

# Smart homes for dummies

Mikkel Werling (201706722)  
Victor Møller Poulsen (201707639)

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## 1 Abstract

This paper uses topic modeling to investigate the debate amongst smart home users on Reddit. We find that the topics generated bottom-up match smart technology categories proposed in Hubert, Carugati, Brock, and Obel (2020) but that some smart home technologies are disproportionately discussed. Keywords “privacy”, “trust” and “security” were used to investigate in more detail the specific debate surrounding data privacy. It was found that this is a marginal topic, but that user’s really care about securing their homes.

Github: <https://github.com/SmartHomeNLP/SmartHomeNLP>

## 2 Introduction

### 2.1 Smarthome - what’s the buzz? (Victor Møller Poulsen)

It is often stated that the world is becoming more connected. While this sentiment usually refers to the connections between people, it is also true for our devices. De-

vices can now share information with each other and interact seamlessly with users. Networks of communication between devices and users in private homes are generally called “smart homes” and their components are called “smart devices” (Novak & Hoffman, 2019). Common for smart devices is their ability to communicate with other devices in a smart home. They can act autonomously, react to information gathered by sensors or received from other smart devices as well as collect data from usage (Hubert et al., 2020). Because of these characteristics, smart homes create an adaptive environment that tailors its behavior to its user’s needs based on the data it receives from usage. The adaptive features of a smart home come with a price however, because the devices rely crucially on information about users which the companies behind the devices collect (Novak & Hoffman, 2019). A 2018 survey (Perez, 2018) found that almost 41% of American adults have access to a smart speaker in their home. As such, these companies are obtaining an unprecedented amount of personal data. This creates a dilemma for users of smart home technologies. To enable more complex and “smart” behavior from a user’s devices, she needs to share increasingly more of her data (Hubert et al., 2020). This dilemma is the main interest of this paper. Is the community of smart home users concerned mainly with functionality and features or are they also concerned with how their personal data is used?

## **2.2 Building on Hubert et al., (2020) (Mikkel Werling)**

This project acts as an attempt to further quantify and expand upon previous research conducted by Hubert et al. (2020) and is pursued in collaboration with the lead author. Firstly, the lead author of Hubert et al. (2020) has expressed interest in obtaining an overview over which topics are generally important to users of smart home technologies. Specifically, we pursue a bottom-up investigation of what users are discussing when unprompted by specific questions or surveys. We will refer to this exploratory task as Research Question 1 (RQ1).

Secondly, Hubert et al. (2020) used a survey to investigate the link between the use of smart home technologies and concerns regarding data privacy. They found no sig-

nificant mediating effect of concerns about trust and privacy on the use of smart home technologies. Hubert et al. (2020) suggests that the lack of a mediating effect could be explained by users being ignorant about privacy concerns in regard to smart home technologies. We investigate the emphasis that users place on “security”, “privacy” and “trust” in what we will refer to as Research Question 2 (RQ2).

In order to investigate both RQ1 and RQ2 we rely on written discussions on Reddit. Specifically, we narrow the scope to two major smart home subreddits. The specifics of the data-collection will be presented later.

### **2.3 Additions to the framework (Victor Møller Poulsen)**

Prior work by a student coder associated with the lead author of Hubert et al. (2020) has already addressed RQ1 and RQ2 before our involvement in the project. We believe that the main shortcoming with the prior work is not so much in the applied methodology, which in most places is similar to what we present here. The approach generally seems sensible for the intended purposes, and although we considered extending the methodology by using seeded-topic modeling as well as contextual word embeddings, we ultimately did not think that this was the most important contribution we could make to the project.

There were two main shortcomings of the work done so far in our opinion. Firstly, only a small subset of all the available data from the Reddit forums was used for the LDA analysis in the previous work on the project. A common sentiment appears to be that simple machine learning approaches generally perform well, and that more is often gained by expanding the amount of data, rather than applying more sophisticated algorithms (Domingos, 2012). We extract more data than what was previously extracted, and we believe that making it possible to use all of this data for analysis is a sensible main priority. The reason that the previous analysis on the project only used a subset of the collected data was due to prohibitively slow processing. Making the code run faster in order to train models on all the available data is a main contribution of this paper.

A second problem that we encountered was that although much of the code that was written on the project previously was sensible, it was not structured so as to be easily reproducible. The code was not structured in a Github-project and this made it difficult for us to reproduce the results of the previous analysis. To make the pipeline reproducible and flexible we made a Github, structured the code into different (reasonable) folders and files and made an extensive Readme-file on the Github, describing how to reproduce (and tweak) the analysis.

## 2.4 Why Topic Modelling? (Mikkel Werling)

We used topic modeling as a primary methodology to investigate both RQ1 and RQ2. Topic modeling is widely used for information retrieval (IT). The idea is to represent the content of a large corpus of text as a relatively small number of topics that humans can interpret (Arun, Suresh, Madhavan, & Murthy, 2010). Topic modeling attempts to group documents into abstract topics, meaning that the topics are not prespecified but found by the implemented algorithm and then interpreted afterwards. A popular topic modeling approach is LDA (Arun et al., 2010; Cao, Xia, Li, Zhang, & Tang, 2009) which is schematically shown in Fig. 1 below. It uses sparse Dirichlet distributions for documents over topics ( $\alpha$ ) and topics over words ( $\beta$ ). The intuition is that documents are typically composed of a small amount of topics and that topics are composed of few central words. The  $\alpha$  distribution will have as many dimensions as the number of topics ( $k$ ) chosen and the  $\beta$  distribution will have as many dimensions as the number of tokens included in the corpus. Based on these distributions multinomial distributions  $\theta$  and  $\phi$  are generated. Topics for each document are sampled from the  $\theta$  distribution, and words based on these topics are sampled from the  $\phi$  distribution. Thus, the two processes combine to provide a list of words which comprise a document. The process will generate as many documents as there are in the original corpus and then evaluate how likely the original corpus is to have been generated by this process. The LDA process is thus clearly generative. The method attempts to maximize the probability that the documents in the original corpus will be generated by the model (Cao et al.,

2009).

LDA can use different algorithms to generate documents using this fundamental approach. The  $\alpha$ ,  $\beta$  and  $k$  hyperparameters are also very important. We specify our implementation and motivate our choice of hyperparameters in the methods section.

