMPUTER VISION

Ethan Wu[1], Jonathan Sahagun[2] and Yu Sun[3]

[1]St John Bosco High School, Bellflower, CA 90706
[2]California State University, Los Angeles, Los Angeles, CA, 90032
[3]California State Polytechnic University, Pomona, CA, 91768

ABSTRACT

The advent and worldwide adoption of smartphones has enriched the lives of many people. However, one particular group--the visually impaired--still need specific apps to help them with their daily lives. Thus, I'm developing this Smart app to specifically help the visually-impaired. Specifically, I hope to integrate the functions of Google Maps into the Smart App. While Google Maps functions well as a GPS for the average person without any impairment, I'm adding additional features to the Smart app so that it would guide the eye-sight impaired. For example, I will use the camera of the Smartphone to guide the user such that it would take the user to the desired destination. Thus, using the inherent functions (camera) of a phone, the Smart app can gently and safely guide any sight-impaired person to a predetermined destination by walking. One can think of Smart app as an improvement upon Google Maps -- for the visually impaired.

KEYWORDS

Object detection, Google Maps, iOS, Android.

1. INTRODUCTION

The primary motivation to create this particular smartphone app is to help visually impaired persons to experience the modern convenience of Google Maps [4, 5] while enriching their lives. Toward this goal, I had previously designed a similar product 2 years ago called "Sonar Stick" [6] that acts as a "GPS guided" walking cane for the visually impaired. Thus, my motivation to help the visually-impaired goes back several years. I just believe that everyone should enjoy the modern convenience of technology, and that technology is meant to transform every one of us, and not leave anyone behind.

However, after I completed my design of the "Sonar Stick," I felt that mass-producing them would become challenging as well as time-consuming. Thus, I began to think of different ways to allow my idea to become fruition while bringing such a product to a wider audience. With the advent and the popularity of smartphones, it's natural that I'm now proceeding to develop an app, which will reach a wider audience without the obstacles of manufacturing. In other words, to realize my goal, I've changed course from hardware (Sonar Stick) to software (Sonar Object Detection) app. With this approach, I feel very confident that I'm able to help the visually-impaired and transform their lives in a much positive way.

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Currently, perhaps Google Maps is the closest tool to help navigate us to destinations we enter. However, Google Maps is intended for the mass, as it works extremely well for those who have regular eyesight. However, for the visually-impaired, Google Maps (even if its speaking function is activated) still have a drawback such that the visually-impaired person does not know WHERE to start. For example, Google maps would start off navigation by announcing go West on Main Street, and then turn left on Washington Ave…."

For the visually impaired, they wouldn't know which direction to start, and it's predictable that someone with bad eyesight could start off in the wrong direction (and possibly spin in circles). That's where my smartphone app comes in--to eliminate this very problem. Specifically, the "Sonar Object Detection" app uses the phone's camera to act as "eyes" for the visually-impaired, such that s/he would start off with the correct direction. Thus, my app would synchronize the very best features of Google Maps and the Smartphone (camera). Together, the app and Google Maps would guide the user to the destination safely--in a time that's comparable to ordinary people. The visually-impaired then would enjoy the benefits of modern technology like the rest of us.

So, one can view my smartphone app as a one to improve upon existing technology (Google Maps). For technology to improve, one possible way is to improve upon existing technology. That's the route I'm taking and I sincerely believe it would make a great difference in people's lives.

In this paper, we follow the same line of research and method by Google, especially Google Maps. Since this is an existing method and product, there's no need to "invent" another Google Maps. Instead, we hope to improve upon Google Maps such that the visually-impaired would enjoy the benefits of Google Maps. As outlined above, we are making this app to tailor specifically to the visually-impaired.

Specifically, we are designing this app such that the user could hold up a smartphone. A quick Google search reveals that there are currently no products or app that cater to the visually-impaired in the area of GPS guidance. Unfortunately, the visually-impaired have been ignored, and ignored for far too long. We seek to change this apathy for the blind and visually-impaired. Therefore, we believe our method will result in helping others, a very worthwhile goal.

To testify that our app actually works we decided to head to the streets and actually test our app out. First, we opened a beta version of the app on our phones and started walking down a variety of paths, from streets next to a busy road to streets next to a shopping plaza. Our app began to read out what was in front of us, showing that our app actually worked as we expected.

When walking on the street, mimicking what a visually-impaired person would do with a cane, we practiced scanning our phone from left to right, and the app announced out loud what the nearby objects were immediately and accurately. On a busy street, where the biggest danger to a visually impaired person would be cars, the app accurately announced incoming cars and traffic lights, going so far as to identify the shape of the car, such as a track. On the street next to a shopping plaza, the app properly identified large plants, trees, and also people as they walked by. Checking accuracy was key to this experiment to ensure that when this is hopefully used by the visually impaired, it will be better than the cane they typically use and will truly help them.

We knew that this experiment proving that our app's capabilities have no mistake was not enough, so we decided to contact a foundation called the American Foundation for the Blind to help us review our app and also to give us any suggestions on anything that we could improve to

achieve our goals which is to ultimately allow visually impaired people to successfully use our app and help their daily life.

The rest of the paper is organized as follows: Section 2 gives the details on the challenges that I met during the experiment and designing the sample; Section 3 focuses on the details of our solutions corresponding to the challenges that I mentioned in Section 2; Section 4 presents the relevant details about the experiment I did, following by presenting the related work in Section 5. Finally, Section 6 gives the conclusion remarks, as well as pointing out the future work of this project.

2. CHALLENGES

2.1. Challenge 1

Initially, the biggest challenge I faced was coding a functional app that incorporated all of my ideas and goals. At the time, I had no experience in coding or creating an app, which was challenging because that meant I had no way of channeling my ideas into reality.

So, I looked for resources elsewhere. I reached out to Professor Jonathan Sahagun of Cal State Pomona, shared my ideas, and requested assistance. Professor Sahagun is a Computer Science professor, and he taught me how to code and how to create this app.

Learning to code was difficult since it was a brand-new language, and I found myself having trouble navigating a brand-new unfamiliar world. As a result, starting the creation of the app was the most difficult. Gradually, however, various aspects of coding started to make sense, and with some guidance from Professor Sahagun, I was eventually able to create the beta version of this app.

2.2. Challenge 2

When creating this app, I did so from an Android standpoint, both because Androids are a very commonly used phone and because I had one myself. So, the resulting app that I currently have is very accurate and useful on an Android [7, 8, 9]. However, this app has not yet been adapted for iOS [10] devices.

When attempting to adapt the app for iOS, I encountered multiple glitches and bugs. This is a critical challenge because iOS phones are extremely common amongst the visually impaired phone. This app was created to help the visually impaired live an easier and more free life, so for this app to only be restricted to Android users would be the opposite of our intention to aid the visually impaired.

At the moment, I have not yet figured out how to properly have this app be available on iOS. I have made multiple attempts and thus, multiple improvements, but it appears there's still some time needed before I can adapt the app so it is suitable for everyone. This is a challenge I must and will overcome for the sake of the visually impaired.

2.3. Challenge 3

It has been challenging to figure out how to spread the information about this new app. This app will be of great aid to the visually impaired population, yet I originally had no way of reaching

out to them and letting them know of this app. I considered advertisements or social media presence, yet I realized those would not be the most efficient way to reach the visually impaired. To solve this challenge, I contacted the American Foundation for The Blind [11, 12, 13], asking on how best to distribute knowledge of the app to reach the visually impaired. This foundation offered a partnership for people who are aiding the visually impaired. Within this partnership, they would help us spread the information of this app to the visually impaired so they can use our app.

With this foundation, an institution with direct and wide access to the visually impaired, I know that our app will be able to reach more people.

3. SOLUTION

The “Sonar Object Detector" App is a smartphone app that directs a visually-impaired person to walk to a destination using the smartphone camera along with Google Map Instructions. Once the user downloads this app (currently the app is only compatible with Android phones), the user can activate the app by tapping on their phone to begin use.

Once activated, the “Sonar Object Detector" app will ask the user to input an address, much like using Google Maps. Once the address is inputted, the app will synchronize with Google Maps and then activate the phone’s camera. The user is then instructed to hold up the camera such that the camera can “see” the direction and, together with the app, locate the exact location of the user on Google Maps.

Thereafter, the app will gently guide the user to his/her destination, with the camera acting as “eyes” and the phone’s speaking blaring out the audio directions of Google Maps.

```
void startStreaming(){
  if (controller.value.isStreamingImages){return;}
  if (controller.value.isTakingPicture){return;}

  controller.startImageStream((CameraImage img) {

    imageStill = img;

    if (!isDetecting) {
      isDetecting = true;
      Tflite.detectObjectOnFrame(
        bytesList: img.planes.map((plane) {return plane.bytes;}).toList(),
        model: "SSDMobileNet",
        imageHeight: img.height,
        imageWidth: img.width,
        imageMean: 127.5,
        imageStd: 127.5,
        numResultsPerClass: 1,
        threshold: 0.60,
      ).then((recognitions) {

        _recognitions = recognitions;

        setState(() { });

        // Add to objectsOnscreen
        if(_recognitions.length > 0) {
          for (var r  in _recognitions){
            if (!objectsOnscreen.contains(r['detectedClass'].toString())){
              print(objectsOnscreen.toString());
              print("Adding: " + r['detectedClass'].toString());
              objectsOnscreen.add(r['detectedClass'].toString());
            }
          }
        }

        speakObjectsTrigger();
        isDetecting = false;
      });
    }
  });
}
```

Figure 1: core code for starting the camera and detecting objects from the camera stream

There are multiple components to this system. First is the camera, which the user moves from side to side in order to capture their surroundings. The camera acts as the “eyes” of the person, absorbing the objects around the user. Next is coding of the app, which allows the recording information from the camera to be transferred into actual objects that are spoken out. The next component is the speaker, which announces the type of objects/people to the user. And of course, the final component is this app’s connection to Google Maps, which verbalizes the directions all while the “Sonar Object Detector” app describes the surrounding environment. This way, the visually-impaired user can reap the benefits of technology that the rest of us enjoy.

Above is the function used to start the camera and detect objects from the camera stream. The function starts by returning if the camera controller is already streaming. Line 4 of the function starts the camera stream. An anonymous function is created as the argument of the camera controller’s startstream function. The anonymous function takes a frame from the camera stream. In the function a lock, isDetecting, is used to make sure tensorflow is only ever running once. The TensorFlowLite package is used for object detection. The camera image from the camera stream is passed to the tflite’s objectDetectionFrame function with some other parameters such as requiring the object detection be 60% confident in its detections. When the detection has completed it returns a list of recognitions that contain the objects it has detected, their location within the camera image and their size. That list is used to draw rectangles on top of the camera feed in the app and to have the app speak the objects that were detected.

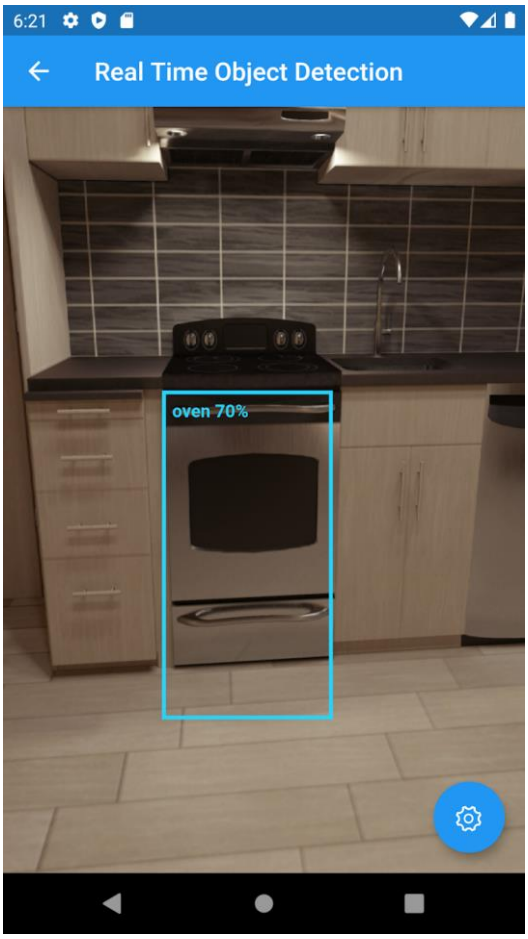

Figure 2: an example of object detection

4. EXPERIMENT

In order to evaluate the accuracy of my app, I had to test it in as many types of situations a visually impaired person would experience in their everyday life. So, I divided my experimentation into two aspects — walking outdoors and indoors in a variety of situations.

I tested the beta version of my app along 3 different scenarios: a busy street full of cars, a shopping plaza, and a pedestrian-filled area. So, the independent variable was the type of area I was in while the dependent variable were the objects recorded. I recorded the types of objects that were identified and also compared it to what I was seeing in order to see if it was accurate. Since the app was able to catch any objects that could serve as a hazard, I only recorded the types of objects in the table below.

Type of Area	**Types of Object**
Busy Street	Cars, traffic lights, curbs, fire hydrants
Shopping Area	Potted plant, people, lamppost, cars
Pedestrian Area	People, trash cars, statues

In the table above, it is evident that many different types of objects were identified in each type of area, demonstrating this app's capabilities.

For my second experiment, I assessed different indoor situations, including different rooms and different shops. Since I had to test out situations both inside the house and indoor moments outside the house, there were more independent variables to test out. I ended up having a total of 5 independent variables: bedroom, bathroom, living room, grocery store, and mall. My dependent variables were the same as Experiment 1 — I was observing the objects that the app announced. The app was very specific in what type of object was announced, allowing me to see that it would be very helpful to the visually impaired.

Type of Area	**Types of Object**
Bedroom	Bed, desk, chair, lamp, picture frame
Bathroom	Sink, toilet, bathtub, soap dish
Living Room	Couch, table, chairs, lamp, plates
Grocery Store	Various produce, tables, counters, baskets, people
Mall	Trash can, people, tables, stands

Similar to Experiment 1, the table illustrating Experiment 2's results offer a variety of objects identified by the app.

Before conducting the experiment, I had several versions of the app that were not as adequate, so I had to make several changes to ensure that the information from the above experiments would be utilized best.

Overall, the results of my experiments illustrate that this app is very sufficient. Upon scanning the camera, the app caught any object that could possibly be a hazard for the visually impaired, showing that it has met my expectation. It is essential that this app works for any environment, and the results demonstrate that this app will be useful both inside and outside the house.

For example, near the shopping plaza, the app was even able to identify a large potted plant, which is very specific and important, because it could be a falling hazard. Additionally, in the house, there are a lot of objects that are easily shattered, so this app being able to identify them offers a greater capability than a cane.

These results show that this app will truly allow the visually impaired to explore and have more freedom than before.

5. RELATED WORK

This academic journal analyzes how location navigation is very simple for the outdoors, but is very lacking in indoor environments. So, the article proposes that buildings set up radio frequency identification (RFID) tags [14] in order to provide the current location of a visually impaired person to help them navigate indoors [1]. This work emphasizes the involvement of building managers or agents, since this is a whole system that must be installed. In contrast, the app I have created is more tailored to individual people and their desire to explore. While RFID tags help a visually impaired person know their location indoors on the way to their destination, the “Sonar Object Detector" App is purely for detecting potential hazards on a visually impaired person’s path. Additionally, the app works both indoors and outdoors, while the article is proposing just an indoor system.

L. Ran, S. Helal, and S. Moore recognizes that there is a lack of navigation system for the visually impaired that works both outdoors and indoors [2, 15]. So, they propose a system called Drishti, a wearable computer with wireless connection and vocal communication, to help direct a visually impaired person wherever they go, both indoors and outdoors. The proposed system of Drishti is very similar to the “Sonar Object Detector” App in the way that it works both indoors and outdoors. The app I have created is just a smartphone app in comparison to Drishti being a wearable computer. As a result, Drishti is more likely to be more like a person offering aid to a visually impaired person than an app announcing objects. However, Drishti is most likely more expensive than the app, which is free.

This research paper, published in 1996, describes an experiment they conducted on how GPS systems can work with the visually impaired [3]. The successful experiment tested how GPS receivers on a wireless phone carried by a visually impaired person would identify their location relative to their environment. This paper is rather similar to my own, in the way that a GPS is involved, especially when synchronizing with Google Maps. It is notable that this paper was published in 1996, so phones have made great improvements since then. The “Sonar Object Detector” App involves using a smartphone app, which did not exist back then. So, this paper is similar to mine, only a bit more outdated.

6. CONCLUSION AND FUTURE WORK

In this project, I proposed using a smartphone app to scan visually impaired person’s surroundings in order to point out any potential hazards. I was successful in creating an app that would accurately identify any hazard in most types of situations a visually impaired person would encounter.

In order to test how accurate my app was after I made a seemingly successful beta version, I had to conduct an experiment. In the first experiment, I tested what kind of objects the app would identify in 3 outdoor environments — a busy street, a shopping plaza, and a pedestrian-filled area. The "Sonar Object Detector" App identified a variety of objects, ranging from a fire hydrant to a truck to a potted plant. In my second and final experiment, I tested how the app would work in 5 indoor environments — a bedroom, a bathroom, a living room, a grocery store, and a mall. I chose these locations thinking about locations a visually impaired person would want to travel to/through independently. Just like with Experiment 1, the "Sonar Object Detector" app was successful in announcing objects ranging from plates to a lamp to baskets to furniture. Overall, the experiment showed that the app was very capable and adaptable in most situations.

During my creation of the app, I encountered three main challenges. First, I had little to none coding experience so I struggled with creating an app from scratch. So, I reached out to a professor who helped guide me through the process. Second, I was creating the app from an Android perspective and have encountered several obstacles on adapting it to iOS, so I have yet to overcome this challenge. Third, I struggled on how to spread knowledge of this app to the visually impaired. As a solution, I reached out to the American Foundation for the Blind who have partnerships for those wanting to help. Through them, I was able to spread the knowledge of this app much farther.

Like stated above, the biggest limitation is that this app is only available on Android. This is significant because iOS devices are so commonly used, meaning that we are currently leaving out a large sector of the visually impaired. So, it is imperative that more work on the app must occur. Furthermore, the accuracy of this app could use more improvement. As of now, the "Sonar Object Detection" App can accurately identify any possible hazards, but only at a short distance. That is sufficient in making sure a visually impaired person is safe, but if the app was able to announce objects that are at a greater distance (and announce the distance as well), this would allow a visually impaired person much more knowledge of their surroundings.

This app is currently available for download on Androids, and I believe that I should not wait until the iOS version is available so people can access it as soon as possible. However, I have already begun working on the iOS version and have made great strides and plan to have that out once I have tested its accuracy. Additionally, I plan to adapt what this app offers to really allow a visually impaired person to navigate the world freely.

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PREDICTING THE 2020 US PRESIDENTIAL ELECTION WITH TWITTER

Michael Caballero

Divison of Computing, Data Science, and Society,
University of California, Berkeley, Berkeley, CA, USA

ABSTRACT

One major sub-domain in the subject of polling public opinion with social media data is electoral prediction. Electoral prediction utilizing social media data potentially would significantly affect campaign strategies, complementing traditional polling methods and providing cheaper polling in real-time. First, this paper explores past successful methods from research for analysis and prediction of the 2020 US Presidential Election using Twitter data. Then, this research proposes a new method for electoral prediction which combines sentiment, from NLP on the text of tweets, and structural data with aggregate polling, a time series analysis, and a special focus on Twitter users critical to the election. Though this method performed worse than its baseline of polling predictions, it is inconclusive whether this is an accurate method for predicting elections due to scarcity of data. More research and more data are needed to accurately measure this method's overall effectiveness.

KEYWORDS

Big Data, Internet of Things, Machine Learning, Data Mining, NLP.

1. INTRODUCTION

Over the course of this past year, I have been conducting independent research to predict the winner of the 2020 presidential election. The specific topic is estimating the public opinion of candidates throughout the 2020 presidential election using social media data. Due to the difficulty of collecting social media data, this project has been simplified to only use Twitter data. The main question for this project is: can social media replicate or outperform the accuracy of national polls in predicting the vote share of the 2020 US presidential election? This these is idea stems from an interest that I have always had in politics and government. This research allows me to combine my data science skill set with my passion and informal knowledge of politics.

The use of data in political campaigns has been publicly highlighted in recent years, and research on effectively utilizing data is quite relevant to the future of political science. A robust and repeatable methodology for polling support of campaigning politicians would significantly affect campaign strategies; a method with similar accuracy to traditional polling techniques could potentially replace those systems. In some races, like those for state senators or governors, it could be the only reliable method for polling as traditionally these races do not have accurate polling data. Nevertheless, prediction with social media runs into other significant obstacles already tackled with traditional polling platforms and techniques. For instance, traditional polling specifically accounts for geographical and demographical issues. In particular, Gayo-Avello mentions how traditional polling methods accounts for noise like spam tweets, self-selection bias, likely voters, and demographical biases [1]. Classical polling focuses heavily on these methods

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to create a strategy for measuring public opinion that emphasizes only including opinions from prospective voters, removing information not related to the election, and correcting any bias based on the demographic bias of those surveyed. While the field of polling through social media has high aspirations, there are still many important challenges to overcome.

More accurate polling insights would help parties decide which races are highly competitive and thus where precious party funds could be spent most effectively. Pouring party resources and funding into a tight race is an effective strategy for political parties. And, this method could even be important for races with extensive polling data. Traditional polling methods are often expensive and time-intensive so a cheap, efficient model that relieson social media data would provide valuable complementary data. In sum, Twitter and other social media platforms can provide a huge sample size of data that could allow cheaper polling in real-time.

While the specific case of electoral prediction using social media data is interesting and would be an important contribution to political science, this research is also important for all social sciences. This research shows the potential for social media prediction to impact political science by allowing campaigns, analysts, and politicians to better understand voters and their political support. Specifically, it gives a glimpse into potential future techniques that could facilitate this understanding. But it also furthers social science by contributing to a new method of prediction based on social media data. This type of prediction foreshadows a transition in social sciences as these disciplines are undergoing a shift from data scarcity to abundance. As more interactions happen on digital platforms, the capacity of social scientists to predict the attitudes and behaviors of society should grow. Thus, this field of electoral forecasting using social media data is a representation of a larger transition in the social sciences due to growing data availability.

2. ETHICAL ISSUES

As of now, I do not see any prominent ethical issues with applying this research to political campaigns. There is a small possibility that developing a better method of polling could have negative impacts on groups without a fair share of political power. Better methods of polling would likely first be utilized by politicians in power. These politicians have the most connections and resources and often are the first to adopt new successful campaign techniques. It could give the powerful an unfair advantage in influencing democratic outcomes thus having negative repercussions on those marginalized or excluded from the political sphere like people with disabilities or religious and ethnic minorities (National Democratic Institute). I find this ethical concern to be small because this is only one possibility of developing better polling methods. This development could also be beneficial to those without power by evening the playing field of politics -- making accurate polling data cheaper and thus more accessible to all. As it is difficult to predict how any new technology will affect society, these ethical concerns should be considered though should not prevent progress in this particular research.

One bigger ethical question with this broader subject of research, using social media to measure public opinion, is the use of social media data without the consent of its users. Yes, social media users do sign Terms of Service before utilizing these platforms but it is safe to assume most users do not understand how their data is being used. Third parties' use of social media data is quite extensive and further research and thought are needed to determine whether this type of research is actually ethical.

3. LITERATURE REVIEW

Gayo-Avello's meta-analysis on electoral prediction from Twitter data is the first meta-analysis published on the subject and one of the best introductory resources to gain a better understanding of the literature [1]. While this meta-analysis is slightly outdated, it still relates to the current state of the field and provides a great snapshot of the accomplishments and challenges of early research. It mainly analyzes ten different studies that attempted to predict 16 different elections. This paper suggests that any approach to predict elections from Twitter data should be judged through four aspects: data collected, approach to deal with noise, methods of prediction, and overall evaluation. "Noise" in this context is mainly referring to tweets containing disinformation, propaganda, and rumors, or those originating from spammers or robots that obscure the regular interactions on the platform.

While all four aspects discussed are important, the two that are critical to understanding the field are methods of prediction and evaluation. The data collected has varied with each project and noise has mainly been ignored in recent research likely because it amplifies sentiments already on the platform. At this point, the research only focused on two methods of prediction for inferring votes: counting tweets and sentiment analysis. Tweet counting is a simple method that counts the number of mentions for a candidate or party assuming that the vote is strongly correlated with this number. Sentiment analysis focuses on scoring tweets as positive or negative, then aggregating these scores to determine electoral outcomes. On evaluation, he points out that there is little consensus in the literature currently and thus there should be consistent ways to report and compare findings. Gayo-Avello summarizes three main ways to evaluate electoral predictions. First, predicting the winner; did the method predict the correct outcome? Second, what is the mean absolute error (MAE) between predicted vote share and actual vote share? Lastly, he suggests measuring the correlation with pre-electoral polls using metrics like R^2 or root mean squared error. Importantly, Gayo-Avello suggests using an election baseline to provide more context to the accuracy of reported results. He asserts that MAE "does not allow for comparison neither across papers nor across races" and that underperforming a baseline "should be considered unsuccessful" [1].

Yet Gayo-Avello does heavily criticize the field of research as a whole, arguing that: "(1) baselines chosen to evaluate performance up to now are not realistic; (2) simple methods achieve inconsistent results when replicated; and (3) their presumed tolerance to noise should not be taken for granted but much better substantiated" [1]. And up to this point, common sense would agree as the field of electoral prediction with Twitter data had researchers often concluding different results and disagreeing. His last remarks accurately note that for a method to gain credibility it must correspond to a series of elections and should be generalized for different elections in different countries.

Skoric et al. provide an updated perspective of electoral and public opinion forecasting using social media data in the only other meta-analysis assessing the predictive power of social media data [2]. Skoric et al. first discuss the importance of the field of measuring public opinion; they counter critics of this field saying that "dismissing social media data as being invalid due to its inability to represent a population misses capturing the dynamics of opinion formation" [2]. In their analysis, the starting point for comparing methods of measuring public opinion is in examining the diversity of methods. The two main methods in the literature are categorized as either sentiment-based or structural-based. Sentiment methods have only slightly evolved since their definition in the previous meta-analysis -- utilizing lexicon-based or machine learning approaches to capture positive or negative sentiments and predict vote share. Conversely, previously defined tweet counting methods have evolved into this broad category of structural analyses. These methods utilize metrics of social networks like mentions, likes, and replies, to

encompass the relational connections of the social media platform. Most often in sentiment analysis, researchers will generally sum the number of tweets multiplied by their sentiment and use the proportion of each candidate to represent vote share. In structural analysis, proportion of vote share is simply represented by proportion of total mentions or likes. Combining additional sources of data beyond one social media source is complex with different techniques depending on the literature. Skoric et al. also analyze these different social media sources that literature in this field utilizes, providing insights into what platforms could be the best for measuring public opinion. Lastly, they compare the differences in methodology and data sources using a combination of MAE and R^2. Similar to GayoAvello[1], Skoric et al. emphasize the need for "a more standardized way of reporting data collection methods and statistical estimates of predictive power" [2].

The results of this meta-analysis provide future researchers hints at what methods would work best in measuring the public's political opinion. This meta-analysis focused on 437 estimates from 74 different research studies. In these comparisons between data and methods, they emphasize that R^2 be the primary metric for comparison as R^2 and similar correlation metrics "manifested low variance and thus are more stable across different studies" [2]. They found that structural approaches, with a mean R^2 of 0.605, perform substantially better than sentiment approaches, mean R^2 of 0.492. Interestingly, they also measured studies that combined structural and sentiment approaches and found these to have the highest average R^2, 0.621. For social media data sources, there were a number of different platforms compared including Twitter, Facebook, forums, blogs, and Youtube. Of these platforms, Twitter ranked second-best by MAE, but fourth-best by R^2; blogs performed best by both of these metrics.

Tumasjan et al. is perhaps the most influential piece of literature in this field with many scholars agreeing that this article started this line of research [3]. It used the 2009 federal election in Germany to "investigate whether Twitter is used as a forum for political deliberation and whether online messages on Twitter validly mirror offline sentiment" [3]. In practice, this study used over 100,000 tweets that mentioned a party or politician in the election and performed two separate analyses, one volumetric and one sentiment-based. They concluded that the sentiment analysis reflected some of the nuances of the campaign and found that just the number of messages reflects the election result and was close to replicating the accuracy of traditional election polls.
Jungherr et al. [4] and Metaxas et al. [5] provided a quick criticism to Tumasjan et al..The first study by Jungherr et al. repeated the analysis performed by Tumasjan et al. and found that their claims were unwarranted for a number of reasons. Mainly, Tumasjan et al. failed to specify well-grounded rules for data collection, the choice of parties to track, and the correct period. Jungherr et al. found a larger MAE and concluded that Tumasjan et al. made an incorrect prediction when taking into account all parties running for the election. Conversely, Metaxas et al. tried to duplicate the findings of Tumasjan et al. by performing a volume and sentiment analysis on several senate races. This study concluded that these methods for analyzing Twitter data are slightly better than chance for predicting elections. And Metaxas et al. suggested the use of a baseline, finding that those methods "were not competent compared to the trivial method of predicting through incumbency" [5].

Bermingham and Smeaton used the Irish general election to investigate how to mine political sentiment through social media data [6]. Collecting tweets that mainly mentioned a party name or abbreviation, this study utilized both volume and sentiment-based analyses to measure vote share. They concluded that Twitter does display a predictive quality with the volume analysis being a stronger indicator than sentiment analysis. But,Gayo-Avello does find that this method, while predictive, "was not competitive against traditional polls" [1].

Jürgens et al. investigated political communication on Twitter by extracting a directed network of user interactions [7]. The study found that it exhibits small-world properties with the most well-connected nodes having the strongest influence on information dissemination on the platform. Interestingly, Jürgens et al. concluded that Twitter political communication is "highly dependent on a small number of users, critically positioned in the structure of the network" [7].

Shi et al. analyzed millions of tweets over the course of months leading up to the 2011 republican primary elections [8]. This study analyzed tweets collected over a six-month period primarily using a volumetric analysis with and without a sentiment analysis. The researchers also included a geographic analysis measuring the public opinion in certain states training their linear regression model on the RealClearPolitics (RCP) aggregate polling numbers for certain states. While Shi et al. did accurately predict trends for half of the candidates, they did not accurately replicate patterns in the polling of the other half of the field.

MacWilliams studied 2012 US senate races utilizing fan participation and mobilization metrics from Facebook to make electoral predictions [9]. The two metrics this paper focused on was likes on a candidates Facebook page and Facebook's "people talking about this" (PTAT) metric which counts interactions between users and a candidate's page.This paper concluded that their Facebook model was a better predictor than aggregated polls of outcomes in the senate races for five of the eight weeks they predicted the vote share. Though unrelated, this paper is one of the first to indirectly implement Jürgens et al.'s [7] findings that political communication in social networks is dependent on critical users. This shows that measuring the reaction or popularity of a candidate on social media could be a key factor in accurate electoral prediction.

