

Signatures of subjective quantities

Data, measurements and models



Sagar Joglekar

Department of Informatics, Faculty of Natural and Mathematical Sciences
King's College London

This dissertation is submitted for the degree of
Doctor of Philosophy

April 2019

To Geetika, Medha and Chanda ... The three formidable pillars of my life

DECLARATION

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other University. This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration, except where specifically indicated in the text. The dissertation covers contributions for journals and conferences where I was the main contributor and primary investigator.

Sagar Joglekar
April 2019

ACKNOWLEDGEMENTS

And I would like to acknowledge ...

ABSTRACT

Research in the field of recommendation systems have shown that *subjective preferences tend to follow deterministic patterns, when looked at data in large sample sizes*. This principle underpins several of our present day applications like recommendations while shopping for items online or visiting places to eat or listening to music. With the ever pervasive nature of the internet, we as a society have gone beyond treating the online spaces as a tool to access information, and have started treating them as a natural extension of the self. We spend more time than before as a part of a larger networked community, exchanging thoughts, debating ideas, expressing creativity and “socializing”. We also sometimes indulge in expression of human emotions like empathy, anger, sadness and sometimes seeking help. At such a juncture, I examine the thesis **Can we quantify entities of subjective nature, if the data is large enough, and originates from human responses?**. In this dissertation I develop data driven pipelines with the aim to quantify perceptions of subjective qualities, through two case studies. In the process, I provide a broad overview of how intangible subjective properties exhibit in data and develop metrics to quantify them. I also reason about the utility of said properties when it comes to developing interventions.

In the first study I analyse on-line formal networks where interactions between humans are purely with the intent of helping each other. I develop frameworks to abstract out the structure of these interactions. I then delve into investigating presence of perceived support by finding discriminative local structures in these abstractions. I reason about these local structures using established cross disciplinary theories. This informs my analysis about the nature of peer to peer support in these communities and paves the way to do actionable interventions in the area of peer support in online networks.

In the second study, I investigate utility of perception of aesthetics in physical spaces, by developing a pipeline that capitalizes on crowd sourced responses about urban aesthetics. I propose a deep-learning driven framework, which is able to quantify the perception of intangible abstract qualities like ‘beauty’ through a crowd sourced rating of google street view images. I show that a general pattern of beauty in urban spaces can be learnt through a crowd sourced opinion and deep learning models. I further develop a generative model

to simulate beautification of urban spaces. Through a detailed literature review of the field of urban design, I develop a measurement framework which can provide insights into the predictors of urban beauty on a case by case basis. I then develop the necessary tools to evaluate these metrics using computer vision techniques. I validate the value of these metrics through expert survey and also validate the interventions using crowd sourced perception experiments.

In the course of the work, I contribute original design and implementations of different data driven pipelines, which can be used to quantify signatures of subjective properties in a way that can drive interventions and impact real lives.

[]

TABLE OF CONTENTS

List of figures	xiii
List of tables	xvii
Nomenclature	xvii
1 Introduction	1
1.1 Introduction	1
1.2 Perception and Affect	2
1.3 Intervention and the DIKW model	4
1.3.1 Data	6
1.3.2 Abstractions	8
1.3.3 Knowledge	8
1.3.4 Wisdom	9
1.4 Research avenues	9
1.4.1 Supportive Interactions on the web	10
1.4.2 Leveraging aesthetic perceptions of real spaces	11
1.4.3 Ontologies for intervention	11
1.5 Thesis overview and original contributions	12
1.6 List of peer reviewed publications	13
1.6.1 Original author contributions	13
1.6.2 Collaborative author contributions	13
2 Social networks and social support	15
2.1 Online health communities	16
2.2 Dataset and properties	18
2.3 Abstraction: Graphs	20
2.3.1 Activity Metrics	21
2.3.2 Community resilience	21

2.4	Activity patterns of users	23
2.4.1	Activity	25
2.5	Propensity to help	26
2.6	Not like conventional networks: Anti-rich club effect	27
2.7	Support is contagious	27
2.8	Key takeaways, possible interventions	27
3	Structure of online supportive conversations	29
3.1	Introduction	29
3.2	Results	32
3.2.1	Peculiarity of threads of Support	32
3.2.2	Patterns in local interactions	35
3.3	Methods	36
3.3.1	Data	37
3.3.2	Abstractions	37
3.3.3	Macro and local metrics	39
3.3.4	Structural metrics	41
3.4	Appendix	42
3.4.1	Triadic statistics for twitter conversations	42
3.4.2	42
3.4.3	Network characteristics	42
4	Perceptions in real spaces	49
4.1	Introduction	50
4.2	Related Work	51
4.3	FaceLift Framework	53
4.4	Evaluation	61
4.5	Conclusion	70
4.5.1	Limitations and biases	71
4.5.2	Future work	72
References		73

LIST OF FIGURES

1.1	The DIKW pyramid	4
2.1	Global graphs prepared from Asthma UK community 2.1b and BLF community 2.1a. The size of the node corresponds to the degree of the node and the color corresponds to the community membership	21
2.2	Cumulative distributions of the number of posts as a function of time (weeks) within the Asthma UK (A) and the British Lung Foundation (B) communities. Calendars dates are reported below week numbers. Panels C and D illustrate the average number of posts per user per week within Asthma UK and British Lung Foundation, respectively	22
2.3	Fraction of users that are part of the largest component as a function of time (weeks) for Asthma UK 2.3a and the British Lung Foundation 2.3b. Sensitivity analysis: targeted removal of nodes (users) starting from the most connected ones within Asthma UK 2.3c and the British Lung Foundation.	23
2.4	26
2.5	27
2.6	28
3.1	Panel shows CDFs of different network metrics. Fig.3.1a shows the response time distributions, Fig.3.1b shows symmetrically engaged users, Fig.3.1d shows topical similarities across posts and 3.1e shows the branching factors of reply graphs.	34
3.2	This panel shows the statistical significance of the three over expressed and one under expressed triadic motif.	36

3.3	Example UserGraphs and their corresponding Reply graphs, Figure 3.3b shows a random thread from the SW sub-reddit and 3.3a shows the corresponding reply graph that arises from the response structure of the same thread. In comparison we have Usergraph Fig 3.3d and its corresponding reply graph Fig 3.3c from one of the Front page threads	38
3.4	Figure 3.4a shows the 16 different types of motifs that are looked for in the user graph data. Figure 3.4b shows how three unique users could produce different motifs. The three shapes represent different users and the dotted line means the message order is irrelevant.	43
3.5	The figure shows comparison of occurrence ratios of 9 insignificant motifs. Blue traces are for Suicide watch and Green traces are for Baseline Front page threads	45
3.6	<i>Fig 3.6a shows the branching factor for twitter threads that talk about suicidal tendencies against baseline threads. Fig 3.6b shows the distribution of median centralities per thread, for both the twitter crawls. Fig 3.6c shows Distribution of symmetric messages in reply graphs for both datasets. Fig 3.6d shows the distributions for users participating in a symmetric conversation Fig 3.6e shows the distribution of reply urgency for suicide threads against baseline. The suicide median reponse time for suicide threads is 3 min as compared to 18 mins for non-suicide threads</i>	46
3.7	<i>Fig 3.7a shows the distribution of maximum depths of Reply Graphs for Subreddit r/SuicideWatch and the baseline Frontpage conversations. Fig 3.7b shows the distribution of unique authors per thread in the two datasets. Fig 3.7d shows Distribution of degrees for Reply Graphs, r/SuicideWatch and FrontPage. Fig 3.7c shows the degree distributions for the reply graphs . . .</i>	47
3.8	<i>Distribution of responses per thread on Subreddits r/SuicideWatch and Frontpage</i>	47
4.1	An illustration of the FaceLift framework.	53
4.2	Frequency distribution of beauty scores. The red and green lines represent the thresholds below and above which images are considered ugly and beautiful. Conservatively, images in between are discarded.	56
4.3	Two types of augmentation: (a) rotation of the Street Views camera (based on rotation); and (b) exploration of scenes at increasing distances (based on translation).	56
4.4	The types of scene that have greater propensity to be correctly augmented with similar scenes at increasing distances.	57

4.5	Architecture of the synthetic beauty generator. This consists of a generator of synthetic scenes concatenated with a beauty classifier. The green block is the beauty maximized template \hat{I}_j , which is subject to forward and backward passes (red arrow) when optimizing for beauty.	58
4.6	Number of labels in specific urban design categories (on the x -axis) found in beautified scenes as opposed to those found in uglified scenes.	65
4.7	Count of specific walkability-related labels (on the x -axis) found in beautified scenes minus the count of the same labels found in uglified scenes.	66
4.8	The percentage of beautified scenes (y-axis): (a) having an increasing presence of sky (on the x -axis); and (b) having an increasing level of visual richness (on the x -axis). The error bars represent standard errors obtained by random re-sampling of the data for 500 iterations.	67
4.9	Interactive map of FaceLifted scenes in Boston.	69

LIST OF TABLES

2.1	The summary of salient attributes of the data used for this work	19
3.1	Notations and Terms.	32
4.1	Notations	53
4.2	Percentage accuracy for our beauty classifier trained on differently augmented sets of urban scenes.	57
4.3	Examples of our generator’s outputs. The original scenes and the generated ones are shown side by side.	59
4.4	Examples of the “FaceLifting” process, which tends to add greenery, narrow roads, and pavements.	62
4.5	Urban Design Metrics	64
4.6	Coefficients of logistic regressions run on one pair of predictors at the time.	68
4.7	Urban experts polled about the extent to which an interactive map of “FaceLifted” scenes promotes: (a) decision making; (b) citizen participation in urban planning; and (c) promotion of green cities	69

CHAPTER 1

INTRODUCTION

There are things known and there are things unknown, and in between are the doors of perception - Aldous Huxley - Doors of perception

1.1 Introduction

We live in a world where information is being bombarded on our cognitive faculties from all sides, at all times. The internet is a continuous stream of information and each source is fighting with the other to get a piece of our attention budget. With the advent of machine learning and big-data sources, building systems that predict actions as a response to perceptual triggers is the bread and butter of many companies. The use cases may range from understanding which adverstise made a visitor do an unscheduled purchases on amazon, or which string of music tracks recommendations maximized a users time on a particular music platform. But in the end it all boils down to understanding what triggers result in human action or lack thereof[91]. Nonetheless the systems that surrounds a human interacting with the internet, are all figuring out the best triggers which are perceived by the human as worthy of attention. The term “Attention Economy”[22] was actually coined for this very reason. In the words of Matthew Crawford “*Attention is a resource, a person has only so much of it.*”[21]. We live in the age of distraction, and more often than not, our subjective perceptions are guiding our actions, than our conscious cognitive processes. Several studies have shown that engagement

is almost always a game of stimulating our most basic urges, such as dopamine hits, presence of faces or simply arousal of emotions to increase the working memory.[9, 45][85][90].

An interesting side effect of dwindling attention budgets is the emergence of more formal topical spaces on the internet. The ever pervasive nature of the internet allow these formal spaces to function almost like physical communities, with moderated and effective peer to peer exchange of thoughts, ideas and empathy[41, 52, 93]. In such an environment, as computer scientists, it is worth asking the questions:

How do subjective human perceptions manifest in data?

Can quantifying these help us design better interventions ?

These two questions are going to be the guiding principles of my dissertation. But first of all, we need to clarify the relation between perception, affects and data. To do so we should try and understand each of these terms separately in the context of the field of application.

1.2 Perception and Affect

Across my work , I would try to build frameworks to capture subjective human perceptions in the realm of human to human interactions and subjective intangible qualities like the sense of beauty or the sense of perceived support. The utility of such an attempt, can only be justified if there is a real link between how humans function at the most fundamental cognitive level and how they perceive the intangible, including the aesthetic. There has been an ongoing effort to unravel this link, through psychological, neuro-evolutional and philosophical arguments. I will try to gain inspiration from them, but a detailed critique is beyond the scope of my dissertation and expertise

Affect¹: *Any experience of feeling or emotion, ranging from suffering to elation, from the simplest to the most complex sensations of feeling, and from the most normal to the most pathological emotional reactions.*

¹American Psychological Association definition.

Perception²: *The process or result of becoming aware of objects, relationships, and events by means of the senses, which includes such activities as recognizing, observing, and discriminating. These activities enable organisms to organize and interpret the stimuli received into meaningful knowledge and to act in a coordinated manner.*

Emotions or ‘affects’ and perceptions have long been discussed in the psychology, neuroscience and philosophical literature. Emanuel Kant in his prolific work, first discussed the utility and the philosophical reasoning behind presence of affects or emotions[46]. In his opinion, emotions are pre-cognitive involuntary states, termed as "mere perceptions of unspecified bodily states"[15]. But that does not mean they don’t influence our deepest level of well-being and influence our decision making processes. The link between affect and perception has also been explored in several other cases. An argument to link perception of affect producing aesthetics was made by Perlovsky[76], where they propose that the phenomenon of affects arousing from aesthetics, comes from a fundamental human need to enrich the knowledge about real world. An unexpected thing, stimuli or structure in physical space creates a dissonance between our expected model of the world and the perceived reality at some level and we perceive it as aesthetically pleasing. Another recent study by Zadra et.al[104] evaluated the relation between visual perception and emotions. They demonstrate that the conventional assumption of the disentangled functioning of perception and affects is not necessarily true. Humans are quite susceptible to perceiving different realities based on different aroused affects.

The discussion on the formal definition and process of affects will continue, but there seems to be a consensus, at-least among the computer science and information science community that affects do influence our decisions and we perceive information through a filter of affects. Affective triggers can be generated when information is formatted or packaged in a certain way. In such a setup, it is worth testing if certain affect driven interactions on the web leave a trail of patterns in the data of these interactions. Furthermore it is work asking if these patterns might in some way be used to improve our online and physical environments.

²American Psychological Association definition.

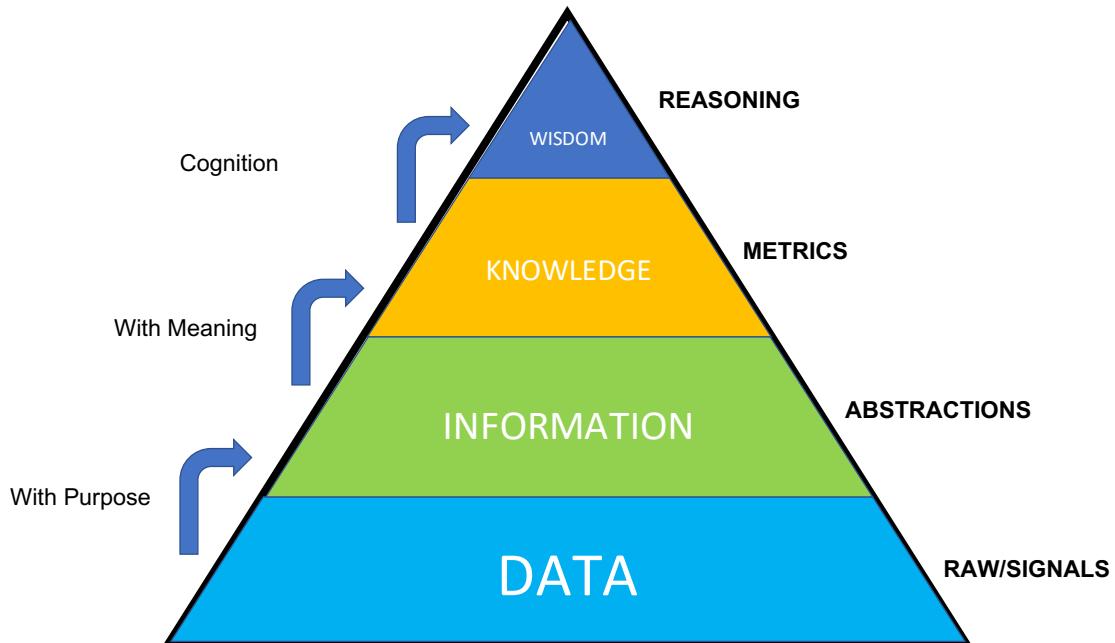


Fig. 1.1 The DIKW pyramid

But to arrive at these patterns, one needs to understand the frameworks of approaching such a problem. The journey from Data to subjective signatures, has to go through a series of operations.

1.3 Intervention and the DIKW model

In attempt to develop metrics and pipelines, one has to reflect on one of the fundamental frameworks about operations on data, that is the **Data , Information, Knowledge and Wisdom** model[82]. In this dissertation I posit and demonstrate through case studies, that for any reasoning about perceptions and affects, you need to develop frameworks that extract knowledge from data in a format that is aligned with the ontological framework of the application. In the context of this dissertation, ontology implies a set of concepts, definitions and relations between entities defined around a common set of axioms. Debating the nature of this ontology is not the purpose of this dissertation, but I show that ‘a’ solution can be reached, if systems are designed to interpret metrics extracted from the data by anchoring

around an ontological framework pertaining to the area of impact. But to reach this step, the data needs to pass through the 4 layers of the DIKW pyramid model.

In this model, the most foundational layer consists of the pure form raw **data or signals** that come from a source. If we are measuring perceptions of humans, this source needs to be tied back to humans in some way. The data needs to be generated as a result of some human-human interaction or as a result of deliberate human input as a form of response to their perception of some event. In this dissertation, I present various data sources and methods of collecting and curating data, which pertain to human-human interactions or human responses.

The **information** layer is the result of the fact that any process done on the data is with a sense of purpose or an end goal. For example, if the goal is to understand how humans exchange messages at times of distress, you would most certainly need to express the raw information about sender and recipient of messages into some form of a networked abstraction. The abstraction preserves the organization of data, but at the same time allows information to be operated on. As a result, almost always the output of this process is some form of a data abstraction. You need to attach some meaning to the patterns in the information to extract knowledge about the fundamental processes that you want to measure.

Knowledge. Defining knowledge has been an ongoing effort in the field of philosophy. But in the context of information science, knowledge involves collation of diverse sources of information and mix of contextual information, values and metrics to deliver a coherent understanding of the real world. For example, if you need to know the most popular user among a social network of users exchanging messages; you would look for the most central user in the network(abstraction) along with several other temporal and structural metrics to arrive at a few candidates. In this particular case, these metrics, along with the context of the social network's design, dawns the meaning of popularity.

The final layer needs a cognitive process and an ontological framework, to extract actionable insights, which we can call **wisdom**. By classical definition of ontology, it defines properties of and relations between objects or concepts. For this very reason, these ontological frameworks need to be originating from the fields of intervention. In our example,

lets assume we need to get some insights about the dynamics of popular users. Particularly in the context of optimizing advertising delivery. For example we need to understand how a particular piece of advertising, might percolate through the network if certain popular users advertise it[56]. However to arrive at these insights we need to be grounded in the ontological frameworks of epidemiology, network physics and depending on the application, advertising or meme theory. Then using the abstractions of social networks, the metrics derived from them, and the ontological basis of all the aforementioned fields, one can design a pipeline that could deliver us these insights to reasonable accuracy.

Figure 1.1 shows an illustration of the adopted version of Rowley’s DIKW model, which I would refer back as a repeating motif for my dissertation.

1.3.1 Data

Data is one of the most fundamental contribution of this work. To develop frameworks around quantification of human perceptions, such that we can do impactful interventions from this approach, we first need to make sure we formalize how we acquire, clean and condition our data. The most base level of this pyramid is the data that the frameworks would work with in order to progress on these lines. I work with diverse forms of data such as textual data , video data and image data to understand how these might exhibit signatures of human perceptive processes. The relation between data and subjective attributes needs to be examined using some proxy. For this reason, my research involved collecting data from sources where either human to human interactions happen or the data is generated on account of a human expressing their opinion about a subjective quality like beauty of a place, or how much someone “likes” an image or a video.

Interaction Data

In the first case study of this dissertation focusses on is online support communities, where human to human interaction is at the centre of the utility of these communities. It has been shown through several studies in medical informatics, that these communities play a very important role in providing support and respite in times of distress [4] [64, 75] [12, 42] [40].

The communities are especially helpful when it comes to people suffering from long term illnesses or mental health issues. The key element that impacts the users is the perceived social support[68], which delivers people in distress a sense of belonging to a group and empathy from the fellow supporters. To understand how users on these communities perceive social support, I work with data acquired from online health forums, where users share, give support and ask for support. I look at communities that deal with long term conditions like Lung illnesses, and communities where mental health patients seek support[44]. The data spans across a duration of 10 years, containing peer to peer support interactions of more than 30,000 users. I also crawled a popular forum based social network called reddit³ to acquire a peer to peer support forum data regarding mental illness and suicidal thoughts. The data covers discussions about more than 30,000 calls to support, and incorporates the complete structure of the way people respond to these calls.

Media data

The other facet of my work looks for quantification of how we perceive physical spaces. Whether a street is considered beautiful is a matter of subjective opinion, yet research has shown that there are specific urban elements that are universally considered beautiful: from greenery, to small streets, to memorable spaces [1, 78, 83]. These elements are those that contribute to the creation of what the urban sociologist Jane Jacobs called ‘urban vitality’ [43]. Apart from vitality, these motifs in urban environments are also highly correlated with feeling of well-being, health and safety [47]. There have been studies where people have tried to use crowd sourcing to acquire subjective ratings of images [86] which have shown some reasonable progress on this front. But the real gap in these studies is understanding the impact of urban elements on the perception of these subjective qualities. E.g. How much does presence of a green garden affect the subjective rating of beauty of that particular area. For this reason, I work with google street view data and subjective ratings of various places around the world[67], with the aim to understand, how people perceive the sense of beauty in urban areas. Then using the ontological basis of urban design and architecture, developed

³www.reddit.com

by a detailed literature review, I aim to develop machine learning pipelines that can suggest interventions to change perceptions of physical spaces.

1.3.2 Abstractions

The act of aggregating information from data, almost always involves building organized abstractions. Throughout my dissertation, I either repurpose well known abstractions in computer science or develop my own using tool from fields like computer vision and Information theory. For the first study, I incorporate user meta data and the textual data of their activity, to build organized networked abstractions representing the conversation structures on the support forums. I use these abstractions to evaluate global and local structures in support communities, which would be discussed in detail in Chapter 2 and 3.

While working with media data, I use several pixel level abstractions to segment and group semantically similar pixels. I also use several state of the art object and scene detection to extract semantic information from an image, with the aim at analysing correlations with the perception of subjective attributes of images with these metrics. I also use deep convolutional networks and generative models, to abstract out a representation of beauty. A more detailed discussion of these abstractions would be done in the later chapters (Chapter 4).

1.3.3 Knowledge

For extracting knowledge, we need to first associate meanings to certain computable metrics that we obtain from the abstractions. As discussed in the previous example, it could be as simple as associating the property of “popularity” to the metric of centrality. In my case, I develop several of these metrics to related subjective properties with measurable structures in data. Some of these metrics are based on intuitions which I validate, and some based on extensive literature survey. To give an example, I develop the concept of anchored triads, which combines local structures in interaction graphs of users, with the role of a user in a supportive conversation, to understand how these conversations evolve.

