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DEPARTMENT OF COMPUTER ENGINEERING

# Retratista



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## Abstract

Throughout history, *portraiture* has been a mean of identifying and finding individuals due to various reasons. Aside from being an art to memorialize famous historical characters, it has been used to identify criminals and missing individuals. The main reason behind using portraits for these purposes is that *visual search* is much easier for humans than any other kind of search. Most people can identify a person or an object, they have seen before. Even with the rise of photography, statistics say that drawn portraits are still used in visual search. Recently, portraits developed other applications as well, especially in the study of historical characters and events.

While being important, sketching a complete face portrait can be very cumbersome and time-consuming. Historically, this process required a professional portraitist and could take him weeks to fully sketch an accurate portrait. However, with the rise of digital design application including *Adobe Photoshop*, this process became much easier. Nonetheless, it still requires a professional and can take hours or even days to accomplish. Moreover, the process of refining a drawn portrait can be very tedious and can cause re-sketching in certain cases. On the other hand, the process of sketching a portrait sometimes needs to be extremely fast, in cases of searching for dangerous criminals or missing children.

**Retratista** addresses both *time* and *accuracy* issues, while keeping the usage as simple as possible for non-professionals. We use the power of modern *generative models* to create an *end-to-end* system for *face portrait generation* from bare description. This description can be a voice, text or manual description. We abstract the complexity of our system from the user by providing a simple *web user interface*. Our system takes just a *few seconds* to generate a complete face. Also, it allows the user to further *refine* the generated face and even render it in *multiple poses* to provide further identification. We include a relatively-sufficient set of *facial attributes* to correctly describe a human face.

## الملخص

على مر التاريخ، كان فن البورتريه وسيلة للتعرف والعثور على الأفراد لأسباب مختلفة. بصرف النظر عن كونه فناً لإحياء ذكرى الشخصيات التاريخية الشهيرة، فقد تم استخدامه لتحديد المجرمين والأفراد المفقودين. السبب الرئيسي وراء استخدام الصور الشخصية لهذه الأغراض هو أن البحث المائي أسهل بكثير على البشر من أي نوع آخر من البحث. يمكن ل معظم الناس التعرف على شخص أو شيء ما، رأوه من قبل. حتى مع ظهور التصوير الفوتوغرافي، تشير الإحصائيات إلى أن الصور المرسومة لا تزال تستخدم في البحث المائي. في الآونة الأخيرة، طورت البورتريهات تطبيقات أخرى أيضاً، لا سيما في دراسة الشخصيات والأحداث التاريخية.

على الرغم من أهميته، إلا أن رسم صورة كاملة للوجه يمكن أن يكون مرهقاً جداً ويستغرق وقتاً طويلاً. تاريخياً، تطلبت هذه العملية رسام بورتريه محترف ويمكن أن تستغرق أسابيع لرسم صورة دقيقة بالكامل. حالياً ومع ظهور تطبيقات التصميم الرقمي مثل ادب عهسهپ، أصبحت هذه العملية أسهل بكثير. ومع ذلك، لا يزال الأمر يتطلب متخصصاً ويمكن أن يستغرق ساعات أو حتى أياماً لإنجازه. علاوة على ذلك، قد تكون عملية تحسين الصورة المرسومة صعبة للغاية ويمكن أن تؤدي إلى إعادة الرسم في حالات معينة. من ناحية أخرى، يجب أن تكون عملية رسم البورتريه سريعة للغاية في بعض الأحيان، في حالات البحث عن مجرمين خطرين أو أطفال مفقودين.

يعالج ريتراستا مشكلات الوقت والدقة، مع الحفاظ على سهولة الاستخدام قدر الإمكان لغير المتخصصين. نحن نستخدم قوة النماذج التوليدية الحديثة لإنشاء نظام شامل لتوليد صورة الوجه من وصف مجرد. يمكن أن يكون هذا الوصف صوتاً أو نصاً أو وصفاً يدوياً. نحن نعزل تعقيد نظامنا عن المستخدم من خلال توفير واجهة مستخدم ويب بسيطة. يستغرق نظامنا بعض ثوانٍ فقط لتكوين وجه كامل. كما أنه يسمح للمستخدم بتحسين الوجه الذي تم إنشاؤه بشكل أكبر وحتى عرضه في أوضاع متعددة لتوفير مزيد من التعريف. نقوم بتضمين مجموعة كافية نسبياً من سمات الوجه لوصف الوجه البشري بشكل صحيح.

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# Contents

<b>Abstract (English)</b>	<b>1</b>
<b>Abstract (Arabic)</b>	<b>2</b>
<b>Acknowledgement</b>	<b>3</b>
<b>Table of Contents</b>	<b>7</b>
<b>List of Figures</b>	<b>9</b>
<b>List of Tables</b>	<b>10</b>
<b>List of Abbreviation</b>	<b>11</b>
<b>List of Symbols</b>	<b>12</b>
<b>Contacts</b>	<b>13</b>
<b>1 Introduction</b>	<b>15</b>
1.1 Motivation and Justification . . . . .	15
1.2 Project Objectives and Problem Definition . . . . .	16
1.3 Project Outcomes . . . . .	16
1.4 Document Organization . . . . .	17
<b>2 Market Feasibility Study</b>	<b>18</b>
2.1 Targeted Customers . . . . .	18
2.2 Market Survey . . . . .	18
2.2.1 FaceApp . . . . .	19
2.2.2 PicsArt . . . . .	19
2.2.3 Facetune2 . . . . .	20
2.2.4 Booth Apps . . . . .	20
2.3 Business Case and Financial Analysis . . . . .	21
<b>3 Literature Survey</b>	<b>24</b>
3.1 Background Review . . . . .	24
3.1.1 Convolutional Neural Networks . . . . .	24
3.1.2 Generative Adversarial Networks . . . . .	24
3.1.3 Latent Space and Entanglement . . . . .	25
3.1.4 Multi-class Multi-label Text Classification . . . . .	26
3.1.4.1 Simple Statistical Approaches . . . . .	27
3.1.4.2 Linguistic Approaches . . . . .	27
3.1.4.3 Graph-based Approaches . . . . .	27
3.1.4.4 Machine Learning Approaches . . . . .	27
3.2 Face Modelling and Generation . . . . .	28

3.2.1	Face Generation . . . . .	28
3.2.1.1	StyleGAN . . . . .	28
3.2.1.2	StyleGAN latent manipulation . . . . .	29
3.2.1.3	Faces à la Carte . . . . .	30
3.2.1.4	NVAE . . . . .	30
3.2.2	Face Refinement . . . . .	31
3.2.2.1	AttGAN . . . . .	31
3.2.2.2	InjectionGAN . . . . .	32
3.2.2.3	Facelet-Bank for Fast Portrait Manipulation . . . . .	33
3.3	Face Rotation . . . . .	34
3.3.1	Rotate-and-Render . . . . .	35
3.3.2	DepthNets . . . . .	35
3.3.3	PosIX-GAN . . . . .	36
3.3.4	CAPG-GAN . . . . .	36
3.4	Comparative Study of Previous Work . . . . .	37
3.5	Implemented Approach . . . . .	37
3.5.1	Face Generation from Description . . . . .	37
3.5.2	Face Refinement . . . . .	38
3.5.3	Multiple Head Poses Generation . . . . .	38
<b>4</b>	<b>System Design and Architecture</b> . . . . .	<b>39</b>
4.1	Overview and Assumptions . . . . .	39
4.2	System Architecture . . . . .	41
4.3	Module 1 : Speech Recognition . . . . .	43
4.3.1	Functional Description . . . . .	43
4.3.2	Modular Decomposition . . . . .	43
4.3.3	Design Constraints . . . . .	44
4.4	Module 2 : Text Processing . . . . .	45
4.4.1	Functional Description . . . . .	45
4.4.2	Modular Decomposition . . . . .	46
4.4.2.1	Dataset Synthesis Sub-module . . . . .	47
4.4.2.2	Deep Learning Sequence Model . . . . .	50
4.4.3	Design Constraints . . . . .	50
4.5	Module 3 : Face Code Generation . . . . .	51
4.5.1	Functional Description . . . . .	51
4.5.2	Modular Decomposition . . . . .	51
4.5.2.1	Feature Directions Generation . . . . .	52
4.5.2.2	Initial Seed Generation . . . . .	54
4.5.2.3	Latent Manipulation . . . . .	54
4.5.3	Design Constraints . . . . .	55
4.5.4	Synthetic Image Clustering . . . . .	56
4.6	Module 4 : Code-to-Face Translation . . . . .	57
4.6.1	Functional Description . . . . .	57
4.6.2	Modular Decomposition . . . . .	57