Cameron et al. examined the ability of social media to predict election results in the 2011 New Zealand general election using both Facebook and Twitter [10]. This study mainly tracked the size of the 453 candidates' social media networks by collecting the number of friends a candidate has on Facebook and the number of followers a candidate had on Twitter. They found that "the social media are often statistically significant, but the size of their effects is small" thus concluding that "social media only has a practical effect in elections that are likely to be closely fought" [10].

Mirowski et al. investigated whether tweets created during the 2016 US presidential campaign could make accurate predictions about changes in a candidate's poll score trends [11]. This study collected 12 million tweets that mentioned candidates and tweets directly from candidates' accounts over the course of 60 days. For prediction, Mirowski et al. utilized a multivariate time series analysis to figure out whether temporal modeling has greater predictive power than attribute-based modeling. As this paper researched into whether the polling trend could be accurately classified as increasing or decreasing, it is difficult to compare their evaluation metrics with most of the other literature in the field. But, they did conclude that time-series models outperformed traditional attribute-based models.

Vepsäläinen et al. attempted to measure public opinion in the 2015 Finnish parliamentary elections using Facebook likes [12]. They collected data on 2.7 million Facebook likes directly from 2146 candidates' Facebook pages to estimate vote share for the 200 seats in the Finnish parliament. While they found a significant positive relationship between votes and Facebook likes, they concluded that their method was less accurate than using incumbency or traditional polling for figuring out whether a candidate would be elected.

Budiharto and Meiliana accurately predicted the Indonesian presidential election before the election occurred, tracking public opinion using Twitter data [13]. They collected tweets from presidential candidates and tweets containing the relevant hashtags for a combination of

structural and sentiment analysis. While this paper did accurately predict the election, it did not publish performance evaluation metrics like MAE or R^2.

Awais et al. accurately predicted the 2018 General election in Pakistan using an array of different data sources from past election data and Twitter to approval polls [14]. Their model effectively predicted the winning candidates for every national assembly seat and predicted the seat share of political parties with 83% accuracy. For their Twitter data, they collected 640,000 tweets containing specific keywords and locations for three weeks before the election, utilizing a combination of sentiment and structural analysis to understand underlying support for the party. In sum, they concluded that "the right mixture of machine learning and artificial intelligence models could have a significant impact on the modern day political landscape" [14].

Sabuncu et al. is the first study attempting to predict the 2020 US presidential election with Twitter data [15]. It attempted to forecast election results using the number of positive, negative, and neutral tweets, ranking these tweets by their structural significance, which they determined to be the number of retweets. For their model, they used an autoregressive fractionally integrated moving average model (FARIMA) and 10 million tweets collected from September to November. They concluded that this method was more accurate than even polling data with a 1.52% MAE.

After a thorough review of the literature in the field, it is clear that there are a number of critical decisions which factor into the overall method for measuring public opinion from social media data. First, should one utilize data not from social media, and if so how should that information be used? Early research in this field focused only on using social media data but it appears that this decision was in part to establish that Twitter was a "forum for political deliberation" [3]. Recent research has found accurate methods for prediction involving polls and surveys to create "the right mixture" of data [14]. Since critical data for election prediction like aggregate polling metrics will not soon be replaced by these social media-based methods, it seems short-sighted to create a model that does not input this information. Second, what type of features should the model focus on from the social media data? From the accuracy of most recent studies and the conclusions of Skoric et al. [2], it seems clear that the combination of a structural and sentiment analysis provides the best accuracy as it utilizes more features from the data. Third, what type of analysis will be performed? This aspect of the model seems to have less impact than the data collected or the features analyzed, but still impacts the overall accuracy of the model. While supervised machine learning methods are common, this type of modeling is a time series problem and studies show that time series analysis provides accurate results -- sometimes more accurate than attribute-based models [11]. While these are the most important aspects of an electoral prediction model based on social media data, a fourth important aspect is the attention to key figures in the election process. Since social media data exhibits small-world properties, it is important to place emphasis on the most important figures and track the response to their use of social media [7].

This paper attempts to create a novel contribution to the field of measuring public opinion by performing a time series analysis on the sentiment and structural components of social media data while emphasizing the critical users and utilizing polling data. So that these results can be compared with others in the field, this paper will evaluate based on the MAE and R^2 standard established by Skoric et al. [2].

4. DATA

One of the biggest challenges of this project was to overcome and work around the scarcity of social media data. Though the preferred method was to perform prediction using multiple platforms, Twitter became the sole source for social media data as it was the easiest platform to

collect data from and had the most publicly accessible datasets for this election. Even though Twitter has the most accessible data, it still provides its own challenges and obstacles.

Most free Twitter data using a developer account to access the Twitter API is only accessible as historical tweets from specific accounts or tweets collected in real-time while searching for keywords, hashtags, phrases, or account mentions. Twitter has recently opened up access to its full historical archive of tweets for academic researchers as of January 2021 but this access is not extended to undergraduate researchers. Unfortunately, this data roadblock was unknown during the course of the election (when I was still performing general research on the field and unsure of what data to collect) and thus limited the amount of data collected. For this project, four different social media datasets were evaluated for potential use but only two were used in the final analysis -- one publicly available online and one personally collected.

The first dataset utilized in this paper's analysis was a 1.7 million tweet data set from Kaggle user Manch Hui which scraped all tweets from 10/15-11/8 that included "#DonaldTrump", "#Trump", "#Biden", or "#JoeBiden" [16]. While this dataset only covered a limited amount of days before the election, it did publish all of the metadata for the tweets and collected tweets with common keywords. It is important to mention that this dataset is potentially biased as it only contains these four hashtags; there may be a large cohort of voters who would not tweet in favor of either candidate but rather use hashtags showing disdain for a certain candidate. Nevertheless, this dataset is this paper's source for tweets pertaining to the general conversations on Twitter for the 20 days before the election.

The second Twitter dataset used in this paper was from personally scraping historical tweets from multiple prominent accounts. This was done using the Twitter API and a python script which scraped the most recent tweets of 57 accounts. This dataset consists of the last 3200 tweets -- the maximum amount of recent tweets from a specific account -- of the presidential candidates and their running mates, 20 news organizations, 20 political pundits, and 20 popular politicians. The accounts of news organizations, political pundits, and politicians were all balanced so that there are 10 right-leaning accounts and 10 left-leaning accounts. These tweets were collected to potentially analyzeJürgens et al.'s [7] supposed small-world effects on Twitter. While only tweets from Trump and Biden's accounts were utilized in the final analysis, the goal for this dataset was to create two indexes of major liberal and conservative figures and measure the response to each over the course of the election.

One public dataset examined but not used was a 20 million tweet data set collected from 7/1-11/11 [15]. This dataset, found on IEEE Dataport, is composed of tweets that were searched by using party names, their abbreviations, candidates' names, and election slogans. While this dataset perhaps might have been useful, it did not contain all of the tweet metadata which prevented a thorough structural analysis. In addition, they collected tweets with a strange assortment of keywords and phrases that likely do not encompass the key political discussions happening on the platform.

The second data set found online but not used was a repository from a research article that collected 868 million tweets from 5/20/2019 to weeks after the election [17]. This was the only dataset found online which collected tweets that mentioned specific keywords and tweets from specific accounts. This dataset would have provided the perfect assortment of data for this project but unfortunately, it is nearly inaccessible. Although the tweet ids are posted on Github, these researchers were prohibited from publishing the entire tweet data due to Twitter's developer policy. Thus, the tweets must be rehydrated before they can be used. But rehydrating a tweet counts towards a monthly tweet cap usage, and a normal monthly cap is 500,000 tweets. To

analyze and extract specific tweets from this dataset would require rehydrating hundreds of millions of tweets which was impossible with this project's resources.

In addition to social media data, this analysis incorporates the aggregate polling data of the two major candidates. This polling data is the forecasted variable in the time series model behind this analysis. To find accurate polling data, polling aggregators that provide robust estimates of public opinion were compared and RealClearPolitics aggregate was chosen. The data was acquired by scraping the RealClearPolitics average of polls from 9/31/2019 to the day of the election.
One very important aspect of this data and this project is its accessibility so that this thesis may be properly reviewed and reproduced. The main goal of this reproducibility plan is to provide as much information as possible for ease of analysis of these findings. All the code, outputs, and graphics have been uploaded to a Github repo so that the final version of this project can be analyzed and reproduced. That Github repo is linked here. As mentioned before, it is against Twitter's developer policy to post any data collected using the Twitter API except the id of tweets. Therefore, I will post the RealClearPolitics aggregate polling data but can only post the ids of tweets and not their metadata.

5. METHODOLOGY

As discussed previously, this paper attempts to combine previous successful methods in research to create a new method for analysis in measuring public opinion. The main goal for this analysis is to separately predict the vote share of Joe Biden and Donald Trump using a time series analysis converted to a supervised learning problem. There are two supervised learning models, one for Biden and one for Trump, each which process the Twitter data for a specific candidate and attempt to predict their vote share.

To begin, it is important to explain how the data was prepared before it was ingested by the model. This paper's method attempts to conduct a sentiment and structural analysis of the conversations on Twitter using Manch Hui's dataset of tweets that were scrapped because they contain a hashtag of the candidates [16]. These tweets were uploaded into data frames from two separate CSV files, one of which contained tweets with #Biden and #JoeBiden, and the other which contained tweets with #Trump and #DonaldTrump. The text of each tweet was analyzed using VADER (Valence Aware Dictionary and sEntiment Reasoner), a lexicon and rule-based sentiment analysis tool that is specifically designed for sentiments expressed on social media and trained on the text of tweets. While VADER does not give insight into the sentiment of media associated with the tweet and rather only analyses the text of the tweet, it does provide a good analysis of most of the tweets in the dataset. VADER provides a combined sentiment score that ranges from -1 to 1 with -1 as the maximum negative score and +1 as the maximum positive score. This gives insight into whether the tweet was talking about the candidate in a positive or negative light. One important caveat to the VADER score is that a simple range from -1 to 1 does not encapsulate many of the complex emotions mentioned in many political tweets. For example, a simple scale from negative to positive may obscure the overall sentiment of a tweet from a political supporter who simply is providing constructive criticism of policy. Then the combined VADER score was multiplied by the number of likes, retweets, and followers of the user who tweeted it. These structural features give context to how the message about the candidate was received by the platform and how many people may have even seen the tweet. In the last step, the sentiment-scored amount of likes, retweets, and followers were aggregated by the day summing the scores for each day. In total, 884,391 tweets were analyzed for sentiment and structural features from 20 days of Twitter activity.

This data regarding the general sentiment and breadth of conversations about candidates on Twitter was complemented by the tweets directly from candidates' accounts. These 1,181 tweets

provided data on how the Twitter community was responding to the candidates. Over the same time period, the number of retweets and likes for each tweet were divided by the number of followers the candidate had. The tweets were aggregated by averaging the two ratios of likes to followers and retweets to followers by the day. Then this data was combined with the previous data from tweets with specific hashtags to generate two data frames (one for Biden and one for Trump) with an index of the days and these columns: Sum of Sentiment*Likes, Sum of Sentiment*Retweets, Sum of Sentiment*Followers, Mean of Biden Likes/Followers, and Mean of Biden Retweets/Followers.

Now that the data was properly formatted for the analysis, the next step was to convert a time series analysis to a supervised learning problem. This conversion was necessary as this prediction is mainly focused on the forecasting of polling data to predict a candidate's vote share. This polling data is a traditional time series dataset with metadata, the features from Twitter, describing each day. To include the metadata in the prediction of the next day's polling estimate, the model was converted to a supervised learning problem by using the sliding window method. This implementation of a sliding window simply added the previous day's polling estimate alongside each day's Twitter features so that the current day's polling estimate could be predicted from the current day's Twitter features and previous day's polling estimate. This first in this process involved checking to ensure each series or column was stationary. Stationary data is important for time series analysis as it enforces that the mean's expected value for the data is similar across different time periods. This helps ensure that the model does not vary in accuracy at any specific time point. To check each series for stationarity, an Augmented Dickey-Fuller unit root test from stats models was utilized with a significance level of 0.05. Removing stationarity helps make the mean and variance of the time series data consistent over time, thus making the time series easier to model. Examining each series concluded that six of the ten series were non-stationary and thus the entire dataset was differenced to make those series stationary. After, the same test was used to check each series again and revealed that eight of the ten series were then stationary. While optimally all series would be stationary, it would have taken seven differencings to reach this goal reducing the dataset from 19 rows with 80% stationarity to 13 rows with 100% stationarity. Due to the scarcity of data, the dataset was only differenced once.
The second step in converting this analysis to a supervised learning problem was to add a lagged variable using the sliding window method for the output of the previous time period. The previous day's aggregate polling metric was added to both of the dataframes. This was the final dataframe describing Biden that was used for the analysis:

Date	Sum of Sentiment*Likes	Sum of Sentiment*Retweets	Sum of Sentiment*Followers	Mean of Biden Likes/Followers	Mean of Biden Retweets/Followers	Previous Polling Estimate
2020-10-16	6.075432	-0.883943	-416.643181	0.000006	0.000069	51.7
2020-10-17	-11.997177	-1.605169	6.600909	0.000174	-0.000176	51.2
2020-10-18	-0.532162	-0.191953	781.941740	-0.000191	-0.000577	51.3
2020-10-19	0.358707	0.119817	295.607700	0.001870	0.013707	51.3
2020-10-20	0.687242	0.297876	-1223.989339	-0.001564	-0.010134	51.3

Figure 1. Dataframe of Features Describing Biden's Vote Share

For prediction, the calculation of vote share for one day was utilized as the previous polling estimate for prediction of vote share in the next day. The training and test set splits were as close to an 80%/20% split as possible with the first 15 days being used for training the model and the last 4 days for evaluating its performance. Additionally, the last three days of the training set

(again aiming for an 80%/20% split) were utilized as a validation set for choosing which algorithm to use. Multiple machine learning regression algorithms, discussed later, were trained on the first 12 days of the data. These algorithms inputted the features from the Twitter data and the previous day's polling estimate for each candidate separately and outputted the estimated polling of the current day. Multiple algorithms were trained on this training set of 12 days and were then evaluated on the next three days of data to see what algorithm had the lowest MAE. The algorithm with the lowest MAE would then be chosen for evaluation on the test set, the last four days of data. The performance on the test set is the performance reported and compared to appropriate baselines.

Because of the lack of data, significant algorithm exploration for which performed best would have overfit the data. More data would allow for algorithm selection to have a larger impact on refining the full model for the best possible accuracy. Five regression machine learning algorithms were used from scikit-learn's python package with the default hyperparameters; they were Lasso, Elastic-Net, Ridge Regression, and two Support Vector Regression (SVR) models, one with a linear kernel and one with an RBF kernel. All five algorithms were trained on the first 12 days of data and then evaluated on the next three to see which algorithm best fit the data. The linear SVR model performed best on the validation set, was trained on the entire training set, and subsequently was used for prediction on the test set.

6. FINDINGS

The findings for predicting the 2020 presidential election are based on three separate evaluation metrics. First in order of importance is whether the model predicted the correct winner. The second is the MAE of the predicted vote shares compared to the actual vote shares recorded for the election. The third is the average R^2 for each model's predictions when compared to aggregate polling numbers from the days in the test set. The best algorithm, an SVR model with a linear kernel, trained on the data from 10/16-10/30 performed well on two out of these three metrics. It correctly predicted the winner, Joe Biden, and recorded an MAE of 1.85%. The R^2 metric performed quite poorly likely due to the very small size of the test set and a best-fitting linear line would have fit the data better. Here are the predicted vote shares for each model compared to the aggregate polling numbers:

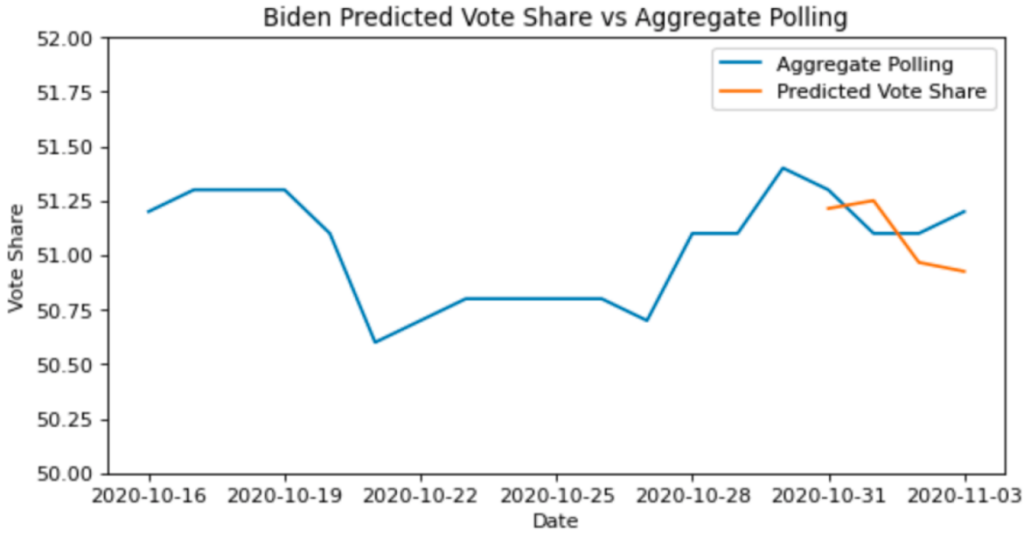

Figure 2. Graph of Prediction of Vote Share vs Aggregate Polling for Biden

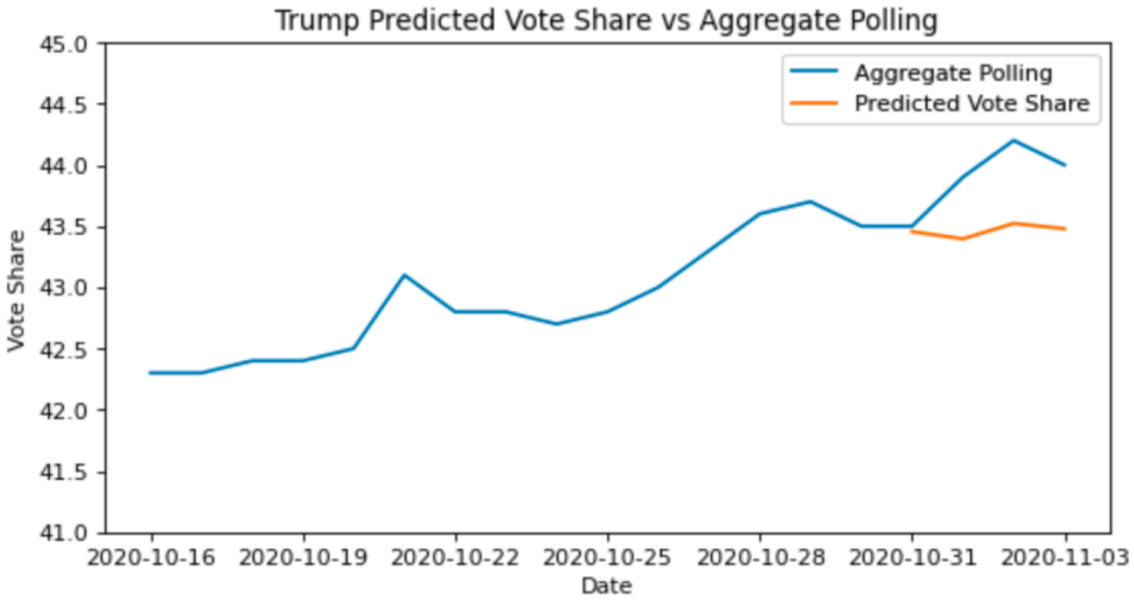

Figure 3. Graph of Prediction of Vote Share vs Aggregate Polling for Biden

Additionally, as the model was trained on polling data unlike most other studies in the field it is difficult to compare this paper's results with others. The influence of polling data gives this research an unfair advantage in comparison to research that did not utilize this type of data. Instead, a fair baseline for the performance of the model would be its comparison to the data it is attempting to perform better than, the aggregate polling data. While one cannot make a comparison based on R^2, it is possible to compare this model by the first two metrics. RCP's aggregate of polls does correctly predict the winner of the election and achieves an MAE of 1.5%, 0.35 less than this model. Thus while this method does achieve a lower MAE than the average MAE for lexi-sentiment (sentiment analysis with a lexicon-based approach) and structure models in research, it does not show an improvement in accuracy when evaluated to a comparable baseline [2].

7. CONCLUSION

With this data, this combination of approaches was not more successful in predicting the results of the 2020 presidential election than an appropriate baseline of the aggregate polling data. Despite that conclusion, I believe a more accurate summary of this research is that it is inconclusive as more data and more research is needed. With such a small sample size of data, only 20 days, it is very difficult to accurately determine if this method is truly effective. Thus, if this research were to be duplicated or expanded upon, my first recommendation would be to utilize more data. Optimistically, this project would have utilized data from early in the summer, around June, when most voters were aware of the likely Democratic and Republican nominees. Twitter data available from June onward would have provided months of data to train and evaluate a model with beyond sufficient test data. With this amount of data, one could conclusively determine whether these combinations of features from Twitter can perform better than the polling data.

Furthermore, there are four other important recommendations that could drastically improve the accuracy of this model. First, one should implement a better sentiment analysis method for determining the sentiment of a tweet. While the VADER analysis is sufficiently accurate, a machine learning model trained specifically on political tweets could provide much greater

insight into each tweet's text. This change should greatly improve the model's ability to monitor conversations each day on Twitter. Second, other major political accounts could be monitored to provide even more data points for how the overall Republican and Democratic bases are reacting to conversations on Twitter. Following just the candidates' accounts biases the data to only reflect the support for those specific candidates, even though many voters vote based on party lines, not specific candidates. Tracking tweets from political pundits, other politicians, or news outlets like Fox News and MSNBC, could provide valuable data into the current enthusiasm of a party's base. While this was attempted in an earlier version of this research, accurately measuring the response to these major political accounts proved quite difficult to combine with the rest of the Twitter data.

A third recommendation for improving the accuracy of the model is to have multiple sources of social media data. As mentioned previously, Skoric et al. found that blogs scored better than Twitter for MAE and Facebook, forums, and blogs all reported better measures of R^2 [2]. Most notably, Skoric et al. reported that using multiple platforms for analysis reported substantially better measures of MAE. Thus, adding more social media data from multiple sources would lead to more conclusive positive results, showing if a technique is truly effective in predicting election results. Lastly, an additional way to validate whether the model was conclusively accurate would be to gather data from past presidential elections and predict their outcomes. This would help ensure that the model did not perform well on simply one election and rather that it is a robust method for predicting presidential elections. Comparison to old elections could also help validate which specific ideas, like sentiment analysis or a special focus on important users, are repeatedly effective.

If all of these changes were made, a model that performed better than the polling data in this one race could not conclusively be determined as an accurate model. It would also have to be used in forecasting future elections. As Huberty[18] shows in his research of multi-cycle election forecasting, performance in back-casting tests does not necessarily correlate with success in predicting future elections. This paper provides likely the best test for any model developed to forecast elections: can the forecasting method perform well for forward-looking predictions? In essence, can the method properly forecast in multiple election cycles? In order for a method to be recognized as successful, it should be tested on future election cycles and perform better than an adequate baseline, whether that is incumbency, polling predictions, or another metric.

In sum, this research proposes a new method for predicting elections that combines sentiment and structural data with aggregate polling, a time series analysis, and a special focus on Twitter users critical to the election. While this method performed worse than its baseline of polling predictions, it is inconclusive whether this is an accurate method for predicting elections due to the scarcity of data. More research and more data are needed to accurately measure this method's overall effectiveness.

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AUTHOR

Michael Caballero recently graduated from the University of California, Berkeley with an Honors Data Science major and Computer Science minor.

CROSS-MODAL PERCEPTION IN KIRUNDI

Emmanuella Ahishakiye[1, 2]

[1]Department of English, Institute for Applied Pedagogy- University of Burundi
[2]Faculty of Languages, Arts and Translation- University of Liège

ABSTRACT

Languages do not always use specific perception words to refer to specific senses. A word from one sense can metaphorically express another physical perception meaning. For Kirundi, findings from a corpus-based analysis revealed a cross-modal polysemy and a bidirectional hierarchy between higher and lower senses. The attested multisensory expression of auditory verb kwûmva 'hear' allows us to reduce sense modalities to two –vision and audition. Moreover, the auditory experience verb kwûmva 'hear' shows that lower senses can extend to higher senses through the use of synaesthetic metaphor (e.g. kwûmva akamōto 'lit:hear a smell'/ururírīmbo ruryōshé 'lit: a tasty song'/ururirimbo ruhimbâye 'lit: a pleasant song). However, in collocations involving emotion words, it connects perception to emotion (e.g.; kwûmva inzara 'lit: hear hunger', kwûmva umunêzēro 'lit: hear happiness'). This association indicates that perception in Kirundi gets information from both internal and external stimuli. Thus, considering feelings as part of the perception system.

KEYWORDS

Sense Modality, Kirundi, cross-modal perception, lexical semantics, synaesthetic metaphor.

1. INTRODUCTION

This paper discusses the lexicalisation of sensory perception in Kirundi [JD62], a native language all Burundians. Burundi, being located in the East Africa at the centre of Great Lakes, some languages spoken in the neighbouring regions such as K*inyarwanda [JD61]*in Rwanda, *Kiha [JD66], Kihangaza [JD65], Kishubi [JD64] and Vinza [JD67]* in Tanzania (Mberamihigo, 2014, p. 27) are mutually intelligible with Kirundi. Moreover, it examines the relationship and/or associations between senses. That is, the identified basic verbs will be analysed in their contexts of use for their different meanings in the physical perception domain.

1.1. Perception Verbs

None would deny the prominence of sensory perception in our everyday communication. Sense organs– eyes, ears, skin, mouth and nose – collect information from the outer world for us, which the language translates it into words. However, languages do not give sense perception the same importance and do not always use specific perception words to refer to specific senses. A word from one sense can metaphorically express another physical perception meaning. Languages differ in how they lexicalize the sense perception (Moravcsik, 2012) and in the number of basic verbs they use to express them(Viberg, 1983). Viberg argues that the more a language avails basic verbs for each sensory modality the less it combines more than one sense modalities into a single verb. Thus, the conflation of senses results into cross-modal meaning extensions.

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To comply with Majid & Levinson's (2011) wish for more knowledge about how people around the world express perceptual experience, the present study deals with Kirundi sensory lexicalization patterns with focus on the semantic extensions of basic Verbs of Perception (henceforth, VoP) across sensory modalities. Although perception has attracted much attention in linguistics and cognitive sciences (e.g., A. Aikhenvald & Storch, 2013; Evans & Wilkins, 2000; Levinson & Majid, 2014; San Roque et al., 2018; Sweetser, 1990; Vanhove, 2008; Viberg, 1983), less is known about Kirundi. Moreover, many studies focusing on meaning extensions of perception words and the various meanings paid more attention on transfield polysemy(Evans & Wilkins, 2000; Sweetser, 1991; Vanhove, 2008) but a few on intra field polysemy (San Roque et al., 2018). As San Roque et al. claim that "Polysemy is a linguistic habit practiced by everyone, every day", this paper describes the lexicalisation of the basic senses to demonstrate cross-modality in Kirundi and their effect on Viberg's (1983) directional hierarchy of sense modalities. The significance of this study lies in enriching literature on the lexicalisation of the field of perception since universal claims (Sweetser, 1991; AAke Viberg, 1983) were criticised for not resulting from representative data. Therefore, there is still need of examining findings from typological studies on the language of perception to make sure they apply to all the worldwide language and language users.

Regarding sense modalities, Viberg's (1984) paradigm reveals that the basic VoP refer to the five Aristotelian senses–*Sight, Hearing, Touch, Smell* and *Taste*– whichhe considers as the most important semantic components of the perception field. However, there is no agreement on the number of senses to consider. Sense recognition is a culturally bound aspect. Speakers, depending on their language and their cultural background may have more than five senses (Classen, 1993) or less (Ritchie, 1991) or can join more sensory modalities together (Howes, 2006c). From the five senses, Viberg claims that vision verbs dominates and that VoP have a unidirectional hierarchy. However, not all scholars agree with it. Evans and Wilkins (2000) attests it, while A. Aikhenvald and Storch (2013) and San Roque et al. (2015)do not. To verify what holds for Kirundi, the present analysis limits itself to how Kirundi expresses perceptual experiences through verbs.

1.2. Method and Data

This study adopted a corpus-based approach for which corpus data are of great importance since they reflect language uses, which can be analysed both quantitatively and qualitatively. In addition, to analyse concordances of VoP from the BantUgent corpus, a construction-based approach was favoured. For a usage-based analysis, the semantics of lexical units are determined by the meaning of the constructions in which they are involved (Goldberg, 1995, 2006) taking into account both perceptual and socio-cultural aspects of the language producer (Caballero & Paradis, 2015).

To find out how Kirundi organizes perceptual experiences, twenty-five native speakers were asked to translate Viberg's (1984:125) basic paradigm of VoP into Kirundi. These native speakers also served of reference for validation of possible uses not found in the corpus.

The grid paradigm contains fifteen sentences referring to the basic five senses (*Sight*, *Hearing*, *Touch*, *Taste* and *smell*) and the three semantic components (controlled perception, uncontrolled perception and the source-based perception) as *Table 1* indicates it.

Table 1: The basic paradigm of VoP (Adapted from Viberg, 1984:125)

Dynamic system:	**Base selection: Activity**	**Experience r-based Experience (state/inchoactive)**	**Source-based Copulative (State)**
Sense modality			
Sight	Peter was looking/ looked at the birds.	Peter saw the birds.	Peter looked happy
Hearing	Peter was listening/ listened to the birds.	Peter heard the birds.	Peter sounded happy
Touch	Peter was feeling/ felt the cloth. /to see how soft it was/	Peter felt a stone under his foot.	The cloth felt soft
Taste	Peter was tasting/ tasted the food. /to see if he could eat it/	Peter tasted garlic in the food.	The food tasted good/bad/of garlic.
Smell	Peter was smelling/smelled the cigar. /to see if he could smoke it/	Peter smelled cigars in the room.	Peter smelled good/bad/cigars.

/ /test frame

As of the corpus used for this study, it contains raw materials compiled from 1485 files containing both spoken and written language productions. A concordance of *BantUgent Kirundi* corpus using *Wordsmith Tools* (Scott, 2016) yielded a wordlist of 3 567 037 tokens. Referring to both the distribution of the basic VoP and their uses, the analysis of VoP constructions gives an in-depth description of how Kirundi users express the basic perceptual experiences and, the linguistic and cognitive mechanisms that allow perception lexicalisation intra- and trans-modal meaning extensions.

2. BASIC VERBS OF PERCEPTION IN KIRUNDI

In this section, the discussion focusses on the different translations of Viberg's grid frames. Examination of translations from the twenty-five participants shows that the fifteen English sentences in the grid paradigm correspond to thirty sentences in Kirundi. The difference in lexicalizing perceptual experiences between Kirundi and English finds motivation from the fact that Kirundi can count more than one verbs for each of the provided English olfactory, gustatory and tactile perception events. For the perceived-oriented event, all the provided events translates into more than one verbs.