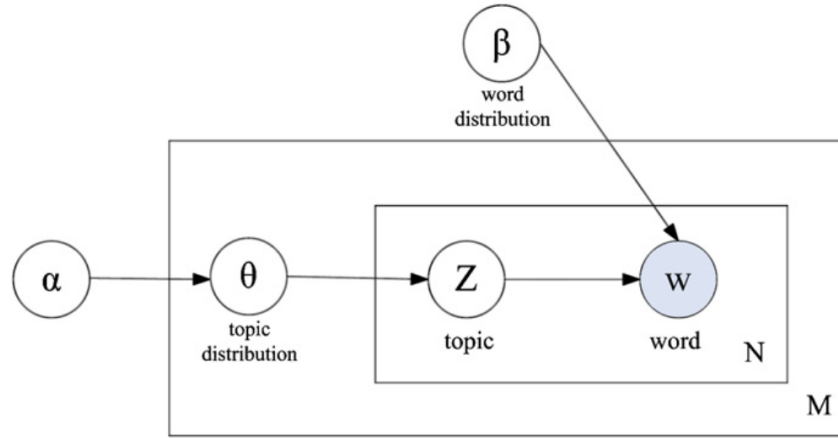


Figure 1: Schematic representation of Latent Dirichlet Allocation

Adapted from Cao et al. (2009).

### 3 Data (Victor Møller Poulsen)

We used Pushshift’s Reddit dataset (Baumgartner, Zannettou, Keegan, Squire, & Blackburn, 2020) to investigate our research questions. This dataset is a data-dump of all submissions and comments on Reddit from Januar 2005 to December 2019. We limited our scope to include two of the largest subreddits concerning smart home technologies. These are “Smarthome” ( $\sim 91\text{K}$  members) and “Homeautomation” ( $\sim 1$  million members). We included data from July 2017 - December 2019. This resulted in 379.883 individual text elements of submissions and comments.

To avoid bots, we took an ensemble approach with both manual and automatic screening of posts. The manual screening was simply based on whether “bot” was a part of the username. A total of 40 accounts were identified as bots using this approach. During this manual screening it was found that many bots explicitly stated that they were indeed bots. This led us to the simple idea of automatically screening users based on a regex expression designed to capture all posts in which “I am a bot” or variations thereof were present. Besides this, it has been found (Skowronski, 2019) that the best predictor of a user being a bot is the similarity of their posts. In an accurate machine learning model this single feature accounted for more than 46% of the decision weight (Skowronski, 2019). In short, bots generally tend to post either identical or similarly worded comments. We automatically excluded users with posts that contains sequences that were more than 40% identical to each other. These two automatic screening processes resulted in the exclusion of 44 accounts, ultimately leading to the exclusion of 84 accounts.

### 3.1 Preprocessing (Mikkel Werling)

We removed stopwords from the text using nltk’s (Loper & Bird, 2002) stopwords as well as our own list of extended stopwords. We also removed submissions and comments where 70% of words were not in nltk’s list of english words. Finally, we used spacy’s (Honnibal & Montani, 2017) english language model to get the lemma for each word.

As Reddit comments often consist of very few words, it makes sense to exploit the hierarchical structure of posts to create documents that consist of several comments that relate to each other. For RQ1 we are interested in simply squeezing as much information as possible out of the discussions on the Reddit forums. We were unsure as to whether it would be easier for LDA models to group the Reddit discussion into interpretable topics based on either (1) documents based on all comments relating directly to each other or (2) documents based on all comments to a post. We call the first case “trees” and the second case “threads”. In the “tree” approach the implicit assumption

is that the comments on Reddit posts diverge and constitute distinct discussions. In the “thread” approach all comments to a post are included in a single document that is fed to the LDA model, and as such the implicit assumption is that all comments to a post will be around a single topic. In addition to finding the best unit of analysis, modelling the data based on two ways of grouping the data should allow us to draw more robust conclusions. For RQ2 we decided to only include text from the user submitting the original post in the documents fed to the LDA. We call this “submissions” and use this as we are interested in whether users initialize a conversation about the three query words “trust”, “security” and “privacy”, and not how these are used more generally in the comments of posts. As “submissions” only include posts and comments made by the original authors, we believe this to be an efficient way of shaping the data to our interests. In sum this results in three different “atomic” units that we investigate in parallel and make different LDA models for (see Fig. 2). The concatenation of text into these groups resulted in submissions consisting of 52115 documents, threads consisting of 52115 documents and trees consisting of 196667 documents.

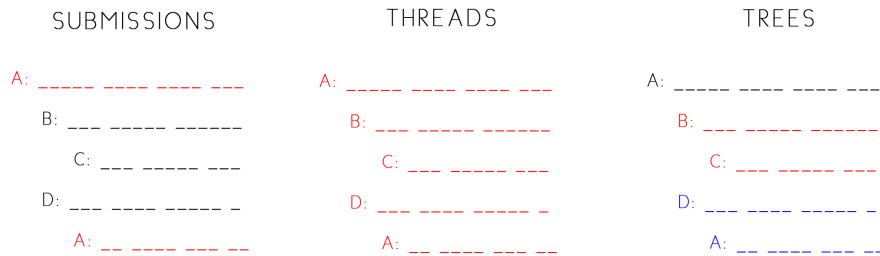


Figure 2: Atomic units of analysis

Atomic units of analysis. Submissions are generated by only considering the original post and the comments from the author of the post. Threads concatenate the original post and all the comments into one document. Finally, trees keeps some of the inherent hierarchical structure from the post. This is done by splitting posts into different documents, by splitting for each first tier comment and all the comments to this comment. Importantly, the text from the original post is pasted into all trees of a post.