1.3.4 Wisdom

Finally the wisdom , in definition underlies insights that come from experience. The experience could come simply from the scale of data or from cross disciplinary literature that puts forth theories of subjective experience. E.g. The theory of social support puts forth four categories of social support 1)Affective/Perceived 2)Instrumental 3)Informational 4)Appraisal. Each type has its own specific traits. My dissertation looks at these theories from the lens of computational social science, and develops processes to quantify signatures of affective support.

1.4 Research Thesis and Questions

The global thesis of my dissertation as described before comprises of asking the two aforementioned questions: **How do human perceptions manifest in data?** and **How do we quantify these perceptions?**. But these questions are quite open ended, and answering them in a generalized manner seems impractical. For this reason, I need to first contextualize my work in the realm of practical applications. To rationalize the pursuit of these questions, I choose application driven case studies, which allow me the luxury to do a data driven exploration with a final goal of designing intervenable frameworks. Across my investigations, I follow the DIKW framework layer by layer, by distilling actionable wisdom from data. Through the two case studies , my work touches a diverse set of data science tools which range from complex networks formulations to generative adversarial models of human perception.

1.4.1 Supportive Interactions on the web

Humans are social animals in every aspect. The presence of social support systems in ones lives have shown to have huge quantifiable benefits. From speeding up recovery in cases of post-partum depression or in the cases of cancer survivors[11, 18, 32] , to signs of positive turn around among patients suffering from alcoholism and depression [16, 74], social support

is a key predictor of positive prognosis for patients under distress. With the advent of internet, a lot of communities have sprung up, which provide a rich platform for patients to interact, exchange support as well as provide a perceived sense of community. These communities do not have any special provisions for the users, but have an emergent behaviour of support and help by the very reason of homogenous membership. In other words, everyone on these communities are either in the same situation, or have been in the same situation in the past, and recovered. The idea of this case study was to quantify how supportive processes evolve over these communities, using abstraction methods from the fields of network science. Doing so, the community would be better poised to tackle any disturbances in the dynamics of these supportive communities in time.

To achieve this I first had to collect data from two different communities designed for online social support. The first community is dedicated for patients suffering from chronic lung diseases, such as Asthma or Chronic Obstructive Pulmonary Disorder (COPD). This community was moderated by self appointed moderators, and everyone on this community was either a survivor or a patient of these diseases. This community allowed patients to ask questions about symptoms and home remedies and sometimes just bond over social interactions. The second community I worked with dealt with people suffering from chronic depression and suicidal thoughts. This community was a safe haven for such people to vent out suicidal thoughts and get support from peers to manage these sudden flares of thoughts of self harm.

Through these two communities, I develop a pipeline to analyse the peer to peer interactions using abstractions derived from network science. I also develop metrics inspired from psychology and sociology literature to quantify how these interactions can be qualified as supportive or non supportive. Through a data driven analysis, I establish confidence on these metrics. Through this process, I also report my findings about the dynamics of users on these communities and key properties of user roles.

1.4.2 Leveraging aesthetic perceptions of real spaces

In this case study I explore the possibility of leveraging the knowledge about perception of physical spaces to improve how we could design them into better versions. The driving question is : Can we quantify how we perceive urban spaces, and generate actionable insights about how to better a given space? I develop an end to end pipeline, that uses crowd-sourced ratings of google street view images along the aesthetic dimensions, to train models that could simulate addition of beautiful urban elements in originally un-attractive spaces, and presenting a ‘beautified what could be?’ version of physical urban spaces. These spaces can then be explained to users, who in our case are urban designers and architects, along the lines of possible interventions to improve the state of things. To generate actionable explanations about aesthetic perceptions of physical spaces, we develop metrics by connecting computer vision methods with urban design literature and presenting summarised changes that could beautify a given scene.

1.4.3 Ontologies for intervention

Ontology in a philosophical context is a branch of information science, which deals with defining objects and their relationships with each other. The definition also looks at definition of concepts and processes using a set of relationships. The idea of my research, apart from developing pipelines was to understand the ontologies of the interdisciplinary applications that I am working with, to develop computational insights into how to quantify the affects and perceptive processes. To that extent these ontologies might touch upon the fields of social science, to define how social ties are defined between agents, or the fields of urban design to define how the concept of walkability links with several urban elements. Once these ontological relationships are defined, we can then use abstractions like graph structure, or segmented pixels in a urban image, to arrive at the metrics of walkability or social tie structures.

1.5 Thesis overview and original contributions

In the first study, I examine the structure behind how people seek engagement on-line. In Chapter 2, I discover that humans are very limited by their attention budgets, and engage with informal social networks in a very atomic and primacy driven way, which makes prediction of engagement using certain attributes of the content very feasible. But on the contrary, in more formal social networks, where the aim is to exchange knowledge and support, the structure of interaction evolves around certain key elements of perception of support and helpfulness, which are well explored in the real world communities(Chapter 3). On the journey to unravel these traits, I develop techniques to abstract out online formal conversations and develop a models for detecting supportive conversations on the web. I discuss the utility of such a model and draw parallels with the offline model of community support(chapter 4).

In the second study, I investigate utility of perceptions of real world places through a crowd sourced rating of google street view images. I develop models to extract the perception of the crowds using data driven inference methods(Chapter 5). I show that a general pattern of beauty in urban spaces can be learnt through a crowd sourced opinion and based on this finding, I develop a generative model to simulate beautification of urban spaces by using deep learning. I validate the quantification of perception of real-world beauty using crowd validation. I contribute a way to use computer vision techniques to abstract out beautification process into explainable metrics used by architects and urban planners. The final contribution is a demo web application, that allows practitioners to examine and validate the utility of such a end to end system that captures citizen perceptions for urban design(chapter 6).

1.6 List of peer reviewed publications

Here I would like to list all the publications which resulted from the past 4 years of primary lead work, as well as collaborations I was able to strike with a diverse group of researchers.

1.6.1 Original author contributions

List of papers, published and in review, which were led by the author or where the author had fundamental contribution

1. **Joglekar, Sagar**, Nishanth Sastry, and Miriam Redi. "Like at First Sight: Understanding User Engagement with the World of Microvideos." International Conference on Social Informatics. Springer, Cham, 2017.
2. **Joglekar, Sagar**, et al. "How online communities of people with long-term conditions function and evolve: Network analysis of the structure and dynamics of the asthma UK and British lung foundation online communities." Journal of medical Internet research 20.7 (2018).
3. **Joglekar, Sagar**, et al. "Online discussions about mental health in Reddit exhibit signatures of supportive conversations" Under Review
4. **Joglekar, Sagar**, et al. "FaceLift: A transparent deep learning framework beautifying urban scenes" Under Review
5. Kauer, T., **Joglekar, S.**, Redi, M., Aiello, L. M., & Quercia, D. (2018). Mapping and Visualizing Deep-Learning Urban Beautification. IEEE computer graphics and applications, 38(5), 70-83.

1.6.2 Collaborative author contributions

List of papers, published and in review, where the contribution was significant, but were not led by the author

1. Bhatt, S., **Joglekar, S.**, Bano, S., & Sastry, N. (2018, April). Illuminating an ecosystem of partisan websites. In Companion of the The Web Conference 2018 on The Web Conference 2018 (pp. 545-554). International World Wide Web Conferences Steering Committee.

2. De Simoni, A., **Joglekar, S.**, Taylor, S. J., Patel, A., Duschinsky, R., Coulson, N., ... & Evans, M. J. (2017). Structure and dynamics of online patients' communities: the case of Asthma UK and BLF online fora.
3. YOUNG, A. P., **Joglekar, S.**, GARIMELLA, K., & SASTRY, N. (2018). Approximations to Truth in Online Comment Networks.
4. Agarwal, P , **Joglekar, S.**, Papadopoulos, P., , SASTRY, N. & Kourtellis, N. (2018) Hyper-partisan websites: Personalization of user experience on polarized websites.
5. Raman, A , **Joglekar, S.**, De Christofaro,E., SASTRY, N. & Tyson, G. (2018) Tooting Your Own Horn: Exploring the Impact of Decentralisation on the Mastodon Social Network.

CHAPTER 2

SOCIAL NETWORKS AND SOCIAL SUPPORT

"The original idea of the web was that it should be a collaborative space where you can communicate through sharing information... In an extreme view, the world can be seen as only connections, nothing else." - Tim Berners Lee[14]

Attention budgets pretty much govern how we as consumers interact with online social networks. It has been shown that the dearth of this budget, promotes an engagement behaviour that prioritizes perceptive features and immediacy in the content. The scrolling user interface of platforms like Instagram and Facebook, allow mere seconds to decide whether a particular content is worth the user's attention [33]. However, there is a whole breed of online social networks, which aim at bringing the offline sense of networking, online. These networks are mostly designed around a specific purpose like technical discussions¹, subject specific questions² or simply around hobbies like knitting³ or art⁴. These communities embody the true essence [14] of the internet, in that they strive at making geographical distance secondary, to the act of social networking and information sharing.

In the context of this dissertation, I wanted to know how signatures of a perceived entity like social support, manifests on these formal social networks. More specifically I have followed the DIKW framework, to look at the signatures of perceived *social support* on communities designed around users who have underwent or are undergoing physical or

¹www.stackoverflow.com

²www.stackexchange.com

³www.ravelry.com

⁴www.artween.com/

mental distress. According to the seminal work by Shumaker and Brownell [89], social support is defined as “*an exchange of resources between two individuals perceived by the provider or the recipient to be intended to enhance the well-being of the recipient.*” Under this construct , these communities are apt Petri dishes to study the signatures of the online social support. Once you could quantify the social support signatures in terms of computable metrics, platforms could then empower the participants of these communities and design interventions to curb negative behaviour like trolling. The first step to this goal, was to understand the structure and utility of these communities. More over, having a primer on these communities would help the reader get an idea about the methods developed over the course of this dissertation.

2.1 Online health communities

Recent work has proposed that online communities have the potential to influence health and health care sectors. Recent studies have suggested that the participation of people with long-term conditions (LTCs) in online communities (1) improves illness self-management [4], (2) produces positive health-related outcomes⁵ [64, 75] , (3) facilitates shared decision-making with health care professionals [12, 42], and (4) may even reduce mortality [40].

There is also evidence that self-management support interventions can reduce health service utilization [70, 98]. This is especially a crucial point as the world health services are facing the brunt of an ageing population.

Online communities have experienced an upsurge in popularity among people with chronic respiratory conditions such as cystic fibrosis [50], asthma [95], pulmonary hypertension [60] and chronic obstructive pulmonary disease (COPD) [101]. More than 15 million people in England suffer from a long-term condition or disability, and they account for at least 50 percent of all general practitioner appointments⁶. Thus, assessing how these online communities function, evolve and provide perceived support, can have important implications for health care sector. More so, understanding the dynamics of these online

⁵<https://bit.ly/2FLcs1F>

⁶<https://bit.ly/2EVFs9v>

communities, have actual repercussions on how the platforms that host them, could become a better resource of self-management of LTCs.

On average, one in four people with an LTC who use the Internet tries to engage online with others with similar health-related concerns [35]. In particular, it has been suggested that the value of participating in an online community lies in the possibility of gaining access to a range of people and resources quickly, easily [6], and anonymously [75], as well as obtaining tailored information and emotional support [3, 19, 27, 28, 88]. However, most of this evidence comes from qualitative studies, whereas only recent years have witnessed an increasing interest in quantitative assessments of online communities as intervention mechanisms [28-33]. Recent studies have been concerned with the users' unequal contributions and engagement patterns, and with the role of superusers. However, the contribution of superusers to the sustainability of online health communities and their structural properties remains mostly unclear.

The potential future integration of online health support systems with formal health care provision should be underpinned by a better understanding of how they are used and by evidence of their effectiveness. Indeed, as suggested by the Medical Research Council [20], integrating online support systems with the more traditional health care provision would require the identification and comparative assessment of potential alternative intervention mechanisms.

In this study, we aim to uncover and understand how these communities function and evolve, and the role that some users have in maintaining integration and cohesion. Ultimately, this study provides evidence for gauging the effectiveness of different interaction patterns, the users' structural positions and their potential for enhancing and sustaining health online communities as a form of scalable self-management support interventions. The key research questions I attempt to answer are :

- What are the structural dynamics of users on these communities ?
- Are there particular users who are more poised to be agents of social support than others?

- How resilient are these communities?

2.2 Dataset and properties

The data was collected from HealthUnlocked⁷, the online platform provider of the Asthma UK and British Lung Foundation communities. Registered users can choose to either write posts publicly or send private posts to one another. In the latter case, posts are shared between 2 users only, whereas when posts are written publicly, a large number of users can become connected through threads of posts. A thread is a series of posts made on one root post, as a response to the root, or as a response to one of the responses to the root. This tree-like structure of posts can evolve indefinitely between posters. Only posts that were shared publicly were collected and analyzed. For this study, user identifiers (IDs) were anonymized by the HealthUnlocked platform, and no demographic information was collected. The data set included posts and their metadata (ie, the anonymized user ID numbers), user roles (eg, user, administrator, or moderator), date of posting, the hierarchical level of the post within the corresponding thread, and the dates in which the users joined and left the community. Both communities were moderated, and HealthUnlocked moderators (identified through metadata linked to posts) were included in the analysis to assess their contribution and compare it with other users. Online communities on the HealthUnlocked platform benefit from additional functionalities compared to other online forums, such as built-in patient groups that moderate the content. In particular, the content accessed by users is tailored to their interests, and profiles highlight users' condition, chosen community, medications and treatments they use or find interesting. No data were collected on participants' characteristics, though only people declaring themselves to be older than 16 years were permitted to create an account and take part in the online communities. Table 2.1 summarizes the salient features of the dataset used for this work.

The data sets span, respectively, 10 years for the Asthma UK and 4 years for the BLF communities (see Table 1).

⁷<http://www.webcitation.org/70Y10rppl>

Dataset Properties		
Property	AsthmaUK	British Lung Foundation
Time span of data	02/03/2006-06/09/2016	13/04/2012-06/09/2016
Total Time (weeks)	548	230
Total number of posts	32,780	875,151
Percentage of posts with at-least 1 reply	87.3%	93.1 %
Total number of users	3345	19,837
Users who contributed > 1 posts (%n)	1053 (31.5)	7814 (39.4)
Users who contributed exactly 1 post(%n)	331 (31.4) 722	1186 (15.2)
Registered users who never posted (ie, lurkers), n (%)	2292 (68.5)	12,023 (60.6)
Number of posts per user, $\mu(\sigma)$	14.2 (55.0)	66.9 (75.1)
Number of posts per users who posted >1, median (min - max)	5.1 (2-1068)	8.0 (2-8947)
Number of posts per users who posted >1, mean (SD)	20.4 (65.6)	88.1 (458.6)
Posts contributed by top 1% users by activity, n (%)	10,457 (31.9)	426,198 (48.7)

Table 2.1 The summary of salient attributes of the data used for this work

Despite the shorter time span, as a result of the larger number of users, the number of posts in the BLF community was higher than in Asthma UK, namely 875,151 compared to 32,780 respectively. Moreover, BLF users wrote a higher number of posts per user and were connected with a higher number of other users when compared with people in the Asthma UK forum (see Figure 2). In both communities, 60%-70% of registered users wrote no posts (ie, they were lurkers). Users who wrote more than one post contributed with a median of 8 (range 2-8947) and 5 (range 2-1068) posts in the BLF and Asthma UK communities, respectively.

The number of official moderators among the highly active users was negligible; there were no moderators in the top 5% contributors to BLF and only 2 in the top 5% for Asthma

UK. Thus, our network analysis predominantly reflects content originated from registered users.

When classified according to posting activity (ie, number of posts written to the forum), the top 5% users contributed to a substantial proportion of all posts: 58% and 79% in the Asthma UK and BLF communities, respectively. Superusers were those who made a high number of connections with other users in both Asthma UK and BLF communities (see nodes of large size in Figure 2). Asthma UK superusers made a lower number of connections than BLF ones. The posting activity of these superusers will be analyzed in more detail in subsequent sections.

2.3 Abstraction: Graphs

From this raw data of user posts and their thread structure, I generated a graph abstraction which abstracts our users as nodes of the graph and edges as exchange of messages between two users. More formally imagine a directed graph $G(V, E)$ involving a set of users $V_i \forall i \in N$ where N is the total number of users interacting on a health community. For every message exchanged between a user i and a user j we create an edge E_{ij} . The complete community would form a global graph based off total interactions between all pairs of users which we call a global graph G_g . Similarly we may decide to only consider the users and messages exchanged across one particular thread discussing a particular issue. Such a graph is called a thread graph G_t .

These graphs are the temporal abstractions of how users interacted on the community either around a particular query (Thread graphs) or over all as a part of the bigger community (Gobal graph). To understand the behaviour of these users, we evaluate several metrics on these graphs to understand the utility of these communities in terms of activity of sharing and support. In the context of this work, we define support as an exchange of information on account of a query.

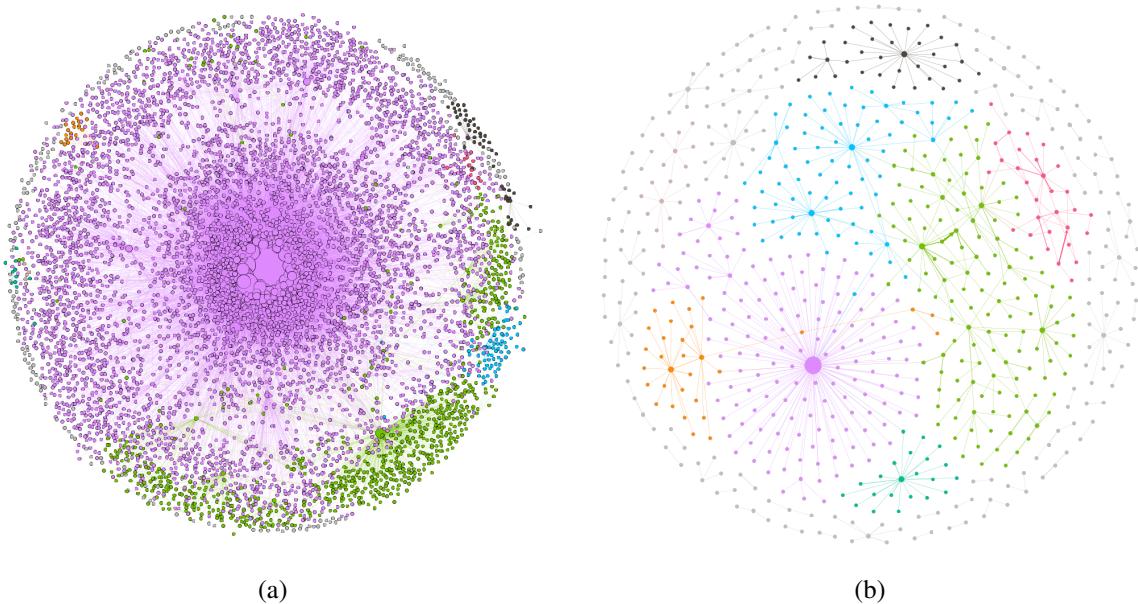


Fig. 2.1 Global graphs prepared from Asthma UK community2.1b and BLF community2.1a. The size of the node corresponds to the degree of the node and the color corresponds to the community membership

2.3.1 Activity Metrics

To calculate the activity patterns of users on these forum, we first work with the most basic of proxies, which is the weekly/daily activity. It is the amount of messages exchanged over a community in a given period of time across the whole life cycle of the data. This is a good metric for the vitality of the community. Another metric to look at is messages exchanged per user per week. This gives an idea of how active an average user is on the community in a given time period. From these basic analysis, it was quite evident that the BLF community was more active of the two.

2.3.2 Community resilience

From table 2.1, it is evident that a minority of users are generating a bulk of data on these communities. E.g. the top 1% users by activity contributed 32% posts to AsthmaUK community. Such level of activity makes these users extremely important in understanding

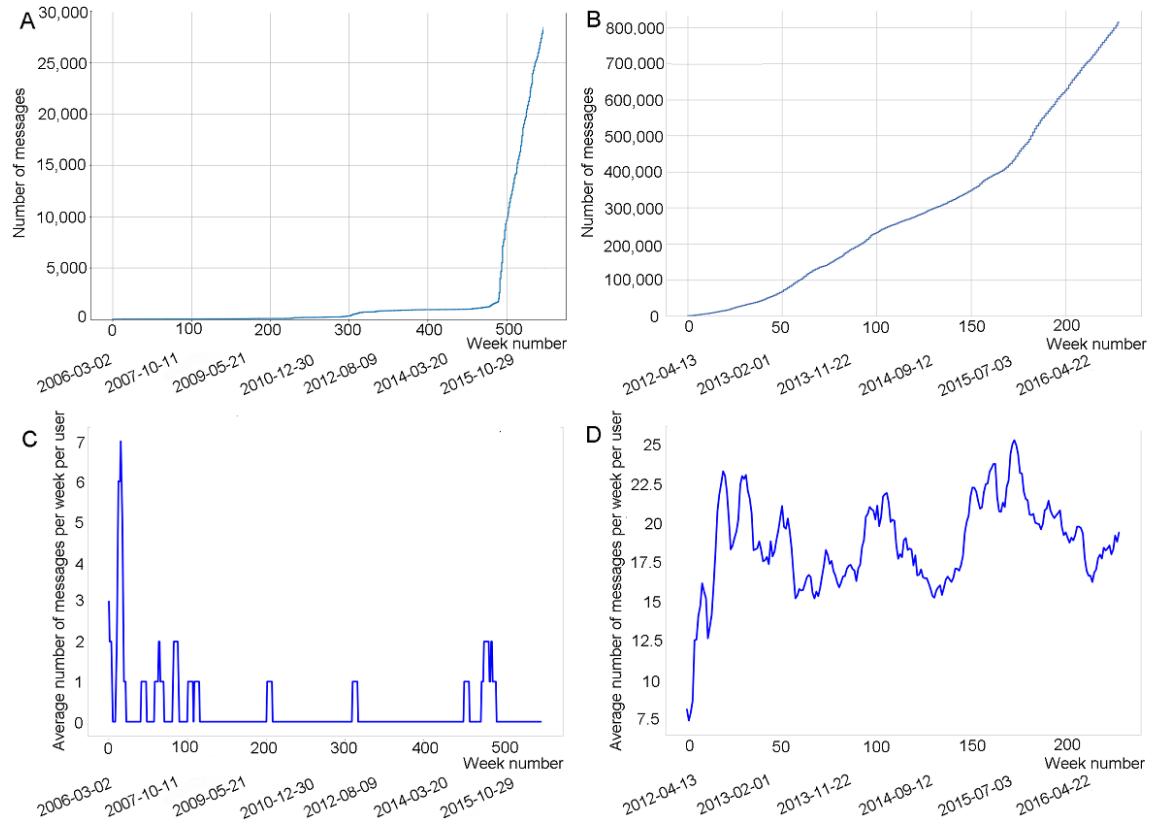


Fig. 2.2 Cumulative distributions of the number of posts as a function of time (weeks) within the Asthma UK (A) and the British Lung Foundation (B) communities. Calendars dates are reported below week numbers. Panels C and D illustrate the average number of posts per user per week within Asthma UK and British Lung Foundation, respectively

the dynamics of support on these communities. For this reason I test the resilience of both these communities by progressively removing the most highly connected nodes from the network and testing the collapse of connectivity in the network. This is done by first sorting the nodes by the degree of the network. Then I progressively remove the top 2% nodes of the nodes in the network and then calculating the size of the weakly connected component as a fraction of original size.

