

香港中文大學

The Chinese University of Hong Kong

Final Year Project Report (Term 1)

Virtual Reality Application Comfort Level Rating Evaluator

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Abstract

VR applications have gradually become popular in recent years, and people are full of endless yearning and anticipation for the metaverse. However, for the special nature of VR applications compared to traditional mobile applications, different VR applications may bring varying degrees of physiological reactions to humans, which is a major obstacle to advancing the development of the metaverse. In general, it is a time-consuming and long-term task to determine the comfort level of VR applications, and through this project, we would like to work on designing a quick evaluator tool for the comfort level rating of VR applications, obtaining a relatively accurate VR comfort level rating in a short period of time to meet the relevant needs of users, VR application developers and VR application release platform. At the same time, we also utilized information from five mainstream VR application platforms, namely steam, oculus store, oculus lab, sidequest, and viveport, to produce our own VR application information dataset to train the comfort level rating evaluator tool and facilitate subsequent research and discussion.

1 Introduction

1.1 Metaverse

The Metaverse is an online, shared, permanent, three-dimensional virtual world that enables connections between individuals from all walks of life. Similar to how the internet links several websites together using a single browser, it would connect multiple platforms.

This idea was first presented in Neal Stephenson's 1992 cyberpunk novel *Snow Crash* [19]. In this case, the idea of a metaverse was first thought to be mere science fiction, but it now seems that it may become a part of our reality in the upcoming years.



Figure 1: Metaverse: A Shared Virtual Environment [1]

1.2 Metaverse and Virtual Reality

Immersing oneself in a digitally created virtual world where we can engage is a part of virtual reality. A human can experience and converse in a three-dimensional, computer-generated world. This person enters or is absorbed into this virtual environment and has power over objects or can carry out a series of acts while there. We might consider virtual reality to

be essentially one of the fundamental automation for the development of the Metaverse. It enables the users to participate in the metaverse.



Figure 2: Virtual Reality Headset

1.3 Virtual Reality Application Comfort Level Rating

There are warnings and ratings for many video games. Because some apps are more likely than others to make users queasy, virtual reality adds another layer to the same experience. It can be evaluated using comfort ratings.

Meta defines comfort rating as a way to let users know the intensity of an app before they decide to try the experience.

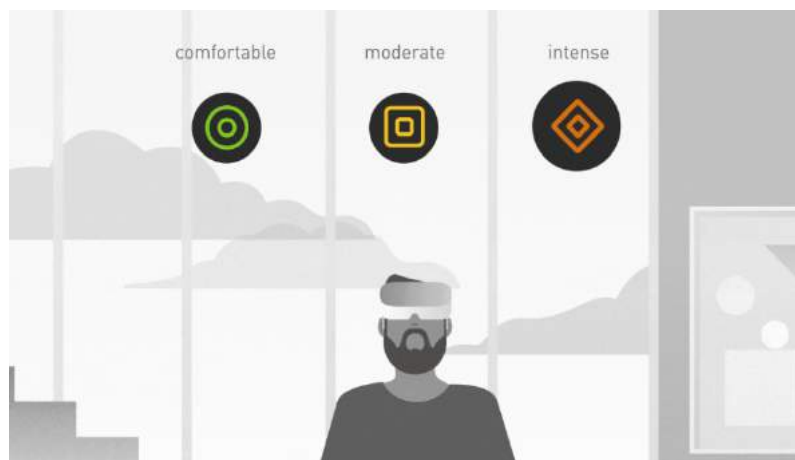


Figure 3: Comfort Level Rating [9]

Comfortable experiences are appropriate for most people, although

this rating doesn't mean that an experience is going to be comfortable for everyone. These experiences generally avoid camera movement, player motion, or disorienting content and effects [9].

Moderate experiences are appropriate for many but certainly not everyone. These experiences might incorporate some camera movement, player motion, or occasionally disorienting content and effects [9].

Intense experiences aren't appropriate for most people, especially those who are new to VR. These experiences incorporate significant camera movement, player motion, or disorienting content and effects [9].

Unrated experiences may contain intense content, which may not be right for most people, especially those who are new to VR. If you experience motion sickness or other VR effects from an unrated experience, you should select another unrated experience, or try an experience in the Store that's rated for your comfort level [9].

2 Background

For the special nature of VR applications compared to traditional mobile applications, different VR applications may bring varying degrees of physiological reactions to humans, which is a major obstacle to advancing the development of the metaverse. For example, if a VR app contains a lot of spinning, jumping, and flashing action content, it is likely to be an app that gives the user an extreme sense of vertigo. However, determining the comfort level of VR applications is a very time-consuming and long-term task, which needs to do lots of experiments on different users.

Now, for the five major VR application release platforms, namely steam, oculus store, oculus lab, sidequest, and viveport, only oculus store and sidequest actively provide information about the comfort level of their related

applications, on oculus, the provider is the official meta, but on sidequest, the provider is its related application developer.

2.1 Application Platform

For VR applications, there are now five mainstream VR application publishing platforms, they are STEAM, Oculus Store, Oculus lab, VIVE-PORT, and SideQuest.

2.1.1 Steam

One of the biggest and most complete digital distribution systems in the world is Steam. On the site, gamers can buy, download, discuss, upload, and share games and software. Of course, this platform offers a wide variety of VR applications.



Figure 4: Steam Platform

2.1.2 Oculus Store

At the Oculus Connect conference, Oculus launched the "Oculus Platform" store for developers to share their virtual reality experiences and apps. This updated Oculus Share marketplace will enable users to browse the Oculus Platform in virtual reality and download apps, games, and en-

tertainment experiences starting in the fall of 2014 for the Samsung Gear VR created by Oculus.

The Oculus Platform was claimed eventually to have Rift, iOS, Android, Windows Phone, Chrome, Firefox, Safari, and Internet Explorer versions. By establishing this market, Oculus might attract an ecosystem to its mobile and PC-based VR devices. Oculus Platform might become one of the first platforms for developers to sell the VR experiences they create [4].



Figure 5: Oculus Store Platform

2.1.3 Oculus App Lab

Oculus is a new way provided by oculus for developers to distribute apps directly to consumers safely and securely, with the help of direct links or platforms like SideQuest, without requiring store approval and without sideloading. App Lab makes it possible that even if the application is early in development, experimental, or aimed at a unique audience, it can still get the application directly to a community [18].

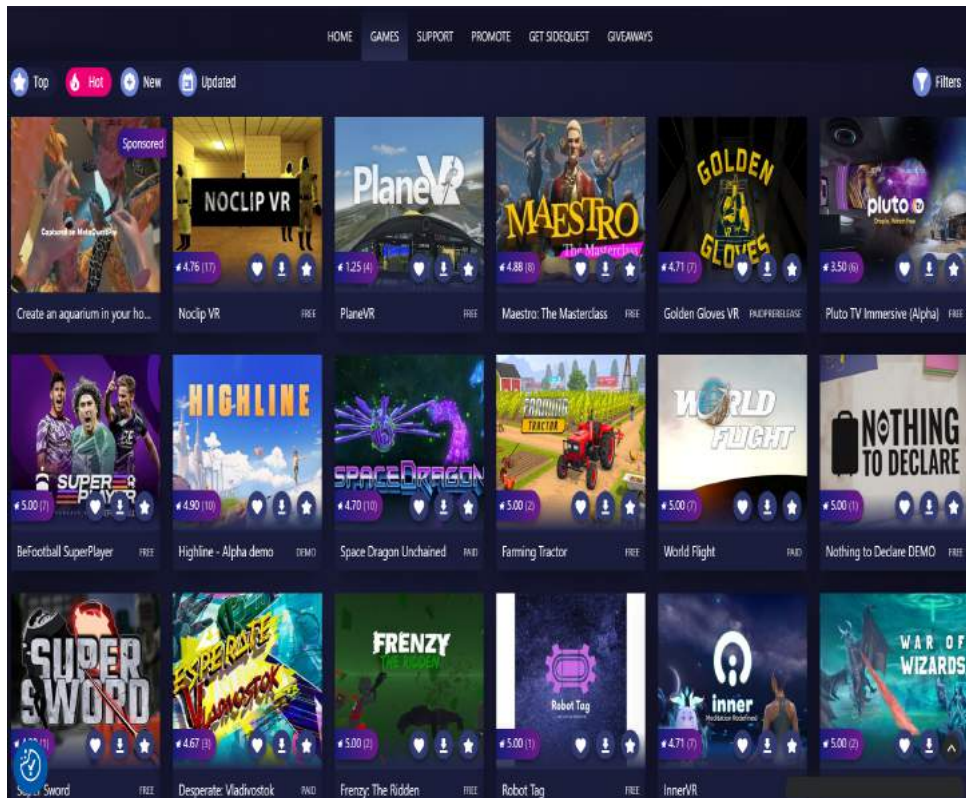


Figure 6: Oculus Lab

2.1.4 Viveport

Viveport is the app store for virtual reality content and experiences. Viveport offers a broad variety of VR experiences that encourage users to explore, create, interact, watch, and purchase in virtual reality. This platform builds on the rapid expansion and popularity of VR gaming.