Table 2: Basic Verbs of Perception in Kirundi

	Perceiver-oriented		**Perceived-Oriented (Phenomenon)**	
Sensory modality	**Activity**	**Experience**	**Copulative**	
Vision	*Kurāba/LOOK1*	*Kubóna/* ***SEE***	***Gusa /LOOK2*** *Kubóneka* ***/SEE****+STAT* ***Kunêzērwa * / BE HAPPY***	
Hearing	*Kwûmviriza /* ***HEAR****+APPL+APPL+CAUS*	*Kwûmva /* ***HEAR***	***Kuvúga/SOUND*** ***Kunêzērwa * / BE HAPPY***	***Gusa/SOUND***
Touch	*Gukórakora/TOUCH-REDUPL* *Gukora (ku)/Touch (on)*			*Kwôroha*/BE SOFT*
Taste	*Guhônja/TASTE*			*Kuryôha*/BE TASTY*
Smell	*Kwîmotereza/* *REFL+****SMELL good****+APPL+CAUS* *Kwînūkiriza* *REFL+****SMELL bad****+APPL+APPL+CAUS* *Kumōtēra/****SMELL SMELL****+APPL*	*Kumōterwa* ***SMELL good****+APPL+PASS* *Kunūkirwa* ***SMELLbad****+APPL+PAS S*	*Kwûmvīkana /* ***HEAR +STAT+ASSOC***	*Kumōta* ***/SMELL good*** *Kunuka/* ***SMELL bad***

Taking into consideration of the translations of the grid and the language uses from the corpus, *Table 2*displays basic verbs that encode both perceiver-oriented and perceived-oriented perception events in Kirundi. In the following sub-sections, usage-based from the corpus illustrates the basic VoP in context per sense modality.

2.1. Sight

For the experiencer-based perception, on the one hand, Kirundi distinguishes two verbs: *kurāba* (1) as an activity verb to mean 'Look at' and *Kubóna* (2) as an experience verb to express 'See'.

(1) ***Rāba Thomas ibigānza…*** (*Turirimbire umukama.txt*)
Rāb-a Thomas i-bi-gānza
IMP-to.look-FV Thomas AUG-NP-palm
Thomas, ***look*** at the palms...

(2) ***Narámubônye ejó*** (*ISA_UburundiBura_2014-10-27.txt*)
n-á-ra-mu-bón-ye ejó
1SG-PST-DISJ-OBJ$_{3SG}$-see-PFV yesterday
I ***saw*** him yesterday.

The source-based perception, on the other hand, the stative construction [[kubóna]V -ik-]V = [x can be seen] is used to mean ' (not) *visible, can be seen'.*

(3***) agakôko katabonéka*** (*Inyigisho zijanye n'inyifato.txt*)
a-ka-kôko ka-ta-bón-ik-a
AUG-NP-animal 3SG-NEG-see-STAT-IMPFV
An ***invisible*** animal.

(4***) […], birabóneka, […]***. (*IragiNdanga.txt*)
[…], bi-ra-***bón***-ik-a,***[…]***

[…] 3PL-DISJ-see-STAT-IMPFV, ***[…]***
[…]*, you* ***can see*** them, ***[…].***
Unlike *kubóneka*, whichexpresses what everybody can see, *Gusa*, which translates into 'look', indicates cases of truth relativity. i.e, the validity of the beauty involved in statement (5) needs to be confirmed.

(5)***[…], zigasa nêzá*** (*Ndayikeza_IntaraKama.txt*)
[…], zi-ka-se-a na-īzá
[…], 3PL-PRST-look-IMPFV CONJ-nice
[…], they ***look*** nice.
Kirundi can also express the English construction V+Adj '*look happy*' into only one word *kunêzērwa* '*be happy*'(6)

(6) ***ntāshe nêzerewe*** (*Akanovera.txt*)
n-tāh-ye n- nêzēr-w-ye
1SG-go.back.home-PFV 1SG-please-PASS-PFV
I go back home ***being happy.***
However, the construction *kubóneka + nka 'as though'* (lit. '*seems/appears as if/look like*') *or* express lack of evidence and certainty in the speaker's proposition (7)-(8).

(7) aboneka nk'ŭnēzerewe
a-bón-ik-a nka u-u- nêzēr-w-ye
3SG-see-STAT-IMPFV as.though REL-3SG-please-PASS-PFV
He ***looks***/***seems*** happy.

(8) ***muboneka nk'âbâna*** (*RPA_Ntusamare.txt*)
mu-Ø-bón-ik-a nka a-ba-âna
2PL-PRS-see-STAT-IMPFV as.though AUG-NP-child
You ***look like*** babies [to me]

2.2. Hearing

The classification of the basic VoP in Kirundi showed that *kwûmva/* HEAR conveys an uncontrolled perception (9), where the perceiver is an experiencer.

(9) ***Ntâbarezi […] yūmva ingoma*** (*L'arbre mémoire.txt*)
Ntâbarezi ***[…]*** a-a-ûmv-a i-n-goma
Ntâbarezi ***[…]*** 3SG-PST-to.hear-FV AUG-NP-drum
Ntâbarezi ***heard*** rhythmic beats of drums.
To express a controlled auditory perception, two derived verbs Kw**ûmv**iriza (10) andkw**ûmv**īra (11) are alternatively used for the same concept "*to listen*" without changing the meaning of the constructions in which they are involved.

(10) ***Ndûmviriza*** **[…].** (*Amazaburi 2.txt*)
n-ra-ûmv-ir-ir-i-a **[…]**
1SG-DISJ-to hear-APPL-APPLCAUS-IMPFV **[…]**
I listen to [God's word].

(11) ***Umvīra*** **[…]** (*Abatagatifu bashasha.txt*)
ûmv-ir-a **[…]**
IMP-to.hear-APPL
Listen to [one of them; he is going to tell us about it].

However, when used in an intransitive construction (12-13), the verb *kwûmva* expresses '(lack of) ability to hear'.

(12) **[…]** ***amatwí yūmvá n'âmâso aboná.*** *(*Impanuro.txt*)*

[…]	*a-ma-twi*	*a-ûmv-a*	*na*	*a-ma-iso*	*a-bón-a*
	AUG-NP-ear	REL-3PL-to.hear-FV	and	AUG-NP-eye	REL-to.see-FV

[…] **receptive ears** and keen eyes.

(13) ***[…] umūntu atūmvá kăndi w'íkiragi.*** (*UbwuzureBushasha.txt*)

u-mū-ntu	a-ta-ûmv-á	kăndi	wa	í-ki-ragi
AUG-NP-person	REL-3SG-NEG-to.hear-FV	and	of	AUG-NP-dumb

[…] **a deaf** and dumb person.

To express a perceived-oriented perception, speakers use a stative derivation *kwûmvīkana 'to be heard'* of the HEAR verb *kwûmva* as illustrated in (14) and (15).

(14) ***hŭmvīkanye umurĭndi*** *(*IcaGatandatu.txt*)*

ha-a-ûmv- ik-an-ye	u-mu-rĭndi
LOC-PST-to.hear-STAT-ASSOC-PFV	AUG-NP-hurried.sound.of.footstep

They ***heard*** a hurried sound of footsteps.

(15) ***[…] inyuma y'ámasásu yūmvîkanye*** *(RPA_JP_2014-10-16.txt)*

i-nyuma	ya	a-ma-sásu	a-a-ûmv-ik-an-ye
LOC-after	CONN	AUG-NP-bullet	3PL-PST-STAT-ASS-PFV

[…] after a burst of gunfire ***echoed***

However, '*he sounded happy'* can translate into *'yavúga nk'úwunêzerewe*' where '*sound*' corresponds to 'Kuvúga/speak/say' a SPEAK verb when the speaker, with low degree of certainty infers from how his interlocutor sounded when speaking (16).

(16) ***yavúga nk'ŭnēzerewe***

i-á-vúg-a	nka	u-u- nêzēr-w-ye
3SG-PST-***speak***-IMPFV	like	REL-3SG-please-PASS-PFV

He ***sounded*** happy

Nevertheless, with high degree of certainty, the SPEAK verb and the conjunction *nka* 'like/as though/as if' are omitted as (17) shows it.

(17) Aranêzerewe

a-ra-nêzēr-w-ye

3SG-FOC-please-PASS-PFV

He ***is happy***

Therefore, the expression of epistemic modality, using HEAR or SEE verbs, is associated with the presence/absence of source-based verbs (*kubóneka* ''*seems/appears/look*' and *kuvúga 'sound'*) and the conjunction *nka* '*as though/as if / like*'.

It is worth mentioning that the same SPEAK verb *kuvúga* can convey the speaker's report of a hearsay (that he heard something being talked about). The passive form (18) of verb is used, read as '*say*/*mention*'.

(18) ***murí abo haravúgwa umushîngamátēká Bernard Busokoza …*** (*IGIHE140331Uprona.txt*)

murí	abó	ha-ra-vúg-u-a	u-mu-shîngamátēká	Bernard Busokoza
among	them	LOC-DISJ-say-PASS-FV	AUG-NP-member.of.parliament	Bernard Busokoza

The Honourable Bernard Busokoza ***is said*** to be among them**.** Or,
Among them, people ***mention*** the Honourable Bernard Busokoza.

2.3. Touch

In Kirundi, there are two verbs for a controlled tactile perception: *Gukóra +ku* (V+Prep) '*Touch*'and its deverbative form *Gukórakora'TOUCH-REDUPL'.*

(19) ***Aca azikora ku mâso***. *(UbwuzureBushasha.txt)*

a-cî-a	a-zi-kór-a	ku	ma-îso
3SG-immediately-IMPFV	3SG-OBJ$_{3PL}$-touch-IMPFV	on	NP-eye

He ***touched***their eyes.

The preposition ku '*on/at*' can attach to the verb as a post verb enclitic (20) when the object is marked in the verb (*V-LOC* construction).

(20) ***Kó ndagukorakó ugasīmba, […]*** (*Giswicinobera.txt)*

Kó	n-ra-ku-kór-a-kó	u-ka-sīmb-a, […]
That	1SG-DISJ-OBJ$_{2SG}$-touch-LOC	2SG-PRST-jump-IMPFV

Why do you get agitated when I ***touch*** you? […].

Derivation is not the only morphological process that Kirundi uses to create lexical perception verbs. It also uses reduplication of a verb stem to show intensity or durativity (21) with the frame */to see how soft x is/*, where the reduplicated form reads '*feel*'. The reduplicated root has an aspectual semantic value and so, adds an atelic meaning to the construction.

(21) Pētéro ***yarákorakoye*** impŭzu. (*adapted from the grid*)

Pētéro	***a-á-ra-kórakor-ye***	i-n-hŭzu
Pētéro	3SG-PST-DISJ-touch.repeatitively-PFV	AUG-NP-cloth

Peter ***felt*** the cloths/ *to see how soft x is*/.

As of the passive tactile perception, Kirundi does not have a separate verb to express it. To fill in the gap, the language associate the uncontrolled HEAR verb with TOUCH (22).

(22) ***Pētéro yumvise impŭzu imukozeko***

Pētéro	a-á- ûmv-ye	i-n- hŭzu	i-Ø-mu-kór-ye-kó
Pētéro	*3SG-PST-hear-PFV*	*AUG-NP-cloth*	*3SG-PRS-OBJ$_{3SG}$-touch-PFV-LOC*

Peter ***felt*** the cloth touching him.

The source-based perception is expressed by the verb *kwôroha* 'be soft', which can be replaced by any other verb related to touch.

(23) ***Naho yoba ari impŭzu yōróshe, […]*** (*Burundi_Culture_Nord-Est.txt*)

Ni	a-ha-ó	i-oo-bā	a-Ø-ri	i-n- hŭzu	i-Ø-ôroh-ye
COP	*AUG-NP-DEM*	*3SG-MOD-BE*	*3SG-PRS-BE*	AUG-NP-cloth	*3SG-PRS-be.soft.PFV*

Even if it would be a ***soft cloth***, […]

2.4. Taste

The gustatory sense modality has only one active verb ***Guhônja*** (24) "*to taste a small quantity of sth or to give a small quantity of something to taste to somebody*" to express a controlled gustatory perception and an evaluative verb *kuryôha* 'be tatsy' (25), which can be replaced by any evaluative gustatory verb. The can be verbs describing the different kind of taste such as ***kubîha*** *'have an unpleasant taste'*, ***kubába*** *'have a spicy taste'*, ***kugāsha*** *'go bad'*, ***gusôsa*** *'have a sweet taste'*, ***kurura*** *'have a sour taste'*, etc.

(24) ***Ivyárivyó vyöse azōza avyîremētse abaríyo abahŏnje.*** (*Marriage Didier & Annick-2019.txt*)

Ivyárivyó	bi-öse	a-zō-əz-a	a- bi-îremēk-ye
Whatever	PP-all	3SG-FUT-to.come	3SG-to.carry.on.one's.head-PFV
a-ba-rí-yo	a-ba-hônj-e		ba-ûmv-ir-ir-i-e
AUG-3PL-to.be-LOC	3SG-3PL-to.taste-IPFV		3PL-to.hear-APPL-APPL-CAUS-IPFV

However it may be, she will bring them a small quantity (of potatoes) so that they can ***taste*** them

(25) ***Ziraryôshe cāne***. (*RPA_Akayabagu_Claude_Irengarenga.txt*)

Zi-ra-ryôh-ye	cāne
3PL-DISJ-be.tasy-PFV	a.lot

They are very ***tasty***.

To express uncontrolled perception, the hearing verb *kwûmva* is involved (26).

(26) ***Igihĭmba twūmvîsha uburyŏhe*** (*Inyigisho menyeshantara 2.txt*)

i-ki-hĭmba	tu-ûmv-ish-a	u-bu-ryôh-e
AUG-NP-part	2PL-to.hear-INST-FV	AUG-NP-to.be.tasty-FV

A body part with which we **taste**.

2.5. Smelling

Apart from the Hearing verb *Kwŭmva*, which can be used with nouns denoting smell, the evaluative verb *Kumōta* and its derivational forms *kumoterwa* and *kumotereza* respectively express source-based, non-controlled and controlled perceptions. We realize that Kirundi distinguishes good from bad smell. The latter brings in another set of verbs *kunūka*, *kunūkirwa* and *kwînūkiriza*. Consequently, SMELL is the sense modality that has a larger number of basic verbs.

(27) ***amasábuné amōta […]*** (*USCRI_H_Asthma.txt*)

a-ma-sabuni	a-Ø-mōt-a […]
AUG-NP-soap	3PL-PRS-smell.good-IMPFV

Sweet-smelling soaps […]

(28) ***Ya mbwa imotewe***, […] (Dusome4.txt)

i-i-á	n-bwa	i-mōt-ir-w-e
AUG-PP-DEM	NP-dog	3SG-smell.good-IMPFV

When the dog ***got a sweet smell***, […]

(29) […], kwîmōtereza.(*Inyigisho menyeshantara 4.txt*)

Ku-i-mōt-ir-ir-i-a
INF-REFL-smell.good-APPL-APPL-CAUS-IMPFV

To smell /to see if something smells good/

(30) *sinzôbá nkíri**mōtēra***. (*Karaba.txt*)
*I will no longer **smell** it*

It is a derived verb form*[-mōt –APPL]* from *kumōta'smell'*, a source-based VoP, where the applicative morpheme does not add the semantic value of '*smelling x for*' but indicate the intension of the agent of the verb.

Although the language has different lexical verbs to encode each of all the five senses, the *Table 2* reveals that the cross-modality extension of the hearing verb *Kwûmva* can reduce the lexicalization of perceptual experiences into two sense modalities only –SIGHT and HEARING – using three basic verbs *–Kurāba* '**LOOK',** *Kubóna* '**SEE**' and *Kwûmva* '**HEAR**'. The two first verbs expressing visual perception and the last for non-visual perception. A question, which arises here, is why or how could it be possible? The verb glosses (*Table 2*) show that the auditory verb *kw**ûmv**a* can extend its meaning to all non-visual perception events. In addition, depending on the degree of the experiencer's consciousness and focus in a perception event, the language creates new verbs *kw**ûmv**iriza 'listen'* and *kw**ûmv**īkana* '*x is audible*' from existing ones to convey the needed interpretation. That is, to distinguish perceiver-oriented controlled from uncontrolled events or perceiver-oriented from perceived-oriented perception ones, Kirundi uses derivational verb extensions devices. Referring to the different mechanisms languages use to encode perceptual experiences (Usoniene's, 1999: 2), the examination of data shows that Kirundi uses both linguistic and cognitive means. To elaborate on this, Section 3 details all the linguistic means Kirundi uses to encode perception experiences.

3. LINGUISTIC WAYS TO CREATING THE MISSING SPECIFIC VERBS

For the linguistic means, the classification of the VoP shows that Kirundi uses both lexical and morphological means. The latter complete lexical ones to avail a perception verb where it initially did not exist. Hence, extended verbs that can express a controlled or a phenomenon-based perception within a sense modality are created. For instance, whereas the visual perception has two basic lexical forms *–kurāba /**LOOK**$_1$* and *Kubóna/ **SEE***– to refer respectively to ACTIVITY and EXPERIENCE, the experience auditory verb Kwûmva/ HEAR needs to be attached to derivational morphemes to express an active perception (31.b). However, both visual and auditory EXPERIENCE verbs need a bound morpheme to make a copulative verb (32. a & b). Therefore, Communicational needs in terms of perception event typology influences the language user to use either a simple lexical or a complex one by deriving a new verb from an existing one to fit in another *class* (Goldberg, 1995). The example is of the causative-applicative morphology, which changes a HEAR-class (31.a) into a LISTEN-class (31.b). The lexicalised verb *kw**ûmv**iriza/to listen to* equals a conative-intensive construction, where the implied attention of X to Y causes him to hear Z. X,Y and Z respectively referring to the listener, the speaker/interlocutor and the message.

(31) *a)* Pētéro ***yarûmvīse*** inyoni/.
Pētéro i-á-ra-ûmv-ye i-n-nyoni
Pētéro 3SG-PST-DISJ-***to.hear***-PFV AUG-NP-bird
Peter ***heard*** birds
b) Pētéro ***yarûmvirije*** inyoni/
Pētéro i-á-ra-ûmv-ye i-n-nyoni

Pētéro 3SG-PST-DISJ-***to.hear***-APPL-APPL -CAUS-PFV AUG-NP-bird
Peter ***listened to*** birds.

(32) *a)* Pētéro ***yŭmvīkana*** nk'úwunêzerewe
Pētéro i-á-ûmv-ik-an-a nka
Pētéro 3SG-PST-***to.hear***-STAT-ASS-IMPFV as.though/as if
u-u-nêz-ir-w-e
REL-3SG-pleasure-APPL-PASS-IMPFV
Peter ***sounded*** happy
b) Pētéro ***yabóneka*** nk'úwunêzerewe.
Pētéro i-á-bón-ik- a nka
Pētéro 3SG-PST-***to.see***-STAT-IMPFV as.though/as if
u-u-nêz-ir-w-e
REL-3SG-pleasure-APPL-PASS-IMPFV
Peter ***looked*** happy

Derivation is not the only morphological process that Kirundi uses to create lexical perception verbs. It also uses reduplication of a verb stem to show intensity or durativity (21). Thus, the present analysis shows that Kirundi, as an agglutinative language, uses derivational and reduplication morphological processes not only to express in one word what other languages would syntactically express in more than many words but also to make semantic and pragmatic nuances among perception events. Therefore, without considering the different forms of the same lexeme and that *kunūka* is an antonym of *kumōta*, *Table 3* display Kirundi basic primitive VoP and their frequencies in the used corpus.

Table 3: Distribution of Kirundi VoP in the corpus

		Root verb	***Root Verb + extensions***	**TOT**
Vision	***Kubóna*** "see"	14727	4208	18935
	Kurāba "look$_1$"	7221	196	7417
	Gusa "look$_2$"	152	0	152
Hearing	***Kwûmva*** "hear"	11415	6337	17752
Touch	***Gukora (ku)****/Touch (on)*	234	51	285
Taste	***Guhônja*** "to taste/give a small quantity of sth (edible/drinkable) to determine its quality"	9	0	9
smell	***Kumōta*** " to smell"	68	71	139
	Kumōtēra " to smell"	3	-	3

Figures in the above table indicate that visual and auditory perception verbs dominate in the corpus with a representation of 59% and 40% respectively. The possible order being *Sight>Hearing>Touch>Smell>Taste*, where SMELL interchanges the place with TASTE when compared to Viberg's directional hierarchy. This predominance in frequency of the two sense modalities *Sight* and *Hearing* in the corpus allows us to predict cross-modal meaning extension of verbs from the two sense modalities. Thus, use of cognitive means to express sensory modality. To verify this hypothesis, *Section 4* discusses cross-modal meaning extensions for Kirundi VoP.

4. CROSS-MODAL MEANING EXTENSIONS

As of the question on what cross-modal meanings Kirundi VoP can express, *Table 4* gives us a picture of what verbs extend their meanings to other modalities.

Table 4: Meaning extensions to other sense modalities

		Vision	**hearing**	**touch**	**smell**	**taste**
Vision	***Kubóna*** "to see"	✓	-	-	-	-
	Kurāba " to look "	✓	-	-	-	-
	Gusa *"to look2"*	✓	✓	✓	-	✓
	Kubóneka *"to be seen/to seem"*	✓	-	✓	-	✓
Hearing	***Kwûmviriza*** " to listen"	-	✓	✓	✓	✓
	Kwûmva "to hear"	-	✓	✓	✓	✓
	Kuvúga *"to speak/say"*	-	✓	-	-	-
	Kwûmvīkana *"to be audible"*	-	✓	✓	✓	✓
Touch	***Gukórakora*** **"**to touch repetitively to see if sth is x	-	-	✓	-	-
	Gukora (ku)*/Touch (on)*	-	-	✓	-	-
	Kwôroha *"to be soft"*	✓	✓	✓	✓	✓
Taste	***Guhônja*** "to taste/give a small quantity of sth (edible/drinkable) to determine its quality"	✓	✓	-	-	✓
	Kuryôha *"to be tasty"*	✓	✓	✓	-	✓
smell	***Kwîmotereza*** " to smell to see if sth/sb smells well"	-	-	-	✓	-
	Kumõterwa "to smell sth which has a good smell"	-	-	-	✓	-
	Kumõtēra/SMELL*+APPL*	-	-	-	✓	-
	Kumõta *"to smell good"*	-	-	-	✓	-
	Kunūka *"to smell bad"*	-	-	-	✓	-

As *Table 4* demonstrates it, there is difference in semantic variation in meaning extension to other sense modalities.

4.1. Sight

The table does not the activity visual perception verb *kurāba 'to look'* covering all the five sensory modalities. This is because *there* were no occurrences attesting meaning extensions of the verb kurāba 'to look' to other senses in the corpus. However, elicitation tests for the correctness and meaningfulness of the different constructions involving the verb *kurāba* allow us to deduce that kurāba/to look does not extend its meaning to all non-visual senses Instead, it bases on them to mean *search for/ find* by listening (33), *check* by touching (34) or tasting (35) and *choose* by smelling (36).

(33) ***Rāba Thomas ikáséti ivugá nêzá.***

Rāb-a	Thomas	***ikáséti***	***ivugá nêzá***
IMP-to.look-FV good	Thomas	AUG-NP-tape	REL-3SG-to.sound-FV

Thomas, ***find/search for*** an undamaged tape.

By the end of the process, as speaker A had ordered B to look for an undamaged tape, A can ask about the result and put the question "***Ni iyîhé kásěti wabōnyé (saw) ivugá nêzá?*** / *which tape did you* ***find*** *undamaged?*" This implies that the experience visual verb too, can extend its meaning to audition.

(34) ***Rāba Thomas impǔzu kó zūmyé.***

Rāb-a	Thomas	i-n-hǔzu	ko	zi-ûm-ye
IMP-to.look-FV	Thomas	AUG-NP-cloth that	3PL-to.be.dry-PFV	

Thomas, ***check if*** cloths are thoroughly dry.

To give feedback to A, B can say it four different statements:

- "***zisa n'ízǔmye***/ *they look dry*" when he only looked at them without feeling them and realized that there are no more drops of water from the cloths.
- "***nūmva zûmye/ I feel*** *that they are dry*", which reflects an individuation of the involved perception modality (Matthen, 2015) after the speaker has touched the cloths to make sure they are thoroughly dry.
- "***mbona zûmye/*** *I see that they are dry*" while touching them to verify the accuracy of the information he acquired through vision. Looking at and touching the cloths mutually certify for the cloths' dryness property, while for the last case "***zirûmye****/they are dry*" the proposal does not tell about which verification means the speaker used.

(35) ***Rāba Thomas indyá ká zihīyé.***

Rāb-a	Thomas	indyá	kó	zi-hī-yé
IMP-to.look-FV	Thomas	AUG-NP-food	that	3PL-to.be.cooke-PFV

Thomas, ***ensure***/**check** that the food is cooked through.

Although the alternatives "***mbona zíhīye****/I see that they are cooked through*" and "***nūmva zíhīye/*** *I find them cooked*" are also possible for the gustatory modality, "*mbona/I see*" does not integrate TASTE. Since the speaker only considered the food appearance without tasting them. Therefore, SEE does not base on TASTE to extend its meaning.

(36) ***Rāba Thomas amavúta amōtá nêzá.***

Rāb-a	Thomas	a-ma-vúta	a-mōt-á	nêzá
IMP-to.look-FV good	Thomas	AUG-NP-body.lotion	REL-3SG-to.smell-FV	

Thomas, ***choose*** body lotion that has a sweet smell.

Although a transitive declarative construction ***mbona amavúta amōtá****/I see sweet body oil*) was not confirmed, the non-controlled visual verb SEE can base on the olfactory sense modality to extend its meaning to '*find*' by smelling in an interrogative construction (e.g: ***Ni ayâhé wabōnyé amōtá?*** *Which one has a sweet smell?*).

As far as perceiver oriented verbs are concerned, two verb forms – *gusa* 'look2' and *Kubóneka 'can be seen'*– are multimodal. **Gusa** "look$_2$" in the construction *Gusa nka…* "Look like", the V+Prep expresses a visual percept as (37a).

(37) ***a) RUBERINTWARI asa nk'ǔshavuye*** (*Nyerek'akaranga.txt)*

RUBERINTWARI	a-sa	nka	u-shávur-ye
RUBERINTWARI	3SG-to.look	like	REL-3SG-to.be.unhappy/nervous-PFV

RUBERINTWARI ***looks*** unhappy.

Depending on the context of production, the construction *Gusa nka[…]* can also mean, "*to sound*" and so refers to auditory modality. The speaker considers the mood and the words he heard from his interlocutor (RUBERINTWARI), in a conversation on telephone for instance, and infers his happiness. That is why, if he wants to specify that he inferred the happiness through what he heard, he uses the derived form "kwûmvīkana" (37c) of the verb *kwûmva*. Instead, in case the speaker refers to the appearance, he uses the verb *Kubóneka* "to seem/be seen" (37b).

b) ***RUBERINTWARI aboneka nk'ŭshavuye***

RUBERINTWARI	a-bón-ik-a	nka u-shávur-ye
RUBERINTWARI	3SG-to.be.seen like	REL-3SG-to.be.unhappy-IMPFV.

RUBERINTWARI ***looks*** unhappy.

c) ***RUBERINTWARI yūmvīkana nk'ŭshavuye***

RUBERINTWARI	a-ûmv-ik-an-a	nka	u-shávur-ye
RUBERINTWARI	3SG-to.hear-NEUT-ASSOC-FV	like	REL-3SG-be.unhappy-PFV

RUBERINTWARI ***sounds*** unhappy.

Although *Kubóneka* "to be seen/to seem" can function as a synonym of *gusa* and can replace it as in *Kubóneka+nka,* the construction implies the involvement of the audience or a shared opinion. That is, RUBERINTWARI appears unhappy to anyone who looks at him. RUBERINTWARI's face serves as the source of evidence for the provided information. Therefore, a clause in which the physical evaluative perception where *Kubóneka* heads the VP has a meaning of inferred evidentiality *(Aikhenvald, 2003:1)*. The speaker can also use these verbs to avoid confirming what he is not sure of. Once more, he uses the verb *Gushávura* "to be unhappy/nervous" as the main verb (19), the proposal reflects a higher degree of certainty on the part of the speaker about the stated information than in (37d). Thus, a case of epistemic modality (Usonienė, 2002).

d) ***RUBERINTWARI arashávuye***

RUBERINTWARI	***a-ra-shávur-ye***
RUBERINTWARI	3SG-DISJ-shávur-ye

RUBERINTWARI ***is unhappy***.

Once more, in *Ruberintwari is unhappy*, the disjunctive marker -ra- shows the focus on the information conveyed by the verb and thus, a case of epistemic modality if we follow Halliday (1970:349). In such contexts, the verb functions as an evaluative adjective. As they are many in Kirundi due to the limited number of lexical adjectives, this study does not elaborate all of them. It only focuses on those that came out from Viberg's paradigm of VoP, where the verb *kuryôherwa* "to be happy", for instance, emerges because the adjective *happy* complemented the verb "to look" in *"Peter looked happy"(Viberg, 1984b:125)*. This is to say that there are as many evaluative verbs as many qualities speakers may attribute to things/objects or people. Although this is valuable to all the sense modalities it extends on, the gist of the construction is that the described thing/object/person lacks the targeted feature in gustatory (38b) and tactile (38a) sense modalities.

(38) ***b) […] impŭzu zisa n'izirêmvye*** (*UbwuzureBushasha.txt*)

[…]	i-n-huzu	zi-sa	na	i-zi-rēmb-ye

AUG-NP-cloth	REL-3PL-to.look	like	REL-AUG-3PL-to.be.soft-PFV

Cloths that ***looked soft****[but which are not]*.

b) ***urwârwá rusa n'úruryōshé***

u-rwârwá	ru-sa	na	u-ru-ryōh-ye
AUG-banana.wine	REL-3SG-to.look	like	REL-AUG-3SG-to.be.tasty-PFV

Banana wine, which***appears to have a goodtaste****[but which is not]*.

Consequently, this discussion reveals that the choice of one of the different constructions '*Gusa nka/na*…, *kubóneka nka*...'' to mean *'looks'* in the basic sentence 'Peter *look*s happy", depends on whether the author makes a subjective or objective evaluation *(Polis, 2009:207)*. Moreover, only source based visual verbs can extend their meanings to all the non-visual perception verbs, except SMELL.

4.2. Hearing

The classification of basic VoP in Kirundi showed that *kwûmva/* HEAR conveys an uncontrolled perception, where the perceiver is an experiencer. Nevertheless, HEAR predicate constructions in Kirundi do not always refer to audition. Despite the fact that all sense modalities may have lexical verbs to express them, the auditory verb can express all the other physical sense perception except sight. The section below demonstrates the multimodal feature of the verb Kwûmva. This simply means that the nose (39), the mouth (40) and the skin (41, 42) can hear too, but that the eye cannot.