2.4 Activity patterns of users

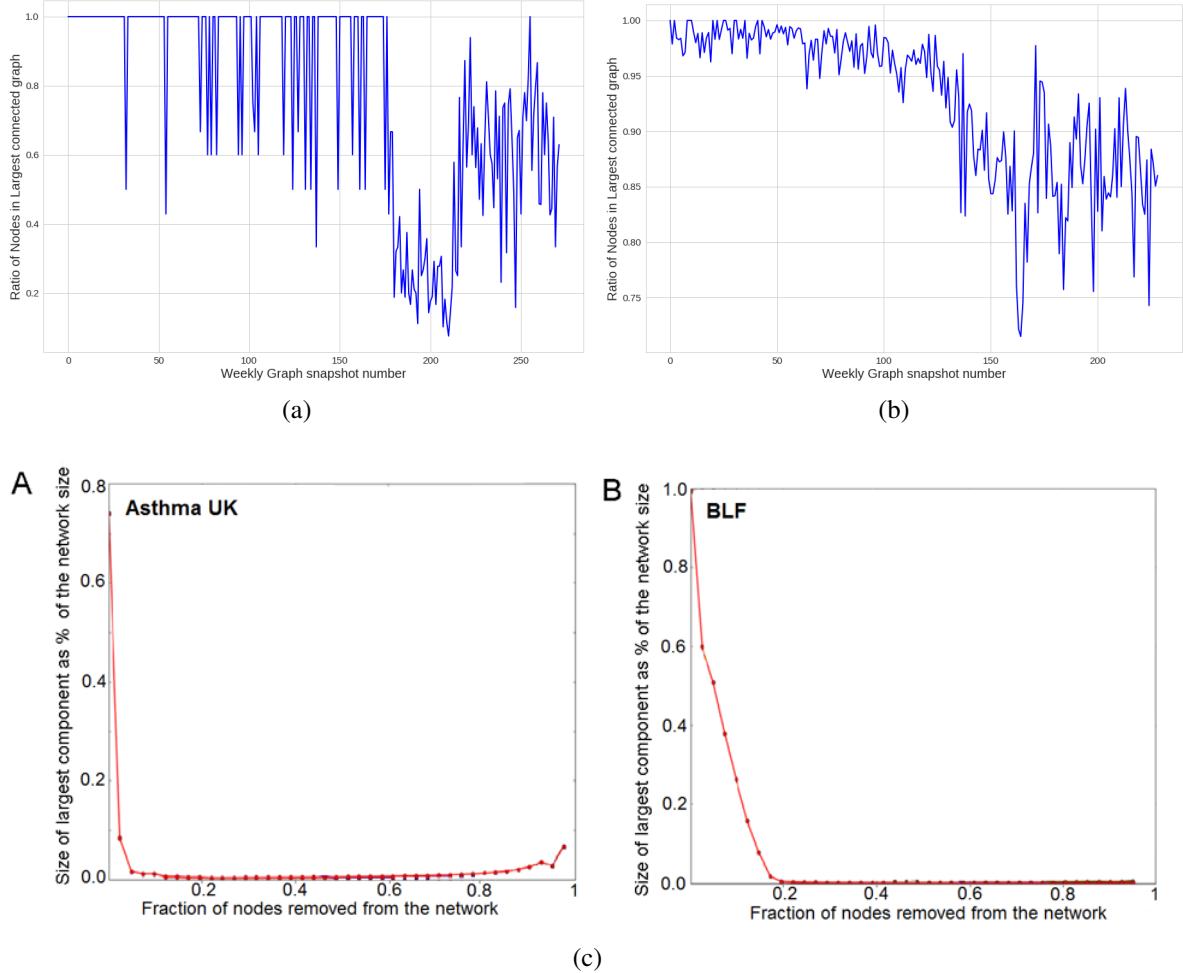


Fig. 2.3 Fraction of users that are part of the largest component as a function of time (weeks) for Asthma UK 2.3a and the British Lung Foundation 2.3b. Sensitivity analysis: targeted removal of nodes (users) starting from the most connected ones within Asthma UK 2.3c and the British Lung Foundation.

The “rich-club” coefficient is a metric designed to measure the extent to which well-connected users tend to connect with one another to a higher degree than expected by chance [43]. To this end, for each value k of a node’s degree (ie, the number of other users a given user is connected with), we computed the ratio between the number of actual connections between nodes with degree k or larger and the total possible number of such connections [47]. We then divided this ratio by the one obtained on a corresponding random network

with the same number of nodes and degree distribution (ie, the probability distribution of the degrees over the whole network) as the real network, but in which links were randomly reshuffled between nodes. Thus, the rich-club coefficients may take values lower or higher than 1, depending on whether the real network has a higher or lower tendency to coalesce into rich clubs than randomly expected. In particular, networks that display a high rich-club coefficient (ie, greater than 1) are also said to show a “rich-club effect,” namely the tendency to organise into a hierarchical structure in which highly connected nodes preferentially create tightly knit groups with one another, thus generating exclusive clubs of (topologically) rich nodes, as illustrated in previous work [48].

In our study, superusers were defined according to their cumulative activity over the entire observation period. In total, we identified 400 superusers. To uncover how many superusers were active within each week, we detected how many unique users, among the 400 identified over the entire period, were active within that time window.

Following Zhang et al [36], the “z-score” was used as a proxy for users’ expertise. According to this measure, replying to many questions suggests one’s expertise, while asking questions indicates lack of expertise. In our analysis, we treated anyone starting a thread as a help-seeker, and anyone commenting on the thread as a help-giver [36]. Accordingly, the proposed z-score aims to capture the combined help-seeking and help-giving patterns. To this end, for each user, we measured how many standard deviations the observed total number of the user’s help-giving posts lies above or below the expected number of help-giving posts for the whole system. We extended the approach proposed by Zhang et al by empirically assessing the probability of posting and answering a question across all users over the entire observation period. In the BLF community, we found that the probability of answering is $P_a=2/3$, while the probability of posting is $P_q=1/3$. We assumed a Bernoulli process of posting an answer or a question to the forum, with probabilities defined as above. The z-score for a given user i was calculated according to equation (a) in Figure 1, where a_i refers to the total number of answers user i posted to the forum, q_i is the total number of questions user i asked in the forum, and $n_i=a_i+q_i$ is the total number of messages posted by user i . To obtain $Zscore_i$, let us define a random user that posts the same total number of messages n_{random}

to the forum as user i (ie, $n_{random}=ni$). We would expect this random user to post an average number of answers to the forum given by equation (b). Plugging in the value of $Pa = 2/3$, we obtained equation (c). Similarly, we would expect the random user to post answers with a standard deviation given by equation (d). Plugging in the value of $Pa = 2/3$, we obtained equation (e). To measure how many standard deviations above or below the expected random value a user i lies, we then computed $Zscore_i$ according to equation (f). Plugging in the values of μ_{random} and σ_{random} , we obtained equation (g). Finally, by substituting $ni = ai + qi$, we obtained equation (h).

2.4.1 Activity

The cumulative number of messages posted grew uniformly over time in the BLF community. By contrast, in 2015, the Asthma UK forum witnessed a substantial increase in posting activity, at a time coinciding with its move to the HealthUnlocked platform (see Figure 3A and B). This increase in activity can be attributed to the online community functionalities offered by HealthUnlocked, as described in the Methods.

The number of posts per user per week oscillated around a decreasing and an increasing trend (Figure 2C and D), while at the same time the number of posts always went up over the study period (Figure 1A and B). This suggests that there were intervals of time during which the rate of increase in new users was larger than the rate of increase in total posts. Moreover, in the Asthma UK forum users wrote according to two time patterns—they posted at an interval of 1-20 days or 6 months (Figure 4A), while those in the BLF community at an interval of 2 days (Figure 4B).

As more users joined the communities and connected to one another through online posts, distinct groups of connected users started to emerge. These groups, called network components (see Textbox 2), have fundamental implications for the effectiveness of processes of network dynamics such as information diffusion [49]. In a relatively short period, both communities underwent the formation of the “largest component” of connected users, namely a connected subset of users whose size increasingly outgrew the size of all other components

(see Figures 1 and 4, and Multimedia Appendices 1 and 2). The largest connected components in both communities included 60

Figure 5 suggests that, as time went by, the number of forum participants and their posting activity increased, and the proportion of users who were part of the largest components decreased. This finding was expected because the number of posts also rose exponentially, yet at times at a lower rate than the one at which new users joined the communities (see Figure 1C and D). It, therefore, became more difficult for the network to self-organize into a connected component that would include 100% of the users. Figure 5A also shows that around week 450, when the forum moved to the HealthUnlocked platform, a larger fraction of users began to join the largest connected component, thus highlighting the role that the new online platform played in strengthening the connectedness of the network (see also Figure 3A and B).

2.5 Propensity to help

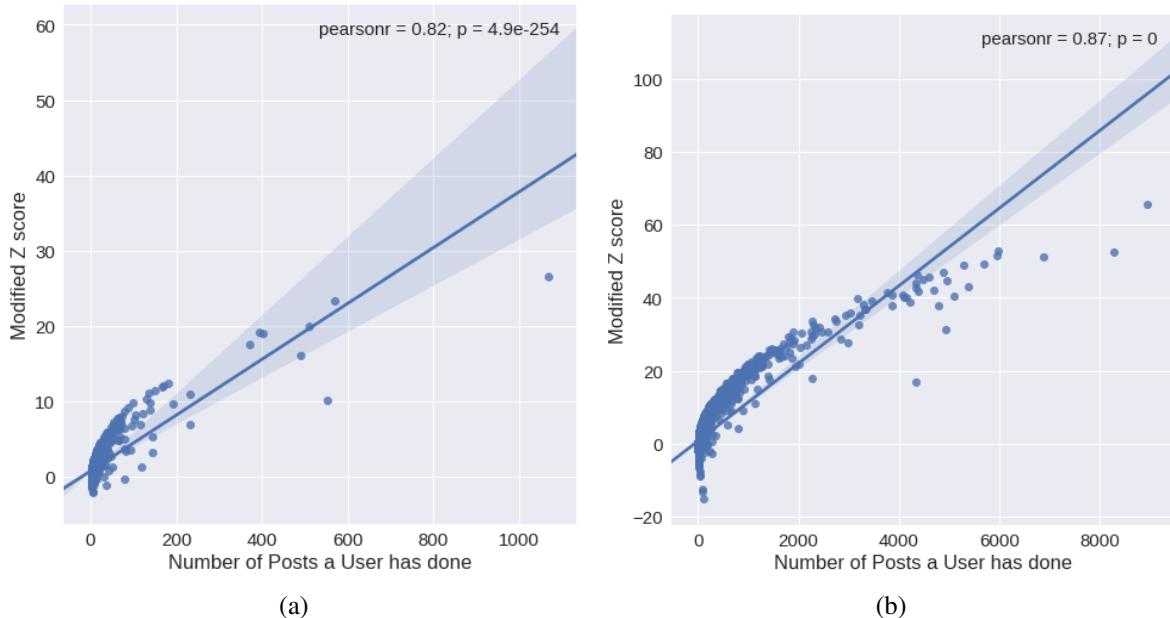


Fig. 2.4

2.6 Not like conventional networks: Anti-rich club effect

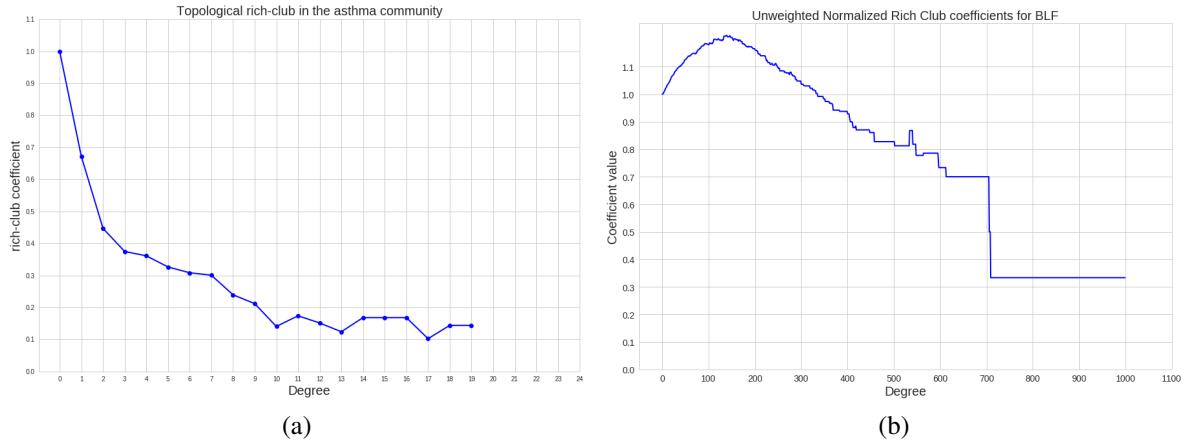


Fig. 2.5

2.7 Support is contagious

2.8 Key takeaways, possible interventions

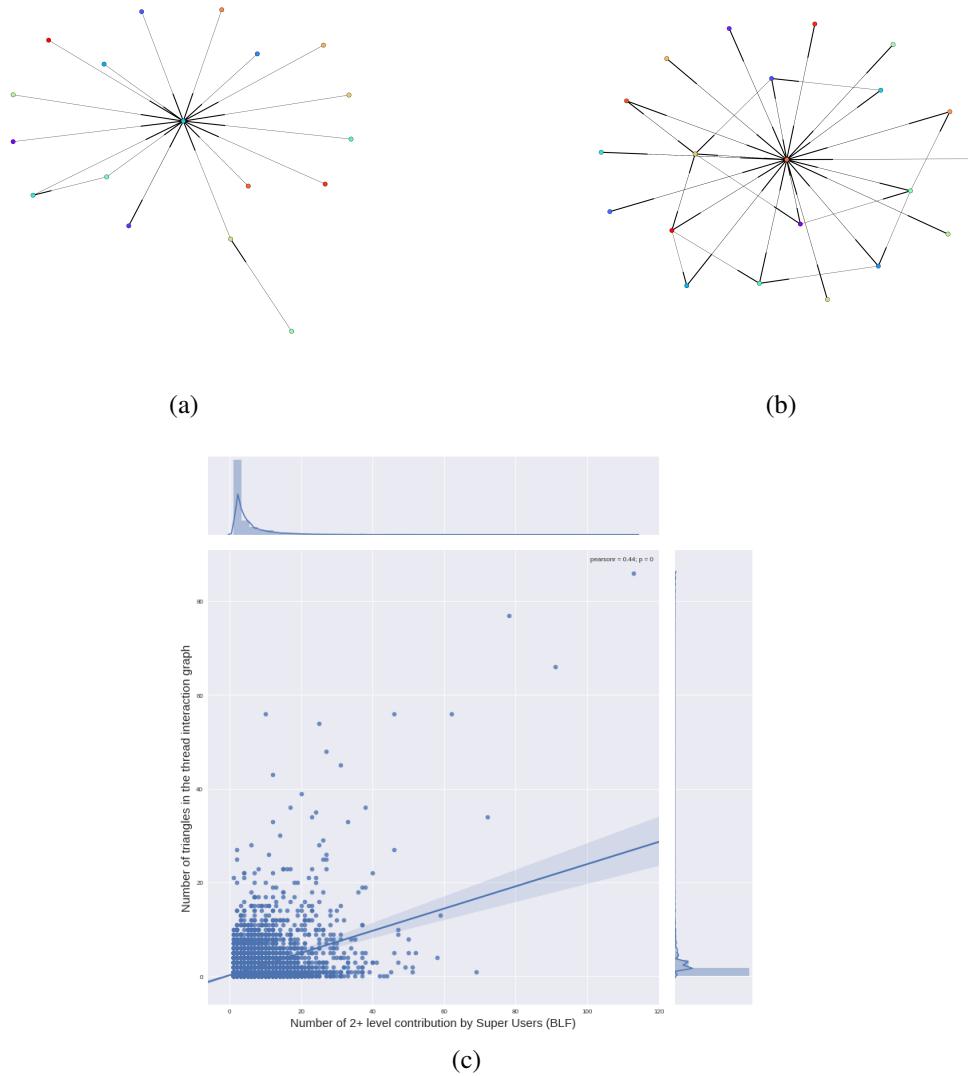


Fig. 2.6

CHAPTER 3

STRUCTURE OF ONLINE SUPPORTIVE CONVERSATIONS

3.1 Introduction

The world has become more connected over the past decades thanks to the networked nature of the technologies of the day. It is seldom possible to spend a whole day without single interaction on the Internet. The Internet gives platforms where we can not only connect with our social counterparts but also exchange ideas and express opinions. These new mediums have become so ubiquitous, that some research suggests that they might be affecting our broader psychological state [17]. But on the positive side, studies have also proposed different ways in which this medium could be used for measuring and intervening in the matters of mental health[24, 25]. Online communities, or *fora*, offer a platform for users to directly interact with each other. Reddit¹ is one of the largest online communities which contains a number of sub-communities (so called *subreddits*) that can be about almost anything. On this platform, several subreddits are specifically tailored to mental health-related topics, such as *depression*, *anxiety* or *alcoholism*. These *fora* offer a unique opportunity to study the way people describe or discuss their problems in their own voice.

One of the most challenging, and devastating, global mental health concerns is suicide. Suicidal behaviour includes any thoughts, plans or acts someone makes towards ending their life. In health care services, preventing death by suicide is a priority, but accurately

¹<http://reddit.com/>

predicting whether or not someone is at risk of committing suicide is difficult. Moreover, a large proportion of deaths by suicide occur in populations that have never been seen by health service providers.you could probably improve the section above...

Several online platforms are used for expressing suicidal thoughts and reaching out for support. On Reddit, the subreddit *SuicideWatch* currently² has almost 94k subscribers, and is a moderated forum that is intended to offer peer support for people at risk of, or are worried about others', suicidal behaviour. The moderators take the message of peer support seriously, and are governed by guidelines that prohibits false promises, abuse, tough love and other clinically frowned upon methods of conversations³

As such it is valuable to understand what characteristics supportive communities like SuicideWatch have, and in what aspects such communities are similar or dis-similar from other casual subreddit conversations.

Recent studies have shown promising results in modeling and measuring signals and patterns in reddit communities related to mental health. For instance, statistical relations of mental health and depression communities with suicidal ideation have been studied [24, 25]. The authors explored linguistic and social characteristics that evaluate user's propensity to suicidal ideation. Approaches to classify reddit posts as related to certain mental health conditions have also been successfully developed, showing that there are certain characteristics specific to mental health-related topics in posts that can be automatically captured[37]. Furthermore, in a study focused on reddit posts related to anxiety, depression and post-traumatic stress disorder, the authors show that these online communities exhibit themes of supportive nature, e.g. gratitude for receiving emotional support[72]. Positive effects in participation in such fora have also been shown by improvements in members' written communication[71]. The supportive nature of comments in the SuicideWatch forum has also been studied by automatic identification and classification of helpful comments with promising results[49].

Most previous studies have aimed at studying the *content* of posts and their characteristics in relation to other posts. One important aspect of online communities is its supportive

²As of 27th June 2018

³<http://www.bbc.co.uk/newsbeat/article/35577626/social-media-and-suicide-what-its-like-being-a-moderator>

function — users turn to these platforms not only to express their thoughts and concerns, but also to receive support from the community. **More references to be added in the introduction.** **Also, we need to add something about the Online disinhibition effect somehow.**

To our knowledge, there are no studies that have specifically focused on modeling the supportive *nature* of online fora related to mental health. This work takes a macroscopic perspective, to quantitatively characterise and model the nature of supportive conversations. SuicideWatch is particularly interesting because of its purpose to offer peer support to people with suicidal thoughts, and also because of the complexity of this clinical construct.

Our aims in this study are to

- Understand similarities and differences between a Suicide watch conversation and a generic conversation using these abstraction.
- Study global properties of these conversations in comparison with control conversations.
- User network metrics to reason about global differences in terms of local interactions between users.

To model the network topology in an online community, we represent conversations in a forum using graph-based abstractions (users and replies) as described in Section 3.3.2. To measure global structure of these conversations, we user network topological metrics such as centrality: which measures importance of nodes in a network in terms of relaying information, branching factor: which measures how a conversation fans out over time, return distance: which measures how soon do users return back to the conversation and symmetric edges: which measures reciprocity of users in a conversation. To measure measure local interactions, we measure inter response times: which measure urgency of response to a message, semantic alignment between messages and local interaction motifs known as Triadic motifs : which gives an idea about how distinctive are interactions between subgroups of users.

Terminology	stands for
<i>RP</i>	Root post which begins a new thread on a subreddit
<i>OP</i>	Original poster who posts the Root post for a thread
<i>SW</i>	The suicide watch Subreddit
<i>FP</i>	Front page of Reddit.

Table 3.1 Notations and Terms.

3.2 Results

Particularly Suicide watch community consists of over 78k subscribers and reader, however is supported by mere 12 Moderators according to the latest count. The moderators are mainly present to prevent any kind of abuse, trolling or non-clinical or non-productive advices. These moderators do not have any form of formal training. However through several accounts they have confessed to learn through interactions and mentorship from more senior moderators on the site⁴ All the moderators have been in that role for at least 3 years and the oldest goes as far as December 2008.

Our study is based on all conversations on SuicideWatch. We represent these conversations through networked abstractions as described in 3.3.2.

Through our analysis we find several discriminatory factors among Suicide watch conversations and generic front page conversation. We show that some of these factors are predictive of suicide watch conversations to a very high degree. We also show that certain properties of these conversations can be backed by sociological theories of real life support conversations.

3.2.1 Peculiarity of threads of Support

We begin by characterizing the two networked abstractions, namely Reply Graphs and Interaction graphs as described in Section 3.3.2. We do so by first comparing these two abstractions with a baseline control conversation threads using certain macroscopic network properties. We first compare the number of unique users per thread. The two communities

⁴<https://bbc.in/24rJYQH>

exhibit considerable difference. SW Sub-Reddit has a median of 5 users per thread and a mean of 6.7 users and BL threads have a median of 25 users and mean of 50 unique users. So this off the bat indicates that Suicide watch conversations are more intimate and involve less participants. Authors tend to participate on a similar level, with a median participation per author of Suicide Watch to be 5 and for baseline conversations to be 3.