With Viveport, the officials hope to further their mission of liberating human imagination from the constraints of reality by providing the most comprehensive and varied collection of VR experiences currently accessible [15].

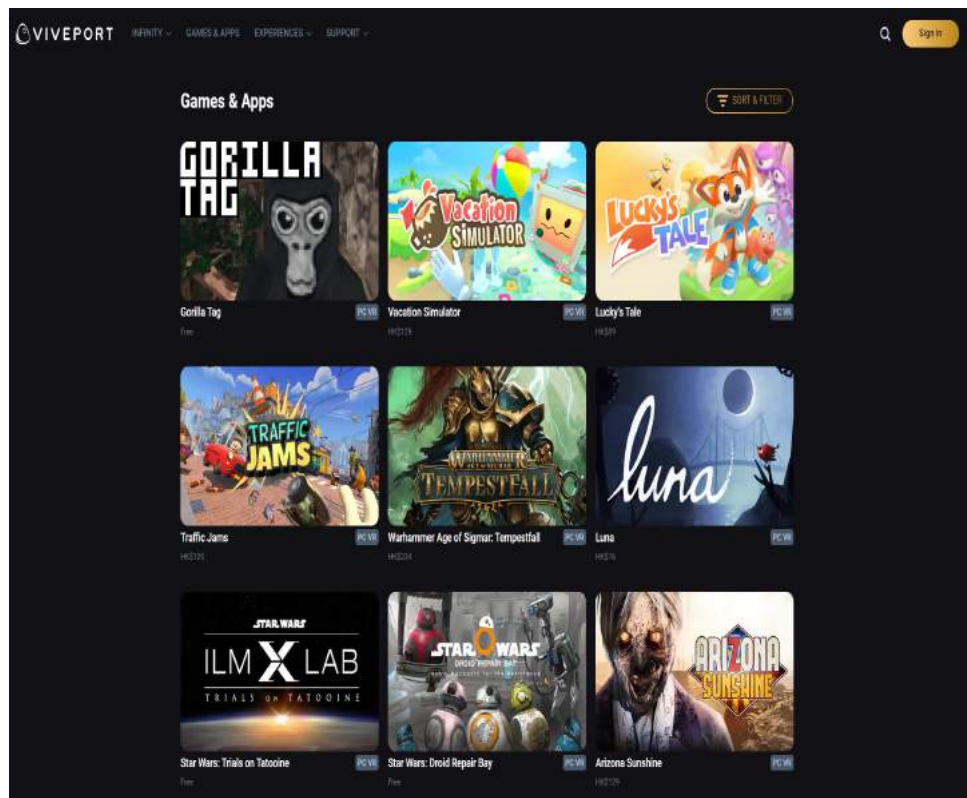


Figure 7: Viveport platform

2.1.5 SideQuest

SideQuest is a VR content platform for standalone headsets like Quest and Quest 2 where users can explore a vast collection of VR titles ranging from experimental games, tech demos, and game ports to full-scale games listed on the official Oculus store and App Lab [16]. This user-driven platform fosters interaction and experimentation with VR apps by fostering meaningful relationships between users and developers. Because of this, SideQuest frequently has some of the most inventive and unusual titles! Games like Gorilla Tag, Pavlov, Puzzling Places, Ancient Dungeon, Gun Raiders, Quest3Doom, and QuestCraft, which have amassed hundreds of thousands of downloads, were all born on SideQuest and have gone on to become real sensations in the VR community.



Figure 8: sidequest platform

3 Motivation

Today, there is no automatic tool for the comfort level rating evaluation of VR applications in the current market, and most of them require a tremendous process to determine, which consumes a lot of time and money resources. In addition, rating the comfort level of a VR application quickly can benefit users, developers as well as VR application platforms.

3.1 User

Nowadays, if users do not have the sources to learn about the comfort level information of VR applications, they can only know the comfort level of VR applications through their personal use. However, using an application without knowing its comfort level may lead to some problems, which may even cause some short-time irrecoverable damage to the body, such as dizziness or even fainting. If users can learn the level of comfort of the VR application before using it, this can be largely effective in avoiding this kind of problem.

3.2 Developer

For developers, during the process of developing applications, to a certain extent, they need some metric to know the comfort level of their applications and make some related modifications to make their applications more suitable to use. Providing comfort level indicators could help developers during the development stage hence improving the quality of the final product.

3.3 Platform

As VR application publishing platforms, they need to consider the user experience of purchasing the application, and the refund rate is an important indicator. If they can provide application comfort information to let users know the application comfort level information in advance, which can effectively reduce the case that the user want to get refund for application causing physiological harm and make negative comments about the platform for misleading application information.

4 Dataset

Since we do not have an existing dataset related to VR application comfort level rating, we need to prepare it on our own. We utilized the crawler tool to get application information from the platform website.

4.1 Web Crawling Tool Scrapy

When scanning websites and extracting structured data from their pages, Scrapy is one of the quickest high-level web crawling and web scraping frameworks available. It may be utilized for a variety of tasks, including monitoring, automated testing, and data mining.