## 4 Methods

### 4.1 Topic Modelling (Victor Møller Poulsen)

As has been mentioned a key methodology for both RQ1 and RQ2 is topic modeling using LDA. There are many options available, two of the most popular python implementations being Gensim’s implementation (Radim, 2010) and the Mallet wrapper (McCallum, 2002) for Gensim. Gensim uses a Variational Bayes sampling method while the Mallet wrapper uses Gibbs sampling. Generally, Gensim’s implementation is faster, while Mallet’s Gibbs sampling method has been found to be more precise (Rafferty, 2019). In the process of our work we tried both approaches but did not find evidence that Mallet was more precise. Because of this we used the Gensim implementation run on multiple CPU cores to optimize run time. Another nice thing about Gensim is that the  $\alpha$ ,  $\beta$  and  $k$  hyperparameters can be easily tweaked by the user from within python. After running into issues with automatically learning asymmetric priors for the  $\alpha$  and  $\beta$ -parameters (Radim, 2010), we chose to do a grid search over all combinations of plausible candidate values for the hyperparameters. Because of demanding run times we limited the grid to the following values for both threads and trees (RQ1) and submissions (RQ2):

$$\alpha : 0.01, 0.1, 1$$

$$\beta : 0.01, 0.1, 1$$

$$k : 5, 10, \dots, 50$$

The values chosen for  $\alpha$  and  $\beta$  are chosen to jump in powers instead of linearly as this ensures that the grid searches a more balanced and wide space. The values for these two parameters should be reasonable since  $\alpha = 1$  and  $\beta = 1$  are uniform distributions, while  $\alpha < 1$  is a symmetric distribution which assumes that documents are composed of few topics and  $\beta < 1$  is a symmetric distribution which assumes that topics are comprised of few words. Generally,  $\alpha$  and  $\beta$  below 1 are reasonable for natural language because of sparsity. We run the Gensim multicore LDA model with the number of



passes set to 10 and chunksize set to 2000. These appear to be reasonably common values. The chunksize is the number of documents processed before the model updates and the number of passes is the number of times that the LDA model goes through the whole corpus of documents.

## 4.2 Different Metrics to evaluate Quality of Topics (Mikkel Werling)

There are several ways of evaluating the quality of a topic model. Because topic models such as LDA are generative, a typical assessment has been to use predictive accuracy such as held-out likelihood and perplexity (Chang, Gerrish, Wang, Boyd-Graber, & Blei, 2009). However, these evaluations do not directly address human interpretability of topics, which is the goal here. In fact, Chang et al. (2009) report an overall negative correlation between these evaluation metrics and human interpretability. In large part due to Chang et al. (2009), coherence measures have been developed for topic models (including LDA). Topic coherence measures how often topic words appear together in a corpus and is a good proxy for human interpretability (Konstantinovskiy, 2016). The baseline implementation in Gensim’s model evaluation “c\_v coherence” is used here as a quantitative measure of model quality. c\_v coherence is bounded in the  $[0, 1]$  range, with larger values being better.

An issue with coherence measures however, is that they tend to continue improving for a larger number of topics, which we also see in our case (see Fig. 3 below). Human interpretability of topics on the other hand typically does not keep improving for a larger number of topics (Chang et al., 2009). To address this issue we used additional evaluation metrics from Cao et al. (2009) and Arun et al. (2010) and based our model selection on an ensemble approach. Both Cao et al. (2009) and Arun et al. (2010) focus specifically on finding the right number of topics ( $k$ ) rather than on optimizing other hyperparameters such as  $\alpha$  and  $\beta$ . Cao et al. (2009) presents a measure based on topic distribution over words. The intuition is that the right number of topics ( $k$ ) will be

the number where words are generally associated with as few topics as possible. The average cosine distance is used to assess the correlation between topics, which should be as small as possible and is experimentally validated (Cao et al., 2009). The measure presented in Arun et al. (2010) is technically pretty involved, and an explanation for the mathematics will not be provided here. The main point for our purposes is that Arun et al. (2010) presents empirical evidence that for the right number of topics ( $k$ ) the measure hits a minimum. We did not develop any rigorous method for combining the values of the three measures (c\_v coherence, (Cao et al., 2009), (Arun et al., 2010)) and as such we based our selection of reasonable  $\alpha$ ,  $\beta$  and  $k$  on eye-balling (see Fig. 3 below).

It should be noted that we do not interpret the absolute values of these evaluation metrics but rely on the relative difference between all of our models' performance against these metrics to find good candidates.

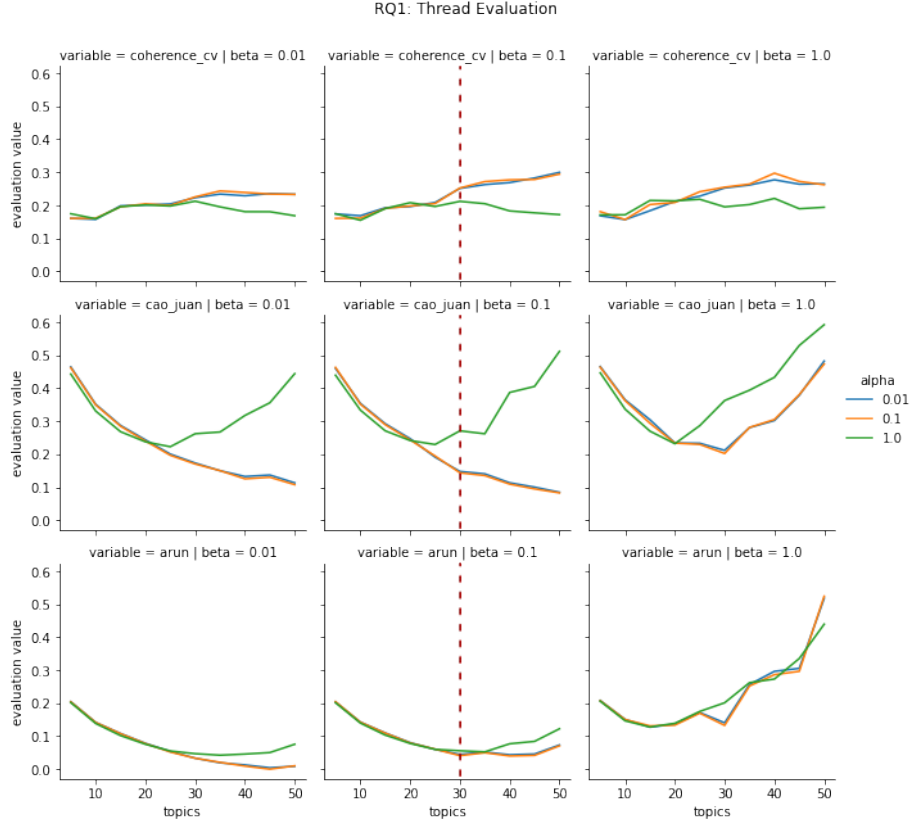


Figure 3: Evaluation of Topic Models (Threads)

Grid search of Topic Models over 50 topics with thread as atomic unit. Columns correspond to different values of  $\beta$ , rows to different evaluation metrics and colors to different values of  $\alpha$ . Red dashed line shows the selected  $k = 30$  and  $\beta = 0.1$ .