How urgent are user responses?

Understanding the inter message times can act as a good proxy for the urgency in a conversation. To understand how Suicide watch subreddit users responds to a *OP* compared to other sub-reddit threads on the frontpage, we calculate differences between the posting times between consecutive messages in a reply graph. Figure 3.1a shows comparison using CDFs of inter-message response times for SW and FP threads. It can be seen that SW *OP* are responded with the highest urgency amongst the 4, especially compared to either the *OP* or any other users or sub-reddits.

How symmetric are the interactions?

Despite signs of urgency and engagement, we ask the question: what percentage of conversations happening on these subreddits are symmetric in nature ? For this The median value for U_{sym} for SW is 20% where as for AS is 0%. This shows that SW subreddit engages in a lot more symmetric conversation than the baseline threads. If we define a set of users who engage in symmetric activity with the *OP* , it would be worth while to investigate how much of the total message activity on the thread is carried out by these set of symmetric users . To calculate this we find the fraction of messages on each thread written as part of this symmetric conversation. Figure 3.1b shows the trend. It can be see that SW threads contain a higher prevalence of symmetric message exchanges compared to the baseline Frontpage threads. This shows a higher engagement from the *OPs* side when participating in a supportive conversations

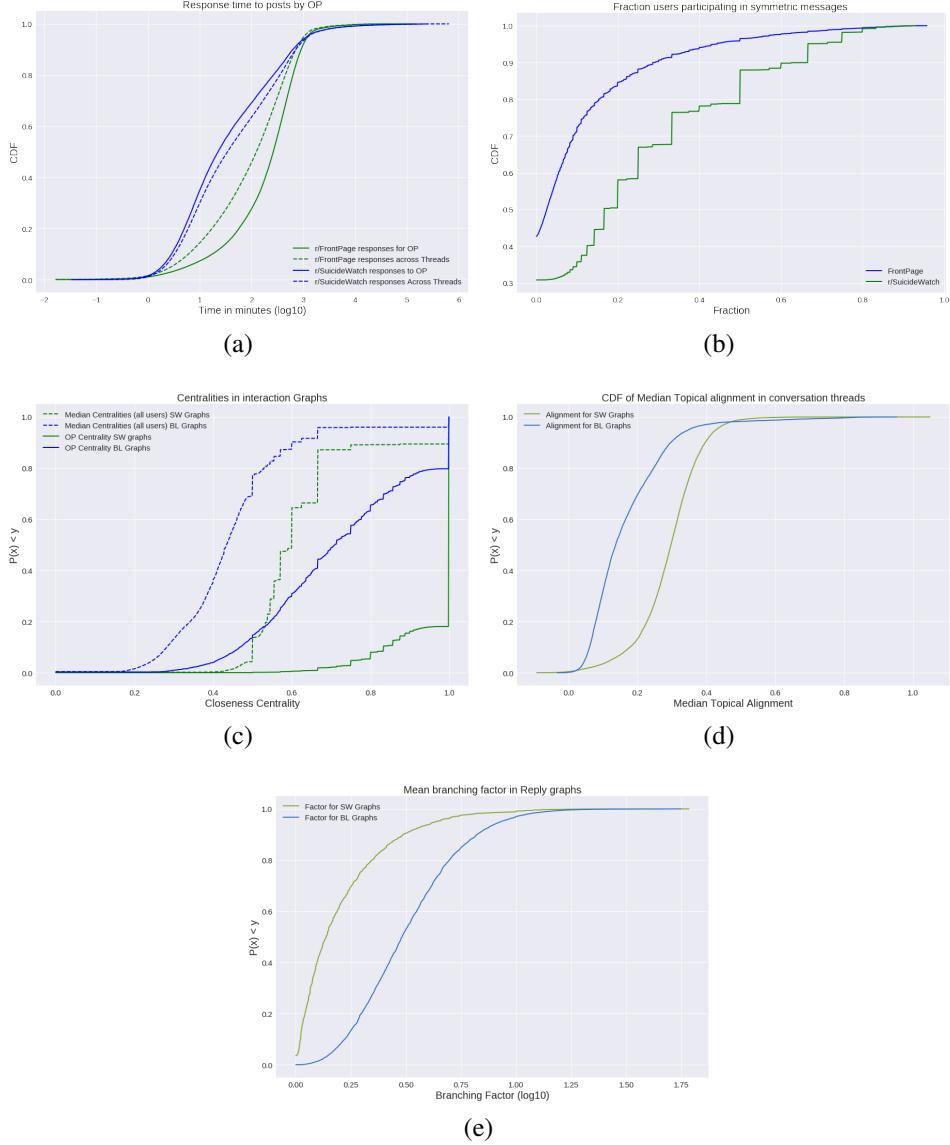


Fig. 3.1 Panel shows CDFs of different network metrics. Fig.3.1a shows the response time distributions, Fig.3.1b shows symmetrically engaged users, Fig.3.1d shows topical similarities across posts and 3.1e shows the branching factors of reply graphs.

How central are the users?

To understand how embedded is the *OP* in a conversation thread, we compare the betweenness centralities of *OPs* in the *SW* dataset with the baseline *FP* dataset. Betweenness centrality is a good proxy of understanding how closely linked is a node with the rest of the network. When we calculate this metric for the user graphs we see that Suicide watch *OPs* tend to have

highest centralities compared to generic *FP* threads moth in terms of *OP* centrality as well as median centrality across all the users. The high centrality of *OPs* in *SW* conversations implies a high level of embedded-ness as well as a *OP* centric approach by other participants in the conversation. The Figure 3.1c shows the Empirical CDFs of centralities.

How semantically aligned are the responses?

We measure semantic alignment based on word embeddings of the source post and the reply post, at every edge of the reply graph. The detailed method of extracting semantic alignment along a post and its response is described in Section 3.3.3. Extracting such similarity metrics, we compare the trend in response text being in semantic alignment with the parent text in the reply graphs.

How branched do conversations become?

Branching in a conversation thread could be either a sign of digression or a sign interestingness resulting in more people joining in. To measure this phenomena, use the reply graphs, which resemble a n-ary directed acyclic graph, to evaluate the branching factor. By using the method described in Section 3.3.3, we found that Suicide watch threads, tend to branch in a much less as compared to our baseline conversations. This implies that suicide watch threads tend to remain a one-on-one conversation with the *OP* albeit many such dialogues may emerge, and hence that explains the high centrality of the *OP* in all interaction graphs. If the helpers on a thread seldom interact with each other, the corresponding interaction graph will have the *OP* as the most central node.

3.2.2 Patterns in local interactions

It is often a useful tool to express large interaction graphs, as the sum of local interactions between two or three nodes at a time. Such analysis is quite useful in expressing local structures in the graphs and has been used in several network analysis works For this reason we use a method more commonly known as network motif analysis (described in Section

3.3.4) to understand triads, or groups of three nodes, and the patterns of edges that exist between them.

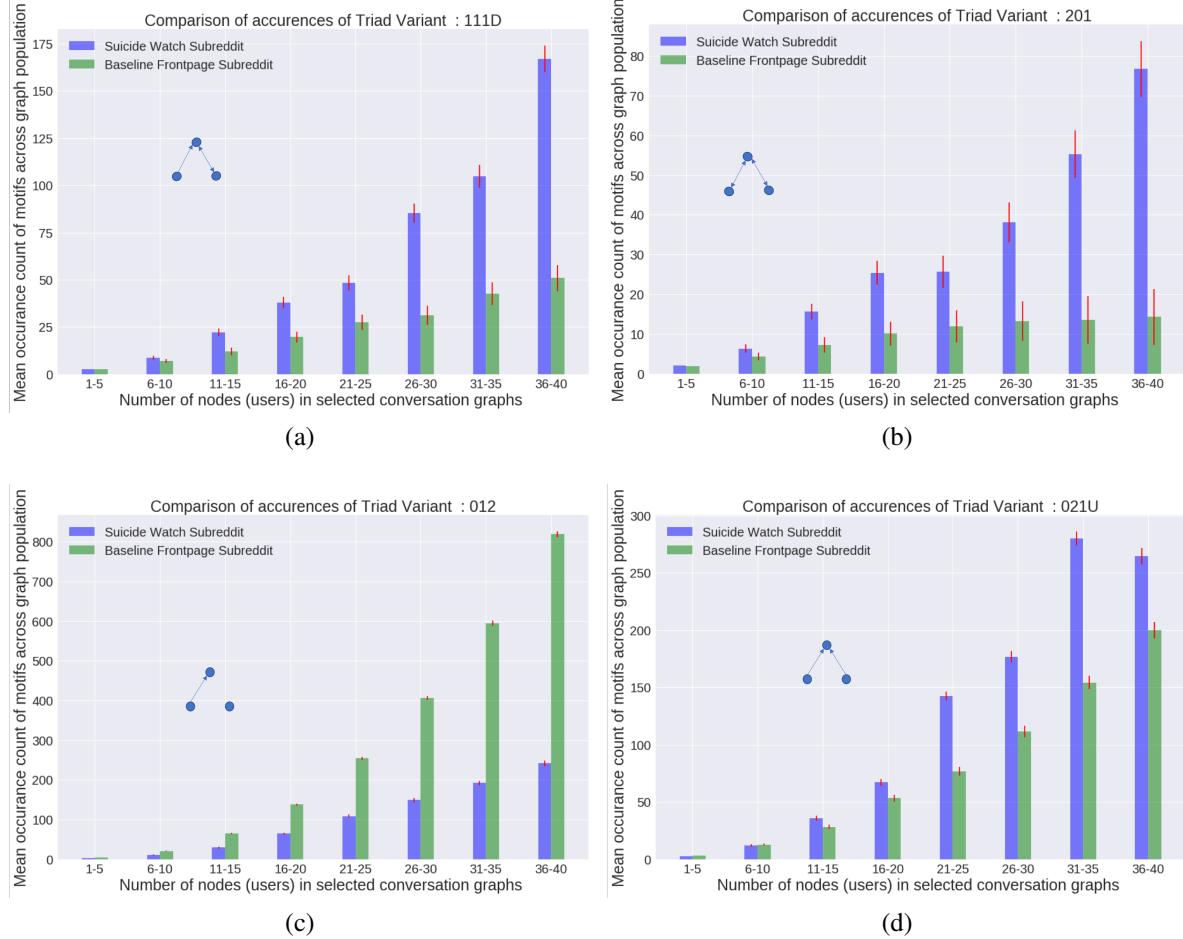


Fig. 3.2 This panel shows the statistical significance of the three over expressed and one under expressed triadic motif.

3.3 Methods

This section discusses the methodological devices used to extract insights from the fora data.

3.3.1 Data

We build on dataset that was used in [37] where they analyze textual content for the root posts in a Subreddit called Suicide Watch⁵. The dataset contains a dump of 53 thousand posts from the suicide watch sub-reddit. However the dataset did not contain the threaded conversations for each thread. Reddit is a platform where a user can create a post on a sub-reddit, to which several members of a given sub-reddit can interact with. The array of interactions may range from simple up or down votes or posting at different hierarchy of the thread. This creates a hierarchical threaded structure of posts where the conversations are organized as threads of posts. To understand the deeper structure that is present in these posts, we crawl Reddit to get the threaded conversations by pursuing each conversation at arbitrary depth.⁶. This results in a dataset of over 50 thousand threads totaling to around 500,000 individual posts on those threads.

To baseline our work and compare theorized supportive nature of conversations with the broader community, we also crawl other reddit threads. To avoid any bias towards a particular type of subreddit, which have their own culture, we acquire roughly 50 thousand baseline posts which have been popular enough to land on the front page⁷. We crawl the Frontpage posts for 2 weeks accumulating over 50 thousand reddit threads in the process. The median amount of responses for a Suicide watch thread were 6 and for baseline Frontpage posts were 8. To understand the structure of these two forums, and find discriminating factors between a supportive community like suicide watch and a general thread on Reddit, we need to build abstractions of the thread.

3.3.2 Abstractions

To understand the dynamics of supportive conversations, we first need to formalize the abstraction of networked conversations. In case of forum based platforms where users

⁵<https://www.reddit.com/r/SuicideWatch/>

⁶The code to crawl reddit for threads can be found at <https://github.com/sagarjoglekar/redditTools>

⁷The reddit front page algorithm is a combination of popularity and decay in popularity as a function of time. More can be found here <https://goo.gl/uVdHjn>

interact in a nested dialogue fashion, and original poster or *OP* posts a start of a thread. This thread is then open for comments by all the community users. In case of Reddit, such a community is called a Subreddit, which is a moderated collection of users who subscribe to it. These users may post new threads onto the subreddit as far as the post follows the subreddit rules. Enforcement of these rules is the responsibility of the moderators. The user who starts a thread is called the Original Poster or **OP** and the headlining post which the *OP* begins with is called the Root Post or *RP*.

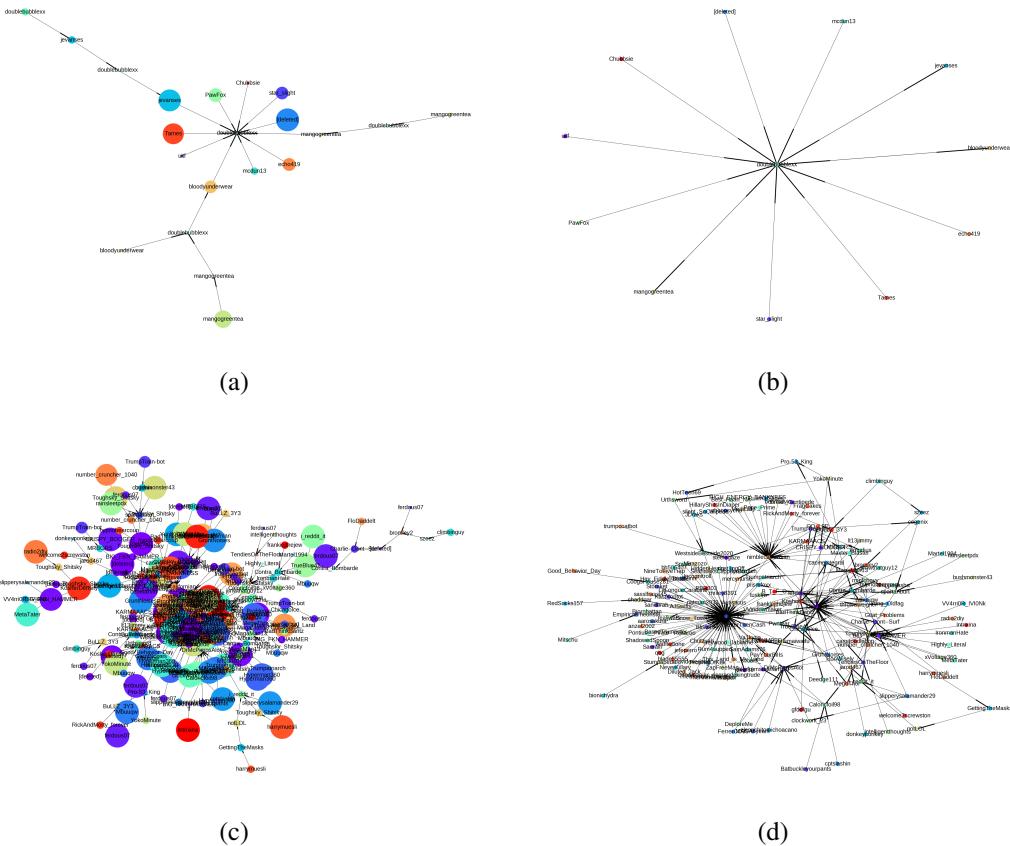


Fig. 3.3 Example UserGraphs and their corresponding Reply graphs, Figure 3.3b shows a random thread from the SW sub-reddit and 3.3a shows the corresponding reply graph that arises from the response structure of the same thread. In comparison we have Usergraph Fig 3.3d and its corresponding reply graph Fig 3.3c from one of the Front page threads

Reply Graphs

The first abstraction mimics directly the structure of conversation threads on Reddit. These abstractions are called Reply Graphs. We formulate a reply graph $R\{P, E, W\}$ as a thread of multi-layered posts in a thread in response to the root post RP in the sub-reddit. Each graph R consists of posts $P_i, P_j, i, j \in N$, where $N+1$ is the total number of responses in the thread and Edges E_{ij} such that Edge E_{ij} exists iff post P_i was in response to post P_j in the hierarchy of responses. The weight of the edge E_{ij} is found by calculating the cosine similarity between topic vector T_i for post P_i and the topic vector T_j of post P_j . For a given dataset, the topic vectors are extracted using the model trained on that particular corpus (LDA_{BL}, LDA_{SW}). This abstraction works well in modeling the conversational nature of these forums. For convenience of the reader, we present a couple of example pairs from SW and Frontpage baseline datasets in Figure 3.3

Interaction Graphs

In this method, we represent each thread as a directed graph $G\{V, E, W\}$ where V is the set of all users participating in a particular thread and E are the directed edges which correspond to interactions between two users $V_i, V_j \in V$. The weight of each directed edge E_{ij} corresponds to the average of all the edges between $V_i, V_j \in V$ in the corresponding reply graph $R\{P, E, W\}$ as described above. This means that each reply graph is then mapped to a User graphs where the nodes are Users rather than posts. Another salient distinction between the two abstractions is that reply graphs resemble an n-ary tree and user graphs are directed cyclic graphs.

3.3.3 Macro and local metrics

The abstractions are used to extract certain structural metrics from the conversation threads. These metrics are then used to validate structural differences between supportive conversations and generic casual conversations from our baseline set.

Centrality

For this metric we use the User Graphs. Node centrality is a metric that measures how central a node is in a network. It directly reflects the importance of the node when it comes to membership of the shortest connecting paths between all the nodes in the graph. More formally, we use betweenness centrality of a node which is defined as Betweenness centrality of a node v is defined as

$$g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

where σ_{st} is the total number of shortest paths from node s to node t and σ_{st} is the number of those paths that pass through v . To understand whether the thread starters (*OP*) have a special place in the network, we evaluate both *OP* centrality as well as median centrality across all the nodes in a User graph.

Symmetrical users

We define a symmetric user and a symmetric edges for user graphs. For a user V_i in the user graph $G\{V, E, W\}$ as described in Section , a symmetric user is a user who interacts with V_o or the *OP* and receives a response back from the *OP*. We find the fraction

$$U_{sym} = \frac{\text{total number of symmetric users}}{\text{Total users in a thread}}$$

Urgency

To understand how Suicide watch subreddit users responds to the *OP* and each other, compared to other sub-reddit threads on the frontpage, we calculate differences between the posting times between consecutive messages in a reply graph. We compute the median response times per thread, for *OP*'s posts and for all other posts.

Branching Factor

Branching factor is a quantity that reflects the fan out of a conversation as it evolves. To measure this phenomena, we use the reply graphs, which resemble a n-ary directed acyclic

graph, to evaluate the branching factor. The branching factor is formally described as

$$\tau = \frac{1}{|D|} \sum_{d \in D} \frac{1}{|N_d|} \sum_{n \in N_d} \text{InDeg}(n)$$

Response distance

A user who interacts frequently with a thread, may contribute at different stages of hierarchy. Intuitively, for a one on one conversation to exist, the user needs to contribute back to the thread at alternate levels of hierarchy. To measure this phenomenon, we assume that a user U contributes in a reply graph at variable depths $d_i \forall i \in [0, D]$. We calculate the average difference between two consecutive contributions d_{avg}

$$d_{avg} = \frac{\sum_{i=0}^D d_{i+1} - d_i}{D}$$

We calculate the values of d_{avg} for both OP and other users in the thread.

Semantic similarity

We use a popular word embedding method called *Word2Vec* [62] which learns representations of a set of words from a corpus of text, which in our case is the text from Suicide Watch and baseline fora. These representations can be used to extract text embedding vectors for each post which belong to a N dimensional space R^N . These vectors are tested for their alignment using cosine distance in R^N , which corresponds to semantic similarity in the textual space. This method is quite popular and used in community based question answering[61], Medical semantic similarity [29] and other medical informatics applications[107].

3.3.4 Structural metrics

Network motifs are local sub-networks between 2 or 3 nodes. Such local patterns are highly useful in quantifying local interactions and the resulting macro structure of the network[63]. They have been used in a variety of applications and networks, from economics [105] to

cellular protein-protein interaction networks [103]. Hence we calculate census of 16 distinct *triadic motif* i.e. possible subgraphs that could be formed between any three chosen nodes.

This probably needs to be briefly introduced/explained earlier in the manuscript? To understand relation of local structures in interaction networks within a conversation with its , we compare the quantity called *motif occurrence ratio*. After calculating motif census across the dataset[13], we select progressive subsets of graphs from both datasets with nodes $n \in [k, k + 4] \forall k \in \{1, 6, 11, 16, 21, 26, 31, 36\}$. This segmentation of the dataset is called binning, and it allows us to not only measure the differences in the census between the datasets, but also observe the trend as the size of the interaction graph becomes larger. We stop at 40 because beyond that, we start getting lower and lower number of graphs samples per bin.

We test each graph for the frequency of occurrence of the 16 possible triadic motifs as shown in Figure3.4a. We start by selecting the subset of graphs from Suicide watch and Frontpage belonging to a particular bin k . We then define the motif occurrence ratio as the fraction values for $\frac{\gamma_{BL}}{K_{BL}}$ and $\frac{\gamma_{SW}}{K_{SW}}$ for all the 16 motifs across all the chosen values of n .

3.4 Appendix

3.4.1 Triadic statistics for twitter conversations

3.4.2

Replication of quantification of the topological metrics for twitter conversations for suicidal ideation and comparison with baseline threads. There are 5k threads for suicidal ideation and 6k for baseline. The baseline threads deal with discussion around westminster and manchester terrorist attacks in the uk.