4.6.3 Design Constraints . . . . .	59
4.7 Module 5 : Face Refinement . . . . .	60
4.7.1 Functional Description . . . . .	60
4.7.2 Modular Decomposition . . . . .	60
4.7.3 Design Constraints . . . . .	61
4.8 Module 6 : Multiple Head Poses Generation . . . . .	62
4.8.1 Functional Description . . . . .	62
4.8.2 Modular Decomposition . . . . .	62
4.8.2.1 3D Face Fitting . . . . .	62
4.8.2.2 Rotating and Rendering the 3D model . . . . .	63
4.8.2.3 Face Inpainting . . . . .	63
4.8.3 Design Constraints . . . . .	64
4.9 Module 7 : Web Application . . . . .	65
4.9.1 Functional Description . . . . .	65
4.9.2 Modular Decomposition . . . . .	65
4.9.2.1 Frontend Design . . . . .	65
4.9.2.2 Backend API . . . . .	66
4.9.3 Design Constraints . . . . .	67
4.10 Other Approaches . . . . .	68
4.10.1 Face Generator Module . . . . .	68
4.10.2 NLP Module . . . . .	68
4.10.3 Dataset and Training . . . . .	68
4.10.4 Results . . . . .	69
<b>5 System Testing and Verification</b>	<b>70</b>
5.1 Testing Setup . . . . .	70
5.2 Testing Plan and Strategy . . . . .	70
5.2.1 Module Testing . . . . .	71
5.2.1.1 Speech Recognition . . . . .	71
5.2.1.2 Text Processing . . . . .	71
5.2.1.3 Code Generation . . . . .	72
5.2.1.4 Code-to-Face Translation . . . . .	73
5.2.1.5 Face Refinement . . . . .	74
5.2.1.6 Multiple Head Poses Generation . . . . .	75
5.2.2 Integration Testing . . . . .	78
5.3 Testing Schedule . . . . .	81
5.4 Comparative Results to Previous Work . . . . .	81
<b>6 Conclusions and Future Work</b>	<b>84</b>
6.1 Faced Challenges . . . . .	84
6.1.1 Data Scarcity . . . . .	84
6.1.2 Few Related Research Work . . . . .	84
6.1.3 Architectural Complexity . . . . .	84
6.1.4 Facial Attributes and Entanglement . . . . .	85
6.2 Gained Experience . . . . .	85

6.3 Conclusions . . . . .	85
6.4 Future Work . . . . .	85
<b>A Development Platforms and Tools</b>	<b>88</b>
A.1 Software Tools . . . . .	88
A.1.1 Ready-made Models . . . . .	88
A.1.1.1 Facial Landmark Detection Model . . . . .	88
A.1.1.2 Neural Face Renderer . . . . .	88
A.1.2 Frameworks and Packages . . . . .	88
A.1.2.1 PyTorch . . . . .	88
A.1.2.2 OpenCV . . . . .	88
A.1.2.3 Flask . . . . .	88
A.1.2.4 Vuejs . . . . .	88
A.1.2.5 Docker . . . . .	88
<b>B Use Cases</b>	<b>89</b>
<b>C User Guide</b>	<b>89</b>
C.1 Main Page . . . . .	89
C.2 Voice Description Page . . . . .	90
C.3 Text Description Page . . . . .	91
C.4 Refine Page . . . . .	92
C.5 Head Pose Page . . . . .	93
C.6 Demo Page . . . . .	94
<b>D Feasibility Study</b>	<b>95</b>
D.1 Technical Feasibility . . . . .	95
D.2 Operational Feasibility . . . . .	95
D.3 Legal Feasibility . . . . .	95
D.4 SWOT Analysis . . . . .	95
D.4.1 Strength (S) . . . . .	95
D.4.2 Weaknesses (W) . . . . .	96
D.4.3 Opportunities (O) . . . . .	96
D.4.4 Threats (T) . . . . .	96

## List of Figures

2.1	Changing age using FaceApp application.	19
2.2	Image refinement using PicsArt application.	19
2.3	Image refinement using Facetune2 application.	20
2.4	Image editing using PhotoBooth application.	20
3.1	A standard CNN with Upsampling layer.	24
3.2	The basic architecture of a generative adversarial network (GAN).	25
3.3	An example 2D latent space of MNIST digits dataset.	26
3.4	Different StyleGAN architectures diagram.	28
3.5	Visual results of StyleGAN2.	29
3.6	Visual results of Faces à la Carte.	30
3.7	Visual results of NVAE.	31
3.8	Complete architecture of AttGAN.	32
3.9	Visual results of AttGAN.	32
3.10	Complete architecture of InjectionGAN.	33
3.11	Visual results of InjectionGAN.	33
3.12	Complete architecture of Facelet Bank.	34
3.13	Visual results of Facelet Bank.	34
3.14	Visual results of Rotate-and-render network.	35
3.15	Visual results of DepthNets.	35
3.16	Visual results of PosIX-GAN.	36
3.17	Visual results of CAPG-GAN.	36
4.1	Block diagram of complete system architecture	41
4.2	Block diagram of application design	42
4.3	Modified DeepSpeech2 network architecture.	43
4.4	Attributes Scores Example	45
4.5	Text Processing Pipeline	47
4.6	Dataset Synthesis Pipeline	47
4.7	Textual Die where each attribute chooses a random slot for itself	49
4.8	Detailed block diagram of the three core modules workflow	51
4.9	Illustration of feature directions in latent space	52
4.10	Illustration of orthogonalization relative to a reference vector	53
4.11	Illustration of directions scale using age direction	55
4.12	Style-based GAN architecture against traditional GAN	57
4.13	Illustration of sequential navigation and invertibility in a 2D latent space	59
4.14	Old Approach	68
5.1	The results of moving along some extracted feature directions.	73
5.2	An example of the consistency in reaching the required facial attributes starting from initial random vector.	74
5.3	The results of sequential navigation along certain feature directions.	75
5.4	Example of input faces from previous stage.	76
5.5	Example of output 8 poses for the first input face	77
5.6	Example of output 8 poses for the second input face.	77

5.7	Example of output 8 poses for the third input face.	78
5.8	Samples of correctly generated face portrait from textual description.	79
5.9	Samples of correctly generated face portrait from textual description.	80
5.10	Samples of incorrectly generated face portrait from textual description.	81
5.11	Plot of FID score of different pipelines against different number of test images (lower is better).	82
B.1	UML diagram for our application.	89
C.1	Main Page	90
C.2	Voice Description Page	91
C.3	Text Description Page	92
C.4	Refine Page	93
C.5	Head Pose Page	94

## List of Tables

2.1	Business Case over 5 years.	21
2.2	Capex Table.	22
2.3	Opex Table.	22
2.4	Cash flow Table over a year (in dollars)	23
4.1	The list of supported facial attributes with their types.	46
5.1	Speech recognition results.	71
5.2	DistelBERT Testing Metrics.	72
5.3	Runtime for different architectures.	72
5.4	Angles (measured in degrees) between different feature directions using a subset of the considered facial features (closer to 90 degrees is better).	72
5.5	LPIPS values against the number of navigated directions for sample text (lower is better).	74
5.6	NME mean and std for test data of AFLW and AFLW2000 dataset. NME is calculated for a various range of poses for 3DMMs	76
5.7	FID scores comparison on different number of test images (lower is better).	82
5.8	LPIPS comparison with Faces à la Carte (lower is better).	82
5.9	The execution time of different stages of the core of our system (measured in seconds).	83

## List of Abbreviation

AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
NLP	Natural Language Processing
CNN	Convolutional Neural Network
RNN	Recurrent Neural Network
GAN	Generative Adversarial Network
API	Application Programming Interface
FFHQ	Flickr-Faces-HQ Dataset
ADA	Adaptive Discriminator Augmentation
FID	Fréchet Inception Distance
LPIPS	Learned Perceptual Image Patch Similarity
AdaIN	Adaptive Instance Normalization
GPU	Graphics Processing Unit
TPU	Tensor processing unit

## List of Symbols

$\ A\ $	Magnitude of a Vector $A$
$Trace(B)$	Trace of a Matrix $B$
$D$	Feature Directions Matrix
$d$	Single Feature Direction Vector
$E$	Face Embedding (Latent Vector)
$l$	Logit (Numerical Value)
$l_{diff}$	Differentiated Logits (Result of Logits Subtraction)

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# 1 Introduction

Face portrait has been used for multiple important tasks related to visual search and study. Visual search of criminals and missing individuals is completely based on visual face portraits. Having an accurate face portrait can enable automated and efficient search through camera feeds and even faster manual search. Also, face portraits are the bases of the many studies related to history and archaeology. Despite of its importance, the process of generating a portrait from bare description is tedious and time-consuming. Traditionally, this process is done by professional portraitists that manually sketch the face portrait. This can take days or weeks to accomplish using traditional sketching and hours using digital sketching. In some cases, this can be unacceptable.

Retratista addresses the problem of *face portrait generation* from *various descriptions*. These descriptions include voice, textual and manual descriptions. We design our system for complete *automated* portrait generation, with a simple *web user interface*. Moreover, rapid face refinement and rotation is provided to further improve face identification. Our system solves both duration and complexity issues of previous portrait sketching methods, while providing a high fidelity results and keeping simple interface. This eases the usage of portraits in many applications.

Retratista combines the power of modern *AI* solutions and the great applications of portraiture into a single tool that is available for everyone to use efficiently without experience and with minimum duration.

## 1.1 Motivation and Justification

Sketching a human face from bare description is a tedious task that requires specialization. Normally, professional portraitists are asked to sketch a face from description. The process of sketching a human face portrait from scratch can involve problems, such as :

- A long time to initially sketch the face that matches the description.
- After being sketched, any refinements in the face might require re-sketching from scratch.
- Sketched faces are not accurate and real enough to be used for facial recognition in both manual and automated (*AI-driven*) visual search.

Despite its difficulty, the process of sketching portrait has many applications, most of which require high accuracy and speed. These applications include :

- Visual search of missing individuals and criminals.
- Visualization of historical and mythical characters.
- Search of surveillance video feeds for individuals' actions.