Figure 9: A Web Crawling Tool: Scrapy

4.2 Application Example on Platform Website

4.2.1 Steam example

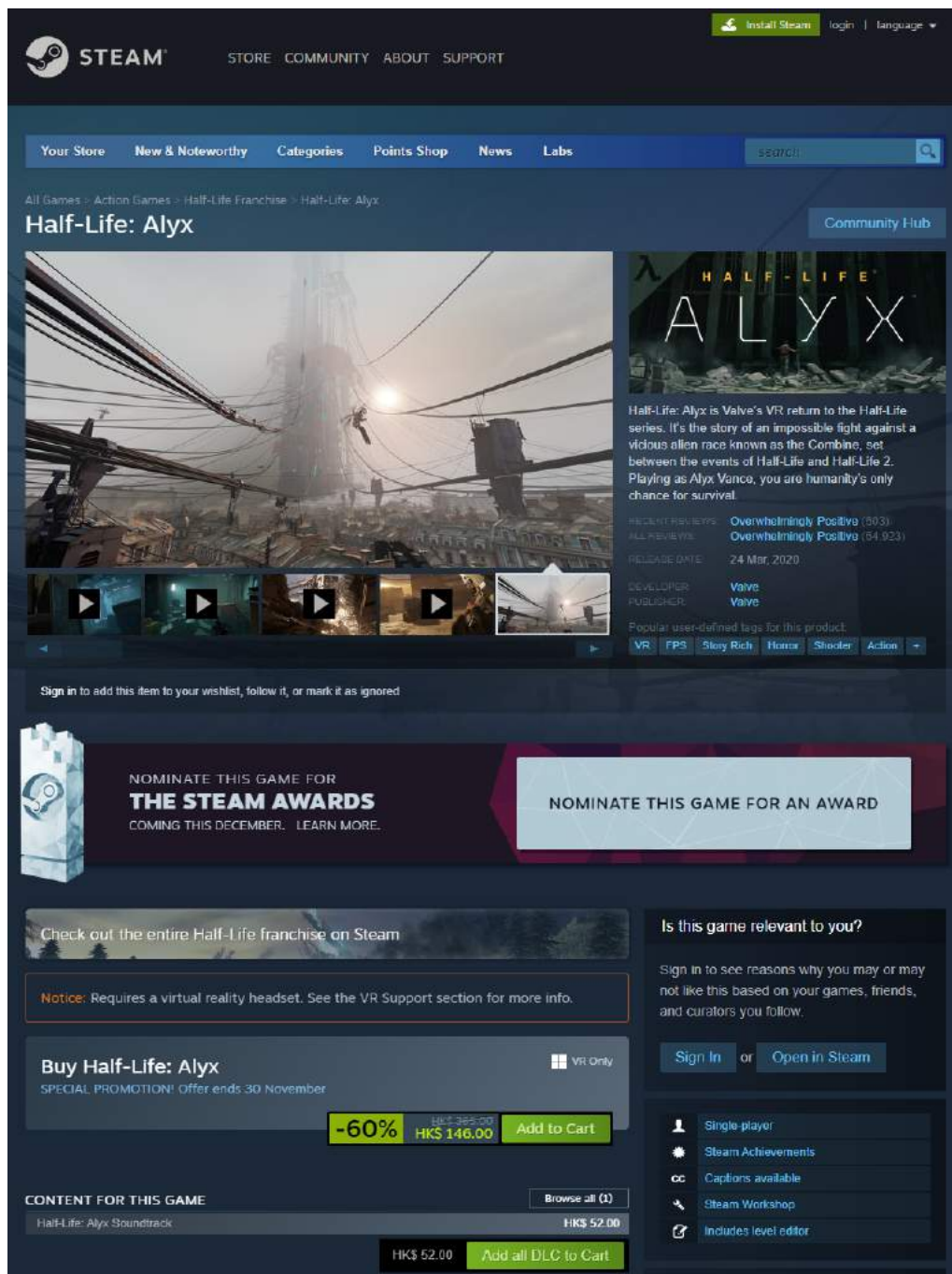


Figure 10: Half-Life: Alyx's information on steam (part1)

The steam platform provides information about the game title, game description, game clips, etc. But users can not get information about the comfort level of that application.

ABOUT THIS GAME

Half-Life: Alyx is Valve's VR return to the Half-Life series. It's the story of an impossible fight against a vicious alien race known as the Combine, set between the events of Half-Life and Half-Life 2.

Playing as Alyx Vance, you are humanity's only chance for survival. The Combine's control of the planet since the Black Mesa incident has only strengthened as they corral the remaining population in cities. Among them are some of Earth's greatest scientists: you and your father, Dr. Eli Vance.

As founders of a fledgling resistance, you've continued your clandestine scientific activity—performing critical research, and building invaluable tools for the few humans brave enough to defy the Combine.

Every day, you learn more about your enemy, and every day you work toward finding a weakness.

ABOUT GAMEPLAY IN VR:

Valve's return to the Half-Life universe that started it all was built from the ground up for virtual reality. VR was built to enable the gameplay that sits at the heart of Half-Life.

Immerse yourself in deep environmental interactions, puzzle solving, world exploration, and visceral combat.

Lean to aim around a broken wall and under a Barnacle to make an impossible shot. Rummage through shelves to find a healing syringe and some shotgun shells. Manipulate tools to hack alien interfaces. Toss a bottle through a window to distract an enemy. Rip a Headcrab off your face and throw it out the window.

COMMUNITY-BUILT ENVIRONMENTS

A set of Source 2 tools for building new levels is included with the game, enabling any player to build and contribute new environments for the community to enjoy through **Half-Life: Alyx's Steam Workshop**. Hammer, Valve's level authoring tool, has been updated with all of the game's virtual reality gameplay tools and components.

MATURE CONTENT DESCRIPTION

The developers describe the content like this:
Includes violence and gore.

SYSTEM REQUIREMENTS

MINIMUM:	RECOMMENDED:
Requires a 64-bit processor and operating system	Requires a 64-bit processor and operating system
OS: Windows 10	
Processor: Core i5-7500 / Ryzen 5 1600	
Memory: 12 GB RAM	
Graphics: GTX 1060 / RX 580 - 6GB VRAM	

MORE FROM HALF-LIFE

Half-Life 2

-90% HK\$ 66.00
HK\$ 6.60

Half-Life: Source

-90% HK\$ 66.00
HK\$ 6.60

Half-Life

-90% HK\$ 66.00
HK\$ 5.20

VR Support

Headsets

- Valve Index
- HTC Vive
- Oculus Rift
- Windows Mixed Reality

Tracked Motion Controllers

- Tracked Motion Controllers

Play Area

- Seated
- Standing
- Room-Scale

Languages:

	Interface	Full Audio	Subtitles
English	✓	✓	✓
French	✓		✓
German	✓		✓
Spanish - Spain	✓		✓
Japanese	✓		✓

[See all 28 supported languages](#)

STEAM DECK COMPATIBILITY

Unsupported [Learn more](#)

Includes 42 Steam Achievements

[View all 42](#)

TITLE: Half-Life: Alyx
 GENRE: Action, Adventure
 DEVELOPER: Valve
 PUBLISHER: Valve
 FRANCHISE: Half-Life
 RELEASE DATE: 24 Mar, 2020

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93 **metacritic**
 Read Critic Reviews

Awards

Figure 11: Half-Life: Alyx's information on steam (part2)

It also provides information about system requirements, supported VR headsets, etc.

4.2.2 Oculus Store Example

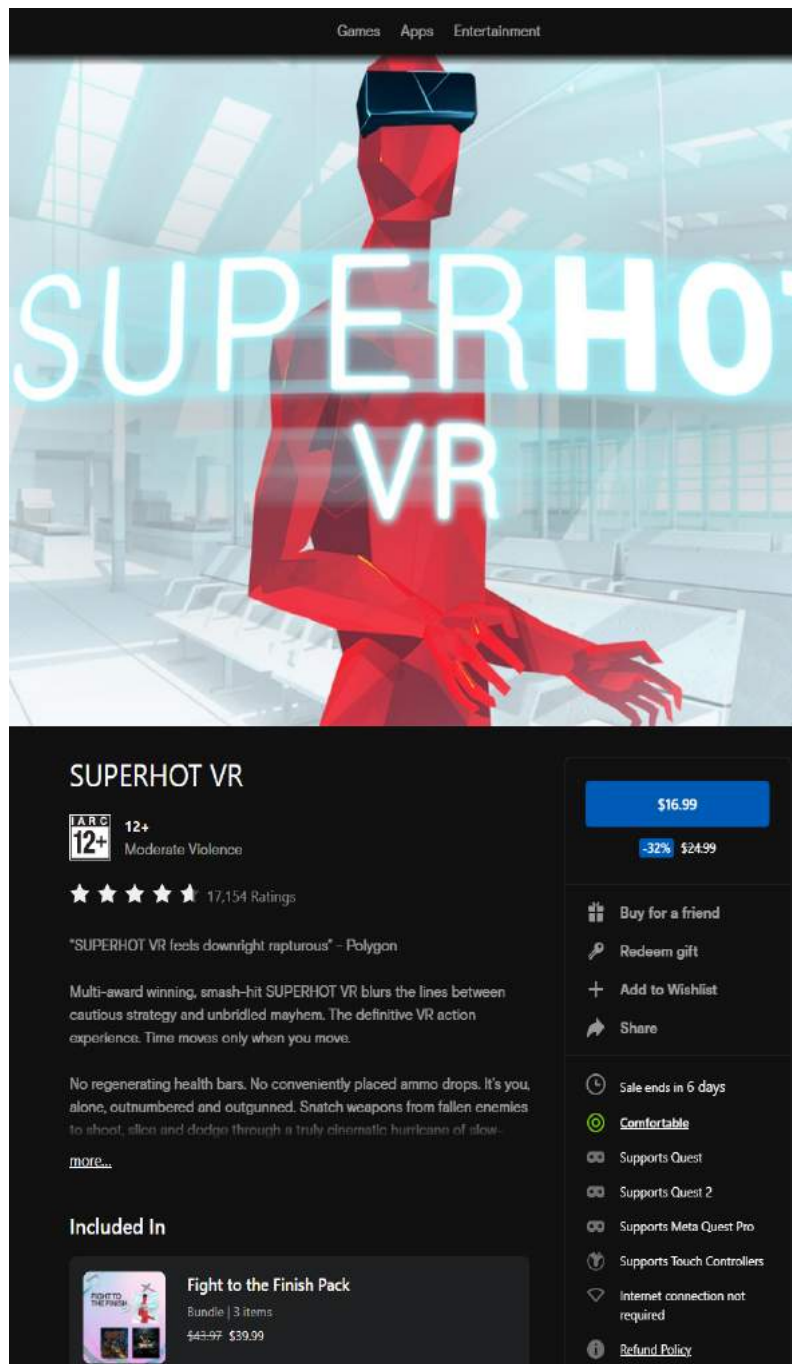


Figure 12: SUPERSHOT VR's information on oculus store (part1)

It provides information about the game title, game description, game pictures, etc. And users can get information about the comfort level for that application at the right bar of this page.