3.4.3 Network characteristics

Figure 3.7a shows the distribution of maximum depths across all Reply graphs for SW and Baseline subreddits. The SW threads depths have a median depth of 2 and mean of 4

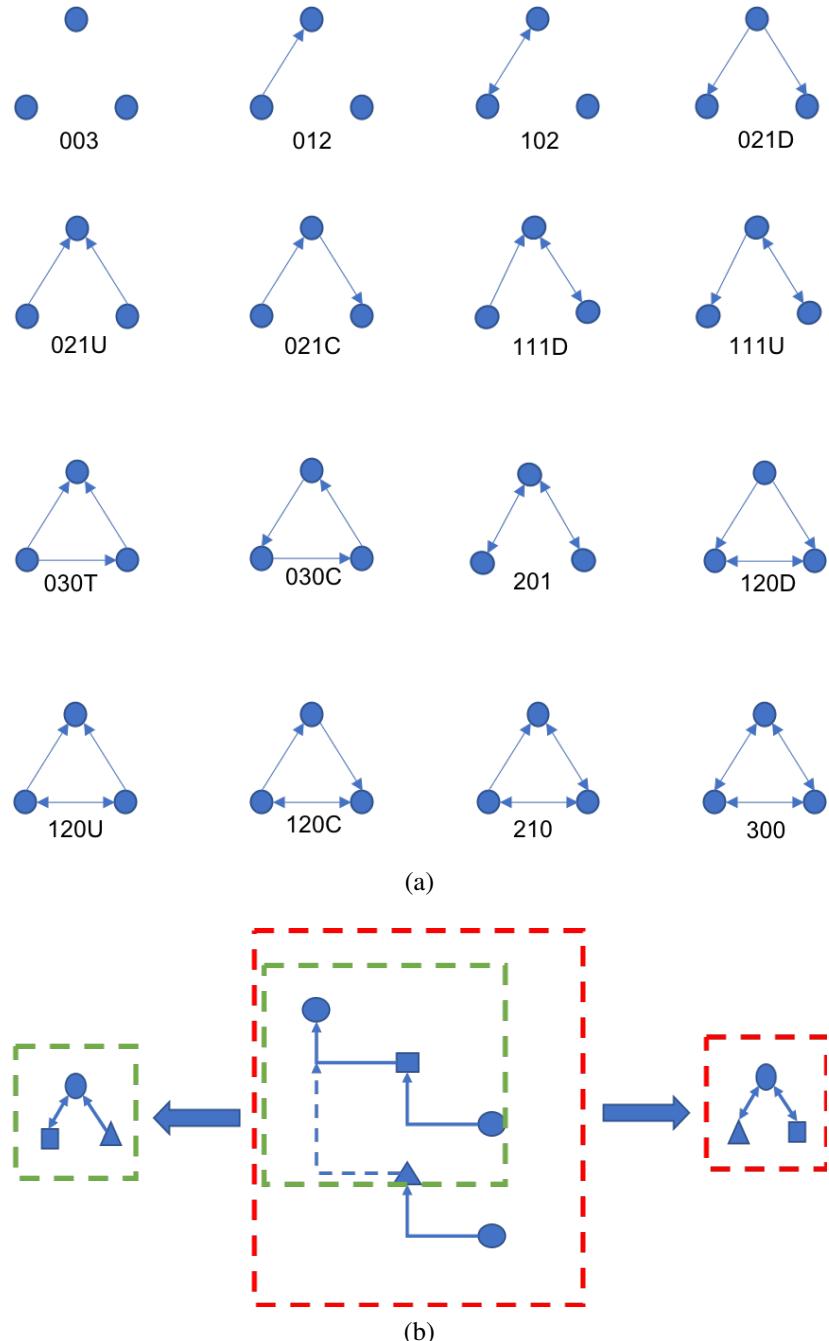


Fig. 3.4 Figure 3.4a shows the 16 different types of motifs that are looked for in the user graph data. Figure 3.4b shows how three unique users could produce different motifs. The three shapes represent different users and the dotted line means the message order is irrelevant.

compared to median depth of 2 for BL and a mean of 2.5. This shows that statistically the depths of Suicide watch and baseline graphs are quite similar.

Figure 3.8 shows the CDF for the number of responses a Root post gets on a thread across the whole dataset. Figure 3.8 shows the CDF for number of comments per thread across the r/SuicideWatch subreddit dataset and the crawled frontpage subreddit.



Fig. 3.5 The figure shows comparison of occurrence ratios of 9 insignificant motifs. Blue traces are for Suicide watch and Green traces are for Baseline Front page threads

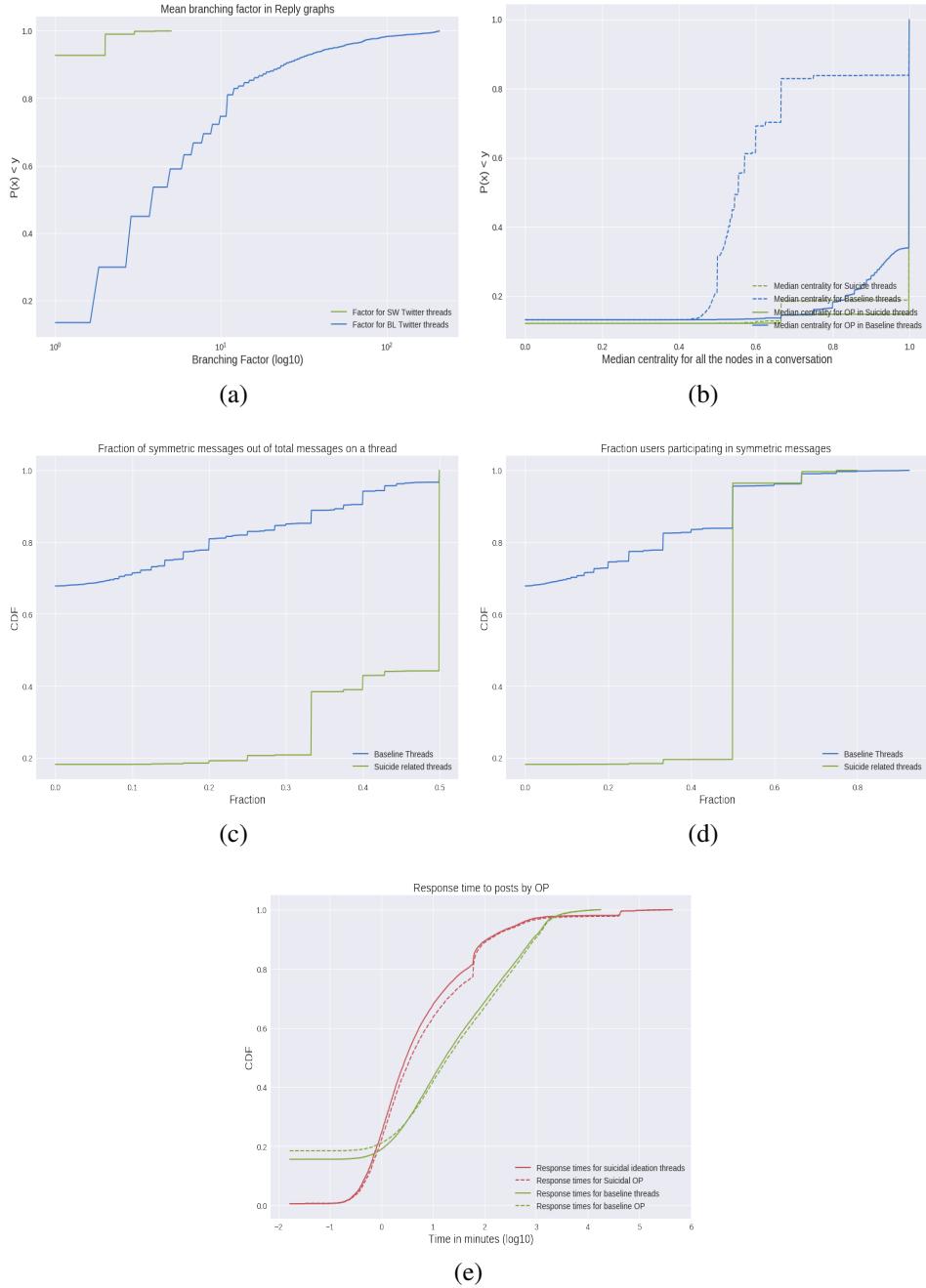


Fig. 3.6 Fig 3.6a shows the branching factor for twitter threads that talk about suicidal tendencies against baseline threads. Fig 3.6b shows the distribution of median centralities per thread, for both the twitter crawls. Fig 3.6c shows Distribution of symmetric messages in reply graphs for both datasets. Fig 3.6d shows the distributions for users participating in a symmetric conversation Fig 3.6e shows he distribution of reply urgency for suicide threads against baseline. The suicide median reponse time for suicide threads is 3 min as compared to 18 mins for non-suicide threads

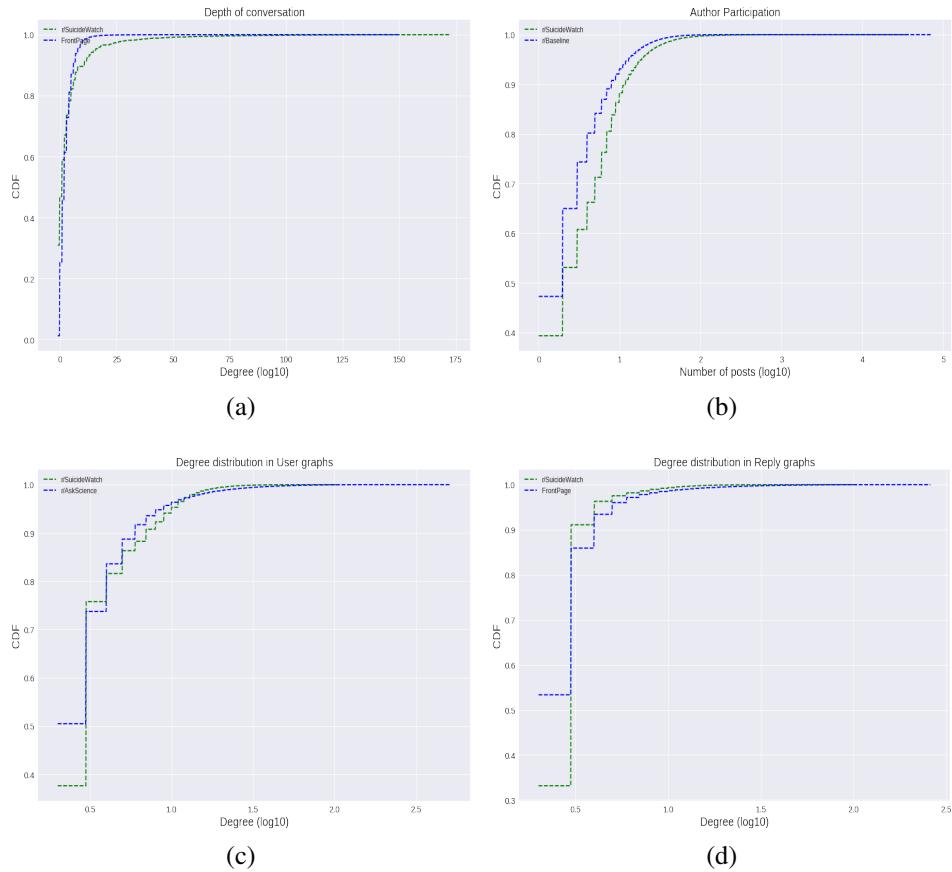


Fig. 3.7 Fig 3.7a shows the distribution of maximum depths of Reply Graphs for Subreddit r/SuicideWatch and the baseline Frontpage conversations. Fig 3.7b shows the distribution of unique authors per thread in the two datasets. Fig 3.7d shows Distribution of degrees for Reply Graphs, r/SuicideWatch and FrontPage. Fig 3.7c shows the degree distributions for the reply graphs

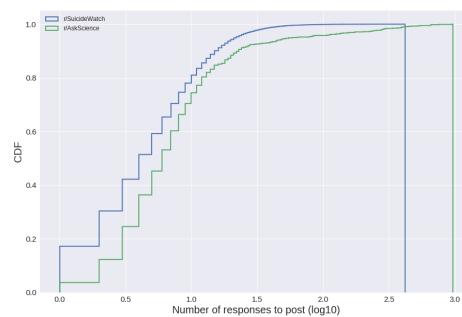


Fig. 3.8 Distribution of responses per thread on Subreddits r/SuicideWatch and Frontpage

CHAPTER 4

PERCEPTIONS IN REAL SPACES

There has been an explosive growth of deep learning technologies and their competency in the recent years, resulting in cross disciplinary use cases of deep learning enabled tools. In the area of computer vision and urban informatics, deep learning techniques have recently been used to predict whether urban scenes are likely to be considered beautiful, and it turns out that these techniques do so quite accurately. However, the technology falls short when it comes to generating actionable insights for AI assisted urban design. To support urban interventions, one needs to go beyond *predicting* beauty, and tackle the challenge of *recreating* beauty and *explaining* the predictors of beauty. Unfortunately, deep learning techniques have not been designed with that challenge in mind. Given their “black-box nature”, they cannot even explain why a scene has been predicted to be beautiful. To partly fix that, we propose a deep learning framework (which we name FaceLift) that is able to both *beautify* existing Google Street views and *explain* which urban elements make those transformed scenes beautiful. To quantitatively evaluate our framework, we cannot resort to any existing metric (as the research problem at hand has never been faced before) and need to formulate new ones. These new metrics should ideally capture the presence (or absence) of elements that make urban spaces great. Upon a review of the urban planning literature, we identify four main metrics: walkability, green, openness, and visual complexity. For all the four metrics, the beautified scenes meet the expectations set by the literature on what great spaces tend to be made of. The transformations and their explanations are also found to be very helpful in understanding interventions for beautification, which we validate using a 20-participant

expert survey. These results suggest that, in the future, as our framework's components are further researched and become better and more sophisticated, it is not hard to imagine technologies that will be able to accurately and efficiently support architects and planners in the design of the spaces we intuitively love.

4.1 Introduction

Whether a street is considered beautiful is subjective, yet research has shown that there are specific urban elements that are universally considered beautiful: from greenery, to small streets, to memorable spaces [1, 78, 83]. These elements are those that contribute to the creation of what the urban sociologist Jane Jacobs called ‘urban vitality’ [43].

Given that, it comes as no surprise that computer vision techniques can automatically analyse pictures of urban scenes and accurately determine the extent to which these scenes are considered, *on average*, beautiful. Deep learning has greatly contributed to increase these techniques’ accuracy [31].

However, urban planners and architects are interested in urban interventions and, as such, they wish to go beyond technologies that are only able to predict beauty scores. They have often called for technologies that would make easier to recreate beauty in urban design [23]. Deep learning, by itself, is not fit for purpose. It is not meant to recreate beautiful scenes, not least because it cannot provide any explanation on why a scene is deemed beautiful, or which urban elements are predictors of beauty.

To partly fix that, we propose a deep learning framework (which we name FaceLift) that is able to both *generate* a beautiful scene (or, better, *beautify* an existing scene) and *explain* why that scene is beautiful. In so doing, we make two main contributions:

- We propose a deep learning framework that is able to learn whether a particular set of Google Street Views (urban scenes) are beautiful or not, and based on that training, the framework is then able to both *beautify* existing views and *explain* which urban elements make them beautiful (Section 4.3). These explanations are automatically extracted with computer vision tools.

- We quantitatively evaluate whether the framework is able to actually produce beautified scenes (Section 4.4). We do so by proposing a family of five urban design metrics that we have formulated based on a thorough review of the literature in urban planning. For all these five metrics, the framework passes with flying colors: with minimal interventions, beautified scenes are twice as walkable as the original scenes, for example. Also, after building an interactive tool with “FaceLifted” scenes in Boston and presenting it to twenty experts in architecture, we found that the majority of them agreed on three main areas of our work’s impact: decision making, participatory urbanism, and the promotion of restorative spaces.

4.2 Related Work

Previous work has focused on collecting ground truth data about how people perceive urban spaces, on predicting urban qualities from visual data, and on generating synthetic images that enhance a given quality (e.g., beauty).

Perception of physical spaces. From Jane Jacobs’s seminal work on urban vitality [43] to Christopher Alexander’s cataloging of typical “patterns” of good urban design [1], there has been a continuous effort to understand what makes our cities livable and enjoyable. In the fields of psychology, environmental design and behavioral sciences, research has studied the relationship between urban aesthetics [81] and a variety of objective measures (e.g., scene complexity [48], presence of nature [47]) and subjective ones (e.g., people’s affective responses [99]).

Ground truth of urban perceptions. So far, the most detailed studies of perceptions of urban environments and their visual appearance have relied on personal interviews and the observation of city streets: for example, some researchers relied on annotations of video recordings by experts [84], while others have used participant ratings of simulated (rather than existing) street scenes [57]. The Web has recently been used to survey a large number of individuals. Place Pulse is a website that asks a series of binary perception questions (such as ‘Which place looks safer [between the two]?’) across a large number of geo-tagged

images [83]. In a similar way, Quercia *et al.* collected pairwise judgments about the extent to which urban scenes are considered quiet, beautiful and happy [78] to then recommend pleasant paths in the city [80]. They were then able to analyze the scenes together with their ratings using image-processing tools, and found that the amount of greenery in any given scene was associated with all three attributes and that cars and fortress-like buildings were associated with sadness. Taken all together, their results pointed in the same direction: urban elements that hinder social interactions were undesirable, while elements that increase interactions were the ones that should be integrated by urban planners to retrofit cities for happiness. Urban perceptions translate in concrete outcomes. Based on 3.3k self-reported survey responses, Ball *et al.* [10] found that urban scenes with positive aesthetics properties not only are visually pleasurable but also promote walkability. Similar findings were obtained by Giles *et al.* [36].

Deep learning and the city. Computer vision techniques have increasingly become more sophisticated. Deep learning techniques, in particular, have been recently used to accurately predict urban beauty [31, 87], urban change [66], and even crime [5, 26]. Recent works have also showed the utility of deep learning techniques in predicting house prices from urban frontages [54], and from a combination of satellite data and street view images [53].

Generative models. Since the introduction of Generative Adversarial Networks (GANs) [38], deep learning has been used not only to analyze existing images but also to generate new ones altogether. This family of deep networks has evolved into various forms, from super resolution image generators [55] to fine-grained in-painting technologies [73]. Recent approaches have been used to generate images conditioned on specific visual attributes [102], and these images range from faces [97] to people [59]. In a similar vein, Nguyen *et al.* [69] used generative networks to create a natural-looking image that maximizes a specific neuron. This method was used to bring out the latent representation of an image, that maximizes its probability of a particular class. In theory, the resulting image is the one that “best activates” the neuron under consideration. In practice, it is still a synthetic template that needs further processing to look realistic. Finally, with the recent advancement in Augmented Reality, the

Symbol	Meaning
I_i	Original urban scene
Y	Set of annotation classes for urban scenes (e.g., beautiful, ugly)
y_i	Annotation class in Y (e.g., beautiful)
\hat{I}_j	Template scene (synthetic image)
I'	Target Image
C	Beauty Classifier

Table 4.1 Notations

application of GANs to generate urban objects in simulated urban scenes have also been successfully shown [2].

To sum up, a lot of work has gone into collecting ground truth data about how people tend to perceive urban spaces, and into building accurate predictions models of urban qualities. However, little work has gone into models that generate realistic urban scenes and that offer human-interpretable explanations of what they generate.

4.3 FaceLift Framework

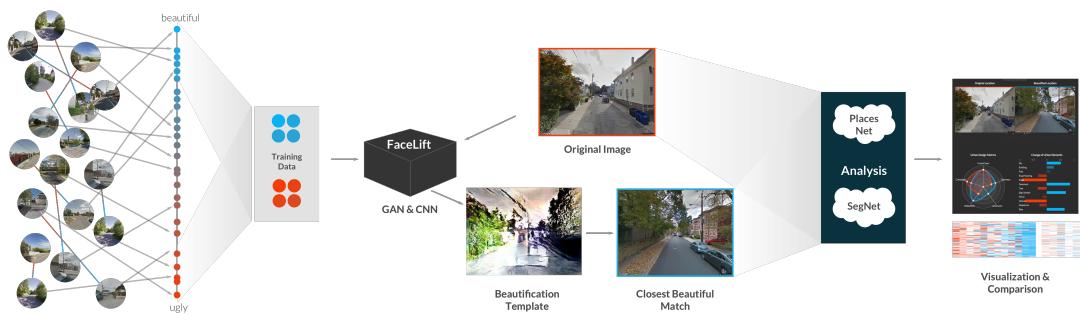


Fig. 4.1 An illustration of the FaceLift framework.

The main goal of FaceLift is to beautify an existing urban scene. To meet that goal, it performs five steps:

Step 1 Curating urban scenes. Deep learning systems need considerable amounts of training data. To augment our initial set of data, we develop a new way of curating and augmenting the number of annotated images.

Step 2 Training a beauty classifier. We design and train a deep learning model that is able to distinguish beautiful urban scenes from non-beautiful ones.

Step 3 Generating a synthetic beautified scene. Based on our classifier’s learned representation of beauty, we train a generative model that is able to generate a beautified version of an urban scene in input.

Step 4 Retrieving a realistic beautified scene. The generated image has a “synthetic look” and, as such, does not look realistic (Figure 4.1). To fix that, we retrieve the image in our set most similar to the generated image.

Step 5 Identifying the urban elements characterizing the beautified scene. In the final step, the framework explains changes introduced in the transformation process in terms of addition and removal of specific urban elements.

Step 1 Curating Urban Scenes

To begin with, we need highly curated training data with labels reflecting urban beauty. We start with the Place Pulse dataset that contains 100k Google Street Views across 56 cities around the world [31]. These scenes are labeled in terms of whether the corresponding places are likely to be perceived beautiful, depressing, rich, and safe. We focus only on those scenes that are labeled in terms of beauty and that have at least three judgments. This leave us with roughly 20,000 scenes. To transform judgments into beauty scores, we use the TrueSkill algorithm [39], which gives us a way of partitioning the scenes into two sets (Figure 4.2): one containing beautiful scenes, and the other containing ugly scenes. The resulting set of scenes is too small for training any deep learning model without avoiding over-fitting though. As such, we need to augment such a set.

We do so in two ways. First, we feed each scene’s location into the Google Streetview API to obtain the snapshots of the same location at different camera angles (i.e., at $\theta \in -30^\circ, -15^\circ, 15^\circ, 30^\circ$). However, the resulting dataset is still too small for robust training. Therefore, again, we feed each scene’s location into the Google Streetview API, but we now do so to obtain other scenes at distance $d \in \{10, 20, 40, 60\}$ meters. This will greatly expand our set of scenes, but it might do so at the price of introducing scenes whose beauty scores have little to do with the original scene’s. To fix that, we take only the scenes that are *similar* to the original one (we call this way of augmenting “conservative translation”). To compute the similarity between a pair of scenes, we represent the two scenes with visual features derived from the FC7 layer of PlacesNet and compute the similarity between the two corresponding feature vectors [106]. For all scenes at increasing distance $d \in \{10, 20, 40, 60\}$ meters, we take only those whose similarity scores with the original scene is above a threshold. In a conservative fashion, we choose that threshold to be the median similarity between rotated and original scenes (those of the first augmentation step).

To make sure this additional augmentation has not introduced any unwanted noise, we consider two sets of scenes: one containing those that have been taken during this last step, i.e., the one with high similarity to the original scenes (*taken-set*), and the other containing those that have been filtered away (*filtered-set*). Each scene is then scored with PlacesNet [106] and is represented with the five most confident scene labels. We then aggregate labels at set level by computing each label’s frequency on the *taken-set* and on the *filtered-set*. Finally, we characterize each label’s propensity to be correctly augmented as: $\text{prone}(\text{label}) = \text{fr}(\text{label}, \text{taken-set}) - \text{fr}(\text{label}, \text{filtered-set})$. This reflects the extent to which a scene with a given label is prone to be augmented or not. From Figure 4.4, we find that, as one would expect, scenes that contain highways, fields and bridges can be augmented at increasing distances while still showing resemblances to the original scene; by contrast, scenes that contain gardens, residential neighborhoods, plazas, and skyscrapers cannot be easily augmented, as they are often found in high density parts of the city in which diversity within short distances might well be experienced.

