





## A Reinforcement Learning and Synthetic Data Approach to Mobile Notification Management

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## Motivation

- Research Design
- Experiment Implementation
- Results
- Limitations & Future Work
- Conclusion



## **Motivation: Anecdotal**





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Notification Growing number of in notifications pushed delivery **not smart** at users (Pielot, M. (Mehrotra, A. et al, et al, 2014). 2016). Unnecessary Large no. of notifications may 432 incoming notifications = dramatically decrease negative user emotions (Sahami productivity (Iqbal, S. T. et al, 2010). Shirazi, A. et al,

2014).



## **Motivation: Observed Problem**



## **Research Design: Gathering Data**





## WeAreUs Android App

- Experience Sampling Method
- Moments of notification interest, moments of phone usage interest
- Anonymised & Synthesised



## **Research Design: Gathering Data**



# **15** participants over **3** months

## **31,329** notifications logged

**291** questionnaire responses **4,940** smartphone usage logs



























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Notification engagement by time of day

































33%	28%	
140	35	
WhatsApp, Gmail, SysUI, Vending	WhatsApp, Gmail, Vending, SysUI	
Whatsapp: 64% Gmail: 32% SytemUI: 7%	Whatsapp: 60% Gmail: 39% SystemUI: 7%	
61%	55%	
msg: 74% call: 66% alarm: 87% sys: 1% err: 6%	msg: 65% call: 50% alarm: 34% sys: 3.9% err: 5%	
240	20	
Arts & Entertain: 67% Online Communities: 65% Education: 69%	Arts & Entertain: 42% Online Communities: 29% Education: 73%	
	33% 140 WhatsApp, Gmail, SysUI, Vending Whatsapp: 64% Gmail: 32% SytemUI: 7% 61% msg: 74% call: 66% alarm: 87% sys: 1% err: 6% 240 Arts & Entertain: 67% Online Communities: 65% Education: 69% Mobile Apps: 88%	



*Train on Real, Test on Synthetic*<sup>1</sup> RMSE F1 scores differ in range 0.02 – 0.07 indicating synthetic data imitates real world data.





## OpenAl Gym

Open source toolkit for "developing and comparing reinforcement learning algorithms" <sup>1</sup>



## Gym-Push

Custom *OpenAI* Gym environment simulating push-notification overload on mobile device users



1. https://gym.openai.com/



## **Gym-Push**

Custom *OpenAI* Gym environment simulating push-notification overload on mobile device users



## Context + Notification Features

## **Action**

Open / Dismiss the notification



## **Experiment Implementation**

#### **Q-learning Agent**

- Learn a policy to maximise total reward
- Create q-table to track quality of state->action pairs
- Updates q-values according to Watkins *one-step Q-learning algorithm* (1)
- Can explore or exploit (ε)

#### **Deep Q-learning Agent**

- Replaces the q-table with a DNN
- Takes the state as input and output is an action
- Weights optimised based on the Huber Loss function (2)

$$Q_{t+1} \leftarrow Q_t + \alpha \left[ R_{t+1} + \gamma \max_a Q(s_{t+1}, a) - Q_t) \right]$$
(1)  
$$L(y, f(x)) = \begin{cases} [y - f(x)]^2 & \text{for } |y - f(x)| \le \delta, \\ 2\delta |y - f(x)| - \delta^2 & \text{otherwise.} \end{cases}$$
(2)





## **Experiment Implementation**

#### Individual User (Synth & Balanced)

- Comprised of ≈6000 synthetic notifications
- Split into sets of size: 50, 100, 250, 500, 1000, 2500, 5000
- Balanced

#### Individual User (Real & Balanced)

- Comprised of ≈6000 real notifications
- Split into sets of size: 50, 100, 250, 500, 1000, 2500, 5000
- Balanced

#### Individual User (Real & Unbalanced)

- Comprised of ≈6000 real notifications
- Split into sets of size: 50, 100, 250, 500, 1000, 2500, 5000
- Unbalanced

#### Multiple Users (Real & Unbalanced)

- Comprised of ≈1000 real notifications
- Unbalanced



- Evaluating agents ability to correctly predict user action of open/dismiss notification
- Feature set: { app, category, time-of-day, day-ofweek }
- Evaluate with 10-fold cross validation
- Accuracy
- Precision important when cost of false positive is high e.g. agent predicts user wants to see it, delivers
  -> they end up dismissing it
- Recall important when cost of false negative is high e.g. agent predicts user doesn't need to see it, caches it -> they miss an important message
  F1







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## Q-Table Average Metrics vs Size of State Space









## Q-Table Average Metrics vs Size of State Space





## Synthetic Data

# Features	Feature Types	State Space Size
4	app, category, time-of-day, day-of-week	2240
3	app, category, time-of-day	320
2	app, category	80
1	app	16

## **Real Data**

# Features	Feature Types	State Space Size
4	app, category, time-of-day, day-of-week	17136
3	app, category, time-of-day	2448
2	app, category	612
1	app	51



## **Applied Research: Observed User Problem**

www.adaptcentre.ie



## **Applied Research: Q-learning Solution**

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## DQN Average Metrics vs Notification Dataset Size



## DQN Training Time vs Notification Dataset Size







## DQN Average Metrics vs Size of State Space



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### DQN Average Metrics vs Notification Dataset Size





## DQN Average Metrics vs Size of State Space





## **Applied Research: Observed User Problem**

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## **Applied Research: DQN Solution**



## Q-Table Average Metrics for Single Feature Spaces









500

400

300

200

100

0

No. Unknown States

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### Q-Table Average Metrics & CTR per User



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## DQN Average Metrics & CTR per User



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- Generative modeling applied to text
- Exploring other RL algorithms e.g. HER, IMPALA
- Larger user study



## **Future Work – Conditional Ticker Text Generation**

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## Future Work – Autonomous Personalised Notifications

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## **Future Work – Autonomous Personalised Notifications**

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	envi	envirc 🎓 🥁	Mobile push notifications are the primary mechanism for communicating new information	
				also have a negative impact



# Shareable notification data set

OpenAl Gym environment for training on notifications

Two methods of RL applied to notification management

Evaluations illustrate agents achieve comparable performance to SOTA





http://evalumap.adaptcentre.ie/

## EvalUMAP 2020

# Towards comparative evaluation in user modeling, adaptation and personalization

To be held in conjunction with the 28th Conference on User Modeling, Adaptation and Personalization, <u>UMAP 2020</u>, June 2020, Genoa, Italy **\*\*Full details on the EvalUMAP 2020 shared challenge/task and on participating in the EvalUMAP 2020 shared challengeare available at <u>challenge details and participating</u>\*\*** 

Register here



# Thank you.

# Questions?

Demo: https://review2019.github.io

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