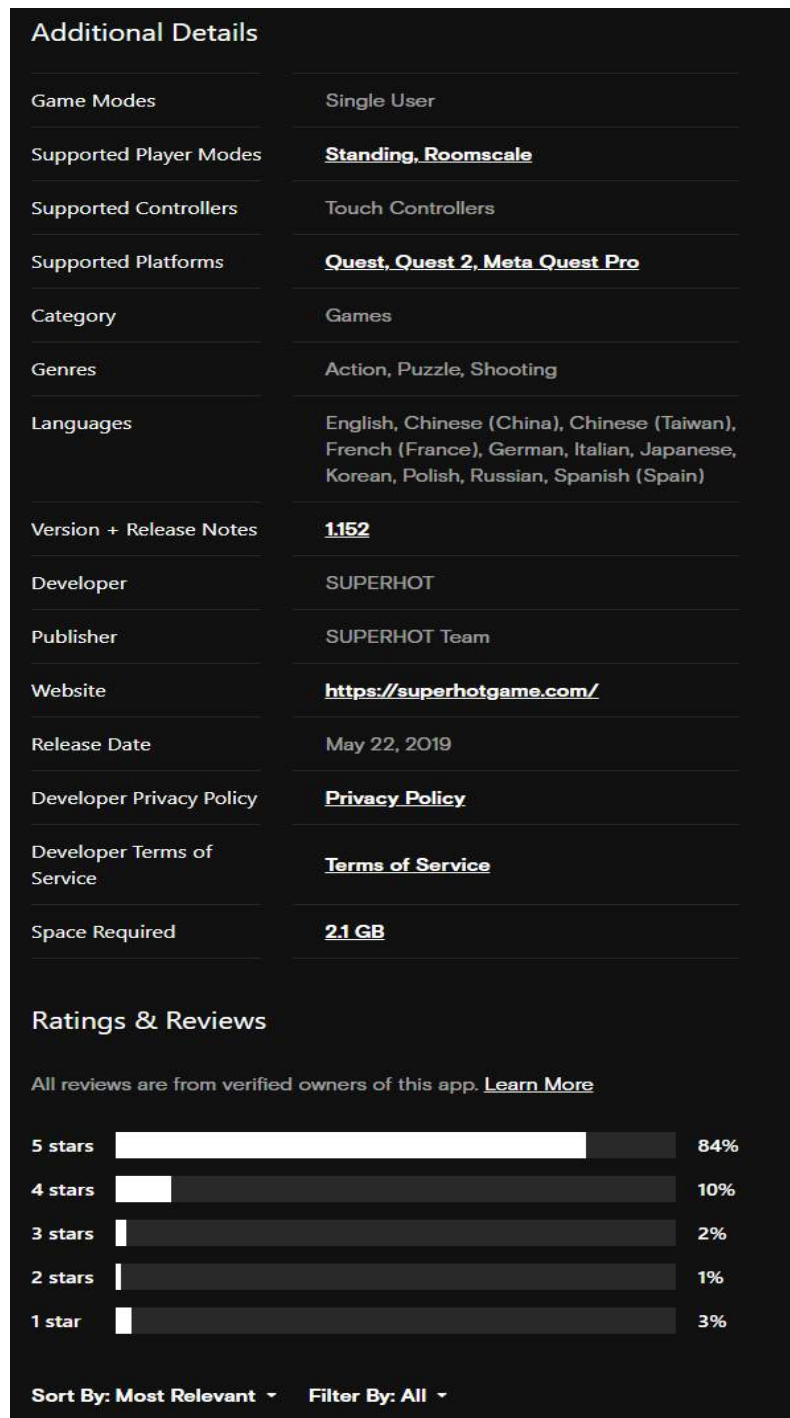


Figure 13: SUPERSHOT VR's information on oculus store (part2)

It also provides information about the game developer, languages, reviews, etc.

4.3 Construct Datasets

Since the layout of the information on the web pages of each platform is different, we use slightly different methods when crawling the web pages of different platforms, of which there are two main ways.

4.3.1 Extra Data from HTML Response

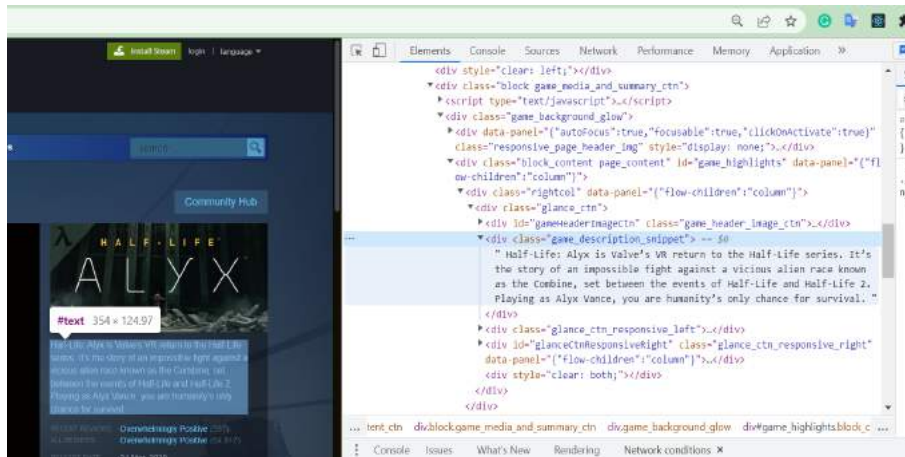


Figure 14: steam page structure

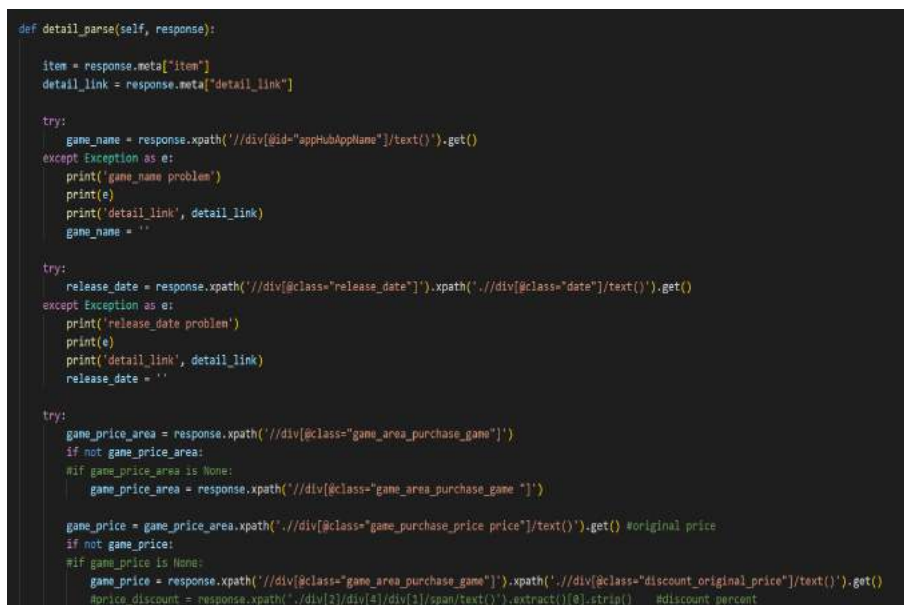


Figure 15: steam crawler codes (parse part)

For example, when we build the steam application dataset, we directly get all related field information utilizing the Document Object Model (DOM) tree.