(39) ***Wūmvírize utuvúta tumōtá cāne*** (*Ndamuhevye.txt*)

u- ûmv-ir-ir-i-e	u-tu-vúta	tu-mōt-a	cāne
IMP-2SG-to.hear-CON-IMPFV	AUG-NP-oil	REL-3PL-to.smell-FV	much

Smell to make sure the oil is fragrant.

Since the verb *kumōta* 'smell' can go through word-formation processes to express active (kwîmōtereza) and experience (kumōterwa) verbs, kwûmva+N or kwûmva+V constructions make light verb-constructions (Jespersen, 1954) because a single derived verb can replace it. This then reveals that *kumōterwa 'catch a smell of x'* can replace the multiword units "*Kwûmva akamōto* (V+N) or *kwûmva ibimôta* (V+ Rel.Clause)" in an experience olfactory perception, while the same is possible for *kwîmōtereza* in the place of *kwûmviriza akamōto* (V+N) or *kwûmviriza ibimôta* (V+Rel.Clause). If we consider the association between sensory modalities, we can also refer to these light verb constructions as synesthetic metaphor constructions (Hui, 2007; Lievers, 2015). As in Lievers' example "*She has a very sweet voice*" (p2), sweet (taste) connects to voice (hearing), the Kirundi verb phrases V +N are cases of synaesthesia too. V stands for *hearing* and N for any noun related to smell, taste (40) or touch.

(40) ***Igihĭmba twūmvîsha uburyŏhe*** (*Inyigisho menyeshantara 2.txt*)

i-ki-hĭmba	tu-ûmv-ish-a	u-bu-ryôh-e
AUG-NP-part	2PL-to.hear-INST-FV	AUG-NP-to.be.tasty-FV

A part with which we **taste**.

For tactile perception, the verb *Kwûmva* "to hear" heads a VP, where the verb collocates with a word related to the tactile field.

(41) ***[…] nūmva ikūntu kīmfashé ukubóko***. (IcaGatandatu.txt)

[…] n-ûmv-a	i-ki-ntu	ki-n-fát-ye	u-ku-bóko
1SG-hear-IMPFV	AUG-NP-thing	3SG-PP_{1SG}- to.hold-PFV	AUG-NP-arm

[…] I **felt** something holding my arm

(42) ***[…] nûmvisegákaze*** (*RTNB_Ninde_2016-08-24.txt*)

[…]	n- ûmv-ye	ka-kár-ye
[…]	1SG-hear-PFV	REL-3SG- be.acrid-PFV

[Today, I decided to soak up the sun until] I ***feel*** it burning.

All the above constructions refers to external information that one can perceive through four sense modalities – *Hearing, smell, Taste* and *Touch*, which the auditory verb *Kwûmva* "to hear" can express. Although *(Wierzbička, 1980, p. 106)* has vindicated that human perception finds motivation from external stimulus, Kirundi speakers' perception can result from an internal stimulus and then use the auditory verb *kwûmva*. Referring to Evans & Wilkins'(2000), we can talk of the body's ear when it comes to associating this auditory verb with emotion or feeling terms (43 & 44).

(43) ***nūmva intŭntu nyĭnshi*** (*UbwuzureBushasha.txt*)

n- ûmv-a	i-ntŭntu nyĭnshi	
1SGt-hear-FV	AUG-sadness	a.lot

I ***feel*** very sad.

(44) ***[…] nūmva ndahîmbāwe.*** (*Ubuzima.txt*)

[…] n-a-ûmv-a	n-ra-hîmbār-u-e	
1SG-PST-hear-FV	1SG-DISJ-plead-PASS-IMPFV	

[…] I ***felt*** pleased.

In a source-based auditory perception event, the extended verb *kw**ûmv**īkana* can extend its meaning to *touch*, *taste* and *smell*. When words relating to the taste field combine with the verb *kwŭmvīkana*, the construction expresses an evaluative gustatory perception event. With it, we express all what can be *audible*, *felt*, *smelled* or *tasted*. However, as of a percept expression in gustatory perception event, where the object of stimulus-based perception is the subject, the enclitic locative -mwó (inside) attaches to the derived form "kwûmvīkana" (45).

(45) ***umutóbe wūmvîkanamwó isúkări***

u-mu-tóbe	*u-ûmv-ik-an-a-mwó*	*i-súkări*
AUG-NP-juice	*REL-3SG-to.hear-STAT-ASSOC-FV-LOC*	*AUG-sugar*

A ***sugary juice***.

Affixation plays an important role in semantic disambiguation of the different syntactic encodings of perception events in Kirundi.

4.3. Taste

The gustatory ***Guhônja***, when associated with words relating to hearing or to sight fields, respectively reads '*hear a piece of x*' and '*see a piece of*'. Therefore, through a metonymic relationship, it conveys that the perceiver gets a small introductory part of what s/he is going to listen to or watch (46). The overall meaning of the construction is that the journalist introduces a part of the program to the followers, who will get more details later.

(46) ***Kwāri ukubáhōnja*** (*ISA_UburundiBura_2014-09-22.txt*)

Ku-a-ri	u-ku-ba-hônj-a
INF-PST-to.be	AUG-INF-3PL-to.tatse

It was an introduction.

Among the considered lower senses in a Perceiver-Oriented perception event, only the gustatory verb ***Guhônja*** can extend its meaning to other sense modalities, upper sense modalities included. This verb contradicts Viberg's hypothesis about the directional hierarchy of VoP. This verb extends its meaning to both *visua*l and *auditory* modalities.

As of the gustatory evaluative verb *Kuryôha* "*to be tasty/delicious or to have taste*", it can also express *auditory* (47a), *visual* (47b) and tactile (47c) perceptions.

(47) a) ***akūnda amajāmbo amuryŏhera*** *(Abahungu.txt)*

a-kūnd-a	a-ma-jāmbo	a-mu-ryôh-ir-a
3SG-to.love-IMPFV	AUG-NP-word	3PL-2SG.OBJ-to.have.taste-APPL-FV

S/he likes ***tasteful*** words

b) igishóbora kuryôhera ijîsho […]*.(Abahungu.txt)*

i-ki-shóbor-a	*ku- ryôh-ir-a*	*i-ri-jîsho*	***[…]***
AUG-NP-to.be.able-IMPFV	*INF--to.have.taste-APPL-FV*	*AUG-NP-eye*	*POSS*

S/he will not neglect anything that can ***attract*** the boy's eye.

c) Unó mŭsi hāri akazûba karyōshé *(Ninde_2020-14-01_RTNB)*

[…]	*ha-a-ri*	*a-ka-zûba*	*ka- ryôh-ye*
	LOC-PST-to.be	*AUG-NP-sun*	*REL-3SP-to.have.taste-PFV*

There was a ***warm sun*** today.

Again, as already discussed above, this is another case of synaesthesia. The perception event involves an association of tactile and gustatory senses. Hence, a gustatory-tactile transfer.

4.4. Touch

Among all the tactile perception verbs, only the tactile evaluative verb kwôroha "to be soft" can extend its uses to all the other modalities as illustrated in (48, a-d).

(48) ***a) Agatāmbāra kōróshe*** *(Inyigisho menyeshantara 4.txt)*

a-ka-tambara	ka-ôroh-ye
AUG-NP-piece.of.cloth	REL-3SG-to.be.soft-PFV

A ***soft*** piece of cloth.

With word related to sound, the verb conveys an auditory perception meaning (47b).

b) umuzikíwōróshe

i-mu-ziki	u-ôroh-ye
AUG-NP-music	REL-3PL-to.be.soft-PFV

A **soft** music

When the mouth is the organ of perception of the lightness/softness, especially with drinks, the evaluative verb indicates a gustatory perception (47c).

c) inzogá yōróshe

i-n-zoga i-ôroh-ye
AUG-NP-beer REL-3PL-to.be.soft-PFV
Light beer

The verb *kwôroha* extends to "smell" to mean *a sweet smell* or *not a strong smell*(47d).

d) parfum yōróshe
parfum i-ôroh-ye
Perfume REL-3PL-to.be.soft-PFV

A ***sweet*** *perfume* (*a perfume, which is not strong*).

Taking into consideration the different meaning extensions, the order of Kirundi VoP reads as follows:

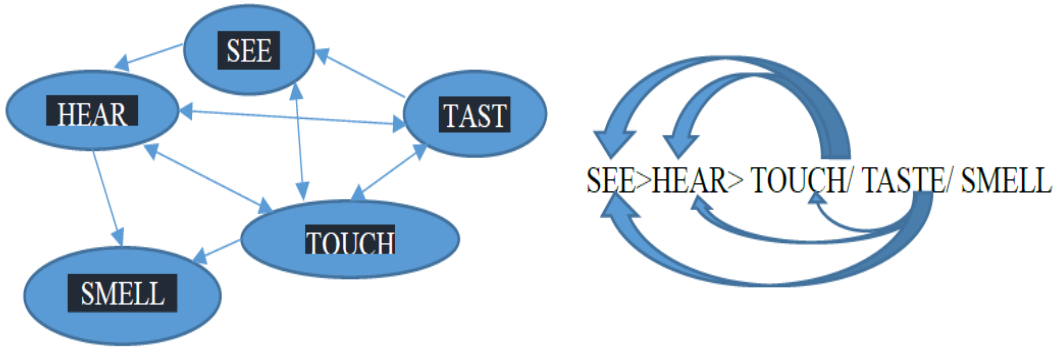

Figure 1: Cross-modal meaning extensions in Kirundi

From both perceiver and perceived-oriented angles, only SMELL cannot expend its physical meaning to other sense modalities. The hierarchy of basic VoP in Kirundi attests bidirectional relationships between some sense modalities such as SEE-TOUCH, HEAR-TOUCH, HEAR-TASTE and TOUCH-TASTE. That is, for Kirundi, the reverse arrows indicates a reverse relationship between the modalities, where the lower sense modality conveys a higher sense. Thus, the Viberg's VoP hierarchy does not apply to Kirundi. Regarding the two predominant senses – *Sight* and *hearing*, SEE connects to other senses through a synaesthetic simile (e.g: *isa nk'íyŏroshe* /it looks soft) while HEAR extends its use through metaphoric synaesthesia (*Kwûmviriza ităbi* 'Taste cigar') and metonymy (*guhônja indirimbo 'taste a song'-play or sing/listen to a short part of a song)*.

5. CONCLUSION

The aim of this paper was to find out the basic VoP in Kirundi, their intra field meaning extensions and the extent to which Viberg's claim on the cross-modal unidirectional hierarchy applies to Kirundi VoP. The analysis attests the use of both linguistic and cognitive means. By linguistic means, Kirundi has lexical items referring to perception(Ku**mōt**a 'SMELL', kw**ûmv**a 'HEAR'). In case of scarcity, Kirundi uses word formation patterns to derive new verbs or reduplicate the roots of the primitive verb to satisfy communication needs. Through cognitive means, the hearing verb *kwûmva* (and its morphologically derived forms *kwûmviriza* and *kwûmvīkana*) extends its physical meaning to non-visual senses –*Touch*, *Taste* and *Smell* –using metonymy or metaphor. Moreover, Kirundi verbs of audition distinguish external from internal world information. Possibly that this poly functionality is not only cross modal. A hypothesis

that needs examination is that, as in other languages, Kirundi VoP can express different domains other than perception. Therefore, further studies would focus on cross-field meaning extensions.

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AUTHOR

Emmanuella Ahishakiye holds an MA. Double Degree in Linguistics and Its Applications for a Multilingual Society (LAMUSO) earned at Université Catholique de Louvain (Belgium) and Oslo University (Norway). As of her career, she works as an Assistant Lecturer at the University of Burundi –Institute for Applied Pedagogy since 2012. Emmanuella is currently interested in lexical semantics, where for her PhD project (University of Burundi- University of Liège) she works on the semantics of Perception verbs in Kirundi and their implications on second/foreign languages learning and teaching.

USE OF ANALOGIES IN SCIENCE EDUCATION, A SYSTEMATIC MAPPING STUDY

Hernandez Pedro and Espitia Edinson

Master of Education, Castle University, university of Cordoba, Colombia

ABSTRACT

This systematic mapping study consisted of tracking the scientific literature that addresses the issue of analogies as a didactic strategy in science teaching. An analogy can be understood as comparing an existing knowledge with a new knowledge to achieve a better understanding of the new knowledge as a result of the comparison of similarities; or in other words, use students' own concepts to introduce new concepts using comparisons between the two. The purpose of this study was to identify, analyze, synthesize and evaluate research works that touched on this topic, with this, to have knowledge about the models of uses of analogies, most used didactic strategies, research methodologies in this field and how to evaluate the learning effectiveness of working with analogies. The methodology that was used is the systematic mapping study; Five questions were posed that guided the information tracking process. Later, the electronic documents in English for the last twenty years were traced in five databases related to the educational field. Finally, it is concluded by responding to the purpose of the study where it is evident that, broadly speaking, the research methodologies in this field are quantitative as well as qualitative, to implement analogies, resources such as images, illustrations, textual indications and audiovisual aids are used, it is usually evaluated the effectiveness of using analogies with multiple choice tests, oral tests of creating analogies by students.

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KEYWORDS

Analogies, science teaching, analog model.

1. INTRODUCTION

A quality education indicates aspects such as infrastructure, qualified personnel and excellent pedagogical processes that promote active learning of students. Thus, improving educational quality, one way or another, leads to an emphasis on pedagogical processes and this represents a special focus on the teaching tools that are implemented in classrooms in order to strengthen pedagogical processes. Analogies over time have been an excellent didactic tool that allows improving the teaching-learning processes.

Harriso y Treagust [1], argue that analogies have long formed tools of discovery in science, and are often used as explanatory devices within the classroom. However, research has shown that analogies can elicit alternative conceptions because some students view the analog differently than the teacher. This position is classic in this field and is the basis for later studies on this particular issue. It should be understood that “analogies are comparisons between relationships from a familiar domain (base) to an unknown domain (target). Due to this, they can be important ways for teaching scientific concepts and at the same time, the analogies drawn by teachers can show their conception, their beliefs and mainly the kn they mobilize when drawing them ” [2, p. 6]

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In other words, "an analogy can be defined as a comparison between the similarities between two different domains, one unknown, or little known, which can be called destination domain and last known destination, for which it is called the analogous domain" [3, p. 5]. In this regard, Guerra [4], confirms that an analogy is a comparison of the similarities of two concepts, the familiar concept that is called the analogous and unfamiliar white. Both the analog and the target have characteristics of their own, (also called attributes). An analogy can be drawn between them. A systematic comparison, orally or visually, between the characteristics of the analog and the target is called a mapping.

There “Analogy is considered a useful way to help students visualize abstract concepts and assimilate new insights from an existing cognitive structure” [5, p. 5]. For this, there are various resources and models to implement analogies in classrooms, Kepceoğlu and Karadeniz [6] whos show that analogies are classified with respect to their analogical relationship, presentation format, abstraction, position of analog with respect to the objective and wealth level.

In this sense, "The creation of analogies are a powerful tool for explanation, as well as a fundamental mechanism to facilitate the individual's construction of knowl, [7 p.5], however these can be "two-edged swords Because the knowledge they generate is often accompanied by alternative conceptions, when people receive analogies, they use their past knowl, experiences, and preferences to interpret the analogy to harmonize with their current thinkin [1, p. 3].

For his part Guerra [4], suggests that analogies as pedagogical tools have strengths and limitations; analogies are clearly not a magical resource to promote understanding of science or its concepts, but their potential can be capitalized if they are used wisely.

However, Harrison y De Jong [8] recommend the use of multiple analogies and insist that teachers always show where the analogy breaks and carefully negotiate conceptual results. Indeed, “the challenge of science education is then to help service teachers to use analogies when teaching science concepts” [7 p. 3].

In this sense, Harrison y Treagust [1] affirm that science classrooms are a common environment in which analogies are used to improve for learning concepts; therefore, improving the way analogies are used in science education, this has had important consequences for improving teaching and learning processes.

De Rosa, Pimentel, y Terrazzan [3] consider that, in the context of teaching and learning subjects in the field of natural sciences, analogies favor students in understanding a scientific domain that is unknown for them, based on a family domain, by comparing common and uncommon attributes and relationships between both domains.

Indeed, “analogical reasoning is known as an important mental process for solving problems of everyday life, specialized problems in mathematics, physics and chemistry, in a creative way. When a new problem must be solved, people remember similar problems that they have solved before and adjust the solutions they used at the time according to the nature and characteristics of new problems to solve them” [9 p. 9].

In accordance with this, a research study was proposed on the use of analogies for science teaching, where the development of contextualized analogies to the rural environment will be addressed, following guidelines of pre-established models, for the development of analogies in said context. In this way, the present work shows the initial phase of this research aimed at developing a systematic mapping study that allows a comprehensive overview of the use of

analogies in the teaching of science, methods, didactic resources that are used, techniques and instruments used in existing research, carried out on this specific area of knowledge.

This document is organized as follows: First, the definition of the research questions; second, conducting the search; in the third moment, the classification of documents; in fourth place, the extraction of data and finally in fifth place, the preparation of the report and the publication.

2. SEARCH METHOD

At the beginning of the process of carrying out the systematic mapping, it was necessary to take into account a series of steps, which will allow to be more successful with the search and tracking of information. Understanding that "a systematic review of the literature is a means of identification, evaluation and interpretation of all available research that is relevant to a specific research question, thematic area or phenomenon of interest" [10, p. 11].

In other words, systematic mapping is a technique that allows to account for the knowledge that exists on a specific topic, in this way, to be certain of scientific advances, as well as the lines of research that occur in a certain field of science. knowledge.

Now, the term systematic mapping is often associated or confused with another type of scientific research such as systematic review, however, they are two different concepts that respond to different purposes and procedures, on this Katy L. James, Nicola P, Neal R. and Haddaway [11] clarify that systematic mapping does not attempt to answer a specific question like systematic reviews, but rather collects, describes and catalogs the available evidence.

Therefore, the steps that will be followed for the elaboration of this systematic mapping are those proposed by Kitchenham [10].

2.1. Definition of research questions.
2.2. Conducting search.
2.3. The classification of the works.
2.4. Data extraction.
2.5. Preparation of report and publication.

2.1. Definition of Research Questions

In order to track information that responds to the topic of using analogies for school teaching in rural contexts, five research questions were defined:

RQ 1. What evidence indicates the use of analogies to facilitate science learning?
RQ 2. What types of models for the use of analogies are used for the development of science?
RQ 3. What type of research methodology has been used to develop studies that use analogies for science teaching?
RQ 4. What type of teaching resources have been used in investigations that use analogies to teach ashes?
RQ 5. What methods have been used to assess learning in studies that use analogies for science teaching?

With these five questions, an attempt was made to cover the subject matter in question in a very complete way and thereby give an account of how research is developing in this field of knowledge, in that order of ideas;

RQ 1: I seek to track information that indicates how analogies have been used as a didactic tool for teaching science, to facilitate teaching-learning processes in classrooms;
RQ 2: I inquire about the way in which analogies have been implemented, that is, criteria, processes and / or steps to use analogies in a correct and effective way, within the classroom;
RQ 3: aimed to identify which research methods have been used in this field, with this we refer to the type of study, design and techniques most used;
RQ 4: I seek to recognize what types of didactic resources are useful to implement analogies (comics, images, among others), and
RQ 5: gave an account of the way they have been used to evaluate the effectiveness of analogies as a didactic tool in the teaching-learning process.

2.2. Conducting Search

To search for the required information, a procedure was carrie out where the research categories were reviewed, then the search strings were elaborated and as a third step, the data bases where the literature searches will be carried out were defined.

This, a review of the categories immersed in the investigation was made, a necessary process to start the development of search steps, that is; It is necessary to be clear about the categories that are going to be worked on in the study, since these are the basis of support for the next step, which will result in the definition of the search strings.

This is important as "defining search parameters implies the selection of search terms, combining them with the help of search operators, and using the appropriate search fields"[12 p. 13], from this it can be inferred that, to build a search chain, it is necessary to be certain of the categories to be investigated and thus use the appropriate terms.

Now to design an appropriate search string. Kitchenham [10], presents a guideline on the definition of these strings to reduce the desired search bias. This, we select the keywords related to the research questions to compose the research chain.

This aspect is important to give credibility and confidence in the investigative process by reducing biases in this process. Consequently, when building a search string, it is important to “define and use search parameters that have a significant impact on search results, so researchers often have to experiment with combinations of search terms and operators [12 p. 14].”

Vom Brocke, Simons, Riemer, Niehaves, Plattfaut y Cleven 2015 [12] when using several search operators to improve the results in the use of search terms, for example, combining them with Boolean operators in search phrases [for example, AND, OR]. are while the exact use and interpretation of the search phrases can be determined with the help of parentheses, the precision of the search can be influenced by quotation marks.

Likewise, Boell and Cecez-Kecmano [13] argue that, to define search strings, the combination of terms using 'OR' indicates that any of the terms used is sufficient to retrieve a document. An important use of 'OR' is to include synonyms in a search. In contrast, 'AND' is used to restrict a search to documents that show different conditions at the same time. Its main use is to join different terms. These terms can represent different concepts that should be show the present at the same time.

Taking into account the previous approaches regarding how the search strings should be elaborated, three search strings were defined, where it is intended to give answers to the research

questions and the following data bases were chosen: jstor, scopus, taylor & francis, proquest and science Direct.

Table 1:

PREGUNTAS	**STRING**
1. What evidence indicates the use of Analogies to facilitate science learning of primary school students in rural educational contexts?	("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)
2. What kind of models of use of analogies is used for the science teaching in rural educational contexts?	
3. ¿What type of research methodology has been used for the development of studies that use analogies for science teaching in rural educational contexts?	(“Use of Analogies" OR “analogies” OR “model analog”) AND (“Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “concept teaching”)
4. ¿What kind of teaching resources have been used in studies that uses analogies for science teaching?	(“didactic resources” OR “resources” OR “pedagogical resources”) AND ("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)
5. What methods have been used to evaluate learning in studies that uses analogies for science teaching?	(“instrument of measurement” OR “evaluation” OR “assessment” OR “evaluation instrument” OR “assessment instrument” OR “evaluation method”) AND ("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)

Table 2:

#	**STRING**	**TOTAL**
STRING 1	("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)	1.834
STRING 2	(“didactic resources” OR “resources” OR “pedagogical resources”) AND ("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)	1.089
STRING 3	(“instrument of measurement” OR “evaluation” OR “assessment” OR “evaluation instrument” OR “assessment instrument” OR “evaluation method”) AND ("Use of Analogies" OR “analogies” OR “analogy”) AND ("scientific education" OR “Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “primary school”) AND ("rural area" OR “rural education”)	2.286

STRING 4	(“Use of Analogies" OR “analogies” OR “model analog”) AND (“Science Teaching” OR “science learning”) AND ("primary education" OR “elementary school” OR “concept teaching”)	7.661

The information tracking only included digital databases; with a total of five databases, of importance in relation to educational issues, which were already mentioned above. Four different strings were elaborated, in table 2, the total results of documents found in each of the different strings are shown, thus, in string 1 1,834 results were found, in string 2 a total of 1,089 and in string 3 2,286 results were found and in string 4 7,661 documents were tracked.

For the following stages of this study, string 4 will be taken into account, since they present a greater number of tracked documents, in order to address each of the research questions in a comprehensive and complete way, and this will be chosen trace string. Now, this information tracking process began in February 2020 and lasted until the middle of June 2020.

2.3. The Classification of the Works

In order to classify and carry out a detailed review of the tracked literature, it was necessary to have defined criteria of inclusion and exclusion in this way to be able to emphasize the documents that are relevant to our work, thus avoiding futile efforts in excautive reviews of literature that do not fit under the research objectives, and do not contribute to answering the research questions already posed.

Similarly, having clear and well-defined criteria to exclude and include information will allow to reduce biases in the investigation process, which indicates that, as long as these criteria are structured and the relevant steps are followed, it will be carried out. more reliable research.

Table 3:

Inclusion criteria	**Exclusion criteria**
1. Primary studies that show the use of analogies in the teaching and learning processes of science. 2. Studies that specify models for the use of analogies in education. 3. Articles that detail the research methodology used in educational interventions that use analogies 4. Research articles that show the different resources used to implement analogies in the educational field.	1. Articles that do not address analogies, although they do inquire about another category of the study. 2. Articles that are not in English since the universality of this language globalizes research. 3. Articles that do not present full text and are not available in electronic format. 4. Technical reports, documents that are available in the form of abstracts or presentations, as well as secondary literature reviews. 5. Duplicate publications, it is considered the most recent in redundant studies of the same authorship. 6. Articles that are not research products (systematic reviews, interpretive studies from other contexts). 7. all documents that are more than 20 years old, that is, those that were published before the year 2000.

2.4. Data Extraction

At this stage, the documents were read completely and in detail to answer the questions that were raised at the beginning and finally to obtain the evidence that supports this mapping study.

Table 4:

STRING	DATABASES	DOCUMENTS INCLUDED	DOCUMENTS EXCLUDED	TOTAL
("Use of Analogies" OR "analogies" OR "model analog") AND ("Science Teaching" OR "science learning") AND ("primary education" OR "elementary school" OR "concept teaching")	**ProQuest One Academic**	22	6.504	6.526
	Jstor	4	596	600
	Taylor & Francis	1	263	264
	Science-Direct	0	268	268
	Scopus	1	2	3

Table 5:

	DATABASES	DOCUMENTS INCLUDED
("Use of Analogies" OR "analogies" OR "model analog") AND ("Science Teaching" OR "science learning") AND ("primary education" OR "elementary school" OR "concept teaching")	**ProQuest One Academic**	22
	Jstor	4
	Taylor & Francis	1
	Scopus	1
TOTAL DOCUMENTS INCLUDED	**28**	

2.4.1. Results

To have greater clarity about what was obtained in the search, three important aspects about the literature searched will be mentioned; in this way, in the first place, the means of diffusion, the type of research method and the population under study.

It was found that 39.29% (11 documents) corresponded to theses to aspire to the doctoral degree published in journals, 7.14% (2 documents) went to theses to aspire to the master's degree published in journals, 25% (7 documents) corresponded to research articles published in journals, 14.28% (4 documents) were book chapters and finally 14.28% (4 documents) were published in conferences.

On the other hand, in terms of methodological research, 17.85% (5 documents) had a qualitative approach of case study and action research, 17.85% (5 documents) corresponded to the non-experimental quantitative approach, 14.28% (4 documents) They were of mixed methodology, 28.57% (8 documents) were quantitative quasi-experimental and pre-experimental with

intervention, and 21.42% (6 documents) corresponded to a quantitative experimental approach of the Solomon type and pretest-posttest with control group.

Regarding the study population, 25% (7 documents) were from primary school, 57.14% (16 documents) corresponded to secondary school, 14.28% (4 documents) were undergraduate and 3.57% (1 document) were from a population open, that is, they included a different population**.**

2.4.2. Answers to Research Questions

Evidence the use of analogies to facilitate science learning

This question inquires about those investigations that show, how analogies in practice can be considered as a powerful tool when teaching concepts in science, an attempt was made to trace all the investigations that included analogies as a didactic strategy to impart knowledges.

Consequently, all the documents that were included for the present study provide evidence of the value of analogies in teaching scientific concepts. It should be noted that 32. 14% (9 documents) of the investigations found study how analogies are used in science textbooks, and the way in which these analogies, present in teaching guide books, can improve the learning of science students.

67.85% (19 documents) are studies that investigate how analogies as a basic didactic strategy in science classes directly influence student learning and contribute to achie meaning ful learn in science. Everything found and presented in this study shows the great importance of analogies in the educational field, and especially in the school teach of scientific concepts, however, it must be borne in mind that, although this document only addresses studies published in the last 20 years, the topic of analogies in the research field as a vital didactic tool in the teach-learn processes, has been studied for several decades behind those contemplated by this study.

Models for the use of analogies in the teaching of science

thats all the research retrieved, only twelve studies were identified where models for the use of analogies in science were mentioned, thus providing an answer to this question.
Rule A, Baldwin S y Furletti [14], The authors showed a way to combine form and function with analogy is through the form and function analogies of boxes of objects. This technique has been used successfully in teaching, to use the object boxes feature form to teach animal adaptations to third graders.

Bennett-Clarke, B Ciana. [15], They take the model of (Duit, 1991; Wittrock and Alesandrini, 1990; Wong, 1993a, b) On the analogies built by the teacher and the analogies that are generated by the student self-generated analogies. Thus, self-generated analogies are meta-cognitive strategies, founded on Generative Learning Theory. They are known to facilitate the understanding of abstract ideas by pointing out similarities familiar to the student in the real world, promote self-generation of meaning and autonomy in learning, and awaken students' interest and motivation to learn.

M Sota [16], They studied contrasting analogies: situations that are not analogous to the concept or principle for which a false idea is carried out. Given the well-documented effects of non-examples on conceptual learning and research on contrasting analogies in problem solving, one might expect that contrasting analogies will have a positive effect on conceptual change.
L Asay [17], Cite models for teaching analogies, highlight the objectives of each, claim that the few existing models for instruction with analogies have often not been quantitatively examined.

The model with analogies is one of the models frequently cited in the variety of investigations on the subject. The model outlines the steps for instruction, including the step of explicitly mapping characteristics from source to destination.

Second model, teaching with analogies Provides principles for evaluate instructional analogies and steps for using analogies, but relied on analysis in science textbooks, rather than pedagogical principles or research on effectiveness.

A third model, the Focus, Action, Reflect or FAR teaching model emerged from Australia, with the use of TWA model teachers. This model includes planning the use of analogies and an evaluation of the process, but again focuses on what teachers do to prepare.

L Atkins [18], developed a count of analogies generated as categorization statements using the events in this classroom investigation from categorization.

B Gary [19], I implement the teaching model that I call the Pre-Analog Step: all to teaching method to improve students' familiarity with important analog features in an analog source before introducing an analogy to understand a target domain.

L Newton [20], Addressed the position of the analogy in the instructional text that can vary. You could introduce yourself as an analog advance organizer, at the beginning of the instructional unit. It could be integrated into instruction at a point where new and / or more difficult information is introduced, what Curtis calls a built-in trigger. As such, it can also help clarify what has happened before and lead to new but related material. Finally, the analogy could occur at the end of the instructional text, to act as a vehicle and synthesize what had happened before and conclude the topic, described as a later synthesizer.

So far, analogies have been mentioned in an undifferentiated way. They can be identified as: Simple: analog statements without elaboration; Enriched: analog statements that include the basis of the analogy; and extended: analog statements that can be applied to various topics and used in various contexts.

K Clement y K Yanowitz [21], show a situation model that includes not only text entities, but also relationships between text entities such as temporal and causal relationships. There, the situation model includes explanations of why text events occur. A well-developed situation model requires an understand of the causal mechanisms explicitly described in the text, as well as inferences about the causal mechanisms. The situation models of a text are. they build on the basis of both the text itself and prior knowledge, was Schémas, general factual knowledge, or knowledge specifically related to the current text.