Here are some statistics from *International Centre For Missing and Exploited Children* (ref: <https://www.icmec.org>) that can tell how our system is critically needed :

- In **USA**, an estimated **460,000** children are reported missing every year.

- In **UK**, an estimated **112,853** children are reported missing every year.
- In **Germany**, an estimated **100,000** children are reported missing each year.
- In **India**, an estimated **96,000** children go missing each year.
- In **Canada**, an estimated **45,288** children are reported missing each year.
- In **Russia**, an estimated **45,000** children were reported missing in 2015.
- In **Australia**, an estimated **20,000** children are reported missing every year.
- In **Spain**, an estimated **20,000** children are reported missing every year.

All cases of missing individuals require a visual face image to ease the search process. Most of them require sketching a face portrait (either for the missing person or a potential suspect), even with all the advances in photography.

## 1.2 Project Objectives and Problem Definition

The main focus of Retratista is to offer as many utilities as possible to identify a human face from any description. To do this, we have to :

- Translate the input description to a complete human face image.
- Refine the generated face image, as needed, in order to reach the target face.
- Render the final face in multiple poses to provide more face identification.

In order for our product to be valuable, these functionalities have to be done as fast as possible, while maintaining output accuracy and quality. Also, it should be an *easy-to-use* interface with no required experience to use, only enter the description and edit what is needed. The output of our system can, then, be used in multiple applications of visual search and identification.

## 1.3 Project Outcomes

The project outcome is a web application that simply takes a description as voice, text or manual input and translates it into a complete realistic face portrait within a *few seconds* in a *fully-automated* way. Then, the application gives the user a chance to further refine the facial attributes to match the target face. Furthermore, the generated face can be rendered in multiple poses for better identification. Our system considers 32 facial attributes for generation and 38 facial attributes for refinement. The facial attributes include *age*, *gender*, *hair color* and *eyes color*.

## 1.4 Document Organization

The document is organized into 6 chapters along with the appendices. Chapter 1 introduces the main idea of the project, along with the formal definition of the problem, our motivation to work on this problem and the project outcome.

Chapter 2 discusses the market study of our project through identifying the target market and listing our potential competitors. Also, it provides a financial analysis for our product.

Chapter 3 gives the necessary background information, along with previous related work in research literature and shows our adopted approach.

Chapter 4 is the main body of our document, where it discusses, in details, our system architecture and application design. This chapter further explains the implementation details of our modules. Finally, it discusses alternative approaches considered in our experimentation.

Chapter 5 explains the metrics, used to assess our system, and our system results. The testing is described both qualitatively and quantitatively. Also, we show the success and failures cases of our system.

Chapter 6 concludes our document, lists the faced challenges and shows how our work can be extended and improved.

Finally, we include 4 appendices for describing development tools, project use cases, user guide and product feasibility study.

## 2 Market Feasibility Study

Face Generation is an important field in the market. It is used widely in missing people organizations or police stations, however it is not automated, using artists to draw the faces from their descriptions. Retratista is the first automated product in that field and it can operate in a fast and accurate way. Retratista, also, offers face refinement, which is offered by many mobile applications just to enhance or edit taken photos for entertainment, not critical issues like the ones we target.

### 2.1 Targeted Customers

Our Project is directed to all governmental and volunteering organizations, that need to generate identical faces of missing people from bare human description of their facial features. Also, it can be used to identify the ancient kings and queens faces from historical descriptions. We can categorize the different target companies into the following :

- **Criminal identification from witnesses descriptions :**
  - INTERPOL.
  - Different Police Stations.
- **Missing People organizations like :**
  - International Center for Missing and Exploited Children (ref: <https://www.icmec.org>).
  - International Red Cross and Red Crescent Movement (ref: <https://www.icrc.org>).
  - International Commission on Missing Persons *ICMP* (ref: <https://www.icmp.int>).
  - Missing Persons Support Center (ref: <https://www.mpsupportcenter.org>).
  - Others.
- **Historical Characters Identification :**
  - Archaeological and Historical Research Facilities.

### 2.2 Market Survey

Retratista is the first innovative product that offers face portrait generation in an automated way. Consequently, we have no direct market competitors. Competitor products depend only on image refinement using limited number of features to manipulate a given face. We have both image generation and refinement using 32 facial features for generation and 38 facial features for refinement, which exceed the number of facial features targeted by any competitor. Besides that, our purpose is more important than just entertainment. Our biggest competitor is *FaceApp*, followed by *PicsArt*, *Facetune2* and *Booth Apps*.

## 2.2.1 FaceApp

*FaceApp* (ref: <https://www.faceapp.com/>) is considered image and video editing mobile application, it generates highly realistic transformations of human faces in photographs using *AI* and *Neural Networks*. The limitation of the application compared to us is that it's only used for refinement using 14 facial feature, which might not be enough for generating face from scratch. Figure 2.1 shows an example of changing a face age using *FaceApp*. The considered facial features include *different styles of beard, hair color and style, makeup filters, blemishes removal, eyes color, gender, age, glasses, smile and lips, eyes and nose size*.



Figure 2.1: Changing age using FaceApp application.

## 2.2.2 PicsArt

*PicsArt* (ref: <https://picsart.com/>) is a company that develops online photo and video editing applications, with a social creative community. The platform allows users to take and edit pictures and videos and draw with layers. It only allows 9 facial features refinement, so it's also not the best choice for image generation. Figure 2.2 shows an example of hair color change using *PicsArt* platform. The considered facial features include *face size, lips, eyes and nose size, eye-bags, hair color, eyes color, blemishes removal and teeth whitening*.



Figure 2.2: Image refinement using PicsArt application.

### 2.2.3 Facetune2

*Facetune2* (ref: <https://www.facetuneapp.com/>) is a photo editing application. It's commonly used to enhance the portrait or selfie images and offers 7 feature refinements. Figure 2.3 shows an example of image refinement using *Facetune2* application. The considered facial features include *face shape*, *skin smoothing*, *makeup*, *teeth whitening* and *eyes and nose size*.



Figure 2.3: Image refinement using Facetune2 application.

### 2.2.4 Booth Apps

*Booth Apps* are a collection of applications for image or video editing and enhancement, can add animation to an image and many other entertaining features. Examples for Booth Apps are : *Simple Booth Classic* (ref: <https://www.simplebooth.com/>), *Pocketbooth*, *Photobooth mini* (ref: <https://photoboothmini.app/>) and *My Photobooth App*. They only consider image enhancement and for entertaining purposes not critical problems like our product. Figure 2.4 shows some filters and edits that can be applied using *Photobooth* application. We can see that it's totally used for entertainment purposes.



Figure 2.4: Image editing using Photobooth application.

## 2.3 Business Case and Financial Analysis

Our product is new in the market, which makes our business case a great one. We can provide our services in two forms as following:

- The first is being a software service that is used in police stations, so that any missing people or theft happens, they enter the description of potential suspects, so they can have an image of him/her to be able to find him faster. Also, it can be used in historical institutions that are responsible for finding information about historical characters and events from ancient descriptions.
- The second one is a website for general users to be able to use it for entertainment purposes or, for example, to generate images of their ancestors from description, so they get the chance to see them.

This means that we have three ways to earn money from our application :

- The first way is the money paid by the institutions that use the application for specific purposes (e.g. police stations or historical researches).
- The second way is the money paid by the users, who will be willing to be premium subscribers in the application. Premium subscription can give the user more server resources for faster generation and manipulation, as well as more number of generated faces per month.
- The third way is the companies that are interested to place their advertisements on our product.

So, we are going to address those three aspects in this section. In the business case, we will show the expected number of product sales over the next 5 years and how we will tune the price to counter the competition. Table 2.1 shows the business case study.

Table 2.1: Business Case over 5 years.

Years	Year 1	Year 2	Year 3	Year 4	Year 5
Avg Number of Customers	30	50	100	120	200
Product Purchase	\$1500	\$1500	\$2000	\$2300	\$2800
Avg Number of Premium Subscribers	200	500	800	1100	1500
Premium Subscription Cost	\$5	\$7	\$12	\$15	\$20
Average Ads earnings (per day)	\$1	\$1	\$3	\$5	\$8
Average usage days per year	100	170	200	180	210
Average Profits from Ads	\$100	\$170	\$600	\$900	\$1680
Average Profits from Subscription	\$1000	\$3500	\$9600	\$16500	\$30000
Profits from Purchasing	\$45000	\$75000	\$200000	\$276000	\$560000
Total Profits	\$46100	\$78670	\$210200	\$293400	\$591680

Based on a business case study and the specifications needed, the cost estimation of our software as a service in a specific institution is the cost behind the hardware. Our application takes around 1 second on an *Nvidia GTX 1080 ti* for generating a face from any description, but this can extend to be multiple seconds based on the connection. The whole system can be deployed on single PC with 11GB VRAM, around 700\$ for the GPU and 1500\$ to 2000\$ for the whole PC. For scalability, we can use 2 PCs, one for face generation and the other for face rotation, to host the whole application. Also, we can scale out our system to more than 2 PCs for improved request parallelism. So, we can conclude the *Capex* as shown in table 2.2 and *Opex* as shown in table 2.3. Given this information, we can construct the financial analysis as shown in table 2.4.

Table 2.2: Capex Table.