4.3.2 Extra data from graphql response

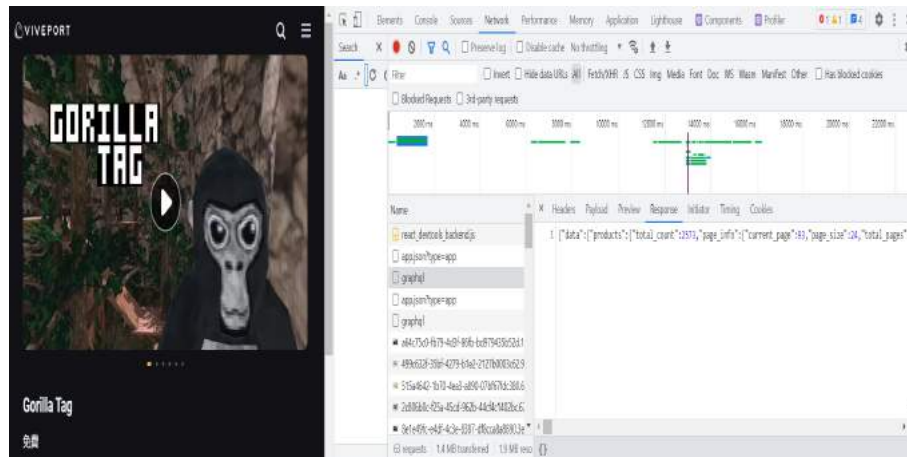


Figure 16: viveport crawler process

```
def review_parse(self,response):  
    #print("enter to review parse")  
    sample = response.meta["sample"]  
    game_detail_request_url = response.meta["detail_link"]  
    game_sku = response.meta["game_sku"]  
    current_review_page = response.meta["current_page"] + 1  
    #print(sample['game_name'], "review current_review_page = ", current_review_page)  
  
    review_page_number = 1  
    if response.meta["current_page"] != 0:  
        review_page_number = response.meta["review_page_number"]  
  
    #if response.meta["current_page"] != 0:  
    sample = response.meta["sample"]  
    data = response.text  
    data = data.replace('\\"', '"')  
    data = data.replace("\\"/, "/" )  
    a_dict = json.loads(data)  
  
    page_reviews = a_dict['data']['products'][0]['items'][0]['reviews']['items']  
    sample["reviews"].extend(page_reviews)  
    review_page_number = a_dict['data']['products'][0]['items'][0]['reviews']['page_info']['total_pages']  
    if current_review_page > review_page_number:  
        yield sample  
  
    base_get_review_post_request= {  
        "operationName": "getProduct",  
        "variables": {  
            "sku": "05144741-96a1-42dc-b636-5a4e00c88be2",  
            "reviewFilter": {},  
            "reviewSortCondition": {  
                "date": "DESC"  
            },  
            "reviewPageSize": 10,  
            "reviewCurrentPage": 1  
        }  
    },
```

Figure 17: viveport crawler parse

For example, when we build the viveport application dataset, we directly make requests to <https://www.viveport.com/graphql> and get its response. Subsequently, we manipulate its response and extract related information about applications.

4.3.3 Sample Data

```
1 {"data": {"viewer": {"user": null}, "node": {"_typename": "Application", "isAppStoreItem": "Application", "id": "415780415213995", "display_name":  
"Pixel Ripped 1989", "platform": "PC", "iarc_cert": {"iarc_rating": {"descriptors": ["Mild Violence"], "interactive_elements": [], "id":  
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oculuscdn.com&oh=00_AT_-2gF89EpEsFyUj_LxEyU36_JG4ezjhoCqjWHLp500A&oe=63425FD5"}, "cover_square_image": null, "is_viewer_entitled": false, "bundle_items":  
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{"star_rating": 4, "count": 15, "starRating": 4}, {"star_rating": 5, "count": 66, "starRating": 5}], "display_long_description": "Pixel Ripped 1989 is a  
wacky multi-dimensional homage to the early days of gaming. The player embarks on a journey into the screen of a classic videogame and beyond. Set in the  
era of portable 8-bit consoles, this game-within-a-game follows the adventures of Dot, an in-game character who sees her world torn apart by the Cyblin  
Lord, a villain able to break through the video game screen and invade the real world. In the game, the player inhabits Nicola, a second-grade student  
who must help Dot save both realities from this menace by facing challenges in the retrogaming 2D world, all while distracting the cranky teacher and  
escaping from the furious headmaster in her own 3D world.", "developer_privacy_policy_url": "http://arvore.io/privacy-policy/",  
"developer_terms_of_service_url": "http://arvore.io/terms-of-service/", "supported_player_modes": ["SITTING"], "publisher_name": "ARVORE Immersive
```

Figure 18: One Oculus Dataset Sample (partial)

4.3.4 Dataset construction Time

For the sake of data consistency, we crawled steam, oculus store, oculus app lab, sidequest and viveport on the same day, October 5, 2022, for all their related VR application data, such as application description, application screenshots, application videos, user comments, etc.

4.3.5 Dataset Quantity

Dataset List	
Platform	Quantity
Steam	4428
Oculus Store	3965
SideQuest	3680
VIVEPORT	2225
Oculus Lab	1375

Since only the oculus store dataset contains the comfort rating for the application published by the oculus official, for the subsequent experiments and their analyses, we concentrate on the dataset from the oculus store.

4.3.6 Dataset Problem

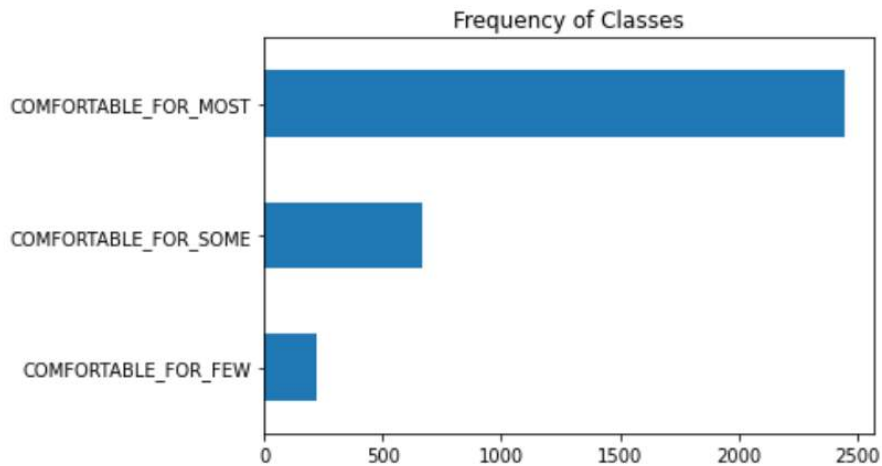


Figure 19: Oculus Store Dataset Each Class Quantity

Here, the label COMFORTABLE FOR MOST indicates comfortable, label COMFORTABLE FOR SOME indicates moderate, and label COMFORTABLE FOR FEW indicates intense.

According to the figure 19, The number of each category differs significantly. When encountering imbalanced data, traditional classification

algorithms that focus on overall classification accuracy as the learning goal focus too much on the majority class, thus degrading the classification performance of minority class samples. The vast majority of common machine learning algorithms do not work well for unbalanced data sets.

Mitigate the Problem

Over-sampling Over-sampling the data samples of a small class increases the number of data samples of the small class, i.e., the number of samples sampled is greater than the number of samples of the class.

Under-sampling Under-sampling the data samples of a large class reduces the number of data samples of the large class, i.e., the number of samples sampled is less than the number of samples of the class.

The sampling algorithm is easy to implement and effective, but it may increase the bias of the model, because the effect of enlarging or reducing some samples is equivalent to changing the distribution of the original data set. Different sampling ratios should also be taken for different classes, but generally not 1:1 because it is far from the reality [8].

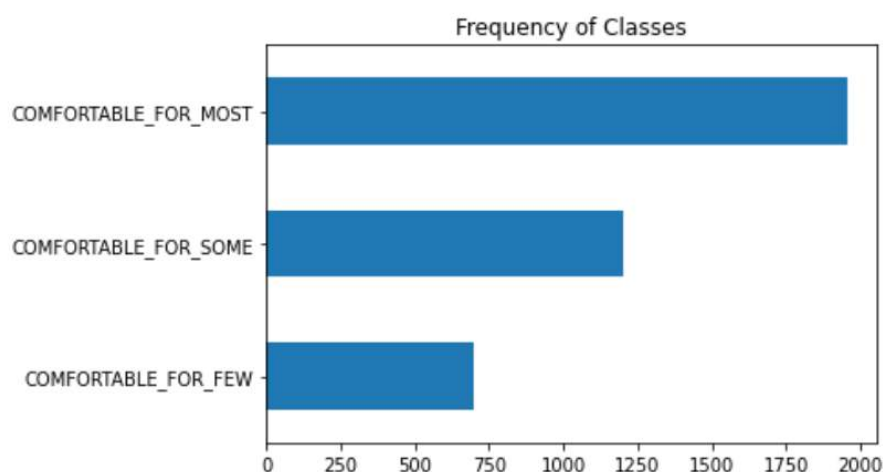


Figure 20: Oversampled Training Dataset

5 Experiment

We first try to use the application description information to predict the VR application comfort level rating.