Madera S [22], mentions three teaching models, have also been identified. WWA is a derived model that adapts to the ideas of both GMAT and TWA. The Working with Analogies model should appeal to teachers as well as students because of its fit with current fashionable constructivist approaches to the teaching and learning of physics.

Murat G [23], I use the student-centered model of analogies. A study was carried out with 6th grade primary school students. Where the students were asked to form their own analogies as a result of the study in which the student-centered analogy technique was used.

Dundar Y [24], It is a study on the analogies presented in the high school physics text books. This model is also called the "raisin cake model" as it looks like raisin cakes This is explained in the

structure analogy by comparing the structure of an atom to a raisin cake. According to previous research, multifunctional analogies have been used primarily in chemistry text books.

Musa D [25] They mention that, for analogies to become effective teaching tools in biology textbooks, they should be created based on guides such as Teaching with Analogies and Focus-Action-Reflection (FAR; Treagust et al., and its limitations should be explicitly described and systematically presented.

Research methodologies in studies on analogies.

After the trace of the literature, it was found that the investigations on analogies rotate in the three methodological directions, that is, works of methods were obtained. qualitative, quantitative and mixed studies were also found. It was observed that 17.85% (5 documents) were of a qualitative approach of case study and action research, 17.85% (5 documents) corresponded to the non-experimental quantitative approach, 14.28% (4 documents) were of mixed methodology, 28.57% (8 documents) were quantitative quasi-experimental and pre-experimental with intervention, and 21.42% (6 documents) corresponded to a quantitative experimental approach of the Solomon type and pretest-posttest with control group.

Didactic resources used in investigations that implement analogies.

This question inquires about those teaching tools or ways of presenting analogies when implementing them in teaching processes. In this way, it was found that the teaching resources used to implement analogies are: verbal instructions by the teacher, videos, images or illustrations [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43] .

It should be mentioned that in the different models that were found, both instructions and images are used in the same analogy, although only the instructions of the teacher or expert can be used to explain the analogy and the relationships to be related.

Methods used to assess post-analog learning learning

When analogy is used as a didactic tool or strategy for better learning, the literature consultation clearly evidenced that there are some reforms to evaluate these processes, in this way to verify how analogies impact the teaching-learning processes.

In the documents tracked, it was found that tests with multiple selection were carried out with several evaluation items, as in the study of. Nita A. [27] where after the text study, the participants returned to complete the questionnaire of nine items, designed to retest your subject interest, perceived knowledge, and self-efficacy in teaching all three concepts.

In addition, the participants were administering text measures and were asked to classify the texts they read with respect, the participants were asked to complete the text by measure the classification of the three versions, with respect to how interesting it was, how useful it was the text to understand the concept and how helpful the text was from the perspective of explaining the concept to fifth graders.

Another type of evaluation that was found was the one proposed by Rule A, Baldwin S. y chell [38] where they mapped analogies, thought about alternative manufactured articles and created new analogies. Smith C. (2007) shows that they participated in individual interviews, before and after the curriculum unit received written pre and post exam assessments from their teacher.

On the other hand, Clement K y Yanowitz K [21] designed three tasks to assess what information the participants believed was central to the target domain. Object Task

The first task, revealed the participants' beliefs about the importance of individual objects in their situation model of the objective passage, and circled 4 objects that you consider most important to the story. "The relationship task Between Objects and the Relationships Between Events Task for the final task, participants had to do similar work to the previous one, except that instead of forming lower-order relationships, they were based on a given list of objects.

Similarly, evaluations such as those by Chuang M y Hsiao-Ching [41] stand out, in which the participants were interviewed and recorded before, a week after and 7 weeks after learning. Bennett-Clarke C. in this study the researcher made a five-minute summary of the lesson generating a discussion, asking the students to identify and briefly summarize the analogy that was used in that lesson of the day the students were assigned approximately three to five minutes by the end of the lesson. The summary for recording the analogy in your analogy journals and completing the journal entry page. In summary, each page of the magazine asked them to identify the analogy that their teacher presented, brief explain the relationship between analogy and concept, and to complete the four self-report items for situational interest, participating students should complete their journals for a project grade over the next two weeks of the course, students were asked to generate their own analogies. Independently in class and out of class based on the concepts covered. Analogies that students were expected to generate during the intervention period mainly simple surface analogies.

Finally, another evaluation strategy to highlight is that proposed by Asay L. [17] here the subjects took a previous test before the instruction, which was used to assign them to a previous level of knowledge about electrical circuits for the analysis of any effect differential. After the instructional modules, students took a posttest on electrical circuits. Two weeks later, they took a delayed posttest. Three different forms of a 20-question multiple-choice test on electrical circuits were used for the pretest, posttest, and delayed posttest.

A bank of 60 multiple, matching and true false options. Questions about electrical circuits were developed. The exam questions were prepared based on a set of item specifications for the components of the electrical circuits topic.

Although most studies in one way or another show how to evaluate procedures that use analogies, those that are different and present different characteristics are highlighted, in reference to the rest of the studies that fit within the mentioned evaluations.

3. CONCLUSIONS

With the detailed review of the twenty-eight documents that were considered relevant within the search, the purpose of this study is answered, which was to identify, analyze, synthesize and evaluate research works that touched on this topic, thereby, having knowledge about the models for the use of analogies, most commonly used teaching strategies, research methodologies in this field and how to evaluate the learning effectiveness of working with analogies.

In this way, it was found that there are several teaching models with analogies (more than three models highlighted in the literature, as shown above where this question was answered in previous pages), a variety of didactic resources that are useful to implement analogies such as illustrations with images, videos, verbal instructions among others. Regarding the way to evaluate the effectiveness of analogies, it was evidenced that written and verbal tests are applied, the

creation of new analogies by the students as well as verbal reasoning about the conceptual change.

These findings can contribute to the decision-making processes on methodologies, indicators, strategies, techniques and instruments that will be used in conducting development-oriented research in the teaching-learning of science and / or analogies as a way of teaching. This study leaves certainty about the fundamental role that analogies have had over time, especially in the last twenty years, as a fundamental strategy that facilitates teaching-learning in schools, and ultimately at all educational levels due to their richness to transmit new knowledge, and make a meaningful learning that generates conceptual changes.

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AUTHORS

Edinson Espitia Correa was born on April 9, 1988 in Colombia in the department of Córdoba. My educational background is a professional title BACHELOR'S DEGREE IN BASIC EDUCATION WITH EMPHASIS IN COMPUTER TECHNOLOGY at the Caribbean University Corporation close to the date of the degree on December 18, 2014 in Sincelejo Sucre. Postgraduate specialization in ETHICS AND PEDAGOGY at the Juan de Castellanos University Foundation dated June 30 2016.
Edinson Espitia Correa with experience in teaching at the Santa Fe Ralito Educational Institution in the position of FULL TIME TEACHER
ES. Espitia

Pedro Nel Hernández Álvarez born in coveñas sucre-a on September 4, 1992 in Colombia my educational background professional studies BA in PHYSICAL EDUCATION, RECREATION AND SPORTS at the University of Córdoba graduated on December 23, 2013 in Montería Córdoba. Postgraduate SPECIALIZATION IN PHYSICAL ACTIVITY AND HEALTH graduated on August 02, 2018.
Pedro nel Hernández Álvarez with experience in teaching at the Piñalito Educational Institution Pueblo Nuevo Córdoba in the position of ACTIVE FULL-TIME TEACHER
ES.Hernandez.

THE COLORED DISCONNECTION NUMBERS OF CELLULAR AND GRID NETWORKS

Xuqing Bai [1] and Xueliang Li [2] and

Yindi Weng[3]

Center for Combinatorics and LPMC Nankai University, Tianjin, China

ABSTRACT

Let G be a nontrivial link-colored connected network. A link-cut R of G is called a rainbow link-cut if no two of its links are colored the same. A link-colored network G is rainbow disconnected if for every two nodes u and v of G, there exists a u-v rainbow link-cut separating them. Such a link coloring is called a rainbow disconnection coloring of G. For a connected network G, the rainbow disconnection number of G, denoted by rd(G), is defined as the smallest number of colors that are needed in order to make G rainbow disconnected. Similarly, there are some other new concepts of network colorings, such as proper disconnection coloring, monochromatic disconnection coloring and rainbow node-disconnection coloring.

In this paper, we obtain the exact values of the rainbow (node-)disconnection numbers, proper and monochromatic disconnection numbers of cellular networks and grid networks, respectively.

KEYWORDS

link- (node-)coloring, connectivity, rainbow link- (node-)cut, (strong) rainbow (node-)disconnection numbers, proper and monochromatic disconnection numbers, cellular network, grid network

1. INTRODUCTION

All networks (also called graphs) considered in this paper are simple, finite and undirected. Let $G = (V(G), E(G))$ be a nontrivial connected network with node set $V(G)$ and link set $E(G)$. The *order* of G is denoted by $n = |V(G)|$. For a node $v \in V(G)$, the *open neighborhood* of v is the set $N(v) = \{u \in V(G) | uv \in E(G)\}$ and $d(v) = |N(v)|$ is the *degree* of v, and the *closed neighborhood* of v is the set $N[v] = N(v) \cup \{v\}$. The minimum and maximum degree of G are denoted by $\delta(G)$ and $\Delta(G)$, respectively. Denote by P_n a path on n nodes. For a subset S of $V(G)$, we use $G[S]$ to denote the subnetwork of G *induced by* S. Let V_1, V_2 be two disjoint node subsets of G. We denote the set of links between V_1 and V_2 in G by $E(V_1, V_2)$. We follow [7] for network theoretical notation and terminology not defined here.

The concept of rainbow connection coloring was introduced by Chartrand et al. [10] in 2008. A rainbow path is a path whose links are colored pairwise differently. A link-coloring of a network G is a rainbow connection coloring if any two nodes of G are connected by a rainbow path. The rainbow connection number of a connected network G, denoted by $rc(G)$, is the minimum number of colors so that G has a rainbow connection coloring. Rainbow node-connection was proposed by Krivelevich and Yuster [12] in 2010. For more details about the rainbow (node-)connection, we refer to [13] and survey papers [14, 16] and book [15].

As we know that there are two ways to study the connectivity of a network, one way is by using paths and the other is by using cuts. The above rainbow connection and rainbow node-connection use paths.

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So, it is natural to consider the rainbow link-cuts and rainbow node-cuts for the colored connectivity in colored networks.

In [8], Chartrand et al. first studied the rainbow link-cuts by introducing the concept of rainbow disconnection of networks, and later produced some other new concepts of colored disconnection colorings, such as proper disconnection coloring and monochromatic disconnection coloring. Let G be a nontrivial connected and link-colored network. A *link-cut* of G is a set R of links of G such that $G - R$ is disconnected. If all (adjacent, no two) links in R have different colors, then R is called a *rainbow (proper, monochromatic) link-cut*. Let u and v be two nodes. A rainbow (proper, monochromatic) link-cut R is called a *u-v rainbow (proper, monochromatic) link-cut* if the nodes u and v belong to different components of $G-R$. A link-coloring of G is called a *rainbow (proper, monochromatic) disconnection coloring* (abbreviated as rd-*coloring,* pd-*coloring* and md-*coloring*) if for every two distinct nodes u and v of G, there exists a u-v rainbow (proper, monochromatic) link-cut in G, separating them. The *rainbow (proper) disconnection number* (abbreviated as rd (pd)-*number*) rd(G) (pd(G)) of G is the minimum number of colors required by a rainbow (proper) disconnection coloring of G. The *monochromatic disconnection number* (abbreviated as md-*number*) md(G) of G is the maximum number of colors required by a monochromatic disconnection coloring of G.

In fact, the rainbow disconnection number has the following application background. In some illegal commodity transactions, we hope to stop the transaction in time and send out a signal (a certain frequency). On the one hand, we need to block all the roads between the two cities and identify the interception locations based on different signals; on the other hand, we want to use as few frequencies as possible in order to reduce costs. Therefore, we want to know what is the minimum frequency required to meet the above requirements? Treat each city as a node. If there is a road between two cities, we add a link between the two nodes, and use G to denote the resulting network. Give a link-coloring for G, where the color on the link corresponds to the frequency of the road. Therefore, the above problem is equivalent to calculating the rainbow disconnection number of the network G.

In order to study the rainbow node-cut, we introduce the concept of rainbow node-disconnection number in this paper. For a connected and node-colored network G, let x and y be two nodes of G. If x and y are nonadjacent, then an *x-y node-cut* is a subset S of $V(G)$ such that x and y belong to different components of $G - S$. If x and y are adjacent, then an *x-y node-cut* is a subset S of $V(G)$ such that x and y belong to different components of $(G - xy) - S$. A node subset S of G is *rainbow* if no two nodes of S have the same color. An *x-y rainbow node-cut* is an x-y node-cut S such that if x and y are nonadjacent, then S is rainbow; if x and y are adjacent, then $S + x$ or $S + y$ is rainbow.

A node-colored network G is called *rainbow node-disconnected* if for any two nodes x and y of G, there exists an x-y rainbow node-cut. In this case, the node-coloring c is called a *rainbow node-disconnection coloring* of G. For a connected network G, the *rainbow node-disconnection number* of G, denoted by rnd(G), is the minimum number of colors that are needed to make G rainbow node-disconnected. A rainbow node-disconnection coloring with rnd(G) colors is called an rnd-*coloring* of G.

Remember that in the Menger's Theorem, only minimum link-cuts play a role, however, in the definition of rd-colorings we only requested the existence of a u-v link-cut between nodes u and v, which could be any link-cut (large or small are both OK). This may cause the failure of a colored version of such a nice Min- Max result. In order to overcome this problem, we introduced the concept of strong rainbow disconnection in networks in [5], with a hope to set up the colored version of the so-called Max-Flow Min-Cut Theorem.

A link-colored network G is called *strong rainbow disconnected* if for every two distinct nodes u and v of G, there exists a both rainbow and minimum u-v link-cut (*rainbow minimum u-v link-cut* for short) in G. Such a link-coloring is called a *strong rainbow disconnection coloring* (abbreviated as srd-

coloring) of G. For a connected network G, similarly, the *strong rainbow disconnection number* (abbreviated as srd-*number*) of G, denoted by srd(G), is the minimum number of colors required to make G strong rainbow disconnected. We call the colored (dis)connection numbers the global chromatic numbers, and the classic or traditional chromatic numbers the local chromatic numbers [6].

The rapid development of computer networks and communication technology, and the rise and wide application of internet technology have strongly promoted the development of commercial applications and scientific applications in the network environment, such as grid networks [1, 2, 9] and cellular networks [18, 19]. The cellular network is a mobile communication hardware architecture that divides the service of mobile phones into small regular hexagonal sub-areas, and each cell has a base station, forming a structure that resembles a "cellular" structure. Therefore, this mobile communication method is called cellular mobile communication method, and its structure can save equipment construction costs. The grid networks were developed to support large-scale scientific collaborative work.

Based on the importance of cellular networks and grid networks, it is natural to consider the disconnection colorings of them.

Consider a (planar, infinite) lattice of congruent regular hexagons (quadrangle) and a cycle C on it. Then the part of the hexagonal (quadrangle) lattice which lies in the interior of C and the cycle C itself, forms a *cellular networks* (*grid networks*) G [11]. We call the C the boundary of the network G. Denote by $E(G) - C$ the inner links of G. Obviously, the cellular networks and grid networks are 2-connected.

This paper is organized as follows. In Section 2, we obtain the (strong) rainbow disconnection numbers of cellular networks and grid networks. In Section 3, we give the rainbow node-disconnection numbers of cellular networks and grid networks. In Section 4, we present the proper and monochromatic disconnection numbers of cellular networks and grid networks.

2. THEIR RD-NUMBERS AND SRD-NUMBERS

For two distinct nodes u and v of G, let $\lambda_G(u, v)$ (or simply $\lambda(u, v)$ when the network G is clear from the context) denote the minimum number of links in a link-cut F such that u and v lie in different components of $G - F$. The minimum cardinality of a link-cut of G is the *link-connectivity* of G, denoted by $\lambda(G)$.

Lemma 2.1 [8] *If G is a nontrivial connected network, then*

$$\lambda(G) \leq \lambda^+(G) \leq rd(G) \leq \chi'(G) \leq \Delta(G) + 1,$$

where the upper link-connectivity $\lambda^+(G)$ *is defined by* $\lambda^+(G) = \max\{\lambda(u, v) : u, v \in V(G)\}$.

Lemma 2.2 [8] *Let G be a nontrivial connected network. Then* $rd(G) = 2$ *if and only if each block of G is either* K_2 *or a cycle and at least one block of G is a cycle.*

Theorem 2.3 *Let G be a cellular network with the number of hexagons h. Then*

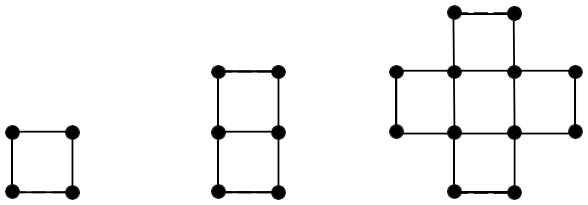
$$\mathrm{rd}(G) = \begin{cases} 2, & \text{if } h = 1, \\ 3, & \text{if } h \geq 2. \end{cases}$$

Proof. If $h = 1$, then $G = C_6$, so $\mathrm{rd}(G) = 2$ by Lemma 2.2. If $h \geq 2$, there exist two nodes u, v of G

satisfying $\lambda(u, v) = 3$. Moreover, we have $\chi'(G) = \Delta(G) = 3$ since G is a bipartite network. Hence, we get $\mathrm{rd}(G) = 3$ by Lemma 2.1.

Theorem 2.4 *Let G be a grid network. Then (see Figure 1)*

$$\mathrm{rd}(G) = \begin{cases} 2, & \text{if } G = G_1, \\ 3, & \text{if } H \subseteq G \text{ and } H \cong G_2, \text{ but no } H \subseteq G \text{ and } H \cong G_3, \\ 4, & \text{if } H \subseteq G \text{ and } H \cong G_3. \end{cases}$$



G_1 G_2 G_3

Figure 1: Grid networks in Theorem 2.4.

Proof. If $G = G_1$, then $\mathrm{rd}(G) = 2$. If $G_3 \subseteq G$, then $\lambda^+(G) = 4$. Moreover, since G is a bipartite network we have $\mathrm{rd}(G) \leq \chi'(G) = \Delta(G) = 4$. Hence, $\mathrm{rd}(G) = 4$.

Suppose that G has a subnetwork that is isomorphic to G_2, but no subnetwork that is isomorphic to G_3. Then we get $\mathrm{rd}(G) \geq 3$ by Lemma 2.1 since $\lambda^+(G) = 3$. It remains to prove that there exists an rd-coloring of G using 3 colors. First, we give two observations.

1. For any two nodes x and y of G with $d(x) = d(y) = 4$, if there has no a parallel 2 (3)-link-cut between x and y, then we can find a 3-link-cut $C(x, y)$ of x, y in G (see Figure 2).

2. For such two different 3-link-cuts in G, they have at most one common link in G, which ensures that there exists a coloring using colors [3] so that each 3-link-cut (like $C(x, y)$ in Figure 2) is rainbow.

We now divide these link-cuts into some families of link-cut: if two link-cuts belong to the same family, then one can find the other link-cut by link transitivity. Let G^* be the network obtained by deleting all such 3-link-cuts (like $C(x, y)$ in Figure 2) of G. Note that each nontrivial block of G^* is a subnetwork of $G_{3,i}$ ($i \geq 3$). We first assign a coloring c_0 for one component of G^*, say H_0, using colors [3] so that each set of links incident with a node of degree less than 4 and parallel 2 (3)-link-cuts in G are rainbow. Then, we color a family of link-cuts connected to the network H_0 so that each link-cut is a rainbow and each node is proper except for the nodes of degree 4 in G, and use H_1 to denote the new colored network. Furthermore, we colored other component of G^* connected with network H_1 and ensure that each node of H_1 is proper except the nodes of degree 4 in G and all parallel 2 (3)-link-cuts in G are rainbow. Repeatedly, we extent the coloring c_0 to a coloring c of G using colors [3] so that each parallel 2 (3)-link-cut and each set of links incident with a node of degree less than 4 in G is rainbow.

Now we can verify that the c is an rd-coloring of G. For any two nodes u, v of G, if there exists a node

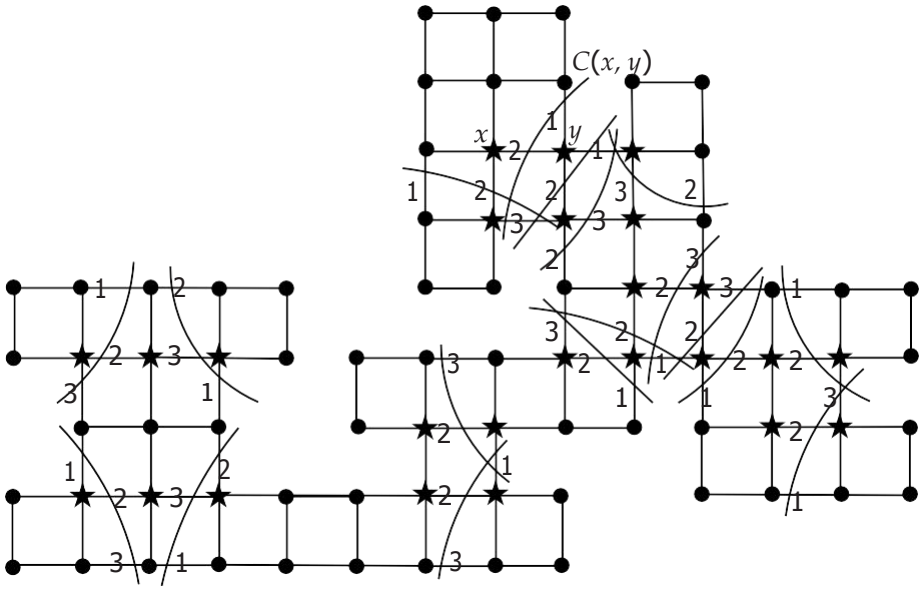


Figure 2: A network used in the proof of Theorem 2.4.

with degree less than 4, without loss of generality, say u, then the set E_u of links incident with node u is a u-v rainbow link-cut. If $d(u) = d(v) = 4$ and there has a parallel u-v 2 (3)-link-cut, then it is a u-v rainbow link-cut. If $d(u) = d(v) = 4$ and there has no parallel u-v 2 (3)-link-cut, then the $C(u, v)$ (like $C(x, y)$ in Figure 2) in network G is a u-v rainbow link-cut in G.

Furthermore, we study the strong rainbow disconnection numbers of cellular networks.

A *trivial link-cut* S of G is a link-cut incident with a node.

Lemma 2.5 [5] *If G is a connected network with link-connectivity $\lambda(G)$, upper link-connectivity $\lambda^+(G)$ and number $e(G)$ of links, then*

$$\lambda(G) \leq \lambda^+(G) \leq \mathrm{rd}(G) \leq \mathrm{srd}(G) \leq e(G). \quad (1)$$

Lemma 2.6 [17] *A 3-connected cubic plane network G is 4-face-colorable if and only it is 3-link colorable, i.e., $\chi'(G) = 3$.*

Lemma 2.7 [4] *A cube network G is 3-connected if and only if G is 3-link-connected.*

Lemma 2.8 [5] *Let G be a nontrivial connected network. Then $srd(G) = 2$ if and only if $rd(G) = 2$.*

Theorem 2.9 *Let G be a cellular network with the number of hexagons h. Then*

$$\mathrm{srd}(G) = \begin{cases} 2, & \text{if } h = 1, \\ 3, & \text{if } h \geq 2. \end{cases}$$

Proof. If $h = 1$, then $G = C_6$. By Lemmas 2.2 and 2.8, we have $\mathrm{srd}(G) = 2$. If $h \geq 2$, there exist two nodes u, v of G satisfying $\lambda(u, v) = 3$, so $\mathrm{srd}(G) \geq 3$ by Lemma 2.5. Now we define two operations o and O as follows.

$$o(\{G\}) = \begin{cases} \{G/V(C_1), G/V(C_2)\}, & \text{if } G \text{ has a nontrivial 2-link-cut } S \\ & \text{and } G \setminus S = C_1 \cup C_2, \\ \{G\}, & \text{otherwise.} \end{cases}$$

$$O(\{G_1, G_2, \cdots, G_p\}) = \cup_{i=1}^{p} o(\{G_i\}).$$

Since the network is split into two pieces when we do the operation, then the operation cannot last endlessly. Hence, there exists a integer r such that $O^r(\{G\}) = O^{r+1}(\{G\})$. Finally, we get a finite sequence of link-colored cubic networks H = $\{H_1, H_2, , \cdots, H_q\}$, where q is a positive integer. Note that the operation does not appear multilinks, and each network of $\{H_1, H_2, \cdots, H_q\}$ is planar. For each planar network $H \in$ H, we can construct a 3-link-connected 3-regular planar network H'. By the above operation, we know that each 2-link-cut in H is trivial and lies on the boundary of network H. Let h be the number of nodes with degree 2. Use h to denote the number of trivial 2-link-cuts in network H and give all nodes with degree 2 a clockwise label using $\{v_i : i \in [h]\}$. If $h \equiv 0 \pmod 3$, then we add $h/3$ nodes, and make each node connect with 3 adjacent 2-degree nodes in H (starting from the node with degree 2 labeled 1, connect the links in turn clockwise, the same below); if $h \equiv 1 \pmod 3$, we add $\lfloor h/3 \rfloor - 1$ nodes, and make each node connect to the 3 adjacent nodes with degree 2 in H. For the remaining 4 nodes with degree 2, we add two links $v_{h-3}v_{h-2}$ and $v_{h-1}v_h$; if $h \equiv 2 \pmod 3$, we add $\lfloor h/3 \rfloor$ nodes, and make each node connect to the 3 adjacent nodes with degree 2 in H, and then add a link between the remaining two nodes with degree 2. It is easy to verify that the network H' is a 3-link-connected 3-regular plane network. By Lemmas 2.6 and 2.7, it implies that H' is 3-link-colorable. Then each network H is 3-link-colorable, and we use color set [3] to assign a proper link-coloring to each network in H. Then we perform the inverse operation of the shrinking operation. Assume that F_1 and F_2 are two proper link-colored networks obtained by shrinking the non-trivial 2-link-cut $\{e_1, e_2\}$ of network F, and let c_1 and c_2 be colorings of networks F_1 and F_2 using colors [3], respectively. Obviously, $c_1(e_1) \neq c_1(e_2)$ and $c_2(e_1) \neq c_2(e_2)$. Now we exchange the colors $c_1(e_1)$ and $c_2(e_1)$, and colors $c_1(e_2)$ and $c_2(e_2)$ in F_1 such that the new coloring c_1' of F_1 satisfies $c_1'(e_1) = c_2(e_1)$ and $c_1'(e_2) = c_2(e_2)$. Obviously, c_1' is still a proper link-coloring of the network F_1 using the color set [3]. Then we can get a link-coloring c_0 of network F: let $c_0(e) = c_1'(\mathrm{e})$, if e $\in F_1$; let $c_0(e) = c_2(e)$, if $e \in F_2$. Obviously, the c_0 is a proper link-coloring of network F. Continue to do this, and finally we get a proper link-coloring c of the network G using the color set [3].

Now we verify that the link-coloring c of G is a strong rainbow disconnection coloring of the network G. Let u and v be two nodes of G, and assume that $d(u) \leq d(v)$. If $d(u) = 2$, then the link set E_u is a minimum u-v link-cut of G and rainbow, so the link set E_u is a rainbow minimum u-v link-cut of G; if $d(u) = d(v) = 3$ and $\lambda(u, v) = 3$, then the link set E_u is a minimum u-v link-cut of G and rainbow, so the link set E_u is a rainbow minimum u-v link-cut of G; if $d(u) = d(v) = 3$ and $\lambda(u, v) = 2$. By the contraction operation, we get that u and v belong to different connected components in H (otherwise, suppose that both u and v belong to a connected component H of H. Since $\lambda(u, v) = 2$, and the shrinking operation does not change the link connectivity of u, v, there is still a nontrivial 2-link-cut between u and v. This is a contradiction with our operation). Therefore, there exists a rainbow 2-link-cut $C(u, v)$ between u and v by the process of operation and coloring, and the $C(u, v)$ is a rainbow minimum u-v link-cut of G. Hence, srd(G) ≤ 3.

Moreover, we conjecture that the strong rainbow disconnection numbers of grid networks are equal to the rainbow disconnection numbers of grid networks.

Conjecture 2.10 *Let G be a grid network (see Figure 1). Then*

$$\mathrm{srd}(G) = \begin{cases} 2, & \text{if } G = G_1, \\ 3, & \text{if } H \subseteq G \text{ and } H \cong G_2, \text{ but no } H \subseteq G \text{ and } H \cong G_3, \\ 4, & \text{if } H \subseteq G \text{ and } H \cong G_3. \end{cases}$$

3. THEIR RND-NUMBERS

Next, we study the node-version of rainbow disconnection coloring.

Lemma 3.1 [3] *If C_n is a cycle of order $n \geq 3$, then $rnd(C_n) = 2$.*

Lemma 3.2 [3] *If G is a nontrivial connected network and H is a connected subnetwork of G, then $rnd(H) \leq rnd(G)$.*

Lemma 3.3 [3] *Let G be a nontrivial connected network of order n. Then $\kappa(G) \leq \kappa^+(G) \leq rnd(G) \leq n$.*

Theorem 3.4 *Let G be a cellular network with the number of hexagons h. Then*

$$\mathrm{rnd}(G) = \begin{cases} 2, & \text{if } h = 1, \\ 3, & \text{if } h \geq 2. \end{cases}$$

Proof. If $h = 1$, then we have $\mathrm{rnd}(G) = 2$ by Lemma 3.1. If $h \geq 2$, we select the common link of some two hexagons, say v_1v_2. We have $\mathrm{rnd}(G) \geq \kappa_G(v_1, v_2) \geq 3$. For the nodes of G, assign column numbers according to the order in which they appear from left to right in the lattice shown in the figure 3. For example, the nodes in the same column which appear first are labeled column 1. Now we give a node-coloring c of G using three colors. For the nodes in the column j of network G, if $j \equiv 1 \pmod 3$, then color them by 1; if $j \equiv 2 \pmod 3$, then color them by 2; if $j \equiv 0 \pmod 3$, then color them by 3. Let v be any node of network G. Assume that v is in the column i of G. If $d_G(v) = 2$, then the neighbors of v are in columns $i - 1$, $i + 1$ or i, $i + 1$ or $i - 1$, i. Since the column labels of the neighbors are different modulo 3, we have $N_G(v)$ is rainbow. If $d_G(v) = 3$, then the neighbors of v are in columns $i - 1$, i, $i + 1$, respectively. Since $i - 1$, i, $i + 1$ are pairwise different modulo 3, we have that $N_G(v)$ is rainbow.