The previously described quantitative metrics for model quality are valuable in that they help us narrow the search space of candidate models. Because we created LDA models for three different subsets of our dataset (threads, trees, submissions) and ran over a grid of parameter values, it was practically impossible to visually inspect all of the models. However, the whole purpose of conducting LDA was in our case to interpret the topics and gain an exploratory overview of the themes discussed on the Reddit forums. As such, the next step was to visually inspect the models. This was

done primarily using pyLDAvis and word clouds (Sievert & Shirley, 2014). Eventually we settled on interpreting LDA models with  $k = 30$ ,  $\alpha = 0.01$  and  $\beta = 0.1$  for both submissions (RQ2) as well as threads and trees (RQ1). These models performed quantitatively reasonable (see Fig. 3 above and Fig. 8 and 9 in Appendix). More importantly however, the topics were found to be generally more interpretable and useful than for larger or smaller values for the  $k$  parameter. As such, all results from here on out will be from models with these hyperparameters.

#### **4.3 Labeling based on Hubert et al. (2020) (Victor Møller Poulsen)**

As mentioned previously, Hubert et al. (2020) provides a list of key terms that cover the categories of smart home devices. In order to structure the bottom-up LDA topics we attempted to label the topics into his six categories. These are “home entertainment” (e.g. smart speakers), “control and connectivity” (e.g. smart assistants), “security” (e.g. camera, windows), “comfort and lighting” (e.g. bulbs), “energy management” (e.g. thermostats) and “smart appliances” (e.g. smart fridges) (Hubert et al., 2020, p. 1). Beyond the categories listed in Hubert et al. (2020), we include two categories; “random” and “misc”. The random category covers topics that are not semantically coherent or simply consist of a bunch of common words. The misc category covers topics that are interpretable and have semantically related words, but which do not appear to fit neatly into the categories of Hubert et al. (2020).

#### **4.4 Investigating “privacy”, “trust” and “security” (Mikkel Werling)**

To investigate how the three keywords “privacy”, “trust” and “security” are used on the two subreddits, we start by simply calculating the frequency of the words in the documents. This is done to get a first indication of whether these are frequently used words on the forums. We calculate which topic is the most associated with each document. We examine topics which include one of the three words of interest as part of the ten

highest weighted words. Finally, we extract the 10 documents that are most representative of these topics while also including the word of interest. These 10 documents are qualitatively assessed to estimate whether the documents are related to concerns regarding the user's data.

## 5 Results

### 5.1 RQ1 (Victor Møller Poulsen)

Our task in the first part of this paper was to gain an overview of the topics discussed in the Reddit forums “homeautomation” and “smarthome”. The central results can be summarized in three figures highlighting different aspects of the discussion of smart home applications on Reddit. Figure 4 shows the prevalence of topics that we labelled as belonging to either of our eight categories, for the three atomic units that we worked with (RQ1: thread and tree, RQ2: submissions). Topic prevalence was calculated by finding the most dominant topic for each document, concatenating these topics into our predefined categories and calculating the relative frequency for each category. In general it is clear that the topics that cover smart home products according to Hubert et al. (2020) are not equally represented in the discussion. Across the models from all different atomic units, “comfort and lighting”, “control and connectivity” and “security” are very prevalent. By contrast “smart appliances”, “home entertainment” and “energy management” are consistently marginal topics. The topic labels “misc” and “random” vary more across models.

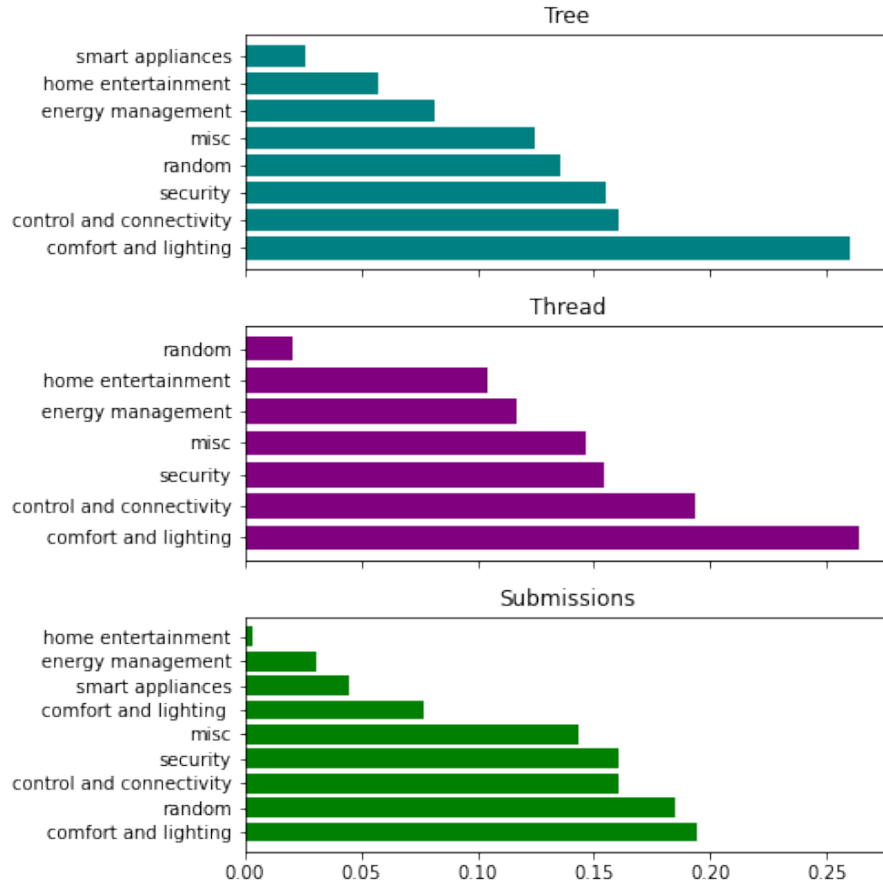


Figure 4: Category prevalence across different atomic units

X-axis is relative contribution of each topic. Missing bars indicate the absence of categories in the LDA models.