Items and Supplies	Cost
Office Preparation ( offices, chairs , etc )	\$4000
PCs and Laptops	\$8000
Servers	\$3000
Total Capex	\$15000

Table 2.3: Opex Table.

Items and Supplies	Cost per month
Salaries	\$4000
Rent	\$300
Bills ( electricity , water, etc )	\$450
Total Opex	\$4750

It's clear from table 2.4 that the break points starts from the third month (March), so we subtract the taxes which consists of 25% from the total profits at every month to get our net profits.

Table 2.4: Cash flow Table over a year (in dollars)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Capex												
Office Equipment	1000	1000	1000	1000	0	0	0	0	0	0	0	0
Laptops and PCs	800	800	800	800	1000	1000	1000	1000	1000	0	0	0
Servers	1500	1500	0	0	0	0	0	0	0	0	0	0
Opex												
Salaries	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
Rent	300	300	300	300	300	300	300	300	300	300	300	300
Bills	450	450	450	450	450	450	450	450	450	450	450	450
Sub Total	8050	8050	6550	6550	5550	5750	5750	5750	5750	4750	4750	4750
Accumulative	8050	16100	22650	29200	34750	40500	46250	52000	57750	62500	67250	72000
Revenue												
Purchasing	6000	8000	9500	12000	15000	15000	10000	15000	12500	16000	14000	18000
Subscription	100	150	180	200	220	180	230	180	200	150	180	190
Ads	60	75	80	110	90	88	97	100	110	114	98	108
Sub Total	6160	8225	9760	12310	15310	15268	10327	15280	12810	16264	14278	18298
Accumulative	6160	14385	24145	36455	51765	67033	77360	92640	105450	121714	135992	154290
Profits	-1890	-1715	1495	7255	17015	26533	31110	40640	47700	59214	68742	82290
Taxes	-	-	373.75	1813.75	4253.75	6633.25	7777.5	10160	11925	14803.5	17185.5	20572.5
Net Profits	-1890	-1715	1121.25	5441.25	12761.25	19899.75	23332.5	30480	35775	44410.5	51556.5	61717.5

### 3 Literature Survey

In this chapter, we explain the necessary background, as well as the related work in the research literature.

#### 3.1 Background Review

We discuss the basic background knowledge that helps us throughout the document.

##### 3.1.1 Convolutional Neural Networks

Convolutional Neural Networks (CNN) is a special type of *feed-forward* neural networks, which uses convolution operations to perform the forward computations. They are used in wide range of applications, especially *computer vision*. There are 4 basic types of layers in a CNN (shown in figure 3.1) that we would like to mention :

1. **Convolution layer** : uses filters (a.k.a. *kernels*) to detect edges and shapes by convolution with the input map. The filter has certain dimensions and scans the map using certain stride. This helps the network to learn sparse connections and local structures.
2. **Pooling layer** : is usually used to reduce the input dimensions through maximizing or averaging using a filter.
3. **Upsampling layer** : increases the dimensions of the input map using traditional up-sampling methods, such as bilinear upsampling, or learnable upsampling using *deconvolution*.
4. **Fully-connected layer** : is a normal feed-forward dense layer, usually used in classification.

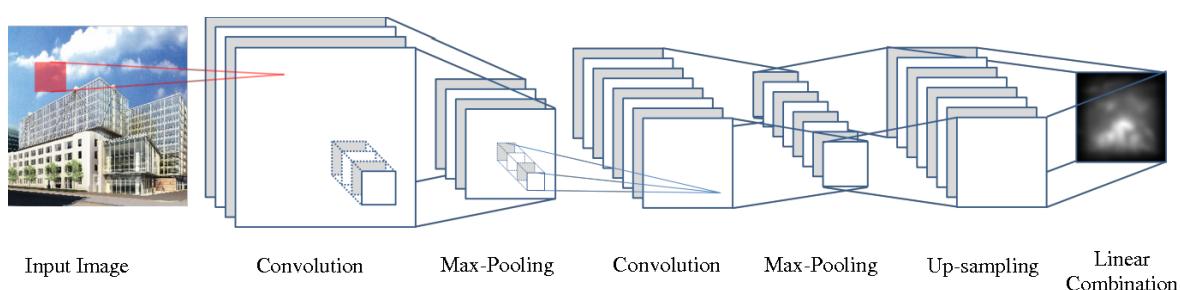


Figure 3.1: A standard CNN with Upsampling layer.

##### 3.1.2 Generative Adversarial Networks

Generative Adversarial Networks (*GANs*) [1] are generative models that can learn through *adversarial training*. GANs have proven to be very good at generating high dimensional data like images. That's why they are used in wide range of applications including image and video generation, image-to-image translation and others.

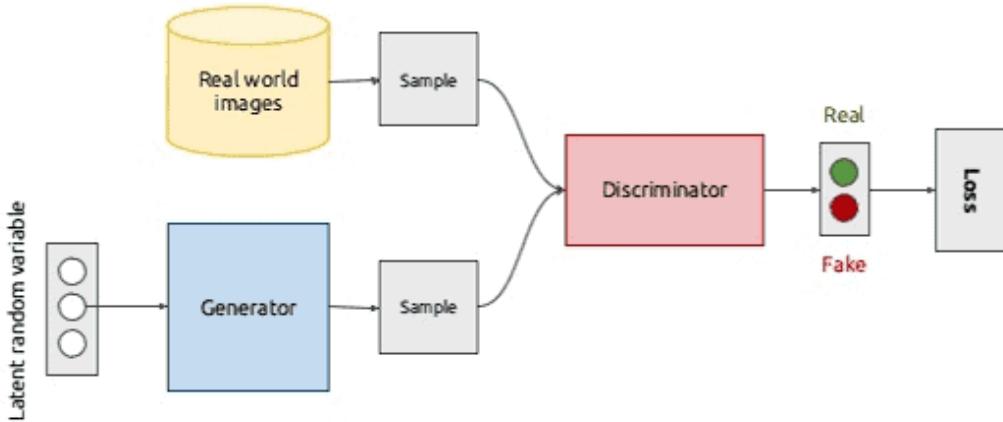


Figure 3.2: The basic architecture of a generative adversarial network (GAN).

The basic architecture of a GAN (as shown in 3.2) consists of 2 main networks. A *generator* takes in random noise (usually *latent random variable*) and convert it into a fake data sample. A *discriminator* judges the quality of the fake data sample by distinguishing between real and fake data samples. The discriminator loss (a.k.a. *adversarial loss*) is used to train both generator and discriminator. So, the whole system can be decomposed into a two-player *minimax* formulated as :

$$\min_G \max_D V(D, G) = E_{x \sim P_{\text{data}}(x)}[\log D(x)] + E_{z \sim P_z(z)}[\log(1 - D(G(z)))] \quad (1)$$

The generator and discriminator networks can be any type of networks. In our case, we use *Convolutional Neural Networks* (CNN), because the output is an image. Consequently, the generator is a CNN that up-samples the latent variable into a complete image. Meanwhile, the discriminator is a classification CNN that encodes the input image and classifies it into real or fake.

The first architecture for a CNN-based GAN goes by the name DCGAN [2]. In our work, we focus on a specific type of GANs, named *style-based* (or *latent-based*) GANs.

### 3.1.3 Latent Space and Entanglement

As mentioned before, we focus on a specific type of generative models named *style-based* GANs. These GANs can have artistic control over their outputs, not just sampling data randomly from a prior distribution. The key idea of these models is to use a *latent variable* to control the output, instead of just considering a random noise. This latent variable is sampled from a *latent space* and, then, used to guide the generation process in the generator network using adaptive instance normalization (*AdaIN*).

*AdaIN* is a normalization method that aligns the mean and variance of the content features with those of the style features. It's an extension over *Instance Normalization*, which normalizes the input to a single style specified by the affine parameters. It can be formulated as follows :

$$\text{AdaIN}(x, y) = \sigma(y)\left(\frac{x - \mu(x)}{\sigma(x)}\right) + \mu(y) \quad (2)$$

The latent space is a made-up space, in which the data is encoded in low dimensional representation. For a good model architecture, the latent space is organized, such that similar features are clustered together and changes in low dimensional latent space maps to similar changes in the generated data. Some the most popular and robust latent-based architectures are BigGAN [3] and StyleGAN [4] [5].

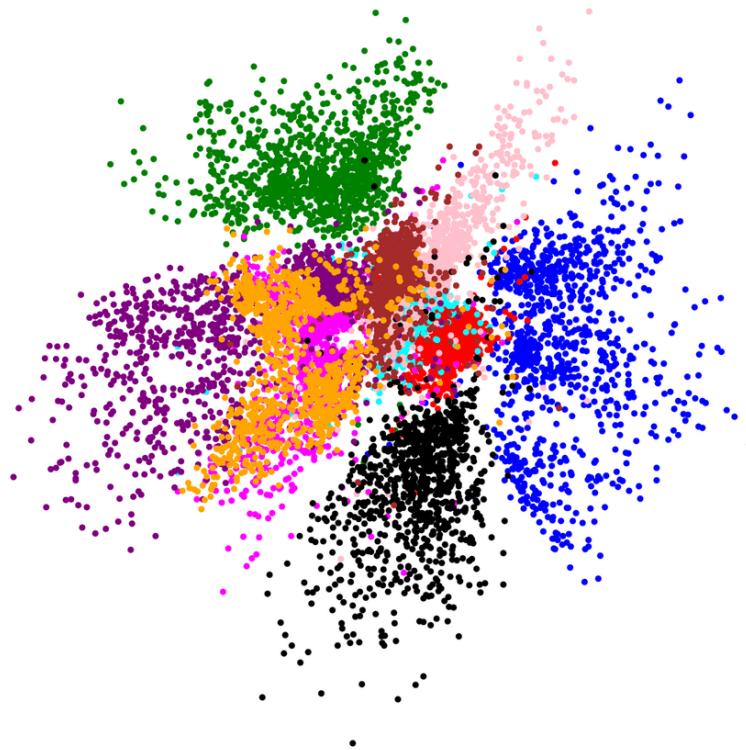


Figure 3.3: An example 2D latent space of MNIST digits dataset.