5.1 Feature Engineering

Feature engineering is an important part of the machine learning workflow, which is to "translate" the raw data into a form that the model can understand. The purpose of feature engineering is to select and find a better feature for predictive models to be more accurate [21].

5.1.1 Count Vectors

Count Vector is a matrix notation of the dataset in which every row represents a document from the corpus, every column represents a term from the corpus, and every cell represents the frequency count of a particular term in a particular document.

text	label
Interact and travel through all the solar system experiencing the amazing life of Annie Amber, from her birth until her final days, solving puzzles of increasing complexity while you unlock her memories. Use just your head to move or to solve the puzzles! From the creator of MIND: Path to Thalamus, the VR, award-winning, indie game of the year.	COMFORTABLE_FOR_SOME
Absolut unveils a new chapter in Absolut Nights. Introducing Absolut deadmau5, an interactive VR experience. Go on an unforgettable night out with deadmau5, from his studio to the club, featuring exclusive music from the artist. To learn more about Absolut deadmau5 or to get a limited edition VR headset, please visit Absolutdeadmau5.com You must be of legal drinking age to use this app. Remain seated when using the app. Stop use if you experience any discomfort.	COMFORTABLE_FOR_SOME

Figure 21: Two Description Sample

```
Vocabulary: {'interact': 44, 'and': 9, 'travel': 81, 'through': 79, 'all': 5, 'the': 77, 'solar': 70, 'system': 75, 'experiencing': 29, 'amazing': 6, 'life': 50, 'of': 61, 'annie': 10, 'amber': 7, 'from': 32, 'her': 38, 'birth': 16, 'until': 84, 'final': 31, 'days': 22, 'solving': 72, 'puzzles': 67, 'increasing': 42, 'complexity': 20, 'while': 91, 'you': 95, 'unlock': 83, 'memories': 52, 'use': 86, 'just': 47, 'your': 96, 'head': 36, 'to': 80, 'move': 55, 'on': 63, 'solve': 71, 'creator': 21, 'mind': 53, 'path': 65, 'thalamus': 76, 'vr': 89, 'award': 14, 'winning': 92, 'indie': 43, 'game': 33, 'year': 94, 'absolut': 2, 'unveils': 85, 'a': 0, 'new': 58, 'chapter': 17, 'in': 41, 'nights': 60, 'introducing': 46, 'deadmau5': 23, 'an': 8, 'interactive': 45, 'experience': 28, 'go': 35, 'on': 62, 'unforgettable': 82, 'night': 59, 'out': 64, 'with': 93, 'his': 39, 'studio': 74, 'club': 18, 'featuring': 30, 'exclusive': 27, 'music': 56, 'artist': 13, 'learn': 48, 'more': 54, 'about': 1, 'get': 34, 'limited': 51, 'edition': 26, 'headset': 37, 'please': 66, 'visit': 88, 'absolutdeadmau5': 3, 'com': 19, 'must': 57, 'be': 15, 'legal': 49, 'drinking': 25, 'age': 4, 'this': 78, 'app': 12, 'remain': 68, 'seated': 69, 'when': 90, 'using': 87, 'stop': 73, 'if': 40, 'any': 11, 'discomfort': 24}
```

```
Encoded result is:
[[0 0 0 0 1 1 1 0 1 1 0 0 0 1 0 1 0 0 0 1 1 1 0 0 0 0 0 0 1 0 1 2 1 0 0
 1 0 3 0 0 0 1 1 1 0 0 1 0 0 1 0 1 1 0 1 0 0 0 0 0 4 0 1 0 1 0 2 0 0 1 1
 1 0 0 1 1 6 0 1 3 1 0 1 1 0 1 0 0 1 0 1 1 0 1 1 1]]
[2 1 4 1 1 0 0 0 2 0 0 1 2 1 0 1 0 1 1 1 0 0 0 3 1 1 1 2 0 1 0 2 0 1 1
 0 1 0 1 1 1 0 0 0 1 1 0 1 1 0 1 0 0 1 0 1 1 1 1 1 1 1 1 1 0 1 0 1 1 0 0
 0 1 1 0 0 3 1 0 4 0 1 0 0 1 2 1 1 2 1 0 0 1 0 2 0]]
```

Figure 22: Sample after Counter Vector Encoded

5.1.2 TF-IDF Vectors

TF-IDF stands for Term Frequency — Inverse Document Frequency and is a statistic that aims to better define how important a word is for a document, while also taking into account the relation to other documents from the same corpus. This is accomplished by examining the frequency with which a term appears in a text as well as the frequency with which the same word appears in other papers within the corpus.[14].

TF-IDF is a score that is applied to every word in every document in our dataset. And for every word, the TF-IDF value increases with every appearance of the word in a document but is gradually decreased with every appearance in other documents[2].

Firstly, let's define some notations, N is the number of documents we have in our dataset, d is a given document from our dataset, D is the collection of all documents, and w is a given word in a document.

To calculate the term frequency, the formula is

$$tf(w, d) = \log(1 + f(w, d)),$$

where $f(w, d)$ is the frequency of word w in document d . To calculate the inverse term frequency, the formula is

$$idf(w, D) = \log\left(\frac{N}{f(w, D)}\right).$$

Finally to calculate the TF-IDF score by the following formula,

$$tfidf(w, d, D) = tf(w, d) * idf(w, D).$$

```
Vocabulary: {'interact': 44, 'and': 9, 'travel': 81, 'through': 79, 'all': 5, 'the': 77, 'solar': 70, 'system': 75, 'experiencing': 29,
'amazing': 6, 'life': 50, 'of': 61, 'annie': 10, 'amber': 7, 'from': 32, 'her': 38, 'birth': 16, 'until': 84, 'final': 31, 'days': 22,
'solving': 72, 'puzzles': 67, 'increasing': 42, 'complexity': 20, 'while': 91, 'you': 95, 'unlock': 83, 'memories': 52, 'use': 86, 'jus
t': 47, 'your': 96, 'head': 36, 'to': 80, 'move': 55, 'on': 63, 'solve': 71, 'creator': 21, 'mind': 53, 'path': 65, 'thalamus': 76, 'v
r': 89, 'award': 14, 'winning': 92, 'indie': 43, 'game': 33, 'year': 94, 'absolut': 2, 'unveils': 85, 'a': 0, 'new': 58, 'chapter': 17,
'in': 41, 'nights': 60, 'introducing': 46, 'deadmau5': 23, 'an': 8, 'interactive': 45, 'experience': 28, 'go': 35, 'on': 62, 'unforgetta
ble': 82, 'night': 59, 'out': 64, 'with': 93, 'his': 39, 'studio': 74, 'club': 18, 'featuring': 30, 'exclusive': 27, 'music': 56, 'artis
t': 13, 'learn': 48, 'more': 54, 'about': 1, 'get': 34, 'limited': 51, 'edition': 26, 'headset': 37, 'please': 66, 'visit': 88, 'absolut
deadmau5': 3, 'com': 19, 'must': 57, 'be': 15, 'legal': 49, 'drinking': 25, 'age': 4, 'this': 78, 'app': 12, 'remain': 68, 'seated': 69,
'when': 90, 'using': 87, 'stop': 73, 'if': 40, 'any': 11, 'discomfort': 24}

Encoded result is:
[[0.      0.      0.      0.      0.10915389
 0.10915389 0.10915389 0.      0.10915389 0.10915389 0.
 0.      0.      0.10915389 0.      0.10915389 0.
 0.      0.      0.10915389 0.10915389 0.10915389 0.
 0.      0.      0.      0.      0.      0.10915389
 0.      0.10915389 0.15532779 0.10915389 0.      0.
 0.10915389 0.      0.32746168 0.      0.      0.
 0.10915389 0.10915389 0.10915389 0.      0.      0.10915389
 0.      0.      0.10915389 0.      0.10915389 0.10915389
 0.      0.10915389 0.      0.      0.      0.
 0.      0.31065558 0.      0.07766389 0.      0.10915389
 0.      0.21830779 0.      0.      0.10915389 0.10915389
 0.10915389 0.      0.      0.10915389 0.10915389 0.46598336
 0.      0.10915389 0.23299168 0.10915389 0.      0.10915389
 0.10915389 0.      0.07766389 0.      0.      0.07766389
 0.      0.10915389 0.10915389 0.      0.10915389 0.07766389
 0.10915389]
[0.19265669 0.09632835 0.38531330 0.09632835 0.09632835 0.
 0.      0.      0.19265669 0.      0.      0.09632835
 0.19265669 0.09632835 0.      0.09632835 0.      0.09632835
 0.09632835 0.09632835 0.      0.      0.      0.28898504
 0.09632835 0.09632835 0.09632835 0.09632835 0.19265669 0.
 0.09632835 0.      0.13707682 0.      0.09632835 0.09632835
 0.      0.09632835 0.      0.09632835 0.09632835 0.
 0.      0.      0.09632835 0.09632835 0.09632835 0.09632835
 0.09632835 0.09632835 0.09632835 0.09632835 0.09632835
 0.09632835 0.06853841 0.09632835 0.06853841 0.09632835 0.
 0.09632835 0.      0.09632835 0.09632835 0.      0.
 0.      0.09632835 0.09632835 0.      0.      0.20561523
 0.09632835 0.      0.27415364 0.      0.09632835 0.
 0.      0.09632835 0.13707682 0.09632835 0.09632835 0.13707682
 0.09632835 0.      0.      0.09632835 0.      0.13707682
 0.      ]]
```