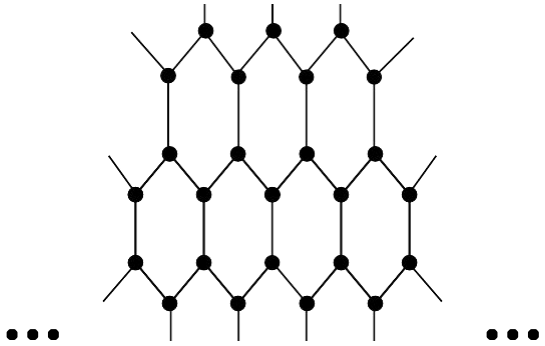


Figure 3: A (planar, infinite) lattice of congruent regular hexagons.

Let x and y be two nodes of network G. If x, y are adjacent, then $N_G(x) \setminus \{y\}$ is an x-y rainbow node-cut. If x, y are nonadjacent, then $N_G(x)$ is an x-y rainbow node-cut. So c is a rainbow node-disconnection coloring of network G. We obtain $\mathrm{rnd}(G) \leq 3$.

The Cartesian product $G \square H$ of two internal disjoint networks G and H is the network with node set $V(G) \times V(H)$, where (u, v) is adjacent to (w, x) in $G \square H$ if and only if either $u = w$ and $vx \in E(H)$ or $uw \in E(G)$ and $v = x$. The $m \times n$ grid network $G_{m,n} = P_m \square P_n$ consists of m horizontal paths P_n and n vertical paths P_m.

Lemma 3.5 *For $n \geq 3$, $rnd(G_{3,n}) = 3$.*

Proof. Define a node-coloring c: $V(G_{3,n}) \rightarrow [3]$ of $G_{3,n}$. Let $c(x_{1,j}) = 1$ for $j \equiv 1, 2 \pmod 4$ and $c(x_{1,j}) = 2$ for $j \equiv 0, 3 \pmod 4$. We color the second row using color 3. Let $c(x_{3,j}) = 2$ for $j \equiv 1, 2 \pmod 4$ and $c(x_{3,j}) = 1$ for $j \equiv 0, 3 \pmod 4$. We show that c is a rainbow node-disconnection coloring of $G_{3,n}$. Let $x_{p,q}$ and $x_{s,\ell}$ be two nodes of network $G_{3,n}$, where $p \leq s$.

If $p = 1$, then $N_{G_{3,n}}(x_{p,q})$ is rainbow. So when $x_{p,q}$ and $x_{s,l}$ are nonadjacent, $N_{G_{3,n}}(x_{p,q})$ is an $x_{p,q}$-$x_{s,\ell}$ rainbow node-cut; when $x_{p,q}$ and $x_{s,\ell}$ are adjacent, $N_{G_{3,n}}(x_{p,q}) \backslash \{x_{s,\ell}\}$ is an $x_{p,q}$-$x_{s,\ell}$ rainbow node-cut. If $s = 3$, then $N_{G_{3,n}}(x_{s,\ell})$ is rainbow. Similarly, there is a rainbow node-cut between $x_{p,q}$ and $x_{s,\ell}$.

Now consider $p = s = 2$. Suppose that $q < \ell$. If $x_{p,q}$ and $x_{s,\ell}$ are nonadjacent, $\{x_{p-1,q}, x_{p,q+1}, x_{p+1,q}\}$ is an $x_{p,q}$-$x_{s,\ell}$ rainbow node-cut. If $x_{p,q}$ and $x_{s,\ell}$ are adjacent, $\{x_{p-1,q}, x_{p+1,q}\}$ is an $x_{p,q}$-$x_{s,\ell}$ rainbow node-cut.

So we have $rnd(G_{3,n}) \leq 3$. Since $\kappa(x_{1,2}, x_{2,2}) = 3$, we have $rnd(G) \geq \kappa(x_{1,2}, x_{2,2}) = 3$ by Lemma 3.3. $\square$

Lemma 3.6 *For $4 \leq m \leq n$, $rnd(G_{m,n}) = 4$.*

Proof. Define a node-coloring c of $G_{m,n}$: $V(G_{m,n}) \rightarrow Z_4$. Let $c(x_{i,1}) = i \pmod 4$, $c(x_{i,2}) = c(x_{i,3}) = i + 2 \pmod 4$ and $c(x_{i,4}) = i \pmod 4$. Other remaining columns repeat the coloring of first four columns.

Let u be a node of $G_{m,n}$ and $N_r(u)$ ($N_c(u)$) denote the neighbors of u in the same row (column). Assume that $c(u) = a$. If $|N_r(u)| = 2$, then two nodes of $N_r(u)$ are assigned a and $a + 2$ respectively; if $|N_r(u)| = 1$, then it is assigned a or $a + 2$. If $|N_c(u)| = 2$, then two nodes of $N_c(u)$ are assigned $a - 1$ and $a + 1$ respectively; if $|N_r(u)| = 1$, then it is assigned $a - 1$ or $a + 1$. Thus, $N_{G_{m,n}}(u)$ is rainbow.

For any two nonadjacent nodes x and y of $G_{m,n}$, $N_{G_{m,n}}(x)$ is an x-y rainbow node-cut. For any two adjacent nodes x and y of $G_{m,n}$, $N_{G_{m,n}}(x) \setminus \{y\}$ is an x-y rainbow node-cut. The coloring c is a rainbow node-disconnection coloring of $G_{m,n}$,. Hence, rnd(G) ≤ 4. On the other hand, $\kappa(x_{2,2}, x_{3,3}) = 4$. It follows by Lemma 3.3 that rnd($G_{m,n}$,) ≥ κ($x_{2,2}$, $x_{3,3}$) = 4.

For a node-cut S of G, we denote the connected components of $G - S$ by $G_1, G_2, \cdots, G_s$. Then we add S to these components and get networks $G[V(G_1) + S], G[V(G_2) + S], \cdots, G[V(G_s) + S]$. This operation is called that we *split* the node-cut S.

If the nodes of a 2-node-cut of G are adjacent, then we say the 2-node-cut is an *adjacent 2-node-cut*.

Theorem 3.7 *Let G be a grid network. Then (as shown in Figure 4)*

$$\mathrm{rnd}(G) = \begin{cases} 2, & \text{if } G = G_1, \\ 3, & \text{if } G_2 \subseteq G \text{ and } G_3, G_4 \not\subseteq G, \\ 4, & \text{if } G_3 \subseteq G \text{ or } G_4 \subseteq G. \end{cases}$$

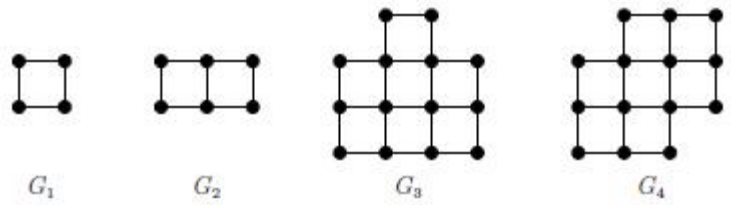


Figure 4: Grid networks in Theorem 3.7.

Proof. If $G = G_1$, then we have rnd(G) = 2 by Lemma 3.1. If $G_3 \subseteq G$ or $G_4 \subseteq G$, then rnd(G) $\geq \kappa^+(G) \geq$ 4 by Lemma 3.3. Since G is the subnetwork of some grid network $G_{m,n}$, we have rnd(G) $\leq$ rnd($G_{m,n}$) = 4 by Lemmas 3.2 and 3.6.

Now consider $G_2 \subseteq G$ and G_3, $G_4 \not\subseteq G$.

We have rnd(G) $\geq \kappa^+(G) \geq \kappa^+(G_2) \geq 3$. If $G = G_{3,n}$, then rnd(G) = 3 by Lemma 3.5.

If $G \neq G_{3,n}$, then there exists an adjacent 2-node-cut. We split all adjacent 2-node-cuts. Then we can get networks $H_1, H_2, \cdots, H_\ell$. Obviously, each H_i is a 4-cycle or $G_{3,n}$. Then we do the following operations.

1. Select the network H_1 and color H_1 using rnd-coloring c_1. Let $H = H_1$ and $c_H = c_1$.

2. Select the network H_i which has a common adjacent 2-node-cut S with network H and color H_i using rnd-coloring c_i.

3. Let $H = H \cup H_i$ and $c_H = c_H + c_i$. If H and G are not isomorphic, then return to step 2.

The rnd-colorings c_i ($i \in [\ell]$) are as follows.

c_1: If H_1 is a 4-cycle, then we assign color 1 to two adjacent nodes and assign 2,3 to the remaining two nodes. If H_1 is $G_{3,n}$, then we color it using the same coloring as Lemma 3.5.

c_i ($i \in \{2, 3, \cdots, \ell\}$): Assume that $S = \{u, v\}$. Let $c_i(u) = c_H(u)$ and $c_i(v) = c_H(v)$.

If H_i is a 4-cycle, we denote the 4-cycle containing link uv in H by C_i. We color the neighbors of u and v in H_i using the colors different from $N_{C_i}(u)$ and $N_{C_i}(v)$ respectively. Obviously, we finish the color of H_i.

Next, consider $H_i = G_{3,n}$. Obviously, u, v have at least one node with degree four in G and degree two in H. Without loss of generality, assume that $d_G(v) = 4$ and $d_H(v) = 2$. Let $N_H(v) = \{u, v_1\}$. We use two stages to color H_i.

- If $d_G(u) = 3$, then color the neighbor of u in H_i such that $N_G(u)$ is rainbow.

  If $d_G(u) = 4$, then $d_{H_i}(u) = 2$. Let $N_{H_i}(u) = \{v, u_1\}$. When $\{u, v, v_1\}$ is rainbow, let $c_i(u_1) = c_i(u)$; otherwise, color u_1 such that $\{u_1, v_1, u\}$ is rainbow.

- Color the remaining nodes of H_i according to Figure 5.

In first stage, we color three nodes of H_i. No matter how we color it, the colors of three nodes have three cases as shown in Figure 5, where the three nodes are marked by stars and $\{a, b, c\} = \{1, 2, 3\}$ are three different colors.

In second stage, for the networks in Figure 5, other columns of H', H'' and H''' repeat the colors of columns 1-4.

Similar to the proof of Lemma 3.5, we can get that c_i is an rnd-coloring of H_i for $i \in [\ell]$.

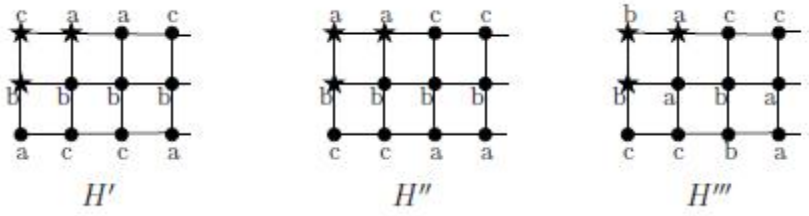


Figure 5: Three node-colorings of $G_{3,n}$.

Now we claim that the node-coloring of $H \cup H_i$ is an rnd-coloring. Based on the process of coloring, the neighborhoods of nodes with degree less than four are rainbow. So we only need to consider two nodes with degree four.

Let x, y be two nodes of $H \cup H_i$ with degree four. Assume that R_H is an x-y rainbow node-cut of H under c_H . Let R_i *be* an x-y rainbow node-cut of H_i under c_i. Consider $\{x, y\} = \{u, v\}$. Then $\{u_1, v_1, v\}$ or $\{u_1, v_1, u\}$ is an x-y rainbow node-cut of $H \cup H_i$.

Consider $\{x, y\} \neq \{u, v\}$. If $x, y \in V(H)$, then R_H is an x-y rainbow node-cut of $H \cup H_i$. If $x, y \in V(H_i)$, then R_i is an x-y rainbow node-cut of $H \cup H_i$. If $x \in V(H) \setminus \{u, v\}$, $y \in V(H_i) \setminus \{u, v\}$ or $x \in V(H_i) \setminus \{u, v\}$, $y \in V(H) \setminus \{u, v\}$, then $\{v, u_1\}$ is an x-y rainbow node-cut of $H \cup H_i$.

So the above operations keep new network $H = H \cup H_i$ rainbow node-disconnected. Therefore, rnd(G) = 3.

4. THEIR PD-NUMBERS AND MD-NUMBERS

Furthermore, we obtain the proper and monochromatic disconnection numbers of cellular networks and grid networks.

Observation 4.1 *Let G be a cellular network. Then pd(G) = 1.*

Observation 4.2 *Let G be a grid network. Then pd*(G) = 1.

Theorem 4.3 *Let G be a cellular network with the number of hexagons h, the number of inner links m and the boundary C. Then md*(G) = $3h - m = |C|/2$.

Proof. Observe that each color appears at least 2 times in an md-coloring, so one hexagon has at most 3 colors. If two hexagons have a common link, then the two hexagon use at most 5 colors under an md-coloring in G. Then an md-coloring of G has at most $3h - m$ colors since G has m pairs of hexagons with a common link. Namely, $\text{md}(G) \leq 3h - m$.

Now we give a coloring f of G. First, we give a link partition for G. For two adjacent hexagons H_1, H_2, let e be the common link of H_1, H_2. Then there are opposite links e_1 and e_2 of e in H_1 and H_2, respectively. If e_1 or e_2 is not a bounded link, then we continue to find the opposite link of e_1 or e_2 in other hexagon, and call all these opposite links a relative link set, denoted by M_i, ($i \in [t]$). Observe that $\mathrm{E(G)} = \bigcup_{i=1}^{t} M_i$ and $t = |C|/2$. Next, for each $i \in [t]$, we assign color i to all links of M_i, therefore $|f| = t$. Moreover, we get $|f| = 3h - m$ since $|C| + m = 6h - m$. It is easy to verify that the coloring f is an md-coloring of G. Hence, $\mathrm{md}(G) = 3h - m$.

Theorem 4.4 *Let G be a grid network with the number of quadrangle h, the number of inner links m and the boundary C. Then md*$(G) = 2h - m = |C|/2$.

The proof of Theorem 4.4 is similar to the argument of Theorem 4.3.

5. CONCLUSIONS

In this paper, we get the exact values of the rainbow (node-)disconnection numbers, proper and monochromatic disconnection numbers of cellular networks and grid networks, respectively, and we conjecture that the strong rainbow disconnection numbers of grid networks are equal to the rainbow disconnection numbers of grid networks.

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CaRE – A Framework for a Multimedia Assistance System for Singletons
"Does IT help?"

Thomas Schirgi

Institute of Technical Informatics, Technical University, Graz, Austria

Abstract

In contrast to the increasing degree of automation in the production industry, commissioning and maintenance activities will essentially be limited to manual activities. Production involves repetitive actions that are manageable and clearly defined as a process. Unlike this, commissioning and maintenance have to deal with uncontrollable, undefined, and non - standardized processes. The paper provides a framework for a multimedia assistance system for singletons. It was found that the paradigm has to consist of five key components to provide tailored assistance to customers. These key components are Expertise, Infrastructure, Application & Platforms, Security & Privacy and Business Process & Business Model. The resulting stack and the overlaying business model are called "CaRE – Custom Assistance for Remote Employees". With a user-centered approach, the needs of the target group were identified. Based on this, the framework was implemented in the form of a prototypical application. To check, whether the assumptions regarding a Multimedia Assistance System are correct, the prototypical developed application was tested with aremote-usability test.

Keywords

Multimedia, Assistance, CaRE, Software.

1. Introduction

During the last decades, many processes and workflows, especially in production environments, changed significantly. Thereby some of the processes are getting more and more complex and sophisticated. With the help of new information systems, it is tried to meet these challenges. The fourth industrial revolution and the fusion of humans and machines to form cyber-physical systems (CPS) are revolutionizing processes and procedures, especially in production-related companies. One of the consequences is that maintenance and service activities are becoming more and more complex and time-consuming. "Smart Maintenance" results in entirely new interconnection, qualification, and support requirements for people involved. Where maintenance-relevant data previously had to be entered manually, these can also be recorded automatically in the future.

In contrast to the increasing degree of automation in production, maintenance and servicing will also in the future be essentially limited to manual activities. Production involves repetitive activities that are manageable and clearly defined as a process. [1] In contrast, maintenance and servicing have to deal with "uncontrollable," undefined, and, above all, non-standardized processes. Furthermore, this is of utmost importance whenever commissioning or maintenance has to be done at singletons in electrical environments. To help users during their tasks, a multimedia assistance system can be used.

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Structure

In chapter 2, some delimitations and state-of-the-art systems are presented. The next chapter describes the CaRE pyramid and the items. In chapter 4, the design guidelines for a multimedia assistance system are presented. The implementation and field-test of the pyramid are described in chapter 5. Finally, the conclusion and future work is represented in chapter 6.

Related Work

With products and singletons becoming more and more complex, it is logistically and for cost reasons, not always possible to send a specialist to the site. As a result, maintenance personnel often have no previous experience with a product to be commissioned or serviced. Nevertheless, implicit knowledge is necessary to carry out most of the work which has to be done on-site. (see [2]). In literature, many possible solutions in terms of "Smart Factory" ([3], [4], [5]), "Cognitive Assistance" ([6], [7]) or "Industry 4.0" ([8], [9])are mentioned. However, there are no examples of how employees can be supported if they are

1. not in a factory,
2. do not have a basic knowledge of the product to be maintained and
3. dealing with singletons

Especially in the energy sector, long-living singletons are common. Parts of an energy network may last for an entire generation in a company. Since such substations are often located outside inhabited areas, the cellular Network might be insufficient. Furthermore, with the help of mobile phones and email, important information might get lost. Multimedia Assistance Systems partially support non-verbal communication, which means that information can be made available more efficiently.

2. MULTIMEDIA ASSISTANCE SYSTEM

According to Tay Vaughan, Multimedia is defined as [10]

"Multimedia is any combination of text, graphic art, sound, animation, and video that is delivered by computer."

This means that multimedia refers to an electronically delivered combination of media, like videos, images, and text. Furthermore, this data can be accessed interactively and on-demand.
Assistance Systems are widely used in daily life and can be seen as indications of an increasing connection between humans and technology. A few examples are stated below:

- Consumer Industry: Cellphones, Laptops, Wearables
- Medical Technology: Implants, Exoskeleton
- Communication Technology: Intelligent Home and Wireless Networks
- Production Technology: Human-Robotics Interaction
- ...

In all of those mentioned examples, it can be distinguished between those two types of technical assistance systems [11]

- Technical systems that substitute a person and thereby relieve the burden lead (technology carries out the task for humans)

- Technical systems that support people in performing their tasks without replacing them (people retain sovereignty and are supported by the technology appropriately)

Taking into account the previous arguments, this paper is based on the following definition of assistance systems:

A technical system is a Multimedia Assistance System if

1. it supports people in activities without substituting them in whole or in part,
2. it leaves the sovereignty over the execution to humans (target value specification by an operator, no mandatory specifications) and
3. the system interactively provides multimedia data.

2.1. State of the Art

In the literature, there are some approaches on how assistance systems can be developed in connection with "Smart Factories" and which advantages companies can achieve from it.

As an example, the maintenance strategy can be changed from reactive maintenance (in case of an error) to preventive maintenance (based on historical values) or even predictive maintenance (based on real-time values). Based on a survey, 57% of companies in Germany do not have any data basis on which maintenance activities are planned, 39% are using historical data [12].

Knowledge management is known as one key factor for a company's success since it protects a company from losing its most important asset called "know-how". The loss of know-how results from rapid changes in personnel, as a consequence of not only demographic change and fixed-term employment contracts, but also data loss because of individual stress on employees. Knowledge management thus ensures that necessary knowledge and skills to achieve strategic and operational goals exist. [13]

The processes and activities in maintenance are characteristic due to a high (technical) complexity and an increased uniqueness compared to production processes. With this background, (multimedia) assistance systems that support employees in complex tasks and thus improve the effectiveness and quality of work are becoming more interesting for companies. [14]

Spare parts management is the basis for solving all tasks effectively and sustainably. It is ensured that necessary work materials are available sufficiently so that maintenance and repair tasks are carried out in a reasonable and – if possible – optimal time. The spare part management influences the stock costs, availability of spare parts, and thus the related expenditure of time during maintenance. [15]

When focusing on commissioning and maintenance for singletons, the following problems may occur:

- Important data (like types or serial numbers) are inserted into multiple systems multiple times. If parts are changed, this leads to inconsistencies among those systems and it is not clear which serial number is the actual one.
- Help with the telephone is hard or nearly impossible because the expert cannot see the problems on-site. Describing sometimes works, but especially when dealing with different languages or jargon, complications may occur.

- Drawings are printed and handed over to supervisors. If changes are made during commissioning or maintenance, those changes are marked directly at the drawing. It takes up to months till the drawings in the factory are updated.
- Damages (either during transport, commissioning or during lifetime) are documented with cellphones or cameras. Emails are sent back and forth, or the pictures are stored on a supervisor's computer.
- The entire lifetime of singletons in electrical environments may last up to 40 years. Unfortunately, this means that hardly any person knows about the changes which were made during their lifetime.

It could be seen that some approaches might be helpful both in an industrial context, smart maintenance, or knowledge management. Nevertheless, non of them fit entirely into the site requirements because of a different context of use.

Furthermore, only parts of the problems above are solved. To eliminate all those problems, the CaRE pyramid was implemented, which can be seen as a framework for Multimedia Assistance Systems for singletons.

3. CaRE Pyramid

A system that users should accept has to be developed together with users. With this in mind, several workshops and interviews were conducted. It could be seen that the two primary needs have to be fulfilled:

- More accessible emergency help: If the expert needs to be called, most of the time, an emergency occurred and immediate help is required (later called Remote Assistance)
- More accessible documentation: The documentation at the site is of utmost importance and takes a lot of time (later called Multimedia Assistance)

It could be seen that for multimedia assistance systems (both remote assistance and multimedia assistance), a holistic approach must be considered. Five key components are necessary to come over those needs. Those components can be visualized in the form of a pyramid. Those five components can be seen as parts of the pyramid which rely on each other:

- Expertise
- Infrastructure
- Applications and Platforms
- Security and Privacy
- Business Processes and Model

The pyramid itself cannot be inverted. Those five components can be applied to both multimedia assistance and remote assistance, where an expert is assisting through telephone or "I see what you see" application. In both cases, those five components have to be fulfilled to provide successful assistance:

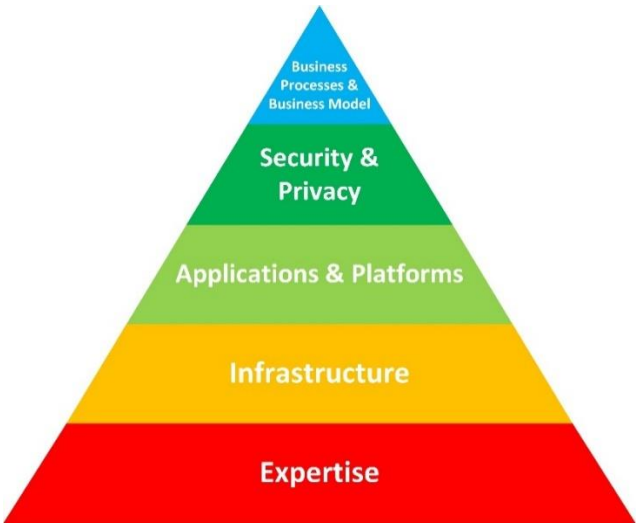

Figure 1: CaRE Pyramid

3.1. Expertise

Expertise describes the basis of the stack, as seen in Figure *1*. Without domain knowledge, assistance is meaningless and not applicable. With remote assistance, it is likelier that the desired expert is available immediately. For example, field engineers have to wait more than one week to get working permissions in some cases. Furthermore, the daily fees for field engineers are expensive, which means that customers have to pay thousands of euros for unproductive dwell times. In this case, it would be possibly cheaper to send engineers from the customer to the site and help them via remote assistance. Furthermore, a single expert can work on more than one site in parallel, even if these sites are located in different places. Another benefit is that there is the possibility to accomplish a group conference call if more than one expert is needed.

When assisting with multimedia assistance applications, the users at the site need to have at least basic domain knowledge. If, for example, a specific jargon is used during maintenance or commissioning, the workers at the site need to at least have a basic understanding.

Moreover, the work on-site must be done in any case. The work which needs to be done is manual and cannot be done by robots or artificial intelligence: Traditional work will not go extinct.

3.2. Infrastructure

The infrastructure part can be divided into a network and hardware part.

3.2.1. Network

A comprehensive availability of broadband internet is necessary for both parties. This is both important for video- and audio conferring, as well as for sending data over the Network. According to recent studies, in more than 80 countries, more than half of the area is covered by 4G [16]. In the US, for example, the coverage is more than 90%. However, poor network quality and low bandwidth remote assistance will lead to dissatisfaction.

Since substations may be in regions that are not entirely inhabited, the internet connection might not be sufficient. Therefore a small box with an embedded router was implemented. The so-called “Remote Access Box” consists of a switch-mode power supply that allows AC/DC and different voltage levels. The power supply cable is connected with so-called bayonet connectors, which are also safe against water intrusion and minor impacts. Whenever the power supply is connected, the box starts automatically. In closed operation, without any connected periphery, the box reaches IP protection class 64.

Inside the box, an LTE router is mounted. Two antennas are located inside the case; for the other two antennas, ducts in the surface are available. These two antennas do have a five-meter cable and can be placed at windows or doors. To connect to the wireless Network, the QR Code on the surface can be scanned.

The SIM card slot is also available with a duct at the surface. In addition, two RJ 45 Ethernet connectors are available for connections with LAN cables. With those cables, it is also possible to supply a wired internet connection.

After booting, the router automatically connects with the VPN Server inside the company network. Thus a secure communication is guaranteed.

3.2.2. Hardware

In terms of Hardware, it must be distinguished between remote assistance and multimedia assistance.

3.2.2.1. Remote Assistance

In maintenance, the service technicians often need both hands free and have to be mobile. Due to that fact, the first evaluation mainly focused on wearables. Four types of wearables are available. [17]

- binocular and non-see-through
- binocular and see-through
- monocular and non-see-through
- monocular and see-though

A literature review has shown that some key criteria have to be met to provide a useful wearable in a maintenance context. ([17], [18], [19]) Those criteria are:

- Wearing Comfort
- Battery Lifetime
- Field of View
- Navigation

Wearing Comfort

In the case of service activities, the device may be worn over a more extended period. The musculature in the neck area is stressed, even if the wearable itself is not heavy. Some devices use nose bridges, brackets for ears, or some sort of neck holder. The device should not be too heavy, but it should be rugged if it falls to the ground. The device should offer the possibility of individual wearing settings. It has to sit well because the wearing feeling is mainly influenced by

the mounting method. Users have to trust that the device is seated well and won't come off suddenly.

Battery Lifetime

The time assistance is needed during maintenance may be between some minutes or hours. Even if the device is not required during the entire working process, the battery shall be durable and have a battery life of approximately one working day. It is worse if the device battery is getting empty when assistance is needed. Therefore, the battery of the device should be fast loading or replaceable.

Field of View (FOV)

The standard FOV of humans is 200° horizontally and 135° vertically. [20]The user sight should not be limited significantly and the users should not lose their situational perception. With a limited field of view, the eyes are stressed, which leads to eye strain and dry eyes. [17] A wide field of view is desirable and also linked to improved user acceptance. It should furthermore be possible to wear eyeglasses beyond the wearable.

Navigation

It must be easy to navigate inside the operating system of the wearable. Therefore, these three input methods are available:

- Buttons directly at the device
- Speech
- Gestures

All of these three types are not useful during maintenance operations. Therefore, a companion app should be available. With these apps, it is possible to interact with the devices. For example, they may offer a keyboard that makes entering text more accessible.

Tests were conducted with the Microsoft Hololens (binocular and see-through), the Daqri Smart Glass (binocular and see-through) and the Realwear HMT-1 (monocular and non-see-through). Binoculars which are non-see-through are not suitable for maintenance activities. Also, Augmented Reality is not necessarily needed. Additionally, it has to be clarified if a full-face display is required. If not, wearable with a microdisplay or a tablet may also fulfill the needs during remote assistance.

It could be seen that situational perception suffers when full-face displays are used. For example, test persons could not see harmful items, even though they occur in their standard field of view. The Realwear HMT-1 has a microdisplay mounted on a small arm. Due to that, it is possible to move the display out of the field of view whenever it is not needed.

Furthermore, it could be seen that the Hololens and the Daqri Smart Glass are becoming heavy, although their weight is only around 370g. Wearing the Hololens or the Daqri Smart Glass underneath a helmet is physically exhausting over a more extended period. Therefore, a device is required which is comfortable to wear for the user. It is often necessary to wear personal safety equipment such as safety glasses or safety helmets in production environments. If engineers wear the Hololens, it is essential to wear safety glasses underneath. In contrast to that, Daqri Smart Glass would count as personal safety equipment (PSE).

Additionally, the Hololens is heating up at the processing unit located right above the ear. The Daqri Smart Glass computing unit is an external device, which can be mounted on a belt. In the case of menu navigation during usage, both Hololens and Daqri Smart Glass are using gestures. It takes some time to learn those gestures, but users got more and more experienced with these gestures after a short time. In contrast to that, the Realwear HMT-1 uses speech recognition for navigation. However, in environments with high sound intensity, speech recognition is not suitable.

Based on the evaluation results, it was decided to use the Realware HMT-1 for remote assistance activities. Despite having the smallest display has the best wearing comfort of all tested devices. Furthermore, it offers the possibility to replace the battery if needed and uses an Android operating system which is standard on many devices.

3.2.2.2. Multimedia Assistance

During commissioning and maintenance, supervisors must be mobile. This means that only a part of devices is suitable as the basis for multimedia assistance applications. Thus the following types were used during the tests:

- Tablet Computer (Vendor Samsung)
- Cell Phone (Vendor Apple)
- Laptop Computer (Vendor HP)
- 2-in-1 Computer Convertible (Vendor Microsoft)

It could be seen that the display of a cellphone is too small for usage. Even if the application is responsive and fits itself to the available screen size, the user interface is no more user friendly. Even if users are familiar with scrolling inside apps, the lists are becoming too long, and searching for specific items is hard. Usage of a tablet computer solves the issue with the screen size. Also, the interaction with fingers in different parts of the application (like annotating) is working well. As a drawback, it must be mentioned that the input of long character sequences is not easy since the ten-finger typing is hardly possible: The heel of the hand cannot be placed in the same way as on usual keyboards, which leads to an unfamiliar posture.

Furthermore, the feedback of the screen keyboard is also unfamiliar in terms of the ten-finger system. As a result of those two drawbacks, only a Laptop computer or 2-in-1 convertible seems suitable for those actions. Since it is sometimes necessary to climb on top of the workpiece, Laptop computers might be impractical. Furthermore, Laptop computers sometimes only have one camera, which is located in front of the screen. With this location, it is nearly impossible to take pictures. If no desk or position is available where the Laptop computer can be placed, it is also impractical to hold the Laptop computer with one hand, whereas the other hand is used to navigate. Even if the Laptop computer weighs only 1.74kg, the device becomes heavy immediately.