Figure 3.3 shows a simple 2D latent space for MNIST dataset for digits classification. We can see that we have 10 clusters corresponding to the 10 digits. Some clusters are more overlapping than others. It's obvious from the figure that we can learn certain directions to move from one cluster to another in the latent space. However, due to overlapping, certain directions might not be clear or even feasible to obtain. This problem is known as **entanglement**, which is one of the most important challenges of our work.

The problem of entanglement arises due to the data and training process of the architecture. Some datasets can show heavy correlation between different features, which causes the latent space to be less organized and the features clusters to be overlapping. Thus, the features are entangled in the latent space and extracting independent directions for every feature is hard or even infeasible. Consequently, moving along a certain direction can cause multiple features to change with certain amounts.

### 3.1.4 Multi-class Multi-label Text Classification

The problem of extracting specific features (or keywords) from an input text and describing the degree of importance for each feature is usually referred to as *multi-class multi-label text classification* or *keywords extraction*. There exists many approaches to such problem on different degrees of complexity, described as follows.

### 3.1.4.1 Simple Statistical Approaches

Using *statistics* is one of the simplest methods for identifying the main keywords and key phrases within a text. There are different types of statistical approaches, including *word frequency*, *word collocations* and *co-occurrences*, **TF-IDF (short for term frequency-inverse document frequency)**, and **RAKE (Rapid Automatic Keyword Extraction)**. Although these methods are very simple and don't require any training data, they tend to overlook relevant words and don't work well in most cases.

### 3.1.4.2 Linguistic Approaches

Keyword extraction methods often make use of *linguistic information* about texts and the words they contain. Sometimes, *morphological* or *syntactic* information, such as the *part-of-speech* of words or the relations between words in a *dependency grammar representation* of sentences, is used to determine what keywords should be extracted. Most systems that use some kind of linguistic information outperform those that don't do so.

### 3.1.4.3 Graph-based Approaches

Many graph-based methods are used to represent the unstructured text and extract certain keywords from it. **HMMs (Hidden Markov Models)** are used to perform *part-of-speech tagging*, in order to structure the sentence and extract keywords from it. Other graph-based methods are used too.

### 3.1.4.4 Machine Learning Approaches

Machine learning-based systems can be used for many text analysis tasks, including keyword extraction. In order to process unstructured text data, machine learning systems need to turn it into vectors of features that represent the text. There are different machine learning algorithms and techniques that can be used to extract the most relevant keywords in a text, including **SVM (Support Vector Machines)** and *deep learning*. Some of the Machine Learning-based techniques for keywords extraction are :

- **Conditional Random Fields (CRF)** : a statistical approach that learns patterns by weighting different features in a sequence of words present in a text.
- **End-to-end Deep Learning with Attention** : using neural network to learn keywords extraction in an end-to-end manner with metrics like : *accuracy*, *precision*, *recall*, *F1 score*, and **ROUGE (recall-oriented understudy for gisting evaluation)**.
- **Deep Learning Transformers-Based Approaches** : especially BERT architectures, which stands for Bidirectional Encoder Representations from Transformers. Unlike recent language representation models, BERT is designed to pre-train deep bidirectional representations from unlabeled text by jointly conditioning on both left and right context in all layers. As a result, the pretrained BERT model can be fine-tuned with just one additional output layer to create state-of-the-art models for a wide range of tasks, such

as question answering and language inference, without substantial task-specific architecture modifications. BERT is conceptually simple and empirically powerful. It obtains new state-of-the-art results on eleven natural language processing tasks.

## 3.2 Face Modelling and Generation

In this sub-section, an overview is given about face generation and refinement methods.

### 3.2.1 Face Generation

Human face generation is a sub-problem of image generation. Usually generative models target face generation from random latent noise. However, the input for a face generation model can be extended to include a description of the desired facial features, not just random face generation. These descriptions can include voice, text or even feature values. The output of such process is a complete human face portrait, whose quality depends on the architecture of the model.

The problem of human face generation is not new to the AI research. Many generative models target the problem of face generation from scratch.

#### 3.2.1.1 StyleGAN

In StyleGAN [4], a new generator architecture is proposed that enables controlling the synthesis of the faces by learning the unsupervised separation of high level features. It generates a complete high quality face image controlled by the latent code.

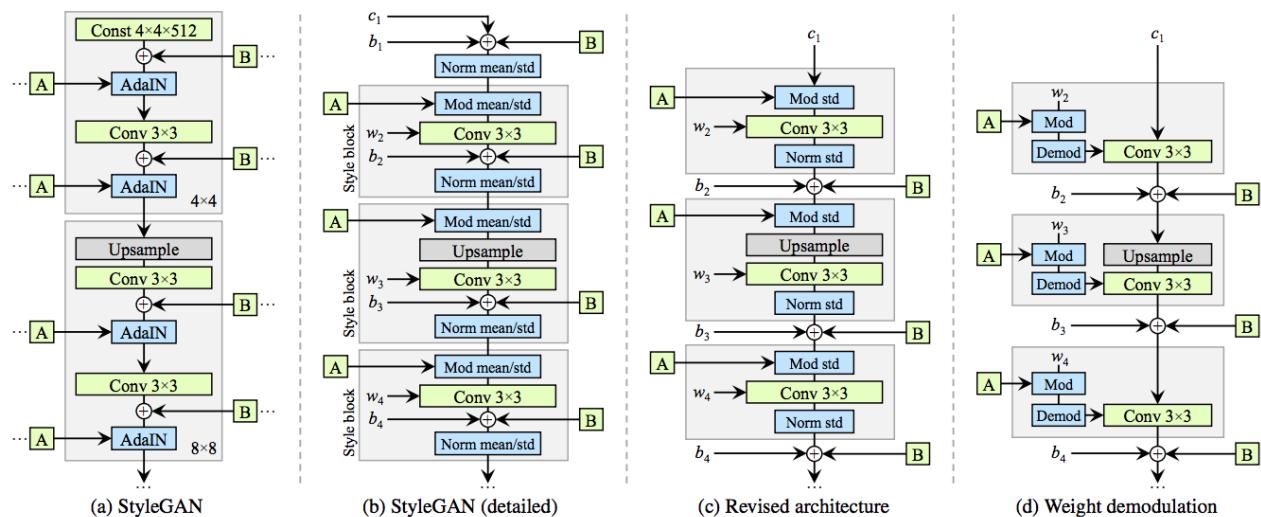


Figure 3.4: Different StyleGAN architectures diagram.

StyleGAN has 2 versions (shown in figure 3.4), where the second version adds more modifications to address generation artifacts. Generally, it works as follows :

- A random latent code  $z$  is first generated.

- Latent code  $z$  is mapped to an intermediate latent space  $w$ , which is then transformed to extended latent space  $w+$  through affine transformation.
- The intermediate extended latent code  $w+$  is used to control the generation process in the synthesis network using adaptive instance normalization (*AdaIN*).

StyleGAN2 [5] introduces improvement on the synthesis network by adding *residuals* and changing the integration of latent variable to the synthesis network, as shown in figure 3.4. These changes improves the output visual results and reduces generation artifacts. Figure 3.5 shows the visual results of face generation using StyleGAN2.



Figure 3.5: Visual results of StyleGAN2.

Figure 3.5 shows visual result samples from StyleGAN2, which is the revisited version of StyleGAN.

### 3.2.1.2 StyleGAN latent manipulation

Subsequent research work follows StyleGAN to try latent manipulation for more control over the generated faces. These methods include Image2StyleGAN [6], Image2StyleGAN++ [7], InterfaceGAN [8], StyleRig [9] and StyleFlow [10]. All of these work targeted the directed

manipulation of *StyleGAN* latent space to change certain facial features. However, none of these methods target complete generation of new face from bare description, which is, also, known as *conditioned sampling*.

On the other hand, our work target face generation from bare description. Consequently, we utilize the concept of directed manipulation to do conditioned sampling, which is described later in this document.

### 3.2.1.3 Faces à la Carte

To our knowledge, *Faces à la Carte* [11] is the only current open-source research work that addressed the problem of face generation from text. It's based on *StyleGAN2* and uses a general framework to extract the feature directions and reach the target face.

We couldn't replicate their results, because the authors don't provide sufficient information about their method. However, we managed to gain some insights that helped us throughout the project.



Figure 3.6: Visual results of *Faces à la Carte*.

Figure 3.6 shows the visual results that the authors included in their paper. While being conservative about some of their work, we still consider this as the only former open-source research work related to our problem.