Figure 23: Sample Dataframe after TF-IDF Encoded

5.1.3 Word Embeddings

Word embedding is a form of representing words and documents using a dense vector representation. The position of a word within the vector space is learned from text and is based on the words that surround the word when it is used. Word embeddings can be trained using the input corpus itself or can be generated using pre-trained word embeddings such as Glove[13], FastText[6], and Word2Vec[10]. Any one of them can be downloaded and used as transfer learning. Using word embedding, semantically similar words will also be more similar in vector space [3]!

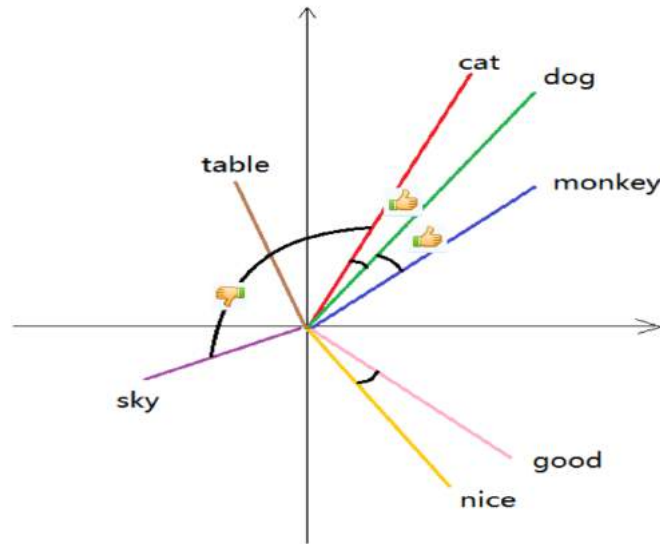


Figure 24: projection of the embedding vectors to 2D

We use pre-trained word embeddings `wiki-news-300d-1M.vec`[11] in our experiment models, which contains 1 million word vectors trained on Wikipedia 2017, UMBC webbase corpus and statmt.org news dataset (16B tokens).

5.2 Models

5.2.1 Naive Bayes Classifier

A Naive Bayes classifier is a probabilistic machine learning model that's used for the classification task. The principle of the classifier is based on the Bayes theorem.

Bayes Theorem:

$$P(A | B) = \frac{P(B | A)P(A)}{P(B)}$$

Using Bayes theorem [7], we can find the probability of A happening given that B occurred. Here, B is the evidence and A is the hypothesis. The assumption made here is that the predictors/features are independent. That is the presence of one particular feature does not affect the other [5]. Hence it is called naive.

For one training sample, X is given as

$$X = (x_1, x_2, x_3, \dots, x_n),$$

where x_1, x_2, \dots, x_n represent the features. By substituting for X and expanding using the chain rule we get

$$P(y | x_1, \dots, x_n) = \frac{P(x_1 | y) P(x_2 | y) \dots P(x_n | y) P(y)}{P(x_1) P(x_2) \dots P(x_n)}.$$

Now you can look at the dataset to get the values for each and then enter them into the equation. Observing the denominator does not change for any of the entries in the dataset, the denominator may be eliminated and proportionality may be added.

Finally, we can make the predicted class, using the below formula,

$$y = \operatorname{argmax}_y P(y) \prod_{i=1}^n P(x_i | y).$$

5.2.2 Shallow Neural Networks

A neural network is a mathematical model that is designed to behave similarly to biological neurons and the nervous system. These models are used to recognize complex patterns and relationships that exist within labeled data. A shallow neural network [20] contains mainly three types of layers – input layers, hidden layers, and output layers.

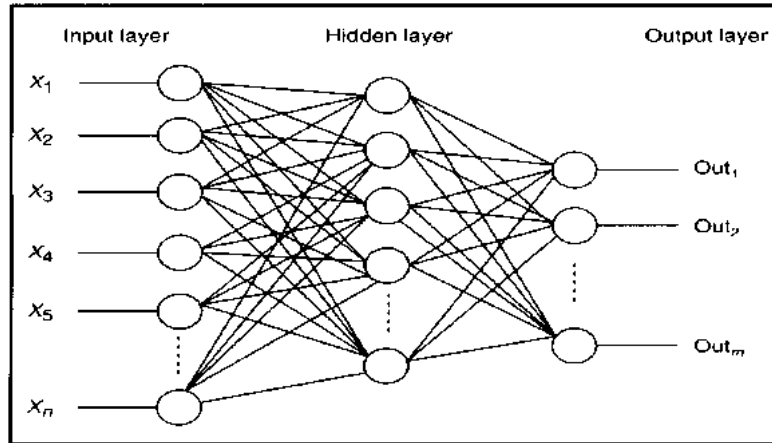


Figure 25: Shallow Neural Networks

5.2.3 Convolutional Neural Network

In convolutional neural networks, convolutions over the input layer are used to compute the output. This results in local connections, where each region of the input is connected to a neuron in the output. Each layer applies different filters and combines their results [12].

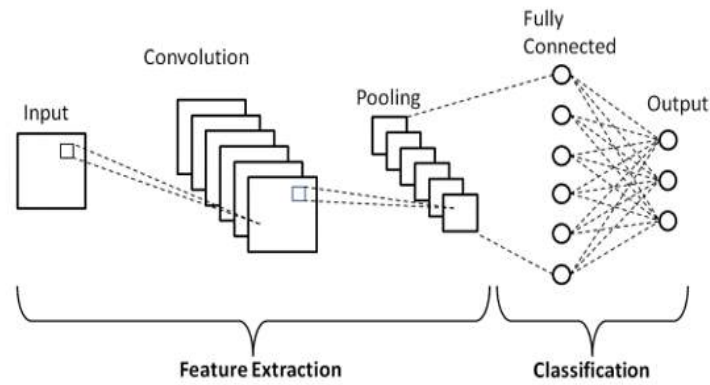


Figure 26: Convolutional Neural Network

5.2.4 Transformer

An encoder-decoder structure is present in the transformer [17]. The encoder in the transformer transforms input discrete value sequences into an intermediary continuous value sequence. The next step is for the decoder to produce each token in the output sequence one at a time using the intermediate sequence since the previous token in the output also serves as the input for the subsequent token.

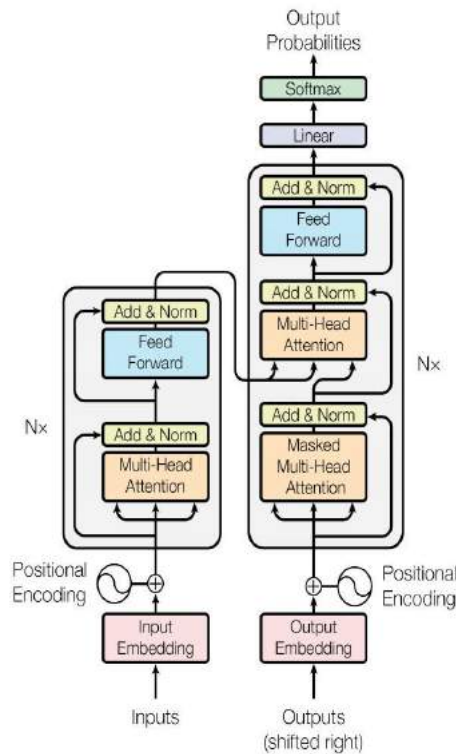


Figure 27: Transformer Model Architecture

It contains a stack of self-attention and fully connected layers in core components encoder and decoder.