We were interested to see whether the labels that we imposed on the topics corresponded to the bottom-up clustering of topics as generated by pyLDavis using Jensen-Shannon distance (Sievert & Shirley, 2014). The three topics that were found to be prevalent across models, “comfort and lighting”, “control and connectivity” and “security” are also the ones that we see clustered in Figure 5. The clusters that we have marked on the plot are not perfectly exclusive, in that they only include topics that we have labelled “comfort and lighting”, “control and connectivity” and “security” but it

is very close. For an interactive view of the plot, [click here](#).

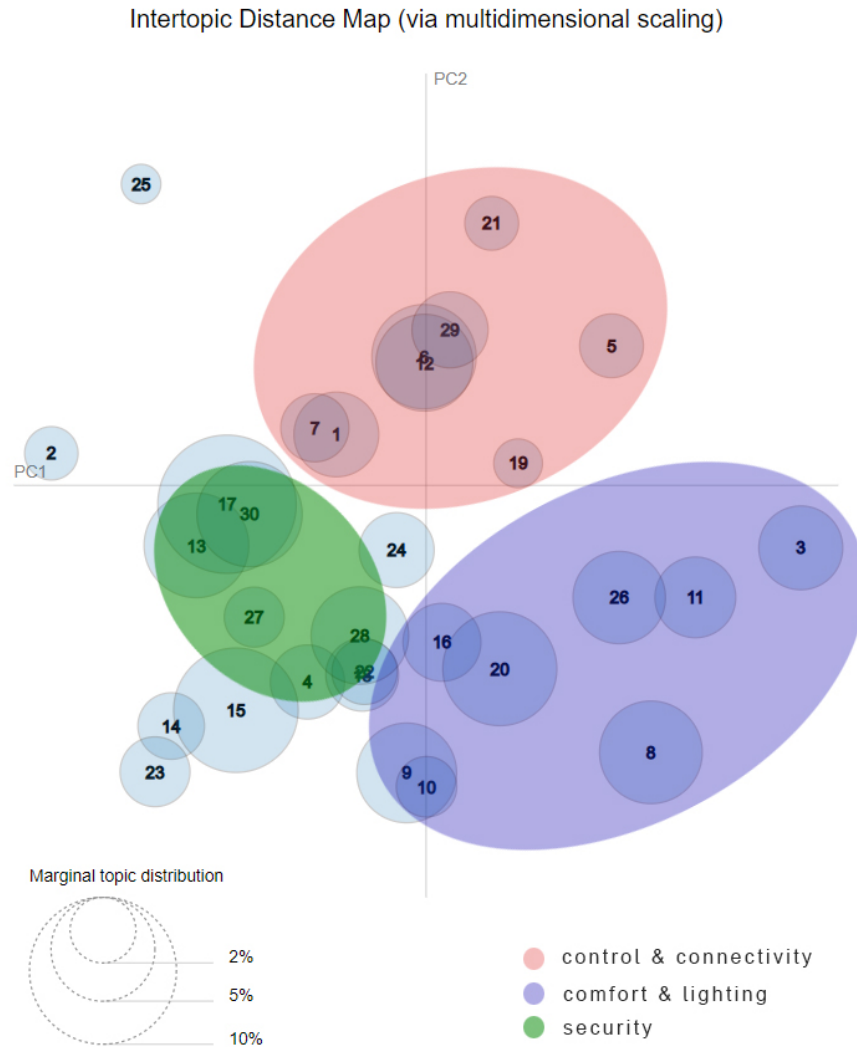


Figure 5: pyLDavis plot of the atomic unit "trees"

Distances between topics calculated using Jensen-Shannon divergence (Sievert & Shirley, 2014). Using our own labels for each topic, rough boundaries between the three largest topics are colored. For more detail, the interactive plot is available [here](#).

Figure 5 above shows that the largest superimposed categories actually do occupy different parts of the model-space. However to really provide a full picture of the topics discussed we must investigate the miscellaneous (misc) category, which is the most prevalent category in RQ1 models besides the three big ones mentioned previously. A word cloud plot of the top 50 terms in each topic labelled by us as “misc” is shown below. There might be an indication that topic 2, topic 17 and topic 25 are related to purchasing items and support (Fig 6, colored red). These three topics are also neighbors towards the upper-left quadrant of Figure 5 above. In addition topic 24 and 28 are neighbors in the middle of Figure 5 and seem to be related to a concrete sense of the “control and connectivity” topic (Fig. 6, colored blue).

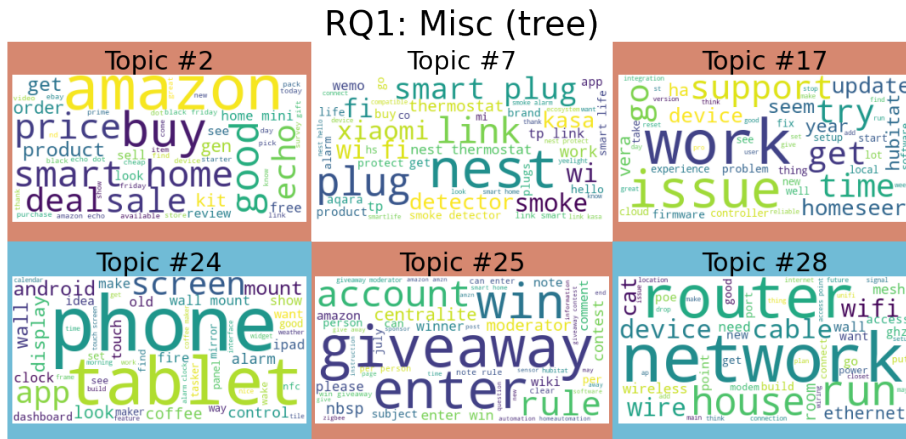


Figure 6: Word clouds of topics in the misc category

Word clouds of the topics that we labelled as miscellaneous (misc) from RQ1 tree model with  $\alpha = 0.01$ ,  $\beta = 0.1$ ,  $k = 30$ . Colors indicate possible category relationships, where red is related to purchasing items and support, while blue is related to concrete senses of connectivity.

## 5.2 RQ2 (Mikkel Werling)

By tracking the three query words “privacy”, “trust” and “security”, we find that they occur in 258, 333 and 2803 submissions out of 52115 respectively. These values cor-



respond to 0.50% of documents containing “privacy”, 0.64% containing “trust” and 5.38% containing “security”.