### 3.2.1.4 NVAE

The paper **NVAE: A Deep Hierarchical Variational Autoencoder** [12] is a recent research work that discusses the usage of Variational Autoencoder (VAE) to generate high quality image controlled by a latent variable. It uses normalizing flows to control the output features. *Normalizing flows* is a method of mapping an unknown distribution to a known distribution (normal or uniform). It's basically used to generate complex distributions from simple normal distributions.

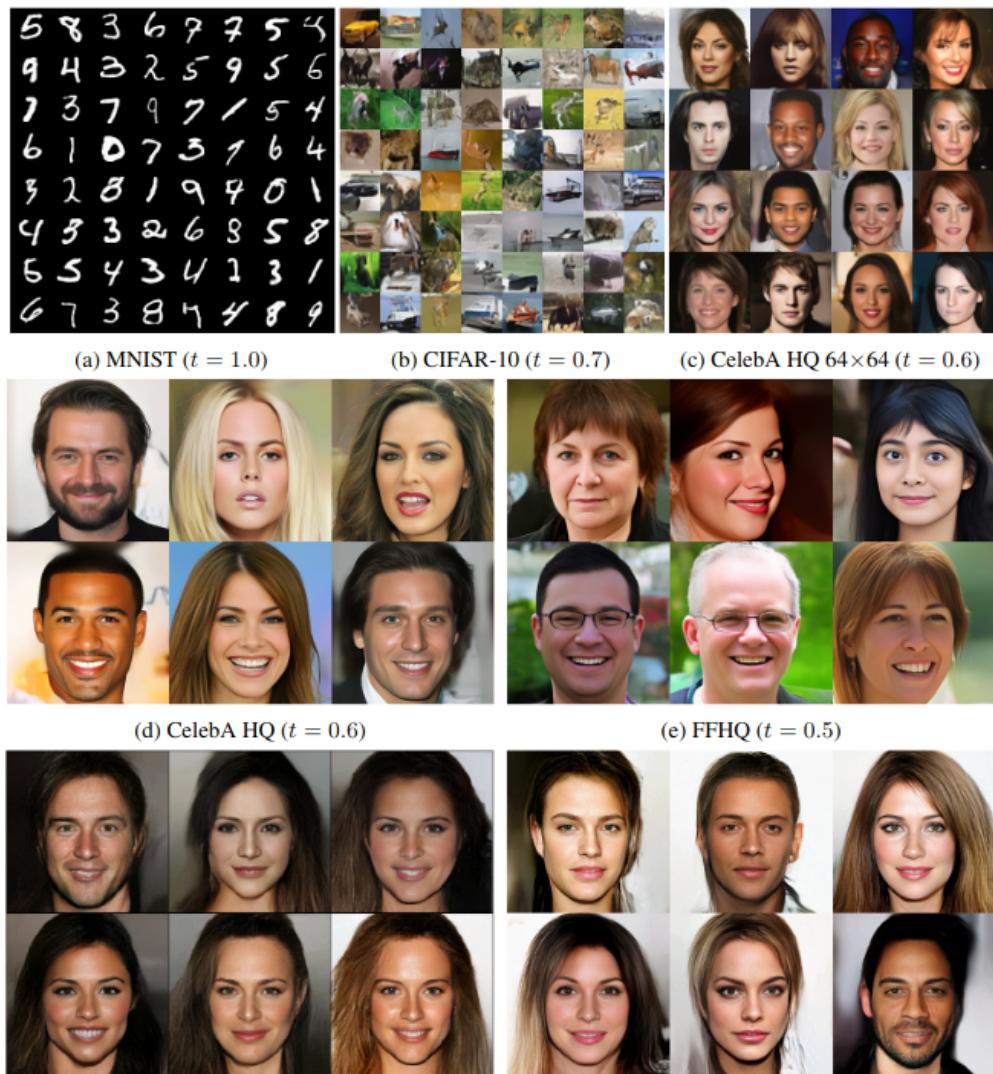


Figure 3.7: Visual results of NVAE.

### 3.2.2 Face Refinement

The process of face generation can be inaccurate, thus the stage of face refinement is a must, in order to be able to independently edit some of the facial features.

#### 3.2.2.1 AttGAN

AttGAN [13] uses an encoder-decoder architecture for the generator, where the decoder takes an attribute vector telling it which attributes are existing and which are not. There's a classifier after the decoder to get the attribute vector of the output image. The decoder is trained to get the same input image if the attribute vector was the input attribute vector and to get an output image with a new attribute vector which makes the classifier get the same attribute vector if the output image was given to it. The architecture is shown in figure 3.8, meanwhile the results are shown in figure 3.9

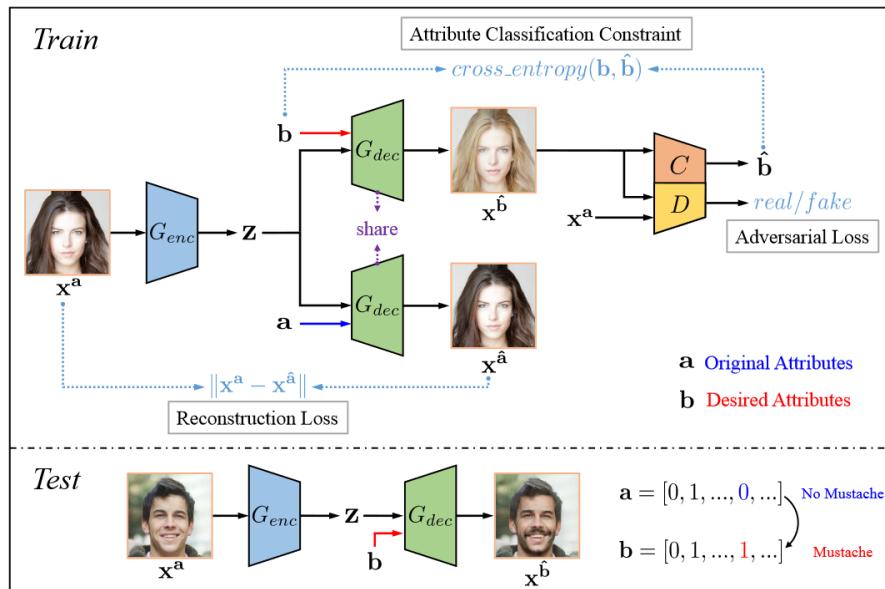


Figure 3.8: Complete architecture of AttGAN.



Figure 3.9: Visual results of AttGAN.

### 3.2.2.2 InjectionGAN

InjectionGAN [14] uses the same concepts as AttGAN, but it has one more concept, which is using Feature-wise Linear Modulation (FiLM) layer which successfully infers information from external data and applies it as an affine transformation parameter to vision tasks, so they propose a new type of skip connection layers between encoder and decoder of the

generator to add the new attributes shown in figure 3.10. Visual results of InjectionGAN are shown in figure 3.11

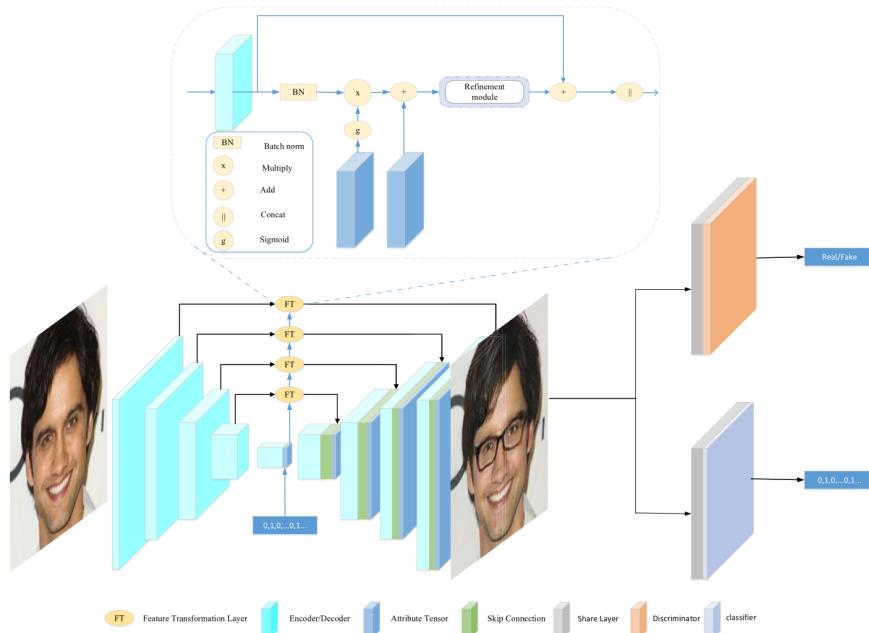


Figure 3.10: Complete architecture of InjectionGAN.



Figure 3.11: Visual results of InjectionGAN.

### 3.2.2.3 Facelet-Bank for Fast Portrait Manipulation

Facelet Bank [15] follows the idea of navigation in GANs latent space, they added a new module called Facelet bank. It's used as skip connections. It takes a bottleneck output from

the decoder as input and passing it to a block of CNN layers and add it to the bottleneck output. This summation does the operation of the navigation in the latent space, so the Facelet layer should be trained to get the correct added value to different bottleneck outputs to the same face with changing a specific attribute. Figure 3.12 shows the complete architecture, while figure 3.13 shows the visual results.