Encoder The N identical layers that make up the encoder can be further divided into two sublayers for each layer in the stack. Before entering the encoder stack, the input sequence is first embedded through an embedding layer to have dimension d for each token. The multi-head attention mechanism is the first sublayer of the encoder stack that receives the input x from the layer. The original input is then combined with the output of the multi-head attention mechanism, which is fed to the normalization layer. The normalization layer's output is then passed to a fully connected feed-forward layer, and this time, a residual connection is used so that the normalization layer follows the full feed-forward layer.

Decoder With the exception of having additional multi-head attention, the decoder is essentially identical to the encoder. The first multi-head attention in the decoder stack is introduced to a mask. The modification's goal is to ensure that output at position k can only refer to the output before position k and to stop positions from attending the unread positions.

Positional Encoding Due to the Transformer's lack of convolution and recurrence, information about the relative and absolute positions of each piece of information in the sequence is added. For this reason, positional encodings of dimension d are added to the input's embeddings before it enters the stacks in order to maintain the ordering and position information. For encoding the odd and even dimension positions, it uses two different functions.

6 Experiment Result

6.1 Experiment Result

Model	Accuracy
Naive Bayes Classifier(counter vector)	0.7207
Naive Bayes Classifier(counter vector oversampled)	0.6723
Naive Bayes Classifier(TF-IDF vector)	0.6301
Naive Bayes Classifier(TF-IDF vector oversampled)	0.5963

Table 1: Naive Bayes Classifier

Model	Accuracy
Shallow Neural Networks(counter vector)	0.6483
Shallow Neural Networks(counter vector oversampled)	0.6703
Shallow Neural Networks(TF-IDF vector)	0.6192
Shallow Neural Networks(TF-IDF vector oversampled)	0.6321

Table 2: Shallow Neural Networks

Model	Accuracy
Convolutional Neural Network(Word Embedding)	0.7074
Convolutional Neural Network(Word Embedding oversampled)	0.7665

Table 3: Convolutional Neural Network

Model	Accuracy
Transformer	0.8316
Transformer(oversampled)	0.8325
Transformer-CNN	0.8432
Transformer-CNN(oversampled)	0.8398

Table 4: Transformer

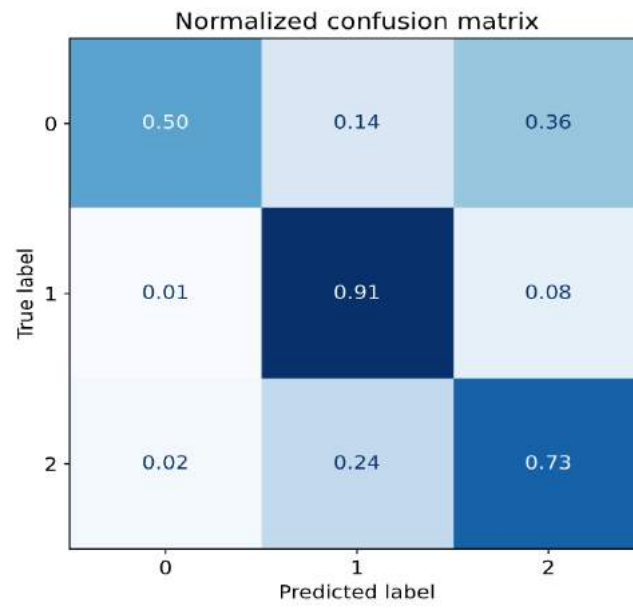


Figure 28: Transformer confusion matrix

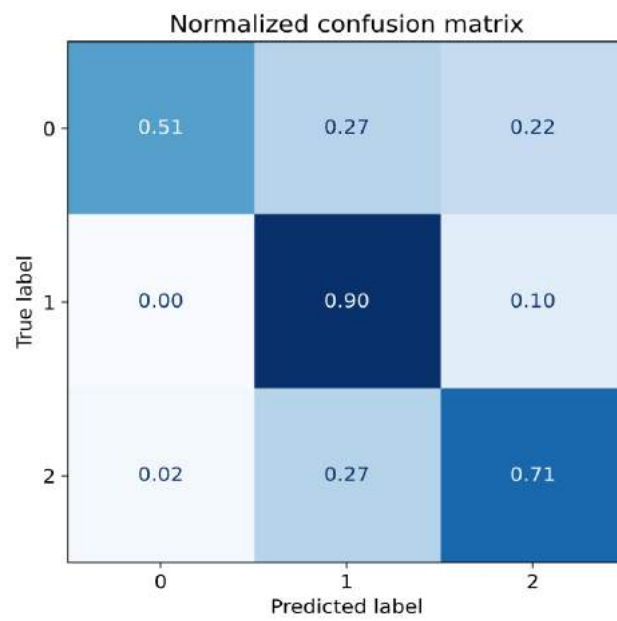


Figure 29: Transformer-CNN confusion matrix

	text	label	predicted_label	loss
437	VRChat offers an endless collection of social ...	0	1	11.104321
73	Chromesthesia: seeing sounds as colors. Immers...	0	1	10.766850
707	Neverout is a unique puzzle game with innovati...	0	1	10.747291
473	Navigate city rooftops like a parkour pro. Gra...	1	0	10.579171
25	Make beats in VR - This is not a rhythm game! ...	2	1	10.390916
371	Explore a virtual anatomical heart in the 'Rea...	2	1	10.143176
195	Whirligig is an immersive media player for pla...	2	1	10.124323
135	Sharecare Windows offers an escape to immersiv...	2	1	10.124310
130	Holopoint is pure archery madness. Fight your ...	0	1	10.038361
552	War Online: Pacific is the first in a series o...	0	1	10.031110
96	You believed tower defense is only about build...	0	1	10.015985
17	Roll your marble to the goal. Try to beat the ...	2	1	9.911517
519	You are trapped by a group of mischievous monk...	2	1	9.856830
810	Explore different locations and face your fear...	1	2	9.650606
674	Digital Domain's Monkey King™ is a visually-ca...	2	1	9.506454

Figure 30: Transformer(description) Data Samples with Highest Loss (cross entropy)

	text	label	predicted_label	loss
42	Welcome to the world of Mini Bowling! In this ...	2	1	10.031266
244	Welcome to the world of Mini Bowling! In this ...	2	1	10.031266
217	Have you ever dreamed of what it would be to s...	2	1	10.028459
142	"All you need is 20 seconds of insane courage ...	0	1	9.992984
316	What is the site of the world's worst nuclear ...	2	1	9.945721
704	Chernobyl VR Project is a virtual experience w...	0	1	9.917863
773	Hyper Dash is a VR multiplayer team based shoo...	2	1	9.883032
203	XING: The Land Beyond is an atmospheric first-...	2	1	9.737484
183	At the edge of the future, people of all races...	1	2	9.728790
195	Inspired by classic survival horror gameplay, ...	1	2	9.675558
135	Georgian winemaking method is a part of UNESCO...	2	1	9.657598
645	Georgian winemaking method is a part of UNESCO...	2	1	9.657598
667	Gangsa Bali VR. You playing game with "Panggul...	2	1	9.608642
55	Become Orion13 – a robot mercenary who fights ...	0	1	9.596140
478	**Note: This game is a VR-only experience and ...	1	2	9.506377

Figure 31: Transformer(description-review) Data Samples with Highest Loss (cross entropy)

6.2 Analysis

In the task of predicting the comfort level for our application, the accuracy results of the two models, Naive Bayes Classifier and Shallow Neural Networks, show that the feature representation of the counter vector is better than that of the TF-IDF, which is more representative of some information about the comfort level. In terms of model accuracy, the transformer model performs the best, reaching about 80 percent, but still has much room for improvement. And, with more information applied, the transformer model learns more and is more accurate. Also, for the neural network model, the training set is processed with oversampling, which can improve the accuracy of the corresponding model to some extent.

7 Future Work

Based on the transformer's model, we try to make the model use more modal information from VR applications, such as images, videos, user comments, etc., to improve the accuracy of our model. Based on this, we adapt the network structure of our model to suit the needs of this particular learning task. Meanwhile, in terms of feature engineering, we plan to investigate how to better represent the information of VR applications.

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