Based on the results of the evaluation, it was decided to use the convertible. Despite having the worst battery, it has the best features and characteristics of all tested devices.

To summarize, the following Hardware was selected as appropriate for an assistance system:

- The Realwear HMT-1 for remote assistance calls. Even if some advertisements show the benefits of apps running on such wearables, it could be seen that this is impractical in real life. As stated above, the perception is suffering, and it is exhausting. Therefore, those devices should only be used if needed for remote assistance calls.

- A 2-in-1 convertible for the usage of the Multimedia Assistance System. Since these kinds of devices are both laptop and tablet, they are flexible in many cases. For multimedia assistance, they can be used to take pictures and make quick notes and documentation in the site office.

3.3. Application and Platform

A supporting application or platform is necessary for sharing knowledge and providing help during commissioning and maintenance activities. In terms of Applications and Platforms, it can be distinguished between remote assistance and multimedia assistance.

3.3.1. Remote Assistance

There are many possible solutions for remote assistance which are already in place. Some of them are listed below:

- Librestream (https://librestream.com/)
- Fieldbit (https://www.fieldbit.net/)
- Stream (https://www.streem.com/)
- Skype for Business (https://www.skype.com/de/business/)
- Teamviewer Frontline (https://www.teamviewer.com/de/loesungen/frontline/)
- and many more.

All of the mentioned systems have their unique selling proposition. After deciding to go along with Realwear HMT-1 for remote assistance, the application Skype for Business, Librestream and Teamviewer was evaluated because licenses were available for further researches. It was decided to use an existing one since all the required features below are already in place in all of the mentioned ones. It would make no sense to develop an own one in this case.

After discussions and interviews with the target group, criteria for a software platform that is usable in maintenance activities were identified:

- Usability & User Acceptance
- Annotations or Pointer Functionality
- Mutliconferencing
- Chat Function
- Reporting

Usability & User Acceptance

The key factor of the software is that it has to be accepted by the users both in the field as well as in the office (experts). Therefore, the user interface has to provide the most important functionalities at a glance so that service technicians can navigate quickly. For example, it should be easy to select the desired expert. The web interface of all systems is user-friendly. Even though Teamviewer and Librestream have more possibilities and features than Skype, the user interface appears to be tidy and well-structured. Depending on the bandwidth and the selected device, the video and audio quality is equal on all systems.

Annotation or Pointing Functionality

The expert should have the possibility to point or annotate certain things in the video. In the field tests, it could be seen that some field engineers – if they are non-native speakers of the language spoken by the expert – have problems understanding what the expert intends. This helps the field engineers to identify objects and makes it easier to understand what the expert is talking about. According [21], visual annotations are a key factor for successful remote assistance. But the usage of annotations on static images is dangerous, especially when using head-mounted devices. They may cause a loss of orientation for a short period, which may become hazardous in industrial environments.

Furthermore, annotations onto a live video stream may limit one's sight. This means that annotations are helpful, but they must be used carefully. Additionally, it should be possible to send documents or drawings, which also might be annotated.

Multi-conferencing

In some cases, one expert alone is not capable of resolving the issues at the site. Therefore the possibility of conference calls should be available. With this feature, a group of people can help one or more engineers at the site.

Chat Function

In some cases – especially in noisy environments – some of the commands to the field engineers are not understandable. In this case, a chat function where an expert can write down requests is necessary. Furthermore, it is imaginable that engineers at the site have to change some parameters of the software. Therefore, it is easier to send text messages with the desired parameter than to describe the values.

Reporting

After finalizing a remote assistance session, it should be easily possible to create a report. So it should, for example, be possible to create a PDF document with all participants written down, the period of the conference, or the text messages sent. This report can be used for internal documentation or as a prove for the customers.

As mentioned above, all of the three systems do have some features and characteristics which are helpful. Thus it cannot be said which of the systems above is the best and which suits most. Skype for Business has the advantage of seamlessly integrating into the Windows environment, which makes it easier to select an appropriate expert. Teamviewer has the advantage of sharing the screen with other participants who can also interact with the remote computer. Librestream has the advantage of providing end-to-end communication with no server in between, which makes it the best in terms of security and Privacy. Unfortunately, there is no mixture of all three systems, selecting the best of all three solutions.

3.3.2. Multimedia Assistance

As already stated, some multimedia assistance applications are already in place. Examples of systems that are already in place are:

- Reportheld (https://www.reportheld.com/)
- Workheld (https://tabletsolutions.at/)

- Evoassist (https://evoassist.evolaris.net/)
- ProWorkFlow (https://www.proworkflow.com/)

Unfortunately, non of them fitted to the needs of the users due to:

- Different contexts of use
- No offline availability
- No spare part management
- No interface for external systems or sources
- Drawings cannot be integrated

So it was decided to create a flexible multimedia assistance application as a prove of concept. Therefore, the CaRE lifecycle shown in

Figure *2* was used:

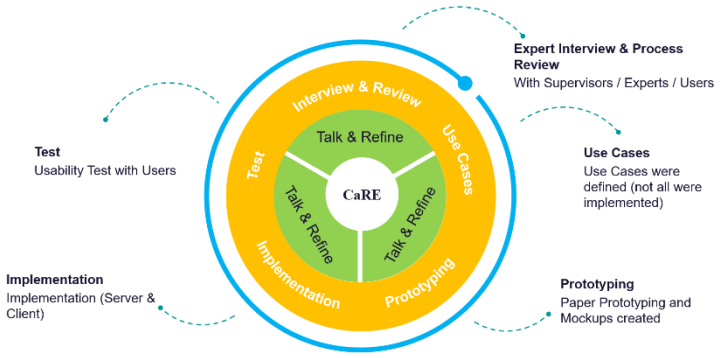

Figure 2: CaRE Lifecycle

As it can be seen, the CaRE lifecycle has its basis in the Deming PDCA (plan-do-check-act) cycle [22] and has the following items:

- Interview and Review
- Criteria Catalogue
- Prototyping
- Implementation
- Test

Above everything, "Talk and Refine" needs to be mentioned, which means that it was communicated with the target group during the entire lifecycle. During the mentioned interview and review part, it was found out that the following topics should be met:

- The application should lower the cognitive workload of the users
- The user interface should only show the topics which are of relevance (parts which are not applicable should be invisible)
- It should be user-friendly and supervisors should get a friendly frontend. If possible, the look and feel of the paper should be indicated.
- Data should be shown in real-time.
- The application should have the same look and feel as it is already known to the supervisors.

- It should work offline without an internet connection.
- New and revised drawings should be available automatically. Furthermore, it should be possible to mark changes on the drawings.
- Serial numbers should be detected automatically.
- It should be able to create markers not to forget work-items
- Data should be already inserted if it is available in another system.

Based on this criteria catalog, a paper prototype was created together with the target group. This prototype was implemented in the form of a prove of concept. Due to Covid-19, no face-to-face usability test was possible. Instead, a remote usability test was done. Therefore an Microsoft Teams session was started. The interviewer launched the application and shared the screen with the participant. The participant turned on the camera and got control over the interviewers' computer. The participant was asked to fulfill the tasks and think loudly. With the camera turned on, the facial expressions and gesturing could be seen.

3.4. Security and Privacy

applications like CaRE provide new challenges regarding time-sensitive networking (TSN) [23]as well as for real-time networks [24]. Security and Privacy have to be met at all levels all the time. Companies must provide security measures to protect their data, Business, and reputation. Security breaches often lead to loss of reputation and monetary loss. In addition to that, data protection regulations, like the GDPR, force business to protect their data. That means that security is mostly driven from top to down, which also means that the usability of these security measures suffers. In former times, the security measures were often bypassed, which should not happen now.

According to Gartner, 124 Billion Dollars were spent on information security from enterprises in 2019 [25]. Not only enterprise security has a high significance. According to Eurostat, approximately 1 in 3 EU citizens reported security-related incidents in 2019. Especially in the electrical industry, security is essential to ensure an undisturbed power supply. In North America, NERC is responsible for highly reliable and secure power systems.

Furthermore, the NIS Regulation (Measures for the high common security of network and information systems) also enforces high-level security and usability. Therefore security tools should be as flexible as possible to allow the best user experience possible. Unfortunately, high security often leads to non-user-friendly systems. One way to achieve usable security is to use the "Security by default" approach. The GDPR encourages that security by default is the fundamental factor in achieving usability and secure products. For example, it should be easily possible to remove personal data from a webpage.

Security and Privacy by default

Security by default is a fundamental factor whenever a high level of usability and security want to be achieved. It means that the default configuration is the most secure configuration which is possible. This should also be the case for Privacy. The principles of "Security by default" enhanced with Privacy are listed below [26].

- Security and Privacy mechanisms should be built into products starting from the beginning.
- The root cause of a threat should be handled, not the symptoms.
- Security must be continued through the entire lifetime of a product.

- Security should not require extensive configuration to work – it should work reliably where implemented.
- Security and Privacy should never compromise usability
- It should defeat the latest threats
- Security through obscurity should be avoided
- Special technical knowledge should not be required

Therefore security tools should be as flexible as possible to allow the best user experience possible. To achieve this goal, it is essential to incorporate users during the design process to improve the user experience.

Security Controls

Users always want to work in a manner they are comfortable with. For example, a system – even a security system – should not hinder users during their day-to-day tasks. [27]. Often there are multiple ways to achieve a task, and security itself should be accommodating of this. When designing user interfaces, considerations in terms of varying levels of security or risk-based features should be taken into account. For example, user interfaces should use new technologies like biometrics (face recognition or fingerprints) or smart cards. If this is not possible, two-factor authentication and authorization (like SMS PINs) would also be possible. To create secure user interfaces on the web, captcha is visible on more and more systems. On the one hand, captchas are perfect if automated access from robots needs to be prohibited. On the other hand, captchas are not ideal in terms of usability and accessibility. [28]

The world-wide-web consortium defined alternatives for captcha like temporary tokens or multi-factor authentication. For users themselves, it is hindering if authorization and authentication must be done for every transaction. This leads to frustration and a cutoff of security mechanisms.

To gain the utmost level of security that users accept, the following topics should be addressed:

- Security must not be hindering: If users feel that the security measured are slowing them during their daily work, the security measures won't be accepted by them.
- Disabled Security measures during commissioning & re established in production: Security measures should not be disabled during commissioning. This could be a backdoor for cybersecurity attacks and also be forgotten.
- Use Best Practices from other companies with more experience: Companies with less experience in cybersecurity should get help from companies with more experience. Furthermore, best practices should be established.
- Use of Multifactor Authentication or Biometrics: Standard Login mechanisms often lead to cybersecurity holes. Enabling multi-factor authentication or biometrics may address this.
- Amount of login processes: the number of login processes should be kept as low as possible. Users will not accept systems where it is necessary to log in for each transaction.
- Disabling of default users: Default users should be disabled or deleted.

3.5. Business Process and Business Model

A business model for revenue strategy needs to be implemented. Even though remote assistance is faster and cheaper than sending people directly to the site, it must be accounted for. So it might be possible to offer remote assistance over a defined period for free. If more time is needed, the

billing is at cost, which might be cheaper than a flight, daily allowance and other fees. The time of assistance can be recorded and accounted minute-wise. With video recording, it is easy to document the work done and these videos may then be used during training. Another advantage is that customer satisfaction may increase due to the quickness of the service. This may also lead to a long-term partnership between the vendor and the customer.

4. DESIGN GUIDELINES

Based on the CaRE Pyramid design guidelines for a Multimedia Assistance System for singletons was developed.

Therefore, based on the Visual Information Seeking Mantra by Ben Shneiderman [29], first, give an overview of the current status on the site (overview first). Then, upon request, it should be possible to provide more precise information about individual sections (zoom and filter). For example, it should be possible to see only data from one specific workpiece. On-demand, users could also be shown more detailed information such as parts (details on demand). Finally, it should be possible to show historical values (maintenance activities or recent changes) and, if desired, also export that information (history and extract).

Based on the “Eight Golden Rules” according to Ben Shneiderman [30] and the “Ten Usability Heuristics” according to Jakob Nielsen [31] seven guidelines are defined below for the design of a user-friendly assistance system for singletons:

Consistency

A Multimedia Assistance System for singletons must be consistent throughout the entire system. For example, the background color, navigation, type of feedback during interactions, or the basic arrangement of the elements should not change within the visualization platform. Since the assistance can affect several parts of the workpiece, a uniform design must be used here.

Feedback

Since delays are typical in data transfer from the backend system to the frontend application, users should get feedback. In this way, users should be made aware of active loading processes. Furthermore, users need to know what is happening and whether an input is being processed or not.

Overwhelm users

When creating the user interface for a Multimedia Assistance System, it has to ensure that the users are not distracted from the actual content for no reason. According to Steve Krug, it is also essential to ensure that the representation is on the human receptivity is adapted ("Don't make me think") (see [#Krug]): For this reason, there should not be too much information which is presented at once. For example, only a few notifications should be shown.

System status

At all times, users must be aware of the state in which Multimedia Assistance System currently is. If there is no connection to the backend system, this must be indicated. Furthermore, it must be shown if there is data available that is not yet synced to the backend services. This point can also be linked back to "feedback" because it has to be shown if the user interface is still responsive when it is loading.

Help

Within a Multimedia Assistance System, it must be ensured that help is provided if it is needed. Context-sensitive help must be offered. For example, only support for a specific part of the workpiece is presented.

Coloring

The coloring schema within a Multimedia Assistance System plays an important role and must be consistent. For example, it can be tried to create awareness of specific inputs for users: Delete buttons, for example, should be red. Furthermore, successful actions can be displayed with a simple change of the respective background.

Another critical point in terms of coloring is the background color of the application. Although neutral colors should be used, background images, animations and decorative graphics should be avoided since it distracts from the actual content.

Elements that belong together

As discussed in the Gestalt laws, elements that belong together should be grouped. This can take the form of lines, differences in brightness, or color. Subsequently, parts that are disconnected from each other should be separated from each other. For example, in CaRE, all points which are of relevance for commissioning should be grouped.

4.1. Interaction

The navigation of a Multimedia Assistance System must be as easy and quick as possible. Users must be able to orient themselves immediately and find any information needed without any problems. It is essential that users only have one obvious option of where content belongs to or where content can be found. Additionally, users need to know where they are in the menu tree. This can be achieved with so-called breadcrumbs.

It must be apparent to every user at which point in the application they are. To guarantee this, the background of the currently active menu item can be changed. In addition, all links and menu items must be marked as such to be recognizable for users. There is no need for a further orientation aid, such as the path specification, since no more than two levels are available.

While CaRE loads data or after a user has made interaction with fields user should receive feedback. This feedback should be visible until the backend has processed the changes made. After that, a success or error message should be presented. If no connection to the backend is available, this should also be recognizable in the application.

4.2. Content

Within the application, loading processes must take less than five seconds. However, it is essential that during the loading process, information is shown that the system is working. A loading time of fewer than five seconds is usually no issue for desktop applications. However, with mobile devices, longer loading occurs since a fast network is not available everywhere.
The content should be provided in a way users are familiar with. Since some supervisors are traveling to the site for years, the look and feel of the former PDF document should be available as good as possible. In this case, the system has to adapt to users' needs and not vice versa. This is of utmost importance since users should accept the application. Applications that are driven

top-down by the management will hardly be accepted. Users are using such systems because of instructions, not because of their free will.

4.3. Error Handling

As stated by Ben Shneiderman and Jakob Nielsen, a Multimedia Assistance System should be error-resistant. This means that no incorrect entries should be possible and that entries must be checked against plausibility. For example, it should only be possible to enter numerical values for threshold value settings. The entered values should be checked in the best-case scenario while they are entered or the input forms should only allow certain data types. Understandable feedback should be presented to users with examples of what the input should look like. In addition, it must be possible to undo changes and default values should be available.

4.4. Criteria for Mobile Devices

The same design criteria can be assumed both for mobile devices and desktop PCs. However, in any case, the changed size of the user interface and the changed context of use must not be forgotten. This results in the following additional criteria:

Building on the usability of mobile applications, the available space on those devices has to be used for the essentials. When creating native apps, the design guidelines of the respective operating system should be consulted, as these already provide an excellent basis. If platform-independent applications are created, the look and feel on all platforms should be the same since devices can change from time to time.

In mobile applications, the use of "responsive design" or "adaptive design" is one way of reacting to the changed screen size. Thus, the layout of the application automatically adapts to the size of the screen. Furthermore, for mobile variants, attention should be paid to the contrast, and transparent feedback should be presented.

Due to the changed context of use and the smaller screen size, it is essential to ensure that the most critical information can be seen immediately. Furthermore, it must be guaranteed that the interaction elements are the right size for operation with a mobile device and can also be identified as interactive elements. Finally, since mobile devices are often used in places with no ideal lighting conditions, a high level of contrast should be ensured. This applies to all interaction elements, fonts, and graphics.

5. IMPLEMENTATION AND TEST

In order to test the proposed pyramid, a prototypical application was implemented. This application can be divided into a Backend System and a Frontend System.

5.1. Backend System

For users, the most crucial part is, of course, the front end of the assistance system. Nevertheless, the central part of the system is running behind, with interfaces to other systems. Therefore, a software architecture was defined, which will be described in this part. It was decided to implement this architecture in terms of a Microservice Architecture because the system should be flexible and capable of dealing with different other systems.

The Architecture, therefore, consisted of ten Microservices and three additional external services, which were used. Microservices overcome the limitations of traditional monolithic architecture [32]. During the implementation of this proof of concept, refactoring was necessary to meet all the desired quality attributes. First of all, it is hard to find the correct granularity for the Microservices. The first approach was more or less a monolith, which was caused due to an implementation start without a clear big-picture, no strategy and no structure. Without those, the implementation will undoubtedly lead to anti-pattern and architectural smells, according to [33].
After the final definition of the entire working process of the supervisors at the site, those process steps were meant to be a single Microservice. This process was identified with the user-centered design approach and interviews with the users, later working with the system. To ensure proper code quality, test-driven development with NUnit was used for both the model and RESTful interface.

With all those Microservices in place, it could be seen that Logging into files was not the best solution to debug. Therefore the interface to the Elastic Stack was implemented. After that, it could be seen that Identity Management should be taken into account from the beginning of the programming. The integration of Identity Management into already existing Microservices took a lot of work and refactoring. If it is integrated from scratch, the work which needs to spend will decrease significantly.

Since the CaRE System is a prove of concept, Scalability, Availability and Performance (see [34]) were not taken into account in terms of the Microservices. Sometimes it makes sense to make use of already existing services rather than implementing them again. As an example, in the CaRE architecture, the TextAnalysis needs to be mentioned. If – for example – a system requires natural language processing, it also makes sense to use already existing services.

To summarize, it needs to be mentioned that a clear understanding of the big picture is necessary before starting with implementation. Otherwise, a lot of refactoring needs to be done. Furthermore, the best solution must be found for each individual project. Solutions of big players like Netflix, Facebook and so on sometimes do not fit for small applications and vice versa. Even if Microservice architecture is emerging, it is not always the best choice and needs to be investigated carefully.

5.2. Frontend System

The frontend application should be platform-independent. Thus the application was implemented as a Xamarin Forms application.

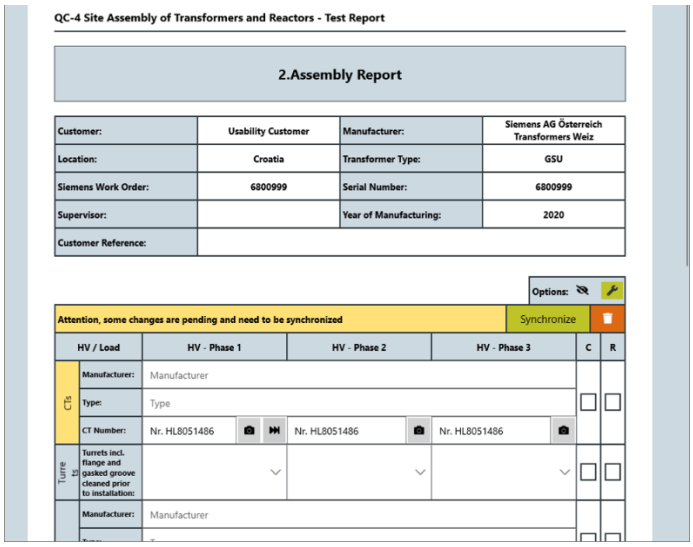

Figure 3: Report View

Figure *3* shows a report which is about to be filled out. It has the same structure and looks and feels like a PDF document, making it easy for users to navigate. In the shown case, the report was filled without connection to the backend system. A hint is shown that the current information, which is filled in, is not yet synchronized with the backend. This can be achieved by clicking on "Synchronize". A click on the red trash bin deletes all offline changes.

5.3. Field-Test and Evaluation

To check whether the assumptions regarding a Multimedia Assistance System are correct, the prototypical developed application was tested with a usability test. With this test, an attempt is made to determine which forms of visualization are suitable for the user-friendly display of data. Furthermore, the interaction methods are tested.

Unfortunately, a lock-down due to Covid-19 occurred and it was not possible to execute the test face to face as planned. Instead of this, a “Remote Usability Test” was conducted. In total, seven Microsoft Teams Sessions took place. Users were asked to turn on the camera on their end to see their gestures and facial expressions. With desktop and mouse sharing, users were able to control the application on the interviewer's computer. It could be seen that users implicitly moved the mouse where they were looking at. With this, it could be tested whether the planned menu navigation is also user-friendly.

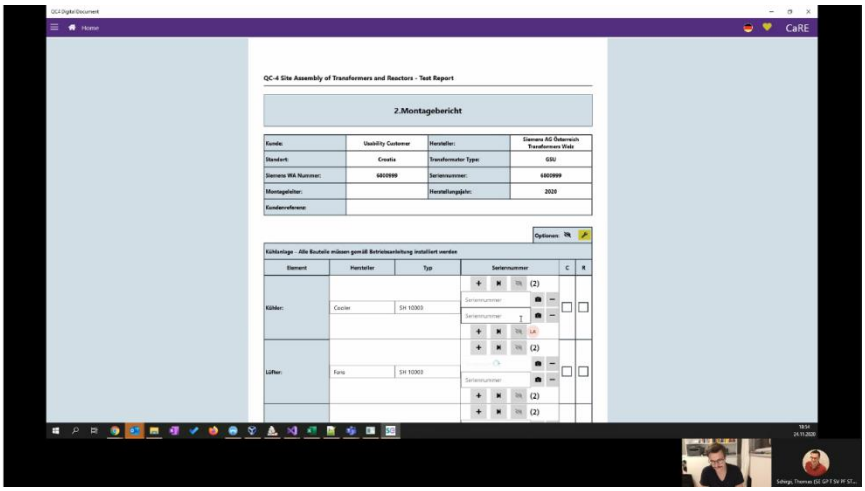

Figure 4: Remote Usability Test

It can be said that most of the tasks could be completed without any problems. With 14 tasks, only minor issues occurred; nine tasks out of 98 possible could not be completed without the interviewer's help, which is effectiveness of 90.8%. In some cases, the jargon was not clear or buttons were not found. The results regarding the general opinion about the application were almost identical. All test subjects described the application as clear, intuitive and visually appealing. It was also emphasized that the application does not appear too overloaded and that the users are not overwhelmed. Those users who found the automatic serial number recognition liked this feature very much since it is sometimes hard to enter such long serial numbers. Some users said that the font size is sometimes too small and that there should be an introduction during first use. One also stated that help text is missing. All those users who were used to the PDF version of the documentation said that it nearly looks the same and that it is for sure faster than before. Furthermore, the following statements were given:

- Buttons with special functions should be emphasized
- A tip of the day should be included
- Rework the wording and jargon. Some texts might not be apparent to supervisors. (e.g., Annotation)
- Datasets should be locked if one user is currently working on them. This prevents already inserted data is overwritten.
- An export into Microsoft Word, a PDF format or the possibility to print should be implemented.
- A back button or restore button should be added to the application.

During interaction with the application, no real problems occurred. The menu points were seen as self-explaining. As stated above, buttons with special functions should be emphasized and highlighted. For actions that finalize something (like signing), a confirmation (“Do you really want to do this?”) should be shown. For signing, an interactive pen is more suitable than using the computer's mouse. This is also the case for the annotation service since it is nearly impossible to mark something with a finger precisely. Annotating with the computer's mouse works, but it is also not user-friendly.

It could be seen that the interaction with the system accelerated with time. As soon as users understood the navigation concept and how certain features were emphasized, they were explicitly looking at it. On average, a goal was achieved in approximately 84 seconds. Therefore

the overall relative efficiency was calculated according to [35] and is 76.5%. The relative time-based efficiency was also calculated according to [35] and is 55,6%. One drawback was that the interaction was sometimes lacked due to Xamarin Forms, which is a bit slower than other frameworks. With this in mind, feedback right after a click onto an item is of utmost importance. It could be seen that the users became more and more familiar the longer the usability test lasted. As soon as the users understood the interaction concept and the navigation strategy, it became more and more intuitive.

6. CONCLUSIONS

The developed prototype is moving in the right direction, which can be seen in the results of the usability tests. The application adjusts to the needs of the users and thus is well accepted by them. It helps users during their work and they can see the current status at the site. With the help of the user-centered design approach, the needs and wishes of users could be identified quickly. The feedback cycles during implementation also helped in this regard.

Additionally, criteria were developed which are necessary to create an assistance system. The usability test showed that the requirements could be confirmed. To be able to exploit the full potential of CaRE, additional functions such as the selection of a power plant based on the GPS position or the operating diary and a native app might have to be implemented. For the annotation functionality also features with augmented reality can be implemented. This, however, is only possible if the selected Hardware is capable of rendering those features. Nevertheless, the usage of Microsoft Hololens or others is not intended. Even if advertisements are showing good-looking features, those functions are not helpful in daily life.

The presented CaRE pyramid helps to ensure a better process during assistance combined with smart devices. Thus, better and tailored commissioning and maintenance can be offered to the customer, and service can be made faster and cheaper. Due to that, higher availability of energy plants can be reached. Furthermore, the failure rate and the number of incorrect assemblies during commissioning and maintenance can be decreased. In addition, both parties may save a significant amount of money. The framework can also be used for other singletons, which are about the be commissioned or maintained. Therefore, the structure and logic behind it should be helpful for all types of singletons.

In some cases, it may be prohibited to use devices with cameras at the site – such as nuclear power plants or military zones – which makes such assistance applications not applicable. Then engineers at the site have to work on their own. Due to that fact, "traditional" service will also remain a critical factor in the future.

The sub-header of this paper is "Does IT help?". This question is freely based on the book "Does IT matter?" by Nicholas Carr. In this book, the question is raised if IT brings a competitive advantage. The answer in the book is no since IT is seen as an enabler, but companies do not have any competitive advantage of using IT. It is also stated that IT might hinder daily Business.

To answer the question in the sub-header, it can be said, "Yes, IT helps, but...". IT during daily work of supervisors might for sure help them if the assistance is not hindering. There are examples where supervisors had to document every step with tools, which impede their daily work. Most of the time, such tools were driven top-down from management. IT helps if, e.g., it accelerates, supports, or takes over some work. A Multimedia Assistance System – regardless of the scope – should assist users and not add additional work.

6.1. Future Work

There is also room for improvement in some areas, which would also provide further assistance to users. For example, context-sensitive help with recommendations would be appreciated, where the application automatically detects desires. Such features have to be handled with care since false positives would lead to disturbances. Another topic would be auditory checklists: With this, the checklist can be spoken to a device and the system is behind automatically detects the part in the checklist. A further possibility would be the detection of emotions with an analysis of the spoken texts. This must also be handled with care since this might be hard in a noisy environment. In terms of the user interface, some research must be done within adaptive user interfaces. Only one application needs to be developed, which adapts itself according to the current device and the available features.

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AUTHORS

Thomas Schirgi completed a MSc in information management in 2013 and worked over years in companies with singleton manufacturing. Today he is responsible for digital services and is currently working on this PhD.

INTELLIGENT COMPUTATIONAL MODEL FOR THE CLASSIFICATION OF COVID-19 WITH CHEST RADIOGRAPHY COMPARED TO OTHER RESPIRATORY DISEASES

Paula Santos[1, 2]

[1]Department of Psychology, University of São Paulo, Ribeirão Preto, Brazil
[2]Department of Head and Neck Surgery, Ophthalmology and Otorhinolaryngology, University of São Paulo, Ribeirão Preto, Brazil

ABSTRACT

Lung X-ray images, if processed using statistical and computational methods, can distinguish pneumonia from COVID-19. The present work shows that it is possible to extract lung X-ray characteristics to improve the methods of examining and diagnosing patients with suspected COVID-19, distinguishing them from malaria, dengue, H1N1, tuberculosis, and Streptococcus pneumonia. More precisely, an intelligent computational model was developed to process lung X-ray images and classify whether the image is of a patient with COVID-19. The images were processed and extracted their characteristics. These characteristics were the input data for an unsupervised statistical learning method, PCA, and clustering, which identified specific attributes of X-ray images with Covid-19. The introduction of statistical models allowed a fast algorithm, which used the X-means clustering method associated with the Bayesian Information Criterion (CIB). The developed algorithm efficiently distinguished each pulmonary pathology from X-ray images. The method exhibited excellent sensitivity. The average recognition accuracy of COVID-19 was 0.93 ± 0.051.

KEYWORDS

Probabilistic Models, Machine Learning and Computer Vision.

1. INTRODUCTION

In November 2019, the first cases of COVID-19 were detecting by China's health authorities. After a few weeks, the virus-infected Wuhan's city and, in March, spread globally.

In Brazil, the Ministry of Health divided the pandemic into two phases for better management: containment and mitigation. The first phase cases were attributing international travel or contact with sick people who traveled abroad. In the mitigation phase, the Ministry of Health recognized the occurrence of community transmission, from person to person, in the country - a late recognition, since there were already deaths unrelated to the transmission chains involving travelers [1].

In this context, one of the first steps towards adopting measures of social isolation and hospitalizations is to know who has been contaminated by COVID-19. The most appropriate tests for COVID-19 are molecular tests, but they can take 24 to 48 hours to be performing. In pandemic conditions, this period can last between 5 and 10 days due to many requests, lack of

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equipment, and health professionals' help. Therefore, rapid tests for mapping and screening patients are necessary. As X-Ray and lung tomography tests indicate patients with respiratory problems, these tests may answer this demand.

Despite several studies on the diagnosis of pneumonia regarding the criteria for confirmation and classification of pneumonia cases, many questions remain open. Thus, to avoid misinterpretation, this work was based on three underlying assumptions [2, 3]:

Pneumonia must be defined as an acute infection of the lung parenchyma by various pathogens, excluding the condition of bronchiolitis.

1. Defining pneumonia as a group of specific co-infections with different characteristics is not a line to be followed since the etiological agents' identification is not always possible.
2. Like other criteria, different types of pneumonia can be classified into more homogeneous groups, producing faster diagnosis advances.