As almost no documents contained “privacy” and “trust” we investigated individual documents using these terms to assess the quality of the search terms. The content of these samples do seem to be revolving around the user’s privacy concerns regarding their data.

Turning to the much more prevalent “security” key term. We first plotted the two topics which have the term “security” among the 10 highest weighted words. This shows that security is used alongside terms such as “door”, “house” and “camera” (see Fig. 7 below).

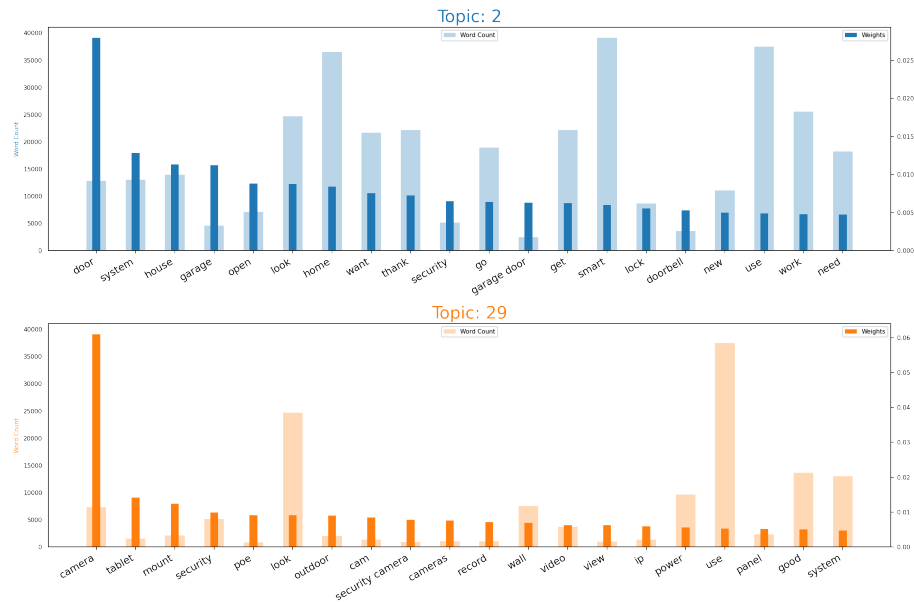


Figure 7: Weights and frequency of top 10 words in topics concerning security

Visualizing word counts and weights for Topic 2 and Topic 29 from the Submission Topic Model. Topics were chosen as they are the only two topics which have security as one of the ten words with the highest weights in the model. Left y-axis and opaque bars are word counts, and right y-axis and solid bars are weights of the model.

We extracted submissions that were grouped into topics 2 and 29 and contained the key-word “security” to qualitatively assess whether these referred to security in a concrete sense (e.g. security cameras or locks) or an abstract sense (e.g. data security). The extracted submissions were found to use “security” in an overwhelmingly concrete sense (e.g. security cameras and locks) (see Fig. 10 and 11 in Appendix).

## 6 Discussion

### 6.1 RQ2 (Victor Møller Poulsen)

Based on the low frequency of the words “privacy” and “trust” in the dataset, there seems to be little evidence that concerns over the privacy of one’s data is a central discussion on the subreddits. The search terms did in fact match documents in which “privacy” and “trust” were used to mean what we had expected, and as such the most natural conclusion seems to be the discussion around privacy and trust is marginal on these forums.

Security is the only query word which is used regularly. This is both in terms of raw frequency, and as an important word in the topics from our topic models. This could suggest that many users are concerned with either data security (e.g. co-occurring with “data” and “surveillance”) or that users are generally concerned with house security (e.g. “security” co-occurring with “house”, “camera” and “lock”). We do in fact find the latter. It seems to us as though the abstract (data) sense of “security” is semantically more related to the terms “privacy” and “trust”. The apparent marginal usage of security in this sense converges with the finding that “privacy” and “trust” are rarely used to clearly indicate that this is not a central topic of discussion.

This finding is surprising to us, since this concern over privacy and data security is generally thought to be a major part of the debate around smart home technologies (Hubert et al., 2020; Tabassum et al., 2019). However, the finding that these are not in

fact major topics of debate does seem to agree with the finding of Hubert et al. (2020) that “privacy” and “trust” were not significant mediators of the use of smart devices.

## 6.2 The Forum (Mikkel Werling)

To us the results from our investigation of both RQ1 and RQ2 suggests that the Reddit forum is overwhelmingly practically oriented rather than oriented towards abstract discussions. This is eminently clear from the finding that “privacy”, “trust” and the abstract notion of “security” are extremely rare. However, it also seems clear that many of the LDA topics from RQ1 seem to revolve around specific types of smart home products. Many of these are low-tech, centering around cables, prices and hue. Based on our results, questions such as “Which light should I buy?”, “Has anyone tried this smart speaker?” should be more common than questions such as “Should I be concerned about my privacy when talking around Alexa?”.

This begs the question of whether smart home users are generally unconcerned with notions of privacy and security surrounding personal data, or whether that is simply not what is primarily discussed on these specific subreddits. It might be the case that genuine users of smart home technologies are simply okay with trading privacy for functionality (Hubert et al., 2020; Tabassum et al., 2019). However, it might also be the case that the discussion on other forums (e.g. Twitter) is different and focuses more on notions of privacy surrounding personal data. In that case it would seem that RQ2 is not best pursued using this dataset.

## 7 Future work

### 7.1 Reddit as a practical forum (Victor Møller Poulsen)

Based on our investigation we are not in a position to tell whether smart home users are generally unconcerned with privacy regarding data security, or whether this topic of discussion is marginal specifically in the investigated subreddits. By analyzing data across different discussion boards from different websites (e.g. Twitter), one could investigate whether our observations generalize. Even if the words “privacy”, “trust” and “security” (in the abstract sense) are found to be rarely used it is not totally clear what conclusions we can draw. The observation is consistent with users either (a) being unconcerned with privacy or (b) having accepted the trade-off between functionality and supplying data. Converging evidence from other approaches, such as in Hubert et al. (2020) might be needed to settle this.