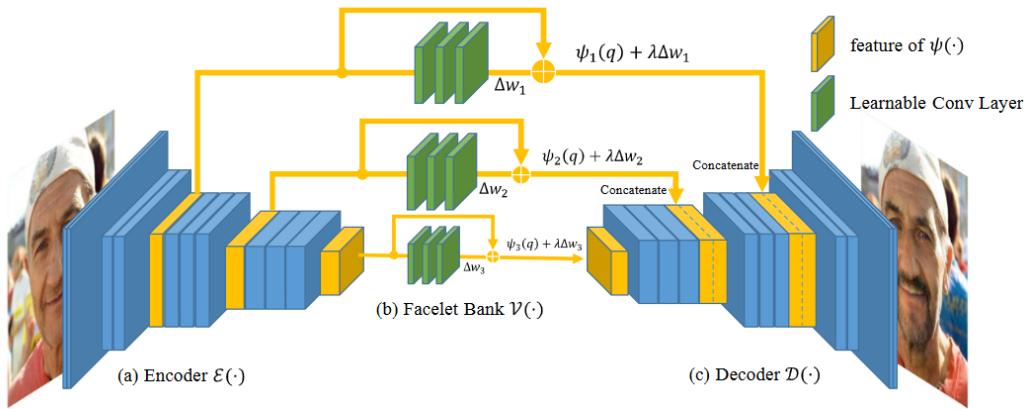


Figure 3.12: Complete architecture of Facelet Bank.

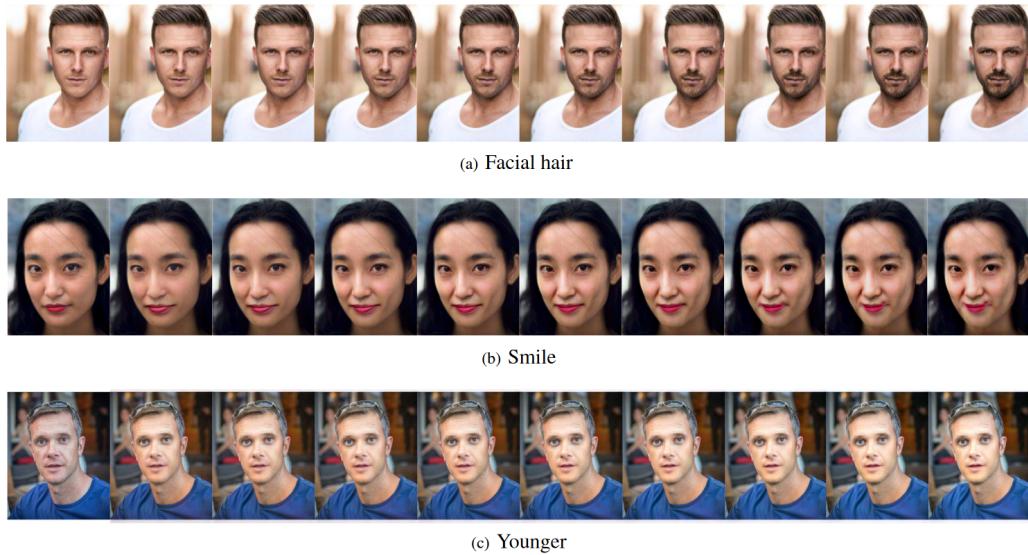


Figure 3.13: Visual results of Facelet Bank.

### 3.3 Face Rotation

In this sub-section, we discuss different methods and approaches to generate multiple head poses from a single image. Note that, we focus on the methods that rotate a face, provided by a single image, with multiple angles of rotation, not just head frontalization. Also, the methods are ordered according to priority based on *performance*, *visual results* and *involved work*.

### 3.3.1 Rotate-and-Render

The network [16] is based on *3D face modelling* with *unsupervised deep learning*. It consists of three stages :

- **3D face fitting** which generates a 3D model of the face and extracts the face texture.
- **Rotate-and-render** which rotates the face in 3D space and renders it in different poses.
- **Render-to-image** which projects the 3D render of the face into a 2D image.

The architecture, also, ensures *cycle-consistency* through re-projecting the face into the initial pose. Figure 3.14 shows the visual results of the network.



Figure 3.14: Visual results of Rotate-and-render network.

### 3.3.2 DepthNets

The network [17] is based on *casting* a specific face to a pose provided by another face in an *unsupervised way*. It consists of three stages :

- **Landmark extraction** from both faces.
- **Image-to-image translation**.
- **Siamese-like architecture** that compares the generated face with the original one.

Figure 3.15 shows the visual results of the network.

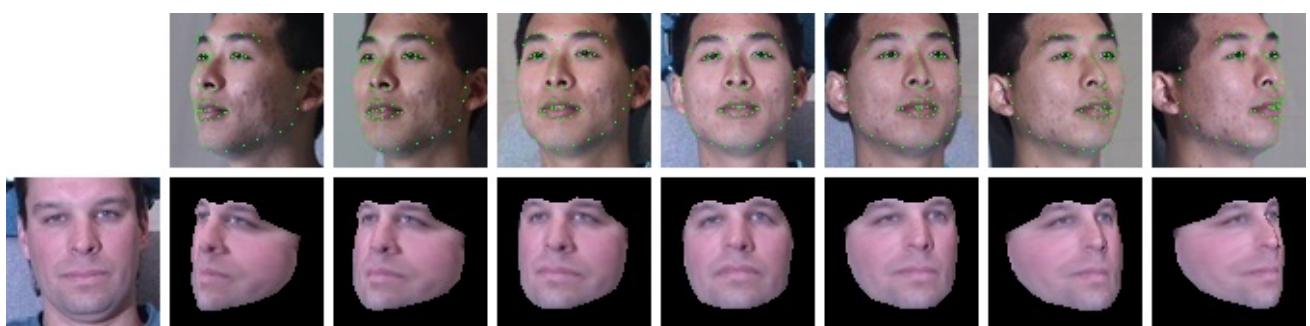


Figure 3.15: Visual results of DepthNets.

### 3.3.3 PosIX-GAN

The network [18] generates the provided faces in *9 angles of rotation* in an *end-to-end manner* that relies on datasets to train GANs. It's an end-to-end network that depends on datasets for training. Figure 3.16 shows the visual results of the network.

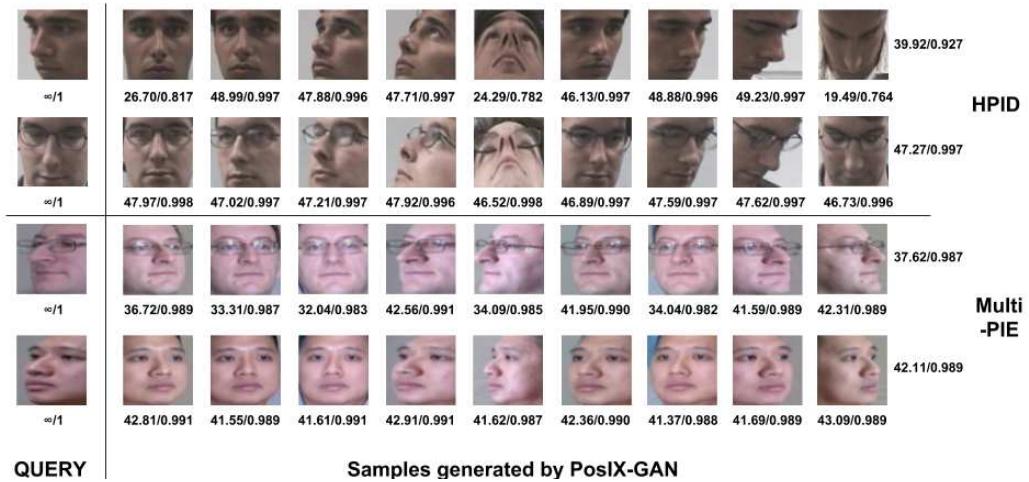


Figure 3.16: Visual results of PosIX-GAN.

### 3.3.4 CAPG-GAN

The network [19] generates different head poses using a *pose-conditioned generator* and *couple-agent discriminator* that discriminates both identity and pose. It's an end-to-end network that depends on datasets for training. Figure 3.17 shows the visual results of the network.

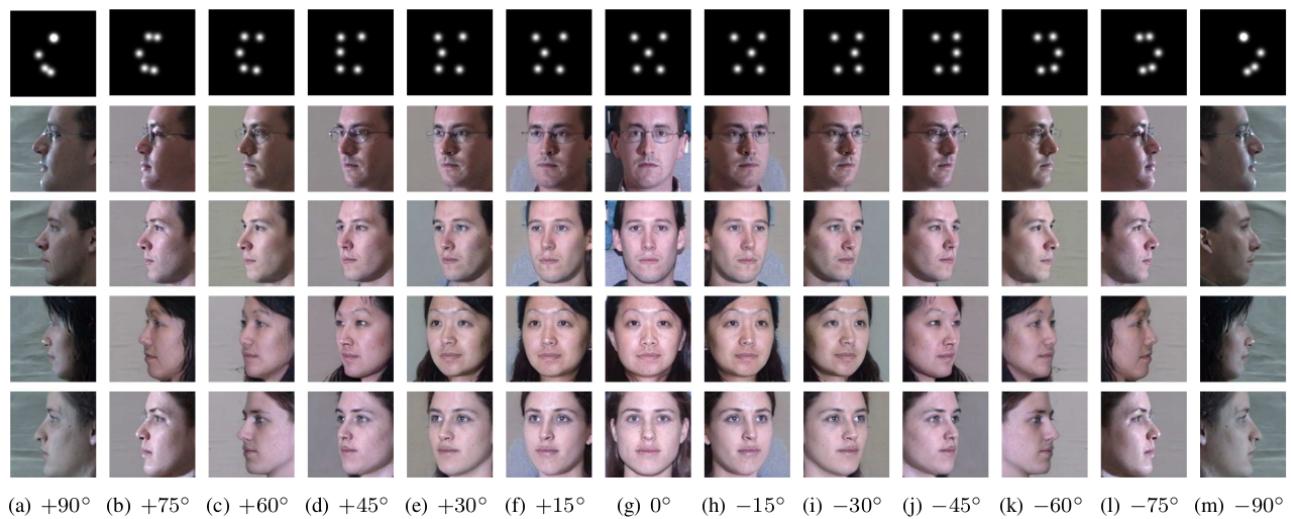


Figure 3.17: Visual results of CAPG-GAN.