Image recognition and analysis were revolutionizing with the introduction of deep learning, which allowed for unprecedented leaps in performance. The rapid advancement of these technologies expands the possibilities of automated, accurate, accessible, and economical medical diagnostics. Still, smart models are faster than humans and can be implemented on a large scale due to clouds' power or even at the edge. Thus, artificial intelligence techniques can help to compare and group similar types of pneumonia.

The present work proposes a criterion to classify pneumonia cases based on pulmonary radiographs. The images analyzed were of patients with COVID-19 and with common bacterial or viral pneumonia. The extraction method used was Haralick, Wavelets, and we used the Bayesian Information Criterion (CIB) as a probabilistic model, and thus we used a decision tree for the classification of images.

2. MATERIAL AND METHODS

2.1. Material Collection

We searched for articles and repositories that could indicate the signs on chest radiographs (Table 1) before comparing some characteristics present in COVID-19 with tuberculosis, H1N1, dengue, and malaria. The main characteristics highlighted were: pleural effusion, ground-glass opacity, pulmonary edema, rounded morphology of opacities, and bronchitis. Subsequently, we grouped the images into three categories: pneumonia type 1 (tuberculosis and Streptococcus pneumonia), pneumonia type 2 (malaria and dengue), and pneumonia type 3 (COVID-19). The separation was based on similar descriptions characteristic of these pathologies (Table 2) [4-25]. For this study, we used a total of 3800 chest X-ray images posteroanterior and anteroposterior positions of COVID-19 (1800), dengue (100), tuberculosis (730), Streptococcus pneumonia (200), malaria (270), normal (700). The set of images was acquired from repositories [4-25](Figure 1). Also, we use only images that a doctor has already diagnosed. That is, we use images from defined case studies. After separating the set of images, we perform manual segmentation of the pulmonary images and then look for five features that are often detectable on chest radiography was doing considering the descriptions made in case studies and articles published in the medical field to describe the intensity in the respective conditions, as shown in Table 1.

Table 1. Manifestations in the images: Diseases typical of countries like Brazil that can trigger viral and bacterial pneumonia.

	Pleural effusion	**Ground glass opacity**	**Pulmonary edema**	**Rounded morphological opacities**	**Bronchitis**
COVID-19	X***[11]	X*[10]	X**[13]	X*[10]	X***[11]
Dengue	X*[12,17]	X**[12]	X**[12,17]	X***[12]	X***[12]
Malaria	X**[8]	X**[1]	X**[13]	X**[1]	X**[8]
Streptococcus pneumoniae	X**[9]	X**[9]	X***[6]	X**[6, 9]	X*[6, 9]
Tuberculosis	X*[15, 18]	X**[2]	X**[14]	X*[15,2,18]	X*[15, 18]

* ordinary; ** 40-60% of cases; *** uncommon; mon * are significantly different; ** are not significantly different.

Table 2. Image groups for character extraction and model training

Pneumonia type 1	**Pneumonia type 2**	**Pneumonia type 3**
Tuberculosis	Malaria	COVID-19
Streptococcus pneumoniae	Dengue	-

3. INTELLIGENT ARTIFICIAL MODEL

The model was inspired in ChestNet [26] a Neural Network for support in diagnosis for problems pulmonaries. The workflow for analysis was developed for identifying the characteristics of regions of an image, using algorithms of Wavelets and Haralick extraction attributes of the image. These texture attributes are essential because they determine partners in the lung and rub through clusterization of pixels in different Chest X-Ray regions. Subsequently, we extract the characteristics to determine the hyperparameters of backpropagation from clustering and of data mining descriptive statistics.

The probabilistic model is essential to determine each parameter in a neural network because the descriptors auxiliary the segmentation of regions and classification from the region of interest from the pattern of variation of shades of gray or color of a given region of interest. These existing partners in physicals superficially noticeable to the human eye, bringing a significant amount of information about the superficial nature, such as smoothness and roughness.

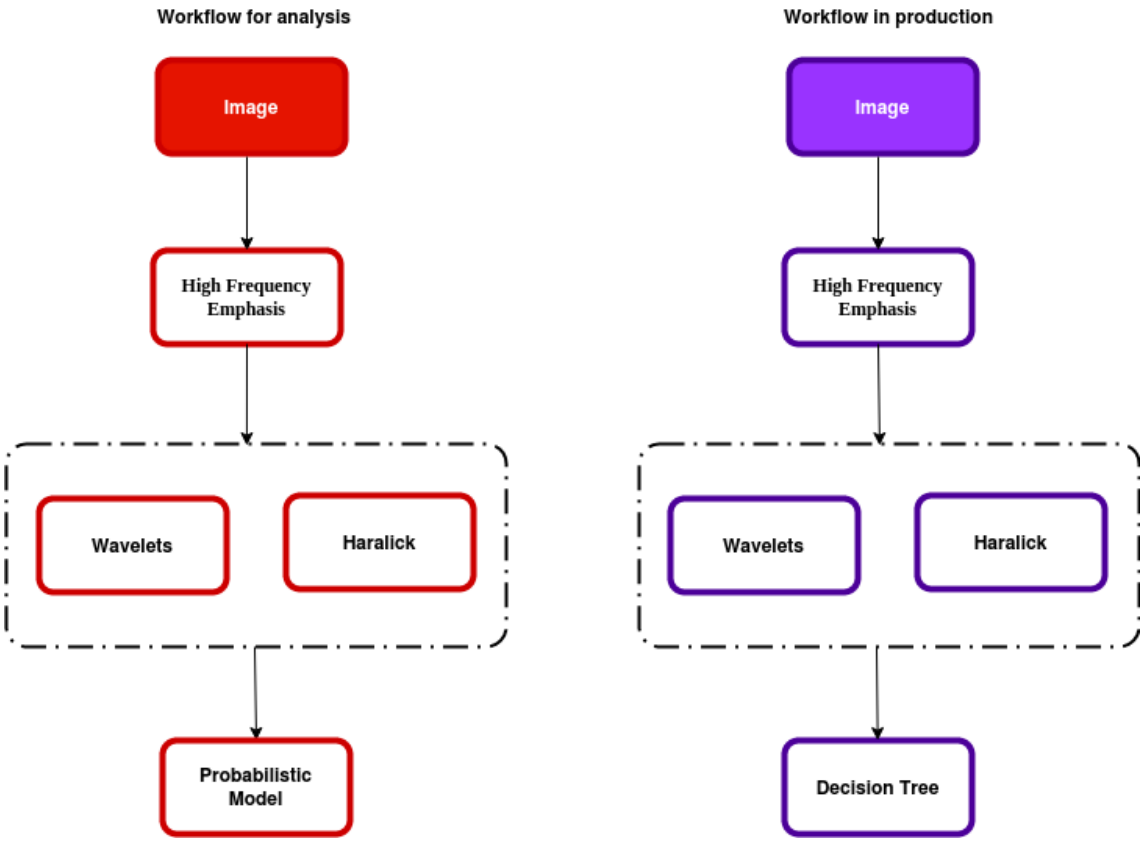

Figure 1. Workflow for analysis and production of the intelligent artificial model in Telegram.

3.1. Pre-Processing

This step's main objective was to improve the visualization of the bones through the implementation of the image enhancement algorithm of the High-Frequency Emphasis (HEF) filter [27]. HEF helps to sharpen an image by emphasizing the edges; since the edges usually consist of an abrupt change in the pixels' color intensity, representing the high-frequency spectrum of the image.

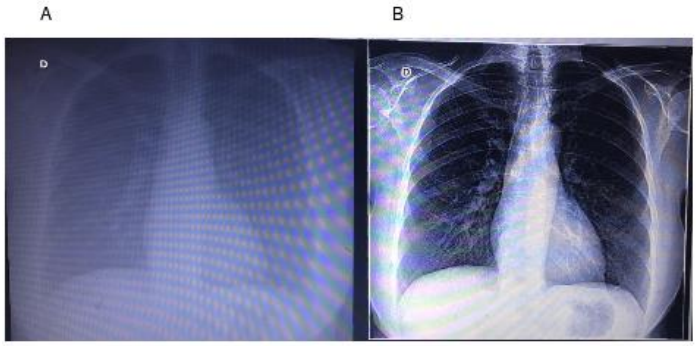

Figure 2. (A) Poor quality image; (B) After using HEF

3.2. Lung Segmentation Using the Mask-Regional Convolution Neural Network (Mask-RCNN).

Mask-RCNN is a deep neural network designed to solve instance segmentation problems in machine learning or computer vision [28]. For this model's training, we used 5000 lung images, segmenting the lung on the right and left sides (Figure 3).

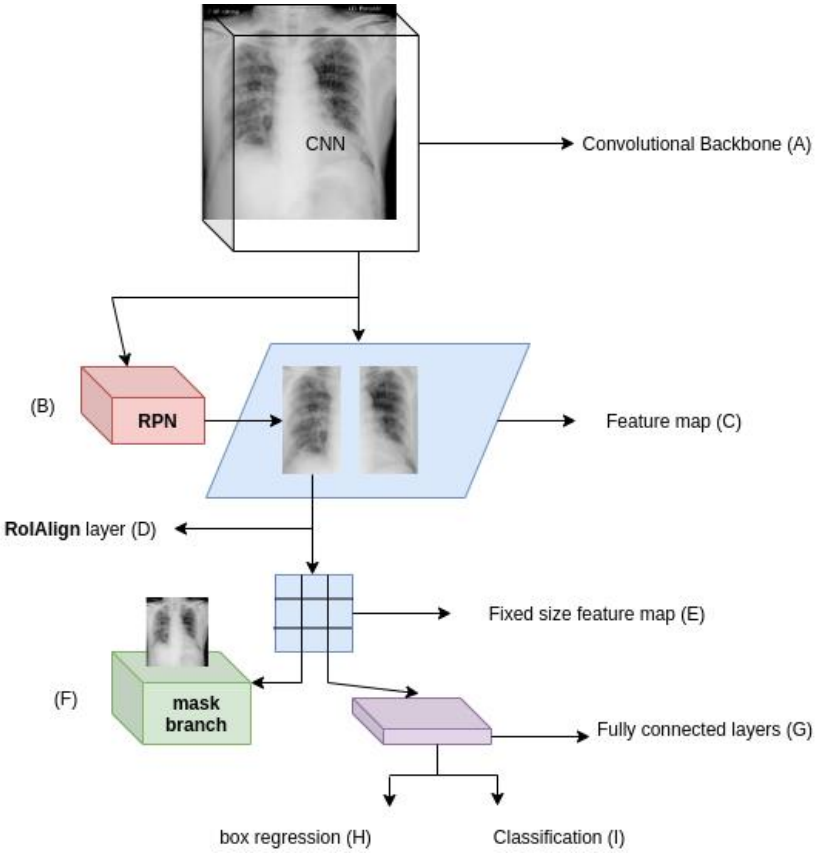

Figure 3. Mask-RCNN architecture model. (A) Convolutional Backbone of ResNet101 for extracting a map of X-ray scanned image characteristics; (B) Region Proposal Network (RPN): a neural network of small weights that provides for the bounding boxes of the lung under analysis on the characteristics map; (C) Feature map: a result of activating the output of filters applied to the image; (D) RoIAlign layer: a bilinear interpolation of nearby points on the feature map to avoid quantizing the region of interest (RoI); (E) Fixed size feature map: Reduced version extracted from the feature map; (F) Mask Branch: Mask of a fully convolutional network (RTC), which provides a segmentation lung mask for each RoI; (G) Fully connected layers use high-level RoI features by remodeling to a forecast vector; (H) Box regression: predicts the values of the pulmonary coordinates; (I) Classification for the prediction of the lung class.

3.3. Characteristics of X-Ray Images and Haralick Extractor

Studies show that chest radiographs are initially based on the visualization of the following three characteristics [2-3]. They are (1) Anatomical structures, such as ribs and other bones, must be visible. (2) The darker (black in the image) the color of the lungs, the more suitable is the functionality. (3) The heart and peripheral blood vessels must be visible. Using these characteristics, we applied the Haralick method (Figure 3) [29] to extract texture characteristics through their attributes, using a gray level co-occurrence matrix. The co-occurrence matrix is a square matrix whose size is the number of gray levels in the image to be analyzed. The developed

algorithm calculates the distances in all possible 360 degrees and normalizes between 0 and 100. Therefore, the co-occurrence matrix contains 100 rows per 100 columns and generates by combining the distances between the current angle and their respective combinations. 10, 45, 90, and 135 degrees. After calculating this matrix, a matrix of the probability of the combinations between the gray levels was calculating. The following texture characteristics' values were calculated from this matrix: energy, entropy, variance, homogeneity, dissimilarity, and correlation measures.

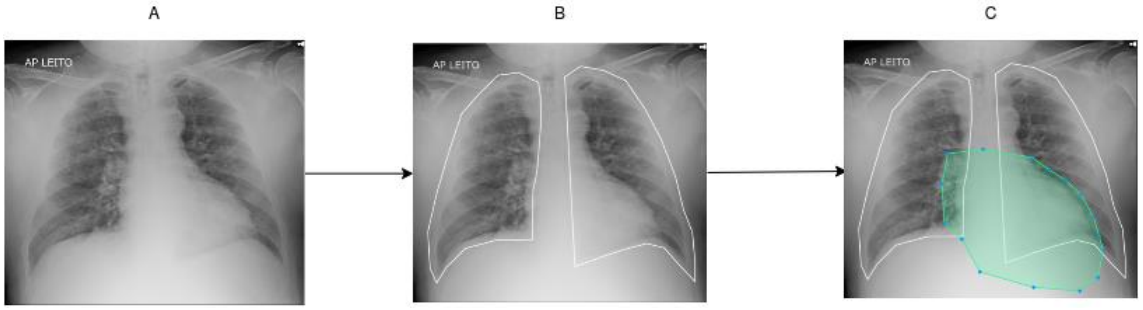

Figure 3. Regions marked for training. (A) Image of a patient with COVID-19; (B) Pulmonary marking; (C) Heart marking

3.4. Characteristics of X-Ray images and Wavelets

The wavelet transform can be time associated with these frequencies, making it very suitable for various fields. As an example, we can mention processing accelerometer signals for motion analysis and fault detection. Success in image compression, using the wavelet transform, is mainly attributed to innovative strategies for organizing and representing data from a transformed image. Such strategies explore implicitly or explicitly the static properties of the coefficients transformed into a wavelet pyramid. Most of the published coders recently used the pyramidal (dyadic) decomposition algorithm in the literature [33] For this project, we use the clustering of significant coefficients in a sub-band.

3.5. Selection of probabilistic model

The model selection problem refers to choosing the best model among a set of candidates built from combinations of parameters. Consider a sequence of models M1, M2, and Mn, with the corresponding parameters. There are many techniques for selecting the best model based on the probability ratio, and others add different types of penalty functions to the likelihood ratio. This is the case of the Akaike Information Criterion (CIA) and the Bayesian Information Criterion (CIB), both of which test two models at a time, and the two can be chosen in ascending order of the number of parameters. After that, there is a sequence of CIB and CIA values, which are optimized. This results in the number of parameters to determine which model is the best. Therefore, in the present study, we used X-means [30], an algorithm that efficiently searches the space of the clusters' locations and the number of groups to optimize the measurement of the CIB. To verify the training, testing, and validation of the model, a decision tree was used to find the hyperparameter and the inference tests [31].

3.6. Statistical Analysis

We used an Analysis of Variance (ANOVA) followed, when appropriate, by the Tukey-Kramer test of multiple comparisons for different sample sizes.

4. RESULTS AND DISCUSSION

Before analyzing the 3800 chest X-ray images, we separated the left lung from the right using Mask-RCNN, as described in the methodology, and each segmented lung pair was labeled as type 1 pneumonia, type 2 pneumonia, or type 3 pneumonia (Table 2), based on the data set information and on the literature review on signs and symptoms. The Shapiro normality test resulted in a p-value less than alpha (p-value = 4.899e-33 <0.05). Thus, the null hypothesis was rejected, and we concluded that the data were not extracted from a normal distribution. However, the information obtained from ANOVA and the Tukey-Kramer test was essential to determine the type of data distribution and the type of model. From these results, non-parametric models were used to determine the number of classes and the most appropriate classification model for this type of data (Table 3). Figure 4 shows that the characteristics were grouped according to the pathologies in pneumonia type 1, pneumonia type 2, and pneumonia type 3.

The wavelet transform can be time associated with these frequencies, making it very suitable for various fields. As an example, we can mention processing accelerometer signals for motion analysis and fault detection (Figure 5).

In this context, model selection is a problem of choosing the set of candidate models with the best performance for training data sets or estimating the model's performance using a resampling technique, such as cross-validation of k-folds. One way to use model selection involves using probabilistic statistical measures to quantify the model's performance in the training data set and the model's complexity, one of which is the Bayesian Information Criterion. The benefit of this information criterion is that it does not require a standby test, although a limitation is that they do not accept the models' uncertainty under consideration and may end up selecting straightforward models.

Table 3. Multiple comparison of means - Tukey HSD, FWER = 0.05 to assess Haralick resources.

Comparisons	Mean difference	Significance
	Contrast	
Contrast 1 x Contrast 2	-170,784	Significant
Contrast 1 x Contrast 3	-195,032	Significant
Contrast 2 x Contrast 3	-2.4248	Significant
	Energy	
Energy 1 x Energy 2	0.031	Significant
Energy 1 x Energy 3	42.3753	Not significant
Energy 2 x Energy 3	423,443	Not significant
	Homogeneity	
Homogeneity 1 x Homogeneity 2	0.031	Significant
Homogeneity 1 x Homogeneity 3	42.3753	Not significant
Homogeneity 2 x Homogeneity 3	423,443	Not significant
	Correlação	
Correlation 1 x Correlation 2	0.007	Significant
Correlation 1 x Correlation 3	101.9509	Not significant
Correlation 2 x Correlation 3	1,019,439	Not significant
	Dissimilarity	
Dissimilarity 1 x Dissimilarity 2	0.8779	Significant
Dissimilarity 1 x Dissimilarity 3	532,676	Not significant
Dissimilarity 2 x Dissimilarity 3	52.3897	Not significant

A B

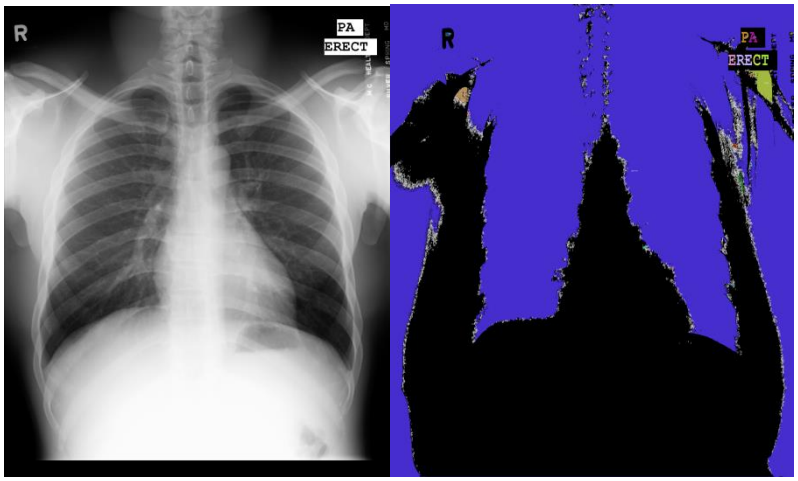

Figure 5. Algorithms of (A) Haralick and (B) Wavelets

In Figure 6, we show that the group grouping was efficient. The X-means method allows a variety of cluster K (K-means) to occur, which deals with the allocations of the clusters, repeatedly, trying to partition and maintain the resulting ideal divisions. In this segmentation, we obtained three clusters, validating the data grouping to use a decision tree model.

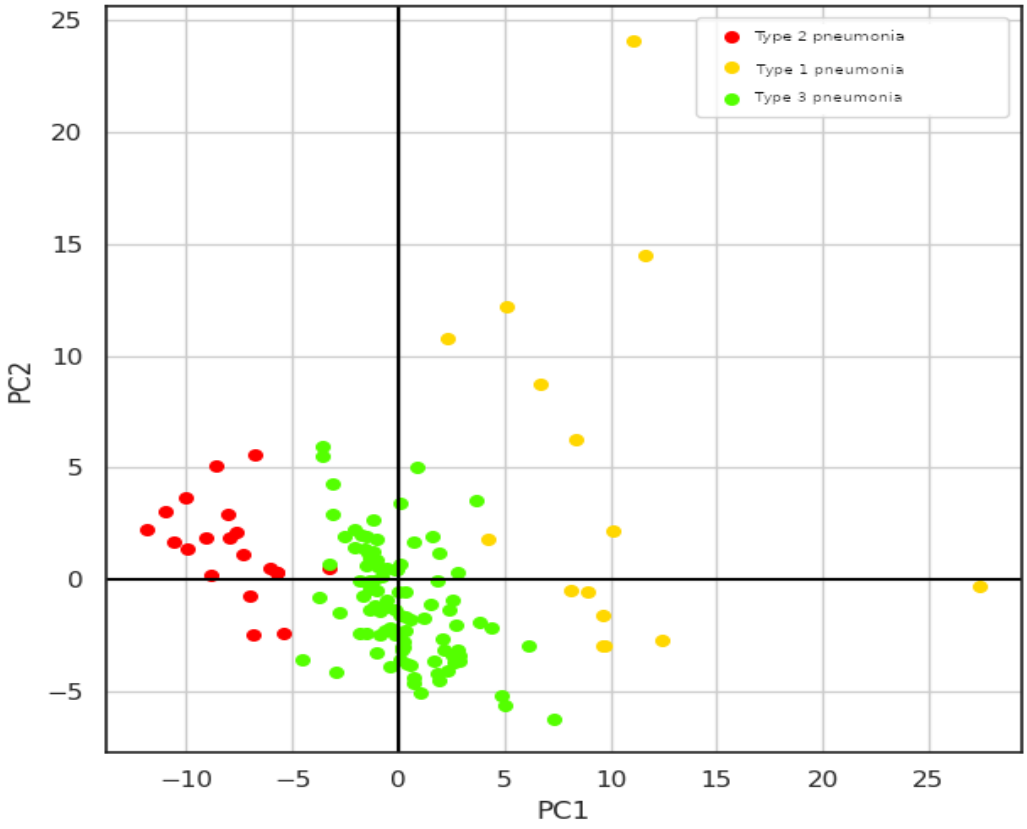

Figure 6. Scatter plot of the partition of the three clusters in the first two main components, for X-means with CIB.

The training was done with 70% of the characteristics and the test with the remaining 30%. The stratified K-Fold approach was using three scores: a minimum score of 0.95, a maximum score of 0.98, and an average score of 0.96. These results show that the average score of 0.96 presents a high assertiveness and indicates the model's high quality with real data. The optimization of the decision tree's hyperparameters was to determine the best criteria, the precision, and the standard deviation of the model (Table 4). The resulted in three scores: a minimum score of 0.95, a maximum score of 0.98, and an average score of 0.96. These results show that the average score of 0.96 is highly accurate and indicates the model's high quality with real data. The optimization of the decision tree's hyperparameters was to determine the best criteria, the precision, and the standard deviation of the model.

Table 4. Hyperparameters of the decision tree model

Best criterion	Best maximum tree depth	Best number of components	Cross validation for model evaluation
Entropy	12	3	0.93 ± 0.051

With the completion of this first stage, we carried out the test in the municipality of Itapeva. In this first stage, we tested 25 patients with suspected viral or bacterial pneumonia. We tested patients who had at least one complaint about this validation stage, such as headache, changes in taste, fever, and other complaints related to acute pneumonia. However, we tested five patients who did not meet the inclusion criteria for COVID-19 or Tuberculosis, but when the model evaluated the X-Ray, a normal patient presented COVID-19 PCR-RT test was negative, and another patient was also asymptomatic. The model was evaluated as COVID-19 and was confirmed with the PCR-RT test. In the case of the patient with Tuberculosis, he already had Tuberculosis previously, but it was positive for COVID-19 by the PCR-RT. All patients underwent the PCR-RT or Bacilloscopy test to confirm the diagnosis.

Table 5. Validation in the health unit with patients with suspected COVID-19

	number of suspect diagnoses	number of diagnoses
Normal	5	4
COVID-19	18	20
Tuberculosis	2	1

Currently, some studies have focused on the diagnosis by computed tomography (CT), a technique that has better sensitivity for the detection of soft tissues. However, radiography devices' availability in countries like Brazil is 1: 25,000 inhabitants, while that of CT devices is 1: 100,000 inhabitants. Some countries in Africa also offer more X-ray equipment than CT. Thus, the study of pattern recognition algorithms on chest radiographs can contribute to doctors and radiologists in diagnosing COVID-19 infection in remote regions or regions without CT devices' availability. Besides, chest X-ray diagnosis can be a screening route for isolation and/or hospitalization measures since there is a limited number of molecular test kits (the main one being RT-PCR) and, depending on the manufacturer, a high index of false-negative results may occur.

In this context, several epidemiological relevance diseases have oscillatory and periodic time patterns related to their transmission in the community. These diseases can be associated with intrinsic factors such as immunity, contact pattern, renewal, virulence rates and extrinsic factors, such as temperature, humidity, and precipitation. Among these diseases, the most common are tuberculosis, malaria, Streptococcus pneumonia, and dengue [2-7]. As these different pathologies can generate conflicting signals in diagnostic imaging, we investigated metrics that can indicate biomarkers capable of avoiding the false-positive diagnosis of COVID-19. The literature indicates that ground-glass pulmonary opacity patterns, usually with bilateral and peripheral pulmonary distribution, are emerging as a hallmark of COVID-19 infection. This disease pattern, somewhat similar to that described in previous coronavirus outbreaks, such as SARS and MERS, also fits the model that radiologists recognize as the archetypal response to acute lung injury, usually initiated by an infectious or inflammatory condition [4, 7]. Inflammation can cause ground-glass opacities in lung images, indicating consolidated dense lesions that can progressively evolve to a linear structure [8-9].

Our research efforts have shown that models using artificial intelligence can determine parameters for different groups with similar symptoms and signs. Our data mostly agree with the work of Pan et al. (2020), showing a preponderance of abnormalities in ground glass in the course of the disease. The recognition of image patterns in this group of images with similar signs and symptoms is an auxiliary tool for understanding the disease's pathophysiology since the definitive diagnosis of COVID-19 requires a positive RT-PCR test. However, current best practices recommend it as an additional test, but not for the final diagnosis of COVID-19. However, the intelligent computational model can help identify complications in the screening systems and the monitoring of pulmonary problems since there is still no effective drug for the disease, and the vaccines are still in the process of validation. The data obtained with our model suggest that the Haralick method can determine the patterns of pulmonary imaging characteristics showing pleural effusion, ground-glass opacity, pulmonary edema, rounded morphological opacities, and bronchitis. These metrics allowed the model to distinguish and significantly classify the three different pneumonia types with high accuracy. Currently, the intelligent computational model is used via Telegram by health professionals in municipalities in Minas Gerais, in Brazil (Figure 7).

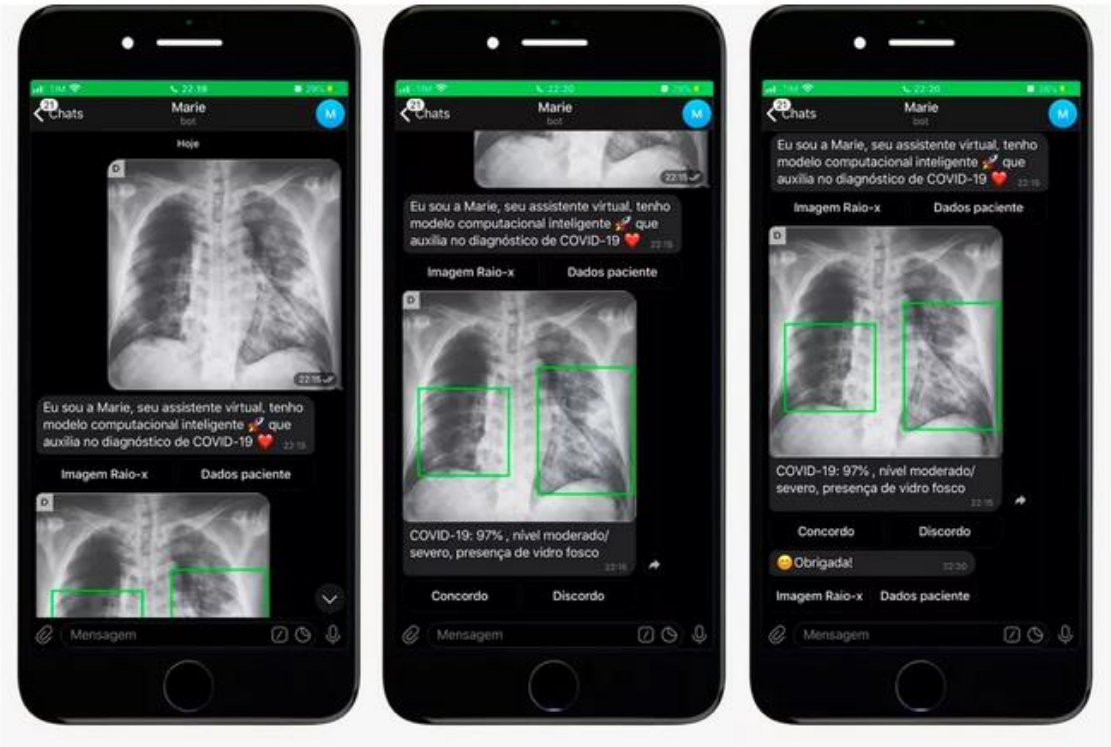

Figure 7. (A) Implementation of the intelligent computational model in the telegram for access to doctors, nurses, and radiologists.

5. CONCLUSIONS

Haralick's texture descriptors were useful for efficiently representing patterns of interest for image analysis and interpretation, as they showed changes in pixel intensity patterns, which were correlating with pathological changes in COVID-19. However, the new approach to extract texture characteristics by the Haralick method provided more results for the predictive analysis of pixel intensity and, when associated with unsupervised methods (X-means) and supervised methods (Mask-RCNN and Decision Tree), showed results with high accuracy. Thus, characteristics such as homogeneity, energy, dissimilarity, and correlation significantly differentiated some pathologies from the pathology of COVID-19. These results suggest that these characteristics can be used as biomarkers. These biomarkers could also be used to understand the course and stage of the disease. Our results and the preliminary test showed that chest X-rays could help healthcare professionals identify and diagnose COVID-19.

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AUTHOR

I obtained three bachelor's degrees in biomedical informatics and speech therapy from the University of Sao Paulo and mathematics from Anhembi Morumbi, a PhD in Sciences with a focus on Bioinformatics data in chronic pain and tinnitus models and a Post-doctorate in Psychology for the development of intelligent models for evaluation of social behaviors by the U. I also acted as Coordinator in projects of Bioinformatics and Artificial Intelligence in Medical Images in the evaluation of good or bad prognosis of childhood cancer by the Department of Pediatrics of the Hospital das Clínicas de Ribeirão Preto.

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