### 7.2 Optimizing (Mikkel Werling)

A focus for our work was to improve both flexibility and efficiency of the code. In several places we were able to speed up processing substantially. In preprocessing for instance we optimized the lemmatization processes, cutting run time by a factor of 20. This was necessary as we increased the amount of documents used (from 5000 to 196667 documents in the biggest corpus) and the breadth of the analysis (from 1 to 3 atomic units of analysis). We had less success with optimizing the speed of the LDA model fitting. Although implementing multiprocessing did speed up processing somewhat it appears that Gensim does not currently support GPU. Further optimizing the efficiency and flexibility of the code, e.g. by implementing LDA which can be run on GPU’s would constitute major progress in our opinion.

## 8 Conclusion

Using LDA as our main methodology we investigated the discussions on two of the biggest subreddits concerning smart home technologies. We find that topics generally tend to fall in previously proposed categories (Hubert et al., 2020), but that “control and connectivity”, “comfort and lighting” and “security” dominate the discussion. Using three query words of interest (“trust”, “privacy”, “security”) we sought to estimate the degree to which users were concerned about data security issues. We find that “trust” and “privacy” are used in less than 1% of documents, while “security” is used in more than 5% of the documents. However, when security is used, it is used to refer to security systems or security cameras, not the security of one’s data. We are not in a position to conclude whether users of smart home technologies are generally unconcerned about data security, or whether the subreddits are simply not used to discuss these issues. We therefore suggest that future research should include additional discussion boards from other sites (e.g. Twitter) to investigate whether the apparent lack of concern regarding data security and privacy is a general feature of the community of smart home technology users, or simply an idiosyncratic property of the forum. In this regard, our efforts to make the pipeline easily reproducible and flexible could help make future efforts easier to conduct.

## 9 Appendix

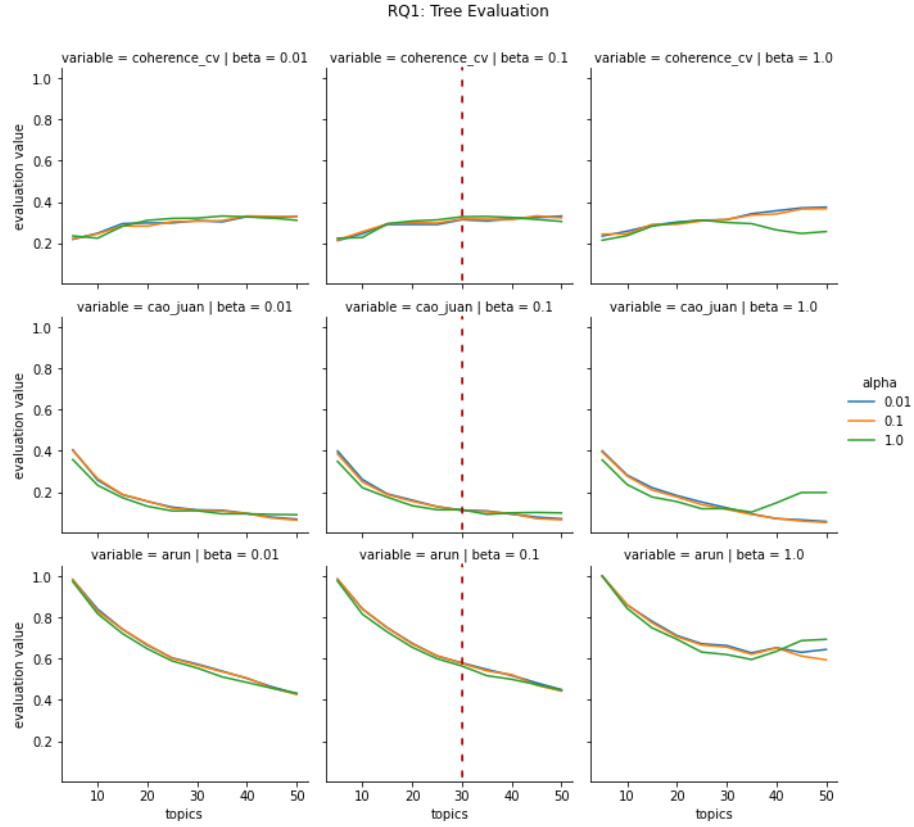


Figure 8: Evaluation of Topic Models (Trees)

Grid search of Topic Models over 50 topics with tree as atomic unit. Red dashed shows the selected amount of topics.

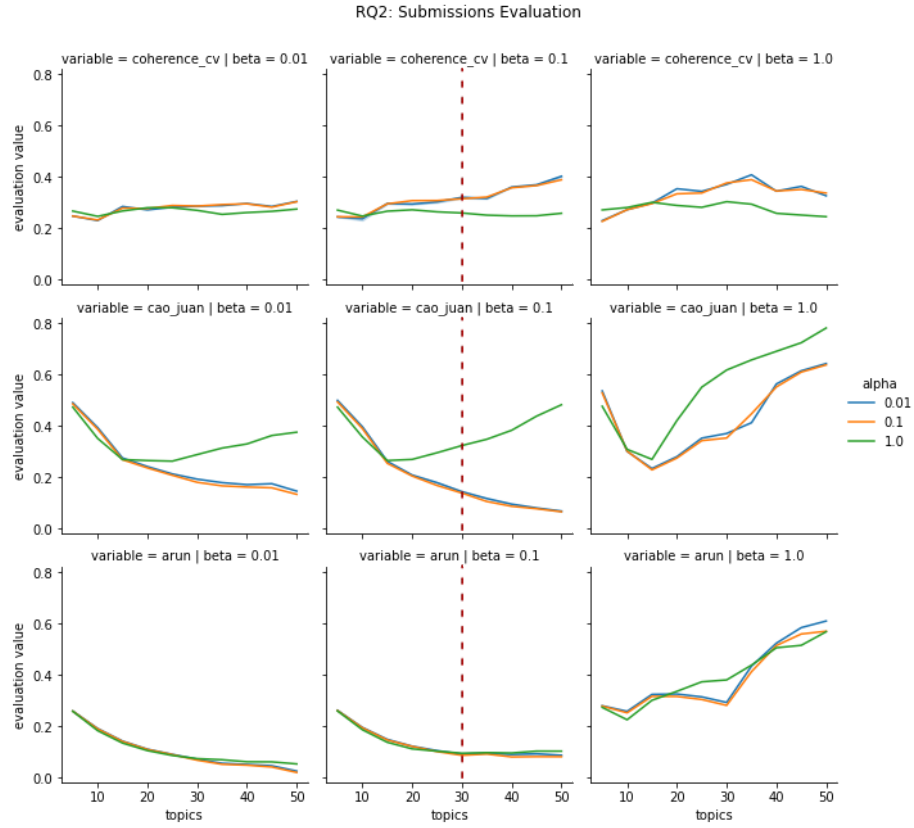


Figure 9: Evaluation of Topic Models (Submissions)

Grid search of Topic Models over 50 topics with Submission as atomic unit. Red dashed shows the selected amount of topics.