### 3.4 Comparative Study of Previous Work

From our previous discussion, we can see that StyleGAN2 offers the best quality of faces, while being very flexible. The architecture is used in various research works related to image generation. Other approaches don't have the same flexibility and robustness. That's why we opted to use StyleGAN2 as our main generative model.

Faces à la Carte paper does not provide enough details about their method, as well. This is one of the reasons that encourages us to work on this project, in order to provide a clear pipeline for the problem solution.

Regarding face refinement, the most promising method is Facelet Bank, which can be used on high quality image. Also, the *facelet bank* module is flexible enough to handle multiple facial features. However, in our final system, we chose not to go with this architecture for reasons, mentioned later in the document.

Finally, for face rotation, Rotate-and-Render and DepthNets offer an unsupervised framework for multiple face poses generation. This is better and much easier to adapt than other supervised methods, mainly because most of head poses datasets are not open-source. Rotate-and-Render can produce better visual results than DepthNets, because it can account for features such as hair through *image inpainting* using *image-to-image translation*. Overall, this yields better visual results.

### 3.5 Implemented Approach

Our system implements 3 main functionalities, which are **text-to-face generation** (input can be *speech* or *text*), **face refinement** and **multiple head poses generation**. After extensive research and experimentation, we come up with our working pipeline that achieves our project goal.

#### 3.5.1 Face Generation from Description

First of all, we start with our core and the most innovative part of our project. Face generation from bare description is very popular problem, yet few research works target it. To our knowledge, Faces à la Carte is the only available research paper that targets this problem. As we mentioned, the authors does not offer enough details about their method. Consequently, we have to utilize the related work to carefully design a fast and robust system for such problem. Our system can take different kinds of descriptions, including audio, text and manual inputs. That's why we have to create multiple stages of input processing and not to use direct end-to-end networks.

The first processing stage is *speech recognition*, which translates the speech into textual description. We opt to use DeepSpeech2 [20], which is one of the most popular speech recognition architectures.

The second processing stage is *text processing*, which converts the textual description into numerical attributes values. For this stage, we have many options, including classical and DL-based methods. However, we choose to work with DistilBERT [21] due to multiple reasons. Basically, DistilBERT is a lightweight architecture that does not have a very big memory footprint. It's fast and easily tuned to our needs. Moreover, it does not use *recurrent*

*neural networks*, which are slow at inference time. Finally, we can adapt it to our desired output, which is not just classification, but the actual numerical values of the facial features.

The third and last processing stage is *code generation*, which transforms the numerical attributes values into a face embedding that is used to guide the face generation process. This stage is completely designed from scratch and refined, iteratively, with face generative model (StyleGAN2). However, some previous research works are used for guidance, especially Image2StyleGAN, which guided our feature directions extraction process. However, our system considers more facial features than any of the previous works.

Finally, we come to the actual face generation model. For this, we opt to use StyleGAN2. The reason behind this choice is that StyleGAN2 is the one of the most powerful image generators that produce high quality images. It's very flexible and can be adapted to many applications. Moreover, it does not require special hardware to be tuned, which is the case in BigGAN that requires *Tensor Processing Units (TPUs)*.

### 3.5.2 Face Refinement

For the face refinement module, we choose to adapt our work in **face generation** to be used for refinement as well. This is mainly done to avoid including another model, which would have increased the memory footprint. Moreover, latent manipulation of StyleGAN2 can offer better results than most face refinement architectures with more facial features to include. Consequently, StyleGAN2 latent manipulation is considered for face refinement with an extended set of facial attributes to refine.

### 3.5.3 Multiple Head Poses Generation

Although it's possible to extract feature directions for the generated head poses for StyleGAN2 as well, we don't consider using it for face rotation. This is mainly because face pose directions suffer from heavy entanglement with other features. Moreover, these directions don't preserve the face identity and can cause serious illumination problems. Consequently, we only keep this method as a backup plan. However, Rotate-and-Render is our main multiple head pose generation method. We used the same workflow to create our face rotation pipeline and integrate it to our system. The main reason behind choosing Rotate-and-Render is that the whole workflow can be decomposed into separate modules to be edited and implemented to fit our needs. Also, it is an unsupervised architecture, which makes it easy to work with. Finally, it offers decent results compared to other architectures.

## 4 System Design and Architecture

In this chapter, we discuss our working pipeline and system architecture in details. Generally, our system takes a speech note, textual description or numerical attributes as an input. It processes the input description and outputs the initial human face portrait that corresponds to the given description. Afterwards, the user is allowed to manually control some facial attributes and morphological features and to rotate the face and render it in multiple poses. In the first section, we give an overview about the final system. Then, we discuss the final system architecture in the second section. In the subsequent sections, each module implementation is discussed in details. In the last section, we discuss the other conducted experiments, why we choose this final system and suggestions that can possibly improve the other experiments.

### 4.1 Overview and Assumptions

As mentioned above, our system basically enables the user to describe a human face in words or using numerical values and turns it into a full human face portrait that can be manipulated and rendered in multiple poses. The system relies heavily on generative models and text processing, both are iteratively designed to obtain the required results. The overall flow can be described as follows :

- The input speech notes are translated to text.
- The textual description (extracted from speech input or manually entered) is processed to extract the numerical values of the required facial features.
- The numerical values are used to generate a face embedding vector that encodes the facial attributes in low dimensional space ( $512D$ ).
- A generative model is specifically designed to translate from the low dimensional embedding into the full face portrait ( $1024 \times 1024$ ).
- The generated face portrait can be further refined by navigating the face embedding space and re-generating the face portrait.
- Once the user settles on the final face portrait, the system can render that face in multiple poses to provide further identification.

The previous flow provides a very versatile framework to generate face portrait and adjust it to your liking. However, there is an extremely large number of facial attributes and morphological features to describe a human face. Consequently, we have to choose a descriptive subset of these attributes to consider in the face description. We consider 32 facial attributes for face description, which are listed as follows :

- Overall face :
  - Gender : Male / Female.
  - Age : Young / Old.

- Thickness : Chubby / Slim.
  - Shape : Oval / Circular.
  - Skin Color : Black / White.
  - Cheeks : Normal / Rosy.
- Eyes :
  - Color : Black / Blue / Green / Brown.
  - Width : Wide / Narrow.
  - Eyebrows : Light / Bushy.
  - Bags Under Eyes : On / Off.
- Nose :
  - Size : Big / Small.
  - Pointy : On / Off.
- Ears :
  - Size : Big / Small.
- Jaw :
  - Mouth Size : Big / Small.
  - Lips Size : Big / Small.
  - Cheekbones : Low / High.
  - Double Chin : On / Off.
- Hair :
  - Color : Black / Blonde / Brown / Red / Gray.
  - Length : Tall / Short.
  - Style : Straight / Curly / Receding Hairline / Bald / with Bangs.
- Facial Hair :
  - Beard / None.
- Race :
  - White / Black / Asian.
- Accessories :
  - Glasses : Sight / Sun.
  - Makeup : On / Off.
  - Lipstick : On / Off.

## 4.2 System Architecture

Now, let's discuss our system architecture. The system consists of 6 modules, 3 core modules of the project and 3 auxiliary modules. These modules are deployed in a *web application* to provide an easy-to-use interface for face generation and manipulation. Figure 4.1 shows the complete block diagram of the system architecture. Meanwhile, figure 4.2 shows the application design and how the modules are deployed in a web application. The *core* modules are listed as follows :

- **Text Processing** : processes the input textual description and extracts the corresponding numerical values of facial attributes. This problem is similar to *multi-label text classification*, however the outputs are normalized scores of facial attributes, which are designed carefully to match the *face code generation* process.
- **Face Generation** :
  - **Code Generation** : converts the numerical attributes values to be low dimensional face embedding. This is the most *important* and *innovative* module of our system, because it glues the desired attributes scored with the latent space of the generative model (used to generate the face), resulting in more accurate quality outputs.
  - **Code-to-Face Translation** : translates the low dimensional face embedding into the actual face portrait. For this purpose, we use StyleGAN2, which is a *state-of-art latent-based generative model*, whose latent space can be manipulated easily to fit our needs.

Meanwhile, the *auxiliary* modules are listed as follows :

- **Speech Recognition** : translates the input speech to textual description.
- **Face Refinement** : uses the same generative model to manually refine the generated face portrait through navigating the latent space.
- **Multiple Head Poses Generation** : rotates the generated face portrait and renders it into multiple poses.