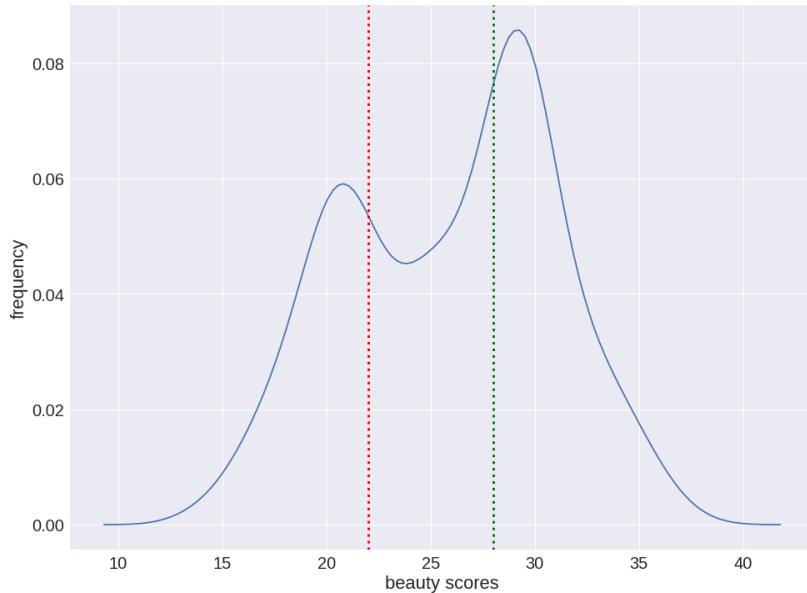


Fig. 4.2 Frequency distribution of beauty scores. The red and green lines represent the thresholds below and above which images are considered ugly and beautiful. Conservatively, images in between are discarded.

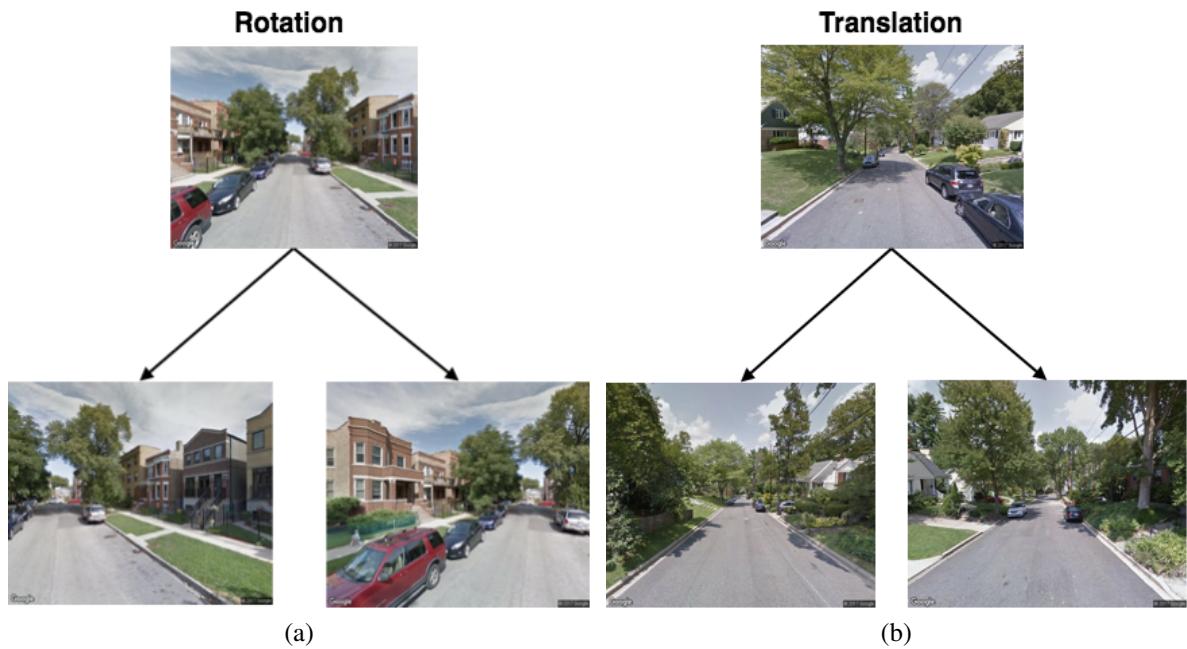


Fig. 4.3 Two types of augmentation: (a) rotation of the Street Views camera (based on rotation); and (b) exploration of scenes at increasing distances (based on translation).

Step 2 Training a beauty classifier

Having this highly curated set of labeled urban scenes, we are now ready to train classifier C with labels reflecting our beauty assessments.

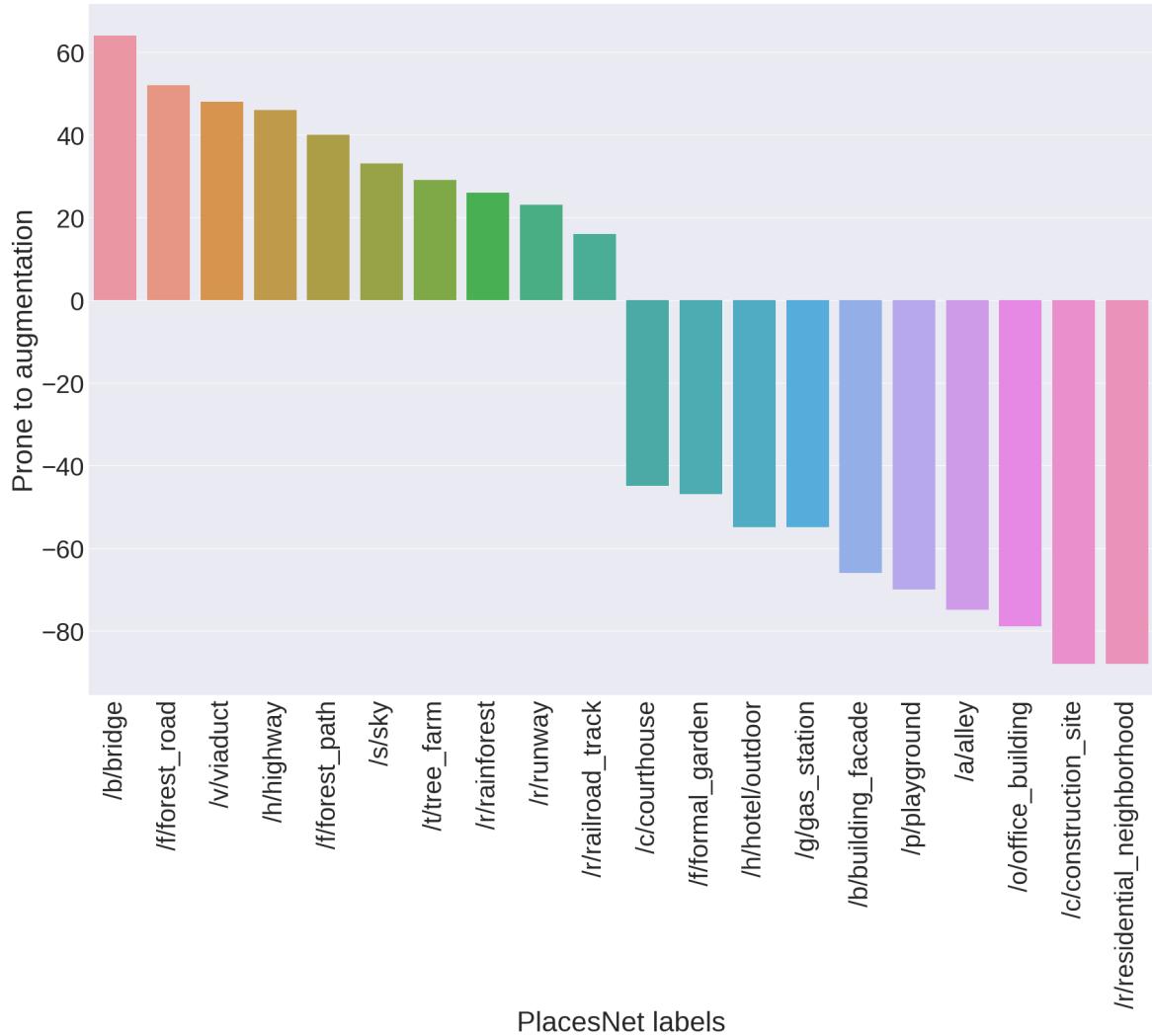


Fig. 4.4 The types of scene that have greater propensity to be correctly augmented with similar scenes at increasing distances.

Augmentation	Accuracy (Percentage)
None	63
Rotation	68
Rotation + Translation	64
Rotation + Conservative Translation	73.5

Table 4.2 Percentage accuracy for our beauty classifier trained on differently augmented sets of urban scenes.

As for classifier C , we use the CaffeNet architecture, a modified version of AlexNet [51, 96]. This has a conventional architecture with 5 convolutional layers; interleaved with max pooling and normalization layers; and terminated by: (i) two 4096 dimensional fully connected layers interleaved with dropout layers [94] (the dropout ratio is set to 0.5 to prevent

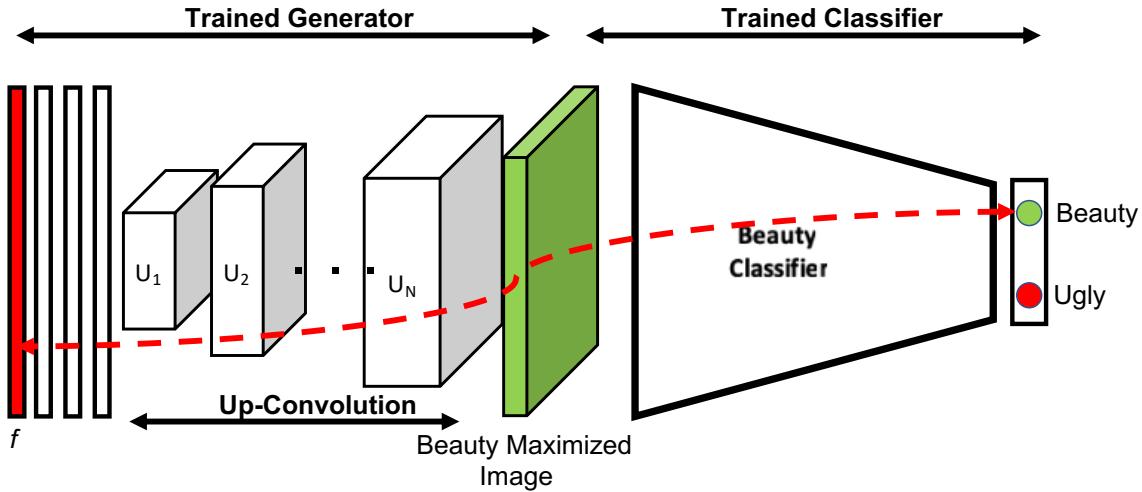


Fig. 4.5 Architecture of the synthetic beauty generator. This consists of a generator of synthetic scenes concatenated with a beauty classifier. The green block is the beauty maximized template \hat{I}_j , which is subject to forward and backward passes (red arrow) when optimizing for beauty.

over-fitting), and (ii) by a Softmax layer that classifies the input image into one of two classes of beautiful(1) and ugly(0).

Having C at hand, we now turn to training it. The training is done on a 70% split of the data, and the testing on the remaining 30%. All this is done on increasingly augmented sets of data. We start from our 20k images and progressively augment them with the snapshots obtained with the 5-angle camera rotations, and then with the exploration of scenes at increasing distance $d \in \{10, 20, 40, 60\}$ meters. The idea behind this data augmentation is that the model's accuracy should increase with increasing levels of augmentation. Indeed it does (Table 4.2): it goes from 63% on the set of original scenes to a value as high as 73.5% on the set of fully augmented scenes, which is a notable increase in accuracy for this type of classification tasks. Furthermore, our results match previous ones: for example, Dubey et.al's [31] model showed an accuracy of 70%, which is comparable to ours.

Step 3 Generating a synthetic beautified scene

Having this trained classifier at hand, we can then build a generator of synthetic beautified scenes. To build such a generator, we retrain the GAN described by Dosovitskiy and

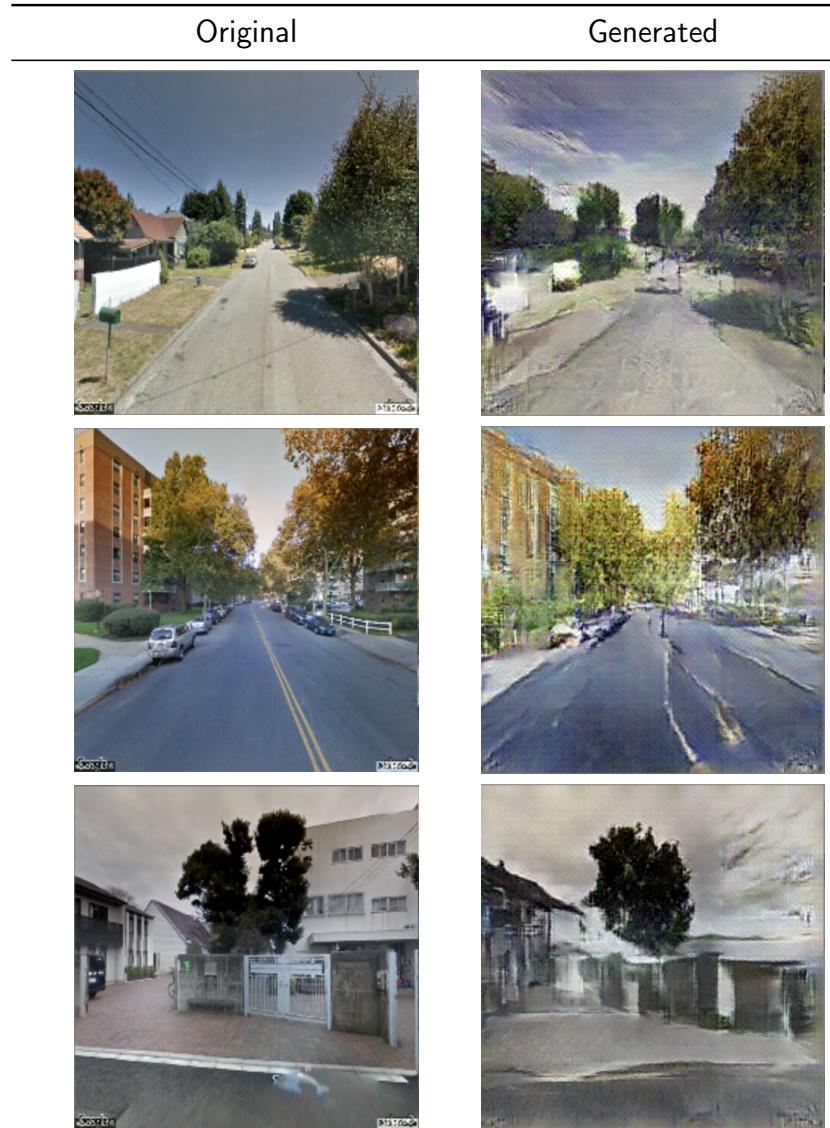


Table 4.3 Examples of our generator's outputs. The original scenes and the generated ones are shown side by side.

Brox [30] on our curated urban scene dataset. This network is trained by maximizing the confusion for the discriminator between the generated images $G(f)$ and the original ones I_f [38]. The resulting generator is concatenated with our beauty classifier (Figure 4.5). As a result, given the two classes ugly y_i and beautiful y_j , the end-to-end model transforms any original scene I_i of class y_i (e.g., ugly scene) into template scene \hat{I}_j that maximizes class y_j (e.g., beautified template scene).

More specifically, given an input image I_i known to be of class y_i (e.g., ugly), our technique outputs \hat{I}_j , which is a more beautiful version of it (e.g., I_i is morphed towards the average representation of a beautiful scene) while preserving I_i 's details. The technique does so using the “Deep Generator Network for Activation Maximization” (*DGN-AM*) [69]. Given an input image I_i , *DGN-AM* iteratively re-calculates the color of I_i 's pixels in a way the output image \hat{I}_j both maximizes the activation of neuron y_j (e.g., the “beauty neuron”) and looks “photo realistic”, which is done by conditioning the maximization to an “image prior”. This is equivalent to finding the feature vector f that maximizes the following expression:

$$\hat{I}_j = G(f) : \arg \max_f (C_j(G(f)) - \lambda ||f||) \quad (4.1)$$

where:

- $G(f)$ is the image synthetically generated from the candidate feature vector f ;
- $C_j(G(f))$ is the activation value of neuron y_j in the scene classifier C (the value to be maximized);
- λ is a L_2 regularization term.

Here the initialization of f is key. If f were to be initialized with random noise, the resulting $G(f)$ would be the average representation of category y_j (of, e.g., beauty). Instead, since f is initialized with the feature vector corresponding to I_i , then the resulting maximized $G(f)$ is I_i 's version “morphed to become more beautiful”.

The input image is also key. It makes little sense to beautify an already beautiful image, not least because such beautification process would result in a saturated template \hat{I}_j in our

framework. For this reason, to generate an image that maximizes the beauty neuron in the classifier C , we restrict the corresponding input image to be in class y_i (i.e., ugly scenes as per the divisions in Figure 4.2). We do the opposite when maximizing the ugly neuron.

Step 4 Returning a realistic beautified scene

We now have template scene \hat{I}_j (which is a synthetic beautified version of original scene I_j) and need to retrieve a realistic looking version of it. We do so by: *i*) representing each of our original scenes in Step 1 (including \hat{I}_j) as a 4096 dimensional feature vector derived from the FC7 layer of the PlacesNet [106]; *ii*) computing the distance (as L_2 Norm) between \hat{I}_j 's feature vector and each of the original scene's feature vector; and *iii*) selecting the original scene most similar (smaller distance) to \hat{I}_j . This results into the selection of the beautified scene I_j .

Step 5 Identifying characterizing urban elements

Since original scene I_i and beautified scene I_j are real scenes with the same structural characteristics (e.g., point of view, layout), we can easily compare them in terms of presence or absence of urban elements extracted by computer vision tools such as SegNet and PlacesNet. That is, we can determine how the original scene and its beautified version differ in terms of urban design elements.

4.4 Evaluation

The goal of FaceLift is to transform existing urban scenes into versions that: *i*) people perceive more beautiful; *ii*) contain urban elements typical of great urban spaces; *iii*) are easy to interpret; and *iv*) architects and urban planners find useful. To ascertain whether FaceLift meets that composite goal, we answer the following questions next:

Q1 Do individuals perceive “FaceLifted” scenes to be beautiful?

Q2 Does our framework produce scenes that possess urban elements typical of great spaces?

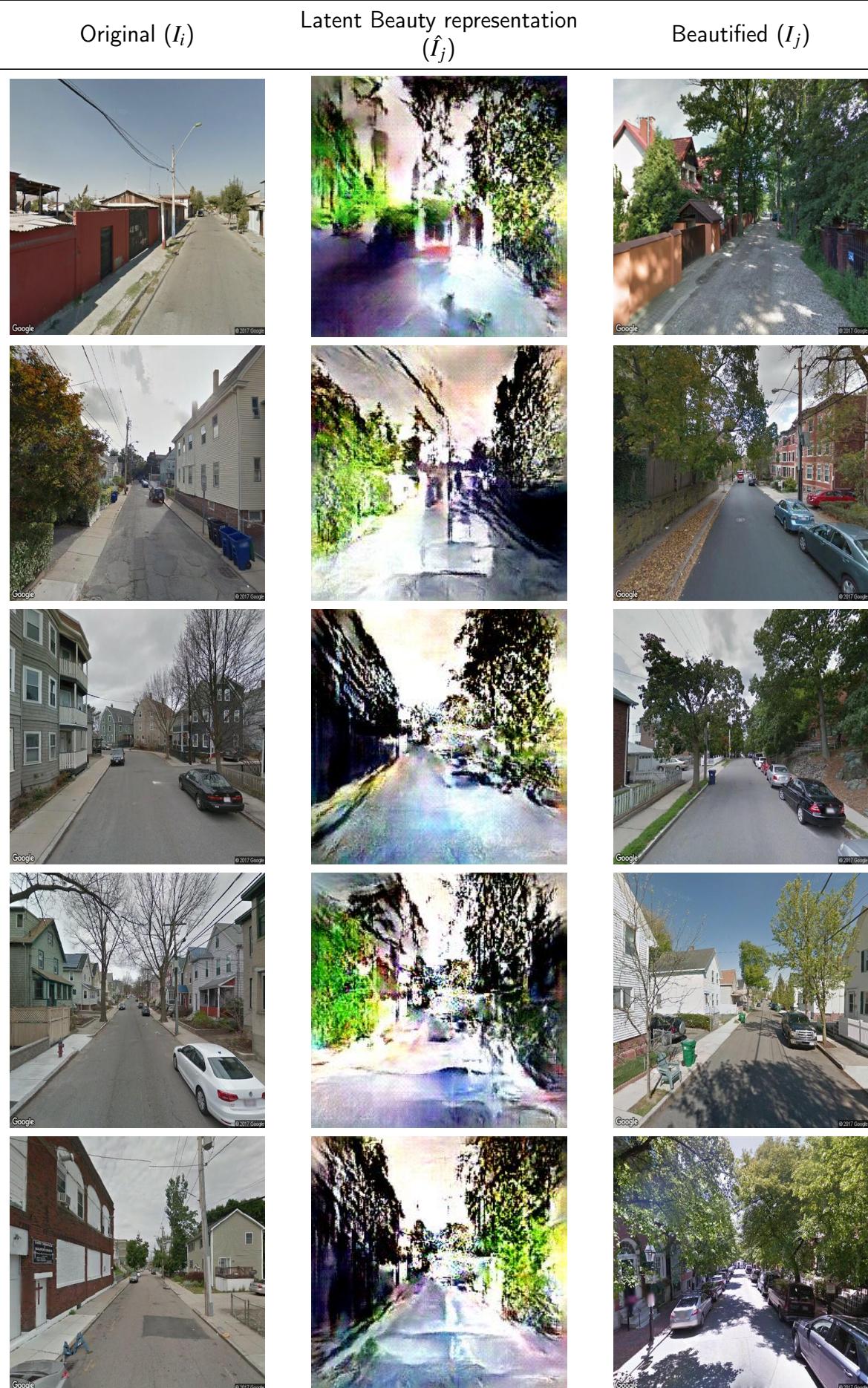


Table 4.4 Examples of the “FaceLifting” process, which tends to add greenery, narrow roads, and pavements

Q3 Which urban elements are mostly associated with beautiful scenes?

