Institution: Aberystwyth University

Unit of Assessment: 11: Computer Science and Informatics

Title of case study: Automatically discovering major usability issues in e-Commerce sites via machine learning

Period when the underpinning research was undertaken: 2004-present

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Dr Richard Jensen	Research Assistant; Lecturer	1 August 2004- present
Professor Qiang Shen	Professor	1 August 2004 – present
Dr Neil Mac Parthaláin	Research Fellow; Lecturer	1 September 2011- present

Period when the claimed impact occurred: 2016- present

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

New data mining algorithms have been developed to effectively and efficiently discover usability issues in e-Commerce sites, employing UserReplay's analytics solutions utlising our work, saving significant amounts of money for businesses globally. Supported with an Innovate UK grant in 2016, the technology is derived from data mining research at Aberystwyth University. Cases have shown estimated annual savings of over USD86Million. UserReplay and their clients have benefitted commercially from this research due to reduced losses, increased automation, and competitiveness. Competitors subsequently had to make similar improvements leading to further economic impact. Ultimately, customers using these sites benefitted from an improved experience.

2. Underpinning research (indicative maximum 500 words)

One aspect of research work in the Advanced Reasoning group (ARG) has focussed on the development of robust techniques for data mining that can handle uncertainty, incompleteness, and imprecision in data. This has been achieved through the use of a hybridisation of fuzzy sets (that model vagueness and noise) and rough sets (that model indiscernibility and sparsity). This theoretical development has been shown to be highly effective for the construction of methods for various steps in the data mining process, such as feature selection, instance selection, missing data imputation, and rule induction. This provided a foundation for the work with UserReplay who were looking to automate the discovery of usability issues in e-Commerce systems as part of their analytics solutions.

The initial work was the development of a feature selection and classification system for the automatic categorisation of Web content in 2004 [3.1]. The complex nature of this kind of data was a good fit for the fuzzy-rough hybridisation approach, enabling efficient data reduction and effective classification for datasets with thousands, or tens of thousands, of dimensions. Since then, a series of further theoretical developments and extensions have enabled the fuzzy-rough feature selection algorithms to be applied with greater effectiveness. For example, one mathematically rigorous and computationally efficient method is archived in [3.2], successfully handling inconsistent, not just imprecise and inaccurate, data.

A particular improvement concerns the time complexity of the underlying approach, enabling its application to even larger datasets and facilitating the development of novel algorithms in related data mining areas [3.3], where existing techniques often require balanced data (i.e., roughly equal proportions of instances per class/category) to learn models effectively. More recently, the work in [3.4] introduced a novel approach that uses bio-inspired search to find the best reductions for imbalanced high-dimensional data using fuzzy-rough sets.

Inspired by the success of fuzzy-rough feature selection, algorithms were developed for classifier learning and classifier ensemble reduction [3.5]. Classifier ensembles generally allow better predictive performance than that achievable with a single model. The removal of redundant or less-contributing constituents helps increase group diversity and enhance overall accuracy, while relaxing memory and storage requirements and minimising run-time overheads.

A key problem with many real-world datasets is that information may be missing as a result of human or computer error. Such missing data are problematic as many mining algorithms do not have the functionality to cope with this. Therefore, given the success of fuzzy-rough sets, an approach was developed to impute missing values using fuzzy-rough constructs, with the data itself being used to determine the likely values that are missing [3.6].

ARG have contributed many programs implementing these and associated data-driven learning algorithms to Weka, the world's largest open-access repository for machine learning and data mining software. Having recognised the track record of the ARG in the relevant areas, a leading software company specialising in e-Commerce, UserReplay approached AU. Collaboration with UserReplay then commenced in 2015 and through which, they subsequently secured the Innovate UK grant in March 2016 [5.1]. AU provided scientific input to and technical support for this project [5.3], and such collaboration continues to date.

3. References to the research (indicative maximum of six references)

3.1 R. Jensen and **Q. Shen**. (2004) *Fuzzy-Rough Attribute Reduction with Application to Web Categorization*. Fuzzy Sets and Systems, 141(3), pp. 469-485. 2004. DOI: 10.1016/S0165-0114(03)00021-6

3.2 R. Jensen and **Q. Shen**. (2009) *New Approaches to Fuzzy-Rough Feature Selection*. IEEE Transactions on Fuzzy Systems, vol. 17, no. 4, pp. 824-838, 2009. DOI: 10.1109/TFUZZ.2008.924209

3.3 R. Jensen and **N. Mac Parthaláin**. (2015) *Towards Scalable Fuzzy-Rough Feature Selection*, Information Sciences, vol. 323, pp. 1-15, 2015. DOI: 10.1016/j.ins.2015.06.025

3.4 A. Moayedikia, K-L Ong, Y.L. Boo, W. Yeoh, and **R. Jensen**. (2017) *Feature selection for high dimensional imbalanced class data using Harmony Search*, Engineering Applications of Artificial Intelligence, vol. 57, pp. 38-49, 2017. DOI: 10.1016/j.engappai.2016.10.008