1. "Looking for video doorbell as well as security camera options for parent's house My mom and step dad (60s) have just moved to a new house. They are in a very safe neighborhood, but their front door has no peephole and no windows to look out and see who is at the door. Normally I wouldn't be concerned, but my step dad's mom (80s) has gone completely r/JustNoMIL with threats against my mom and calling my step dad non stop to just yell at him about nonsense. She lives close to their house and, while hey son wants nothing to do with her, it's totally within her realm to show up unannounced. I just want them to be able to know who is at the door, but I'm also interested in getting them some security cameras for the back screened in porch and a few other windows. I'm not super tech savvy, but with instruction and YouTube I can figure most things out so I'm wondering what's my best option for something they will be able to use easily and will keep them safe."
2. "Replacing Vivint security system My contract is finally up on my vivint panel and I want to replace it with something that can be customized. I have the vivint door bell, and thermostat, with some z-wave devices and sensors. I want to integrate more cameras and my garage door opener with it. I would like to keep as many devices as possible, what is a good system to switch to? I don't have a preference on who the monitoring service is with. Thanks for any suggestions."
3. "Simple home security with remote alerting? I'm purchasing a house that will be under construction for about 6 months or so. It'll be vacant during that time and I wanted to get some basic level security on the house so I can be alerted if anyone attempts to gain entry to the house. I'm trying to stay away from a contract but subscription service like ring would be fine."
4. "Home security system I need suggestions of a home security system. Should I just pay for ADT or some local service? I like that Arlo but its super expensive. Is it really worth it? You must work for them huh?"
5. "Looking for whole home, one or multiple systems to automate things. Lights, camera, security system. Help needed"
6. "Use ADT security system without their service thank you, just the type of thing I was looking for"
7. "2gig equipment LOT I used to do subcontract security installs. Went through all of my stuff and this is what is left."
8. "Smart security system protects your home without costly subscription fees"
9. "Recommend the ideal home security system for 2 level house"
10. "Any feelings o the Envisalink 4 by Eyezon? I just ordered this unit for my cottage. I'll only be controlling the security system for now."

*Figure 10: 10 samples from Topic 2 containing "security"*



1. "Question about home security cameras I have recently purchased a wifi camera for in the home: [This one](weblink).Can anybody tell me if there's a good, free, way to set this up so it records and saves 12 hours of video. I have a spare PC in my house with about 1 TB of hard disk space. It would be neat if I could have it automatically save some video, however much is possible with that PC. Thanks in advance! Thanks, it looks like i can download it, or purchase the "LE" or Full Version? Do I need purchase in order to use it? Or does it work with a free download? Are you British? Cool, thank you for this!"
2. "Weather/Timelapse Webcam? I'm trying to find the best outdoor PoE webcam to be able to capture still images of landscape. Unfortunately, everything I find seems to be video/security cameras. I'd rather get a camera than can take high resolution pictures at the expense of fps since I don't really need video. Anyone have any suggestions? These pictures will be stitched together for a timelapse video daily."
3. "Considerations for a home security camera system"
4. "4G security camera for timelapse photos?"
5. "Is this a good security camera?"
6. "Best wired security camera?"
7. "What home security cameras of good quality do you use?"
8. "Has anyone used backup cameras as security cameras?"
9. "Looking for recommendation for outdoor security camera"
10. "Hidden IP cameras and security."

Figure 11: 10 samples from Topic 29 containing "security"

## References

- Arun, R., Suresh, V., Madhavan, C. V., & Murthy, M. N. (2010). On finding the natural number of topics with latent dirichlet allocation: Some observations. In *Pacific-asia conference on knowledge discovery and data mining* (pp. 391–402).
- Baumgartner, J., Zannettou, S., Keegan, B., Squire, M., & Blackburn, J. (2020). The pushshift reddit dataset. In *Proceedings of the international aaai conference on web and social media* (Vol. 14, pp. 830–839).
- Cao, J., Xia, T., Li, J., Zhang, Y., & Tang, S. (2009). A density-based method for

- adaptive lda model selection. *Neurocomputing*, 72(7-9), 1775–1781.
- Chang, J., Gerrish, S., Wang, C., Boyd-Graber, J., & Blei, D. (2009). Reading tea leaves: How humans interpret topic models. *Advances in neural information processing systems*, 22, 288–296.
- Domingos, P. (2012). A few useful things to know about machine learning. *Communications of the ACM*, 55(10), 78–87.
- Honnibal, M., & Montani, I. (2017). *spaCy 2: Natural language understanding with Bloom embeddings, convolutional neural networks and incremental parsing*. (To appear)
- Hubert, M., Carugati, A., Brock, C., & Obel, B. (2020). Take it personally—the role of consumers’ perceived value of personalization on cross-category use in a smart home ecosystem. In *Proceedings of the 53rd hawaii international conference on system sciences*.
- Loper, E., & Bird, S. (2002). Nltk: the natural language toolkit. *arXiv preprint cs/0205028*.
- Novak, T. P., & Hoffman, D. L. (2019). Relationship journeys in the internet of things: a new framework for understanding interactions between consumers and smart objects. *Journal of the Academy of Marketing Science*, 47(2), 216–237.
- Perez, S. (2018). *Smart speakers hit critical mass in 2018*. Retrieved 2021-01-03, from <https://tinyurl.com/ybvnq78q>
- Sievert, C., & Shirley, K. (2014). Ldavis: A method for visualizing and interpreting topics. In *Proceedings of the workshop on interactive language learning, visualization, and interfaces* (pp. 63–70).
- Skowronski, J. (2019, July). *Identifying trolls and bots on Reddit with machine learning (Part 2)*. Retrieved 2021-01-03, from <https://tinyurl.com/y7bojtax>
- Tabassum, M., Kosiński, T., Frik, A., Malkin, N., Wijesekera, P., Egelman, S., & Lipford, H. R. (2019). Investigating users’ preferences and expectations for always-listening voice assistants. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 3(4), 1–23.