Q4 Do architects and urban planners find FaceLift useful?

Q1 People's perceptions of beautified scenes

To ascertain whether “FaceLifted” scenes are perceived by individuals as they are supposed to, we run a crowd-sourcing experiment on Amazon Mechanical Turk. We randomly select 200 scenes, 100 beautiful and 100 ugly (taken at the bottom 10 and top 10 percentiles of the Trueskill’s score distribution of Figure 4.2). Our framework then transforms each ugly scene into its beautified version, and each beautiful scene into its corresponding ‘uglified’. These scenes are arranged into pairs, each of which contains the original scene and its beautified or uglified version. On Mechanical Turk, we only select verified masters as our crowd-sourcing workers (those with an approval rate above 90% during the past 30 days), pay them \$0.1 per task, and ask each of them to choose the most beautiful scene for each given pair. We make sure to have at least 3 votes for each scene pair. Overall, our workers end up selecting the scenes that are actually beautiful 77.5% of the times, suggesting that “FaceLifted” scenes are indeed perceived to be more beautiful by people.

Q2 Are beautified scenes great urban spaces?

To answer that question, we need to understand what makes a space great. After reviewing the literature in urban planning, we identify four factors associated with great places [1, 34] (Table 4.5): they mainly tend to be walkable, offer greenery, feel cozy, and be visually rich.

To automatically extract visual cues related to these four factors, we select 500 ugly scenes and 500 beautiful ones at random, transform them into their opposite aesthetic qualities (i.e., ugly ones are beautified, and beautiful ones are ‘uglified’), and compare which urban elements related to the four factors distinguish uglified scenes from beautified ones.

We extract labels from each of our 1,000 scenes using two image classifiers. First, using PlacesNet [106], we label each of our scenes according to a classification containing 205 labels (reflecting, for example, landmarks, natural elements), and retain the five labels with

Metric	Description
Walkability	Walkable streets support people's natural tendency to explore spaces [34, 77, 92].
Green Spaces	The presence of greenery has repeatedly been found to impact people's well-being [1]. Under certain conditions, it could also promote social interactions [78]. Not all types of greenery have to be considered the same though: dense forests or unkempt greens might well have a negative impact [43].
Landmarks	Feeling lost is not a pleasant experience, and the presence of landmarks have been shown to contribute to the legibility and navigability of spaces [34, 58, 78, 79].
Privacy-Openness	The sense of privacy conveyed by a place's structure (as opposed to a sense of openness) impacts its perception [34].
Visual Complexity	Visual complexity is a measure of how diverse an urban scene is in terms of design materials, textures, and objects [34]. The relationship between complexity and preferences generally follows an 'inverted-U' shape: we prefer places of medium complexity rather than places of low or high complexity [99].

Table 4.5 Urban Design Metrics

highest confidence scores for the scene. Second, using Segnet [7], we label each of our scenes according to a classification containing 12 labels. Segnet is trained on dash-cam images, and classifies each scene pixel with one of these twelve labels: road, sky, trees, buildings, poles, signage, pedestrians, vehicles, bicycles, pavement, fences, and road markings.

Having these two ways of labeling scenes, we can now test whether the expectations set by the literature describing metrics of great urban spaces (Table 4.5) are met in the FaceLifted scenes.

H1 Beautified scenes tend to be walkable. We manually select only the PlacesNet labels that are related to walkability. These labels include, for example, *abbey*, *plaza*, *courtyard*, *garden*, *picnic area*, and *park*. To test hypothesis *H1*, we count the number of walkability-related labels found in beautified scenes as opposed to those found in uglified scenes (Figure 4.6):

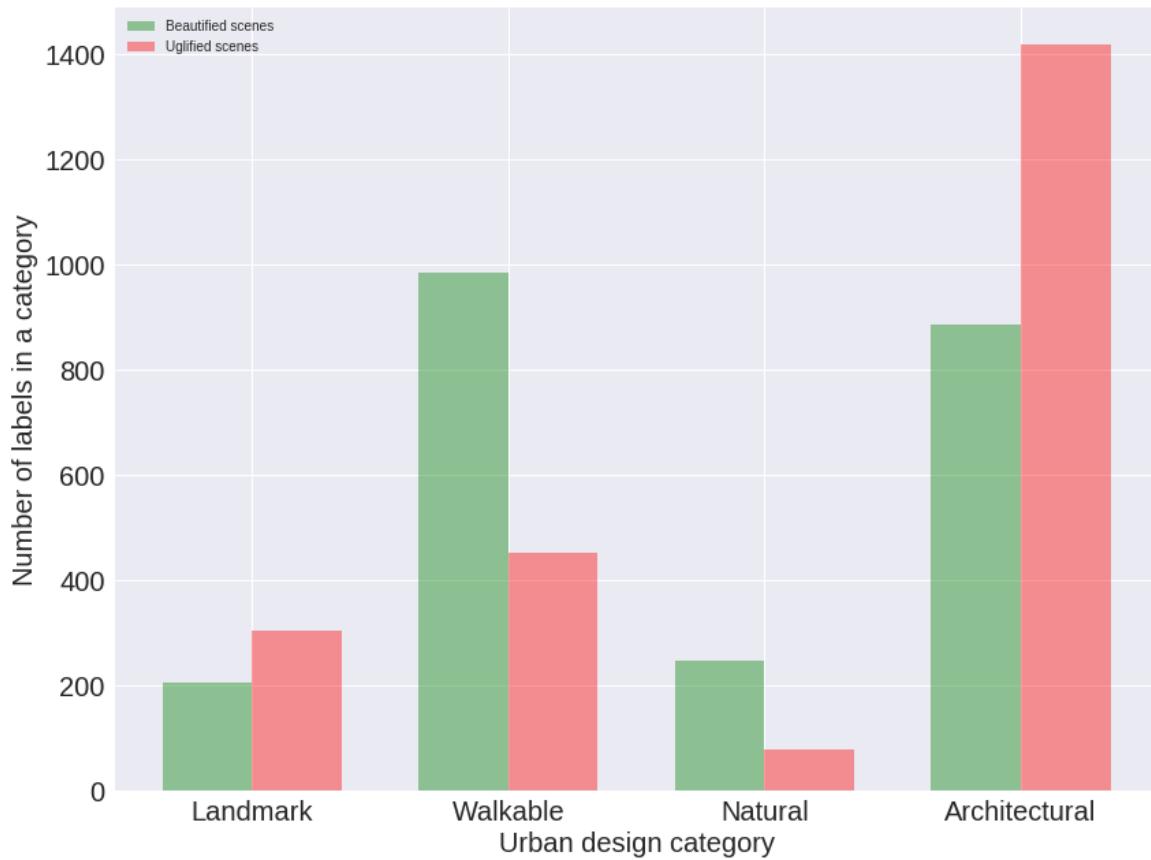


Fig. 4.6 Number of labels in specific urban design categories (on the *x*-axis) found in beautified scenes as opposed to those found in uglified scenes.

the former contain twice as many walkability labels than the latter. We then determine which types of scenes are associated with beauty (Figure 4.7). Unsurprisingly, beautified scenes tend to show gardens, yards, and small paths. By contrast, uglified ones tend to show built environment features such as shop fronts and broad roads.

H2 Beautified scenes tend to offer green spaces. We manually select only the PlacesNet labels that are related to greenery. These labels include, for example, *fields*, *pasture*, *forest*, *ocean*, and *beach*. Then, in our 1,000 scenes, to test hypothesis *H2*, we count the number of nature-related labels found in beautified scenes as opposed to those found in uglified scenes (Figure 4.6): the former contain more than twice as many nature-related labels than the latter. To test this hypothesis further, we compute the fraction of ‘tree’ pixels (using SegNet’s label

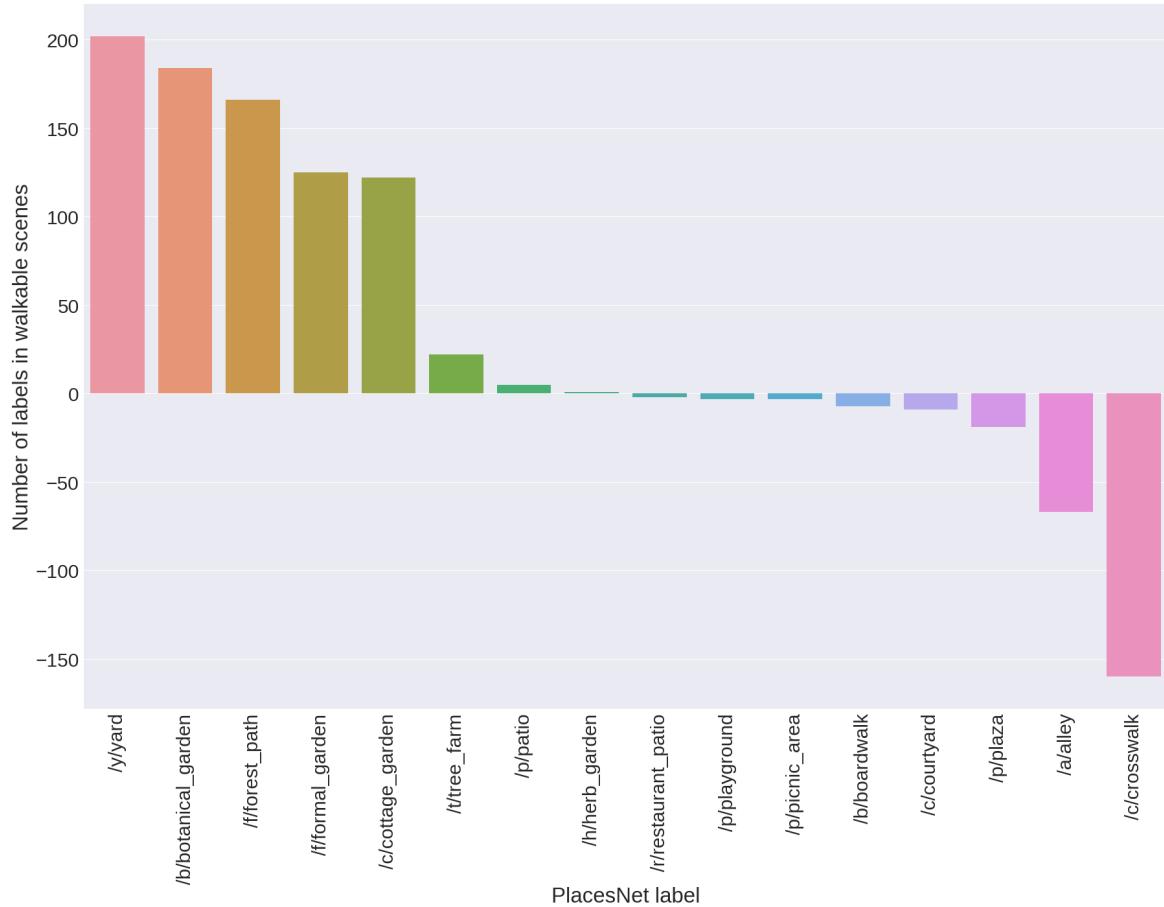


Fig. 4.7 Count of specific walkability-related labels (on the *x*-axis) found in beautified scenes minus the count of the same labels found in uglified scenes.

‘tree’) in beautified and uglified scenes, and find that beautification adds 32% of tree pixels, while uglification removes 17% of them.

H3 Beautified scenes tend to feel private and ‘cozy’. To test hypothesis *H3*, we count the fraction of pixels that Segnet labeled as ‘sky’ and show the results in a bin plot in Figure 4.8a: the *x*-axis has six bins (each of which represents a given range of sky fraction), and the *y*-axis shows the percentage of beautified *vs.* uglified scenes that fall into each bin. Beautified scenes tend to be cozier (lower sky presence) than the corresponding original scenes.

H4 Beautified scenes tend to be visually rich. To quantify to which extent scenes are visually rich, we measure their visual complexity [34] as the amount of disorder in terms of

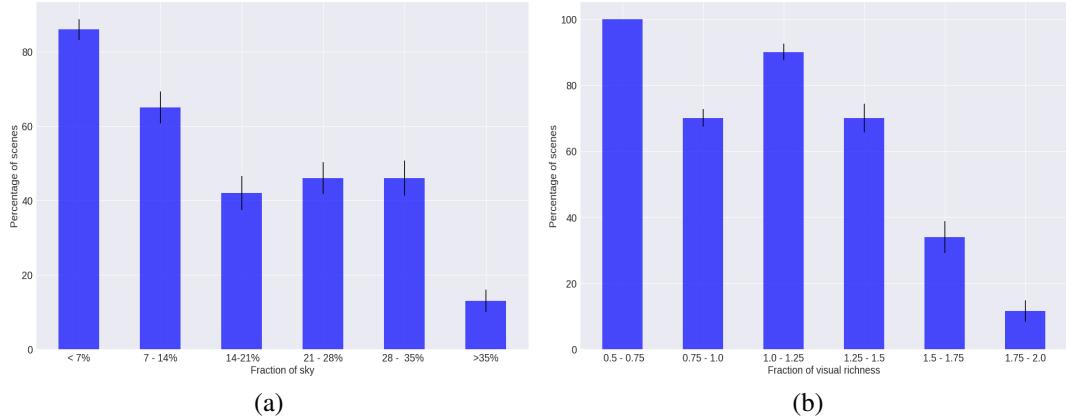


Fig. 4.8 The percentage of beautified scenes (y-axis): (a) having an increasing presence of sky (on the x-axis); and (b) having an increasing level of visual richness (on the x-axis). The error bars represent standard errors obtained by random re-sampling of the data for 500 iterations.

distribution of (Segnet) urban elements in the scene:

$$H(X) = - \sum p(i) \log p(i) \quad (4.2)$$

where i is the i^{th} Segnet's label. The total number of labels is twelve. The higher $H(X)$, the higher the scene's entropy, that is, the higher the scene's complexity. It has been suggested that the relationship between complexity and pleasantness follows an 'inverted U' shape [99]: we prefer places of medium complexity rather than places of low or high complexity. To test that, we show the percentage of beautified scenes that fall into each complexity bin (Figure 4.8b): we do not find a strong evidence of the 'inverted U' shape hypothesis, in that, beautified scenes are of low to medium complexity, while uglified ones are of high complexity.

Q3 Urban elements of beautified scenes

To determine which urban elements are the best predictors of urban beauty and the extent to which they are so, we run a logistic regression, and, to ease interpretation, we do so on one pair of predictors at the time:

$$Pr(\text{beautiful}) = \text{logit}^{-1}(\alpha + \beta_1 * V_1 + \beta_2 * V_2 + \beta_3 * V_1.V_2) \quad (4.3)$$

Pair of urban elements	β_1	β_2	β_3	Error Rate (Percentage)
Buildings - Trees	-0.032	0.084	0.005	12.7
Sky - Buildings	-0.08	-0.11	0.064	14.4
Roads - Vehicles	-0.015	-0.05	0.023	40.6
Sky - Trees	0.03	0.11	-0.012	12.8
Roads - Trees	0.04	0.10	-0.031	13.5
Roads - Buildings	-0.05	-0.097	0.04	20.2

Table 4.6 Coefficients of logistic regressions run on one pair of predictors at the time.

where $V1$ is the fraction of the scene’s pixels marked with one Segnet’s label, say, “buildings” (over the total number of pixels), and $V2$ is the fraction of the scene’s pixels marked with another label, say, “trees”. The result consists of three beta coefficients: β_1 reflects $V1$ ’s contribution in predicting beauty, β_2 reflects $V2$ ’s contribution, and β_3 is the interaction effect, that is, it reflects the contribution of the dependency between $V1$ and $V2$ in predicting beauty. We run logistic regressions on the five factors that have been found to be most predictive of urban beauty [1, 34, 78], and show the results in Table 4.6.

Since we are using logistic regressions, the quantitative interpretation of the beta coefficients is eased by the “divide by 4 rule” [100]: we can take the β coefficients and “divide them by 4 to get an upper bound of the predictive difference corresponding to a unit difference” in beauty [100]. For example, take the results in the first row of Table 4.6. In the model $Pr(\text{beautiful}) = \text{logit}^{-1}(\alpha - 0.032 \cdot \text{buildings} + 0.084 \cdot \text{trees} + 0.005 \cdot \text{buildings} \cdot \text{trees})$, we can divide $-0.032/4$ to get -0.008 : a difference of 1 in the fraction of pixels being buildings corresponds to no more than a 0.8% *negative* difference in the probability of the scene being beautiful. In a similar way, a difference of 1 in the fraction of pixels being trees corresponds to no more than a 0.021% *positive* difference in the probability of the scene being beautiful. By considering the remaining results in Table 4.6, we find that, across all pairwise comparisons, trees is the most positive element associated with beauty, while roads and buildings are the most negative ones. These results match previous literature in urban design of what makes spaces great, adding further external validity to our framework’s beautification.

Use case	Definitely Not	Probably Not	Probably	Very Probably	Definitely
Decision Making	4.8%	9.5%	38%	28.6%	19%
Participatory Urban Planning	0%	4.8%	52.4%	23.8%	19%
Promote Green Cities	4.8%	0%	47.6%	19%	28.6%

Table 4.7 Urban experts polled about the extent to which an interactive map of “FaceLifted” scenes promotes: (a) decision making; (b) citizen participation in urban planning; and (c) promoting green cities.

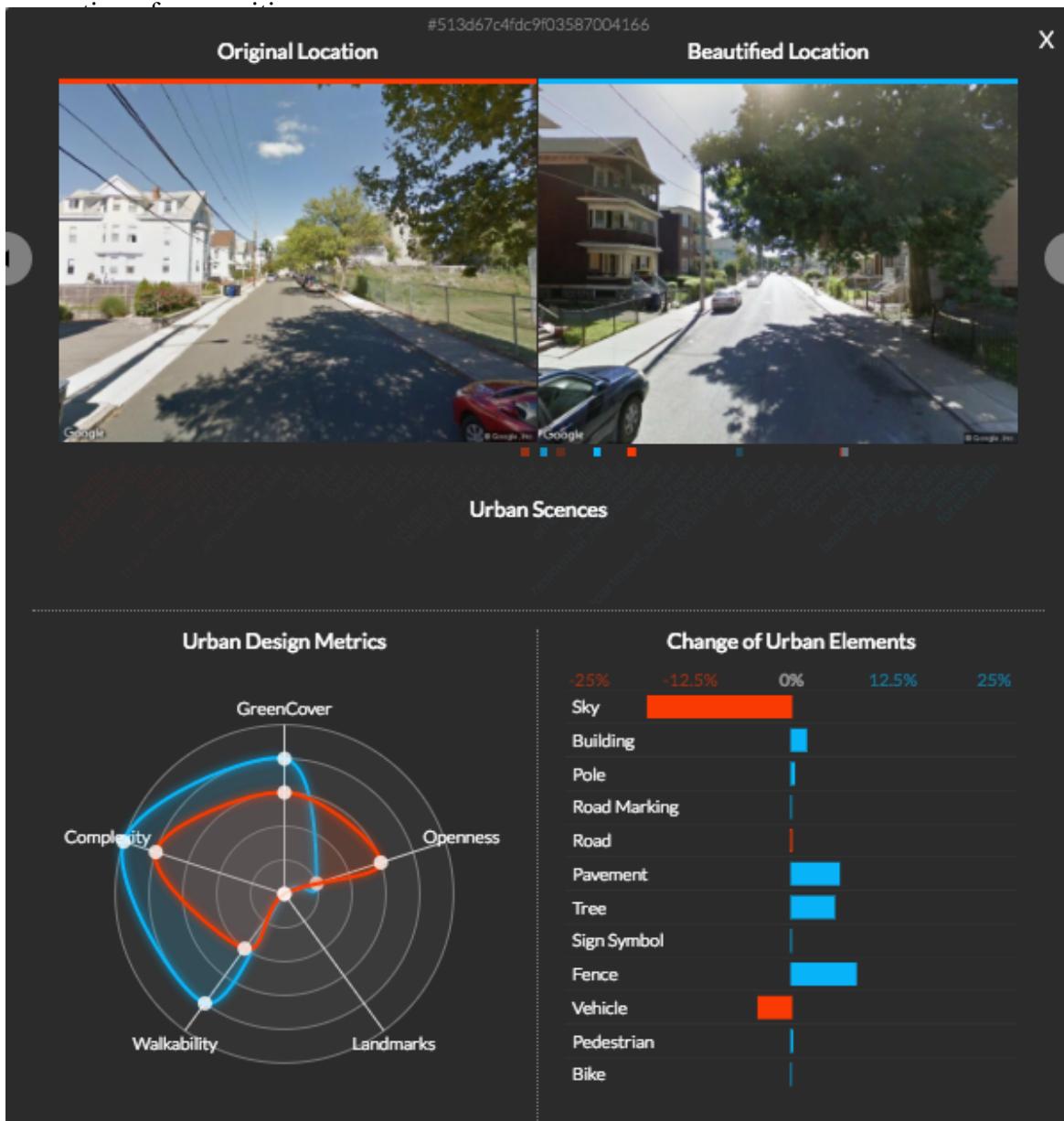


Fig. 4.9 Interactive map of FaceLifted scenes in Boston.

Q4 Do architects and urban planners find it useful?

To ascertain whether practitioners find FaceLift potentially useful, we build an interactive map of the city of Boston in which, for selected points, we show pairs of urban scenes

before/after beautification (Figure 4.9). We then send that map along with a survey to 20 experts in architecture, urban planning, and data visualization around the world. Questions were asked with a non-neutral response Likert scale (Table 4.7). That is because previous work [8, 65] has shown that such a scale: (i) pushes respondents to “take a stance”, given the absence of a neutral response; and (ii) works best if respondents are experts in the subject matter of the survey as responses of the “I don’t know” type tend to be rare (as it is has been the case for our survey). The experts had to complete tasks in which they rated FaceLift based on how well it supports decision making, participatory urbanism, and the promotion of green spaces. According to our experts (Table 4.7), the tool can very probably supports decision making, probably support participatory urbanism, and definitely promote green spaces. These results are also qualitatively supported by our experts’ comments, which include: *“The maps reveal patterns that might not otherwise be apparent”*, *“The tool helps focusing on parameters to identify beauty in the city while exploring it”*, and *“The metrics are nice. It made me think more about beautiful places needing a combination of criteria, rather than a high score on one or two dimensions. It made me realize that these criteria are probably spatially correlated”*.

4.5 Conclusion

FaceLift is a framework that automatically beautifies urban scenes by combining recent approaches of Generative Adversarial Networks and Deep Convolutional Networks. To make it usable by practitioners, the framework is also able to explain which urban elements have been added/removed during the beautification process.

There are still important limitations though. One is data bias. The framework is as good as its training data, and more work has to go into collecting reliable ground truth data on human perceptions. This data should ideally be stratified according to the people’s characteristics that impact their perceptions. The other main limitation is that generative models are hard to control, and more work has to go into offering principled ways of fine-tuning the generative process.