3.5 R. Diao, F. Chao, T. Peng, N. Snooke, and **Q. Shen**. *Feature selection inspired classifier ensemble reduction*. IEEE Transactions on Cybernetics, vol. 44, no. 8, pp. 1259-1268, 2014. DOI: 10.1109/TCYB.2013.2281820

3.6 M. Amiri and **R. Jensen**. (2016) *Missing data imputation using fuzzy-rough methods*, Neurocomputing, vol. 205, pp. 152-164, 2016. DOI: 10.1016/j.neucom.2016.04.015

4. Details of the impact (indicative maximum 750 words)

The research described above facilitated the development and deployment of a data mining system that effectively detects customer struggle points in e-Commerce sites. UserReplay had no machine learning (ML) or AI capabilities ahead of the collaboration with Aberystwyth University. [text removed for publication]. From this, a novel sequence mining algorithm and

feature (attribute) selection method are developed, on the basis of AU's existing techniques, to discover sequences that are unusual or repetitive.

Initially, the collaboration led directly to UserReplay successfully raising a GBP249,684 Innovate UK Grant in March 2016 [5.1]. The proposed product innovation enabled by the machine learning project also contributed significantly to the company's successful venture capital funding in 2016, which itself led to the recruitment of approximately 20 new roles across all business functions [5.2].

The prototype was first tested in May 2016 with immediate positive results, including the detection of a current fault in a large e-Commerce site preventing all Canadian customers from being able to check out. The further development of the prototype was then prioritised, and the product launched in September 2016 [5.3].

The approach has since discovered many usability issues potentially costing e-Commerce sites significant revenue [5.3]. For example, one case study [5.4] is available where the developed machine learning approach found an unknown anomaly on a customer's website where multiple presses of the "Buy" button were occurring, affecting up to 40% of possible transactions. This bug was undiscovered by prior system testing or human analysts and would have cost millions if it had remained active during the Black Friday trading season. A similar example is given in the press release [5.5], where the availability of stock was not being reported correctly on the website preventing customers from completing their purchases. The error was occurring 53 times per day, resulting in an estimated annualised revenue opportunity of USD1,479,000. Another example is shown in the evidence as per [5.6], where customers were unable to pay when one of the items in their baskets had sold out. The error message did not inform the customers which item was causing the problem, and caused great inconvenience leading to cart abandonment. The annualised opportunity of fixing this problem with a clearer error message was estimated to be GBP986,000.

A summary of some further identified issues, thanks to the aforementioned research, is given in [5.7] for major clients. From these cases alone, the total estimated annualised revenue opportunity is USD86,200,000. It is stated that the machine learning technology is used "to record, analyse, and segment over 2.5 billion user sessions a month", which would be impossible to achieve manually. The problems flagged by the analytics include usability issues, technical issues, and fraudulent activity, demonstrating the range and complexity of issues that can be detected.

A patent was filed by UserReplay in December 2016 detailing the above approach and an extension using neural networks to aid prediction [5.8]. Following on from the successful R&D conducted with Aberystwyth University, the company has focused more on data mining and machine learning, recruiting full-time machine learning experts [5.3]. Aberystwyth University also continues to work with them and Briggs Associates Ltd, of whom the former CEO of UserReplay is the Director, for such development.

Machine learning is at the centre of UserReplay's latest product which performs analytics and session replay for mobile shopping apps [5.9]. This uses the data mining developments described above and their associated additional tools. [text removed for publication].The technology today is deployed to at least 22 companies across the world including some of the Fortune 50 in the USA [5.10]. Of course, further to the substantial commercial benefits that UserReplay's clients have been enabled to enjoy by the research, the general customers also have an improved experience when utilising the e-Commerce sites.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Innovate UK grant #720768 "UserReplay Analytics machine learning project"
gtr.ukri.org/projects?ref=720768

5.2 User Replay Raises $4.7M in Funding.
www.finsmes.com/2016/02/user-replay-raises-4-7m-in-funding.html

5.3 Letter from the CEO during this period, John Thompson (07/01/21).

5.4 User Replay case study: Black Friday case study – intermittent issue identified affecting up to 40% of possible transactions.

5.5 Press release: UserReplay Unveils Machine Learning Feature for Automatic Detection of Customer Experience Pain Points. www.prweb.com/releases/2016/09/prweb13681065.htm

5.6 User Replay case study: Surface anomalies and emerging issues.

5.7 User Replay case study: How UserReplay saved 12 e-commerce clients $86,247,000 in annual revenue.
userreplay.com/resources/conversion-rate-optimization/ecommerce-case-studies/

5.8 Patent pending GB2557998 - Predictive analytics system and method. www.ipo.gov.uk/p-ipsum/Case/PublicationNumber/GB2557998

5.9 UserReplay announces new Machine Learning Powered Analytics for Mobile Apps.

5.10 UserReplay's featured customers www.featuredcustomers.com/vendor/userreplay