Despite these limitations, FaceLift has the potential to support urban interventions in scalable and replicable ways: it can be applied to an entire city (scalable), across a variety of cities (replicable). To turn existing spaces into something more beautiful, that will still be the duty of architecture. Yet, with technologies similar to FaceLift more readily available, the complex job of recreating restorative spaces in an increasingly urbanized world will be greatly simplified.

After all, “we delight in complexity to which genius have lent an appearance of simplicity.” [23] In the context of future work, that genius is represented by future technologies that will help us deal with the complexity of our cities.

4.5.1 Limitations and biases

Like any supervised deep learning based framework, this work is only able to learn what is present in the data. Hence the method of acquiring annotations for urban images can introduce huge biases in the model. The current model is trained on images acquired from the study on streetscore [67]. However their annotation is open to general public and there is not way we can remove biases that come with culture and location, in a highly subjective effect like beauty. Moreover because the pair wise choice is simply done by clicking one of the two images, the data might have noise introduced by non-serious participants. Such biases are bound to be picked up by the deep learning model. One can argue that the preference of our model for greenery , is a form of bias in the data. Another bias introduced because of data is the model’s lack of preference to pedestrians. This bias was established well in advance because Google tries to remove most of the people from their street view images for privacy reasons. Hence people, which make up a major aspect of urban vitality, are completely missing from most dataset images and hence from the facelift transformations. Another Limitation of our work is in the metric formation. The computational metrics developed to capture the real urban design metrics are designed using heuristics. There needs to be more crowd and expert validation to establish the validity of their formulation.

4.5.2 Future work

The framework is generalizable for geotagged and annotated images. The aim of this paper is to propose a framework with uses state of art methods in generative models to understand perception of emotions in urban images and explain them. As an extension, understanding how intervention would look like against outcome variables such as depression, safety or mental well-being in general would be very valuable.

REFERENCES

- [1] Alexander, C. (1977). *A Pattern Language: Towns, Buildings, Constructions*. Oxford University Press.
- [2] Alhaija, H. A., Mustikovela, S. K., Mescheder, L., Geiger, A., and Rother, C. (2018). Augmented reality meets computer vision: Efficient data generation for urban driving scenes. *International Journal of Computer Vision*, 126(9):961–972.
- [3] Ali, K., Farrer, L., Gulliver, A., and Griffiths, K. M. (2015). Online peer-to-peer support for young people with mental health problems: a systematic review. *JMIR mental health*, 2(2):e19.
- [4] Allen, C., Vassilev, I., Kennedy, A., and Rogers, A. (2016). Long-term condition self-management support in online communities: a meta-synthesis of qualitative papers. *Journal of medical Internet research*, 18(3).
- [5] Arietta, S. M., Efros, A. A., Ramamoorthi, R., and Agrawala, M. (2014). City forensics: Using visual elements to predict non-visual city attributes. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2624–2633.
- [6] Armstrong, A. and Hagel, J. (2000). The real value of online communities. *Knowledge and communities*, 74(3):85–95.
- [7] Badrinarayanan, V., Kendall, A., and Cipolla, R. (2015). Segnet: A deep convolutional encoder-decoder architecture for image segmentation. *arXiv preprint arXiv:1511.00561*.
- [8] Baka, A., Figgou, L., and Triga, V. (2012). ‘neither agree, nor disagree’: a critical analysis of the middle answer category in voting advice applications. *International Journal of Electronic Governance*, 5(3-4):244–263.
- [9] Bakhshi, S., Shamma, D. A., and Gilbert, E. (2014). Faces engage us: Photos with faces attract more likes and comments on instagram. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 965–974. ACM.
- [10] Ball, K., Bauman, A., Leslie, E., and Owen, N. (2001). Perceived environmental aesthetics and convenience and company are associated with walking for exercise among australian adults. *Journal of Preventive Medicine*, 33(5):434–440.
- [11] Baron, R. S., Cutrona, C. E., Hicklin, D., Russell, D. W., and Lubaroff, D. M. (1990). Social support and immune function among spouses of cancer patients. *Journal of Personality and Social Psychology*, 59(2):344.

- [12] Bartlett, Y. K. and Coulson, N. S. (2011). An investigation into the empowerment effects of using online support groups and how this affects health professional/patient communication. *Patient education and counseling*, 83(1):113–119.
- [13] Batagelj, V. and Mrvar, A. (2001). A subquadratic triad census algorithm for large sparse networks with small maximum degree. *Social Networks*, 23(3):237–243.
- [14] Berners-Lee, T. and Fischetti, M. (2001). *Weaving the Web: The original design and ultimate destiny of the World Wide Web by its inventor*. DIANE Publishing Company.
- [15] Borges, M. (2004). What can kant teach us about emotions? *The Journal of Philosophy*, 101(3):140–158.
- [16] Brown, G. W., Andrews, B., Harris, T., Adler, Z., and Bridge, L. (1986). Social support, self-esteem and depression. *Psychological medicine*, 16(4):813–831.
- [17] Cecchi, L., Liccardi, G., Pellegrino, F., and Sofia, M. (2012). 2 social networks: A new source of psychological stress or a way to enhance self-esteem? negative and positive implications in bronchial asthma. *Journal of Investigational Allergology and Clinical Immunology*, 22(6):402.
- [18] Collins, N. L., Dunkel-Schetter, C., Lobel, M., and Scrimshaw, S. C. (1993). Social support in pregnancy: Psychosocial correlates of birth outcomes and postpartum depression. *Journal of personality and social psychology*, 65(6):1243.
- [19] Coulson, N. S. (2005). Receiving social support online: an analysis of a computer-mediated support group for individuals living with irritable bowel syndrome. *CyberPsychology & Behavior*, 8(6):580–584.
- [20] Craig, P., Dieppe, P., Macintyre, S., Michie, S., Nazareth, I., and Petticrew, M. (2008). Developing and evaluating complex interventions: the new medical research council guidance. *BMJ*, 337.
- [21] Crawford, M. (2015). *The World Beyond Your Head: How to Flourish in an Age of Distraction*. penguin publishing.
- [22] Davenport, T. H. and Beck, J. C. (2001). *The attention economy: Understanding the new currency of business*. Harvard Business Press.
- [23] De Botton, A. (2008). *The Architecture of Happiness*. Vintage Series. Knopf Doubleday Publishing Group.
- [24] De Choudhury, M. and De, S. (2014). Mental Health Discourse on reddit: Self-Disclosure, Social Support, and Anonymity. *Proceedings of the Eight International AAAI Conference on Weblogs and Social Media*, pages 71–80.
- [25] De Choudhury, M., Kiciman, E., Dredze, M., Coppersmith, G., and Kumar, M. (2016). Discovering shifts to suicidal ideation from mental health content in social media. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI ’16, pages 2098–2110, New York, NY, USA. ACM.

- [26] De Nadai, M., Vieriu, R. L., Zen, G., Dragicevic, S., Naik, N., Caraviello, M., Hidalgo, C. A., Sebe, N., and Lepri, B. (2016). Are Safer Looking Neighborhoods More Lively?: A Multimodal Investigation into Urban Life. In *Proceedings of the ACM on Multimedia Conference (MM)*.
- [27] De Simoni, A., Horne, R., Fleming, L., Bush, A., and Griffiths, C. (2017). What do adolescents with asthma really think about adherence to inhalers? insights from a qualitative analysis of a uk online forum. *BMJ open*, 7(6):e015245.
- [28] De Simoni, A., Shanks, A., Balasooryia-Smeekens, C., and Mant, J. (2016). Stroke survivors and their families receive information and support on an individual basis from an online forum: descriptive analysis of a population of 2348 patients and qualitative study of a sample of participants. *BMJ open*, 6(4):e010501.
- [29] De Vine, L., Zuccon, G., Koopman, B., Sitbon, L., and Bruza, P. (2014). Medical semantic similarity with a neural language model. In *Proceedings of the 23rd ACM international conference on conference on information and knowledge management*, pages 1819–1822. ACM.
- [30] Dosovitskiy, A. and Brox, T. (2016). Generating images with perceptual similarity metrics based on deep networks. In *Advances in Neural Information Processing Systems*, pages 658–666.
- [31] Dubey, A., Naik, N., Parikh, D., Raskar, R., and Hidalgo, C. A. (2016). Deep learning the city: Quantifying urban perception at a global scale. *arXiv preprint arXiv:1608.01769*.
- [32] Dunkel-Schetter, C. (1984). Social support and cancer: Findings based on patient interviews and their implications. *Journal of Social issues*, 40(4):77–98.
- [33] Eikelboom, R. (2017). Irresistible: The rise of addictive technology and the business of keeping us hooked. *Perspectives on Science and Christian Faith*, 69(4):253–256.
- [34] Ewing, R. and Clemente, O. (2013). *Measuring Urban Design: Metrics for livable places*. Island Press.
- [35] Fox, S. (2011). *The social life of health information 2011*.
- [36] Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., and Donovan, R. J. (2005). Increasing walking: how important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine*, 28(2):169–176.
- [37] Gkotsis, G. (2017). Characterisation of mental health conditions in social media using informed deep learning. *Scientific Reports*, 7:45141.
- [38] Goodfellow, I., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., Courville, A., and Bengio, Y. (2014). Generative adversarial nets. In *Advances in Neural Information Processing Systems*, pages 2672–2680.
- [39] Herbrich, R., Minka, T., and Graepel, T. (2007). Trueskill: a bayesian skill rating system. In *Advances in Neural Information Processing Systems*, pages 569–576.

- [40] Hobbs, W. R., Burke, M., Christakis, N. A., and Fowler, J. H. (2016). Online social integration is associated with reduced mortality risk. *Proceedings of the National Academy of Sciences*, 113(46):12980–12984.
- [41] Hwang, K. O., Ottenbacher, A. J., Green, A. P., Cannon-Diehl, M. R., Richardson, O., Bernstam, E. V., and Thomas, E. J. (2010). Social support in an internet weight loss community. *International journal of medical informatics*, 79(1):5–13.
- [42] Izuka, N. J., Alexander, M. A., Balasoorya-Smeekens, C., Mant, J., and De Simoni, A. (2017). How do stroke survivors and their carers use practitioners' advice on secondary prevention medications? qualitative study of an online forum. *Family practice*, 34(5):612–620.
- [43] Jacobs, J. (1961). *The Death and Life of Great American Cities*. Random House.
- [44] Joglekar, S., Sastry, N., Coulson, N. S., Taylor, S. J., Patel, A., Duschinsky, R., Anand, A., Evans, M. J., Griffiths, C. J., Sheikh, A., et al. (2018). How online communities of people with long-term conditions function and evolve: Network analysis of the structure and dynamics of the asthma uk and british lung foundation online communities. *Journal of medical Internet research*, 20(7).
- [45] Joglekar, S., Sastry, N., and Redi, M. (2017). Like at first sight: Understanding user engagement with the world of microvideos. In *International Conference on Social Informatics*, pages 237–256. Springer.
- [46] Kant, I. (1987). *Critique of judgment*. Hackett Publishing.
- [47] Kaplan, R. and Kaplan, S. (1989). *The experience of nature: A psychological perspective*. CUP Archive.
- [48] Kaplan, S., Kaplan, R., and Wendt, J. S. (1972). Rated preference and complexity for natural and urban visual material. *Perception & Psychophysics*, 12(4):354–356.
- [49] Kavuluru, R., Ramos-Morales, M., Holaday, T., Williams, A. G., Haye, L., and Cerel, J. (2016). Classification of helpful comments on online suicide watch forums. In *Proceedings of the 7th ACM International Conference on Bioinformatics, Computational Biology, and Health Informatics, BCB '16*, pages 32–40, New York, NY, USA. ACM.
- [50] Kirk, S. and Milnes, L. (2016). An exploration of how young people and parents use online support in the context of living with cystic fibrosis. *Health Expectations*, 19(2):309–321.
- [51] Krizhevsky, A. et al. (2012). Imagenet classification with deep convolutional neural networks. In *NIPS*, pages 1097–1105.
- [52] Kummervold, P. E., Gammon, D., Bergvik, S., Johnsen, J.-A. K., Hasvold, T., and Rosenvinge, J. H. (2002). Social support in a wired world: use of online mental health forums in norway. *Nordic journal of psychiatry*, 56(1):59–65.
- [53] Law, S., Paige, B., and Russell, C. (2018a). Take a look around: using street view and satellite images to estimate house prices. *arXiv preprint arXiv:1807.07155*.

- [54] Law, S., Seresinhe, C. I., Shen, Y., and Gutierrez-Roig, M. (2018b). Street-Frontage-Net: urban image classification using deep convolutional neural networks. *International Journal of Geographical Information Science*, pages 1–27.
- [55] Ledig, C., Theis, L., Huszár, F., Caballero, J., Cunningham, A., Acosta, A., Aitken, A., Tejani, A., Totz, J., Wang, Z., et al. (2017). Photo-realistic single image super-resolution using a generative adversarial network. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 4681–4690.
- [56] Li, Y.-M. and Shiu, Y.-L. (2012). A diffusion mechanism for social advertising over microblogs. *Decision Support Systems*, 54(1):9–22.
- [57] Lindal, P. J. and Hartig, T. (2012). Architectural variation, building height, and the restorative quality of urban residential streetscapes. *Journal of Environmental Psychology*.
- [58] Lynch, K. (1960). *The image of the city*.
- [59] Ma, L., Sun, Q., Georgoulis, S., Van Gool, L., Schiele, B., and Fritz, M. (2018). Disentangled person image generation. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 99–108.
- [60] Matura, L. A., McDonough, A., Aglietti, L. M., Herzog, J. L., and Gallant, K. A. (2013). A virtual community: concerns of patients with pulmonary hypertension. *Clinical nursing research*, 22(2):155–171.
- [61] Mihaylov, T. and Nakov, P. (2016). Semanticz at semeval-2016 task 3: Ranking relevant answers in community question answering using semantic similarity based on fine-tuned word embeddings. In *Proceedings of the 10th International Workshop on Semantic Evaluation (SemEval-2016)*, pages 879–886.
- [62] Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S., and Dean, J. (2013). Distributed representations of words and phrases and their compositionality. In *Advances in neural information processing systems*, pages 3111–3119.
- [63] Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., and Alon, U. (2002). Network motifs: simple building blocks of complex networks. *Science*, 298(5594):824–827.
- [64] Mo, P. K. and Coulson, N. S. (2012). Developing a model for online support group use, empowering processes and psychosocial outcomes for individuals living with hiv/aids. *Psychology & Health*, 27(4):445–459.
- [65] Moors, G. (2008). Exploring the effect of a middle response category on response style in attitude measurement. *Quality and Quantity*, 42(6):779–794.
- [66] Naik, N., Kominers, S. D., Raskar, R., Glaeser, E. L., and Hidalgo, C. A. (2017). Computer vision uncovers predictors of physical urban change. *Proceedings of the National Academy of Sciences*, 114(29):7571–7576.
- [67] Naik, N., Philipoom, J., Raskar, R., and Hidalgo, C. (2014). Streetscore-predicting the perceived safety of one million streetscapes. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshop*, pages 779–785.

- [68] Nambisan, P. (2011). Information seeking and social support in online health communities: impact on patients' perceived empathy. *Journal of the American Medical Informatics Association*, 18(3):298–304.
- [69] Nguyen, A., Dosovitskiy, A., Yosinski, J., Brox, T., and Clune, J. (2016). Synthesizing the preferred inputs for neurons in neural networks via deep generator networks. In *Advances in Neural Information Processing Systems*, pages 3387–3395.
- [70] Panagioti, M., Richardson, G., Small, N., Murray, E., Rogers, A., Kennedy, A., Newman, S., and Bower, P. (2014). Self-management support interventions to reduce health care utilisation without compromising outcomes: a systematic review and meta-analysis. *BMC health services research*, 14(1):356.
- [71] Park, A. and Conway, M. (2018). Harnessing reddit to understand the written-communication challenges experienced by individuals with mental health disorders: Analysis of texts from mental health communities. *J Med Internet Res*, 20(4):e121.
- [72] Park, A., Conway, M., and Chen, A. T. (2018). Examining thematic similarity, difference, and membership in three online mental health communities from reddit: a text mining and visualization approach. *Computers in human behavior*, 78:98–112.
- [73] Pathak, D., Krahenbuhl, P., Donahue, J., Darrell, T., and Efros, A. A. (2016). Context encoders: Feature learning by inpainting. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 2536–2544.
- [74] Peirce, R. S., Frone, M. R., Russell, M., Cooper, M. L., and Mudar, P. (2000). A longitudinal model of social contact, social support, depression, and alcohol use. *Health Psychology*, 19(1):28.
- [75] Pendry, L. F. and Salvatore, J. (2015). Individual and social benefits of online discussion forums. *Computers in Human Behavior*, 50:211–220.
- [76] Perlovsky, L. (2014). Aesthetic emotions, what are their cognitive functions? *Frontiers in Psychology*, 5:98.
- [77] Quercia, D., Aiello, L. M., Schifanella, R., and Davies, A. (2015). The Digital Life of Walkable Streets. In *Proceedings of the 24th ACM Conference on World Wide Web (WWW)*, pages 875–884.
- [78] Quercia, D., O'Hare, N. K., and Cramer, H. (2014a). Aesthetic capital: what makes london look beautiful, quiet, and happy? In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW)*, pages 945–955.
- [79] Quercia, D., Pesce, J. P., Almeida, V., and Crowcroft, J. (2013). Psychological Maps 2.0: A web gamification enterprise starting in London. In *Proceedings of ACM International Conference on World Wide Web (WWW)*.
- [80] Quercia, D., Schifanella, R., and Aiello, L. M. (2014b). The shortest path to happiness: Recommending beautiful, quiet, and happy routes in the city. In *Proceedings of the 25th ACM Conference on Hypertext and Social Media*, pages 116–125.

- [81] Real, E., Arce, C., and Sabucedo, J. M. (2000). Classification of landscapes using quantitative and categorical data, and prediction of their scenic beauty in north-western spain. *Journal of environmental psychology*, 20(4):355–373.
- [82] Rowley, J. (2007). The wisdom hierarchy: representations of the dikw hierarchy. *Journal of information science*, 33(2):163–180.
- [83] Saleses, P., Schechtner, K., and Hidalgo, C. A. (2013). The collaborative image of the city: mapping the inequality of urban perception. *PloS one*, 8(7):e68400.
- [84] Sampson, R. J. and Raudenbush, S. W. (2004). Seeing Disorder: Neighborhood Stigma and the Social Construction of Broken Windows. *Social Psychology Quarterly*, 67(4).
- [85] Schupp, H. T., Flaisch, T., Stockburger, J., and Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in brain research*, 156:31–51.
- [86] Seresinhe, C. I., Preis, T., and Moat, H. S. (2015). Quantifying the impact of scenic environments on health. *Scientific Reports*, 5:16899.
- [87] Seresinhe, C. I., Preis, T., and Moat, H. S. (2017). Using deep learning to quantify the beauty of outdoor places. *Royal Society Open Science*, 4(7):170170.
- [88] Shoebottom, A. and Coulson, N. S. (2016). Therapeutic affordances of online support group use in women with endometriosis. *Journal of medical Internet research*, 18(5):e109.
- [89] Shumaker, S. A. and Brownell, A. (1984). Toward a theory of social support: Closing conceptual gaps. *Journal of social issues*, 40(4):11–36.
- [90] Soat, M. (2015). Social media triggers a dopamine high. *Marketing News*, 49(11):20–21.
- [91] Song, Y., Dixon, S., and Pearce, M. (2012). A survey of music recommendation systems and future perspectives. In *9th International Symposium on Computer Music Modeling and Retrieval*, volume 4.
- [92] Speck, J. (2012). Walkable City: How Downtown Can Save America, One Step at a Time. In *Farrar, Straus and Giroux*.
- [93] Squire, M. (2015). "should we move to stack overflow?" measuring the utility of social media for developer support. In *2015 IEEE/ACM 37th IEEE International Conference on Software Engineering*, volume 2, pages 219–228. IEEE.
- [94] Srivastava, N., Hinton, G., Krizhevsky, A., Sutskever, I., and Salakhutdinov, R. (2014). Dropout: a simple way to prevent neural networks from overfitting. *The Journal of Machine Learning Research*, 15(1):1929–1958.
- [95] Stewart, M., Letourneau, N., Masuda, J. R., Anderson, S., and McGhan, S. (2011). Online solutions to support needs and preferences of parents of children with asthma and allergies. *Journal of Family Nursing*, 17(3):357–379.
- [96] Szegedy, C., Liu, W., Jia, Y., Sermanet, P., Reed, S., Anguelov, D., Erhan, D., Vanhoucke, V., and Rabinovich, A. (2015). Going deeper with convolutions. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 1–9.

- [97] Taigman, Y., Polyak, A., and Wolf, L. (2016). Unsupervised cross-domain image generation. *arXiv preprint arXiv:1611.02200*.
- [98] Taylor, S. J., Pinnock, H., Epiphaniou, E., Pearce, G., Parke, H. L., Schwappach, A., Purushotham, N., Jacob, S., Griffiths, C. J., Greenhalgh, T., et al. (2014). A rapid synthesis of the evidence on interventions supporting self-management for people with long-term conditions: Prisms—practical systematic review of self-management support for long-term conditions.
- [99] Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. In *Behavior and the Natural Environment*, pages 85–125. Springer.
- [100] Vaughn, B. K. (2008). Data analysis using regression and multilevel/hierarchical models. *Journal of Educational Measurement*, 45(1):94–97.
- [101] Wentzer, H. S. and Bygholm, A. (2013). Narratives of empowerment and compliance: studies of communication in online patient support groups. *International journal of medical informatics*, 82(12):e386–e394.
- [102] Yan, X., Yang, J., Sohn, K., and Lee, H. (2015). Attribute2image: Conditional image generation from visual attributes. corr abs/1512.00570.
- [103] Yeger-Lotem, E., Sattath, S., Kashtan, N., Itzkovitz, S., Milo, R., Pinter, R. Y., Alon, U., and Margalit, H. (2004). Network motifs in integrated cellular networks of transcription–regulation and protein–protein interaction. *Proceedings of the National Academy of Sciences*, 101(16):5934–5939.
- [104] Zadra, J. R. and Clore, G. L. (2011). Emotion and perception: The role of affective information. *Wiley interdisciplinary reviews: cognitive science*, 2(6):676–685.
- [105] Zhang, X., Shao, S., Stanley, H. E., and Havlin, S. (2014). Dynamic motifs in socio-economic networks. *EPL (Europhysics Letters)*, 108(5):58001.
- [106] Zhou, B., Lapedriza, A., Xiao, J., Torralba, A., and Oliva, A. (2014). Learning deep features for scene recognition using places database. In *Advances in Neural Information Processing Systems*, pages 487–495.
- [107] Zhu, Y., Yan, E., and Wang, F. (2017). Semantic relatedness and similarity of biomedical terms: examining the effects of recency, size, and section of biomedical publications on the performance of word2vec. *BMC medical informatics and decision making*, 17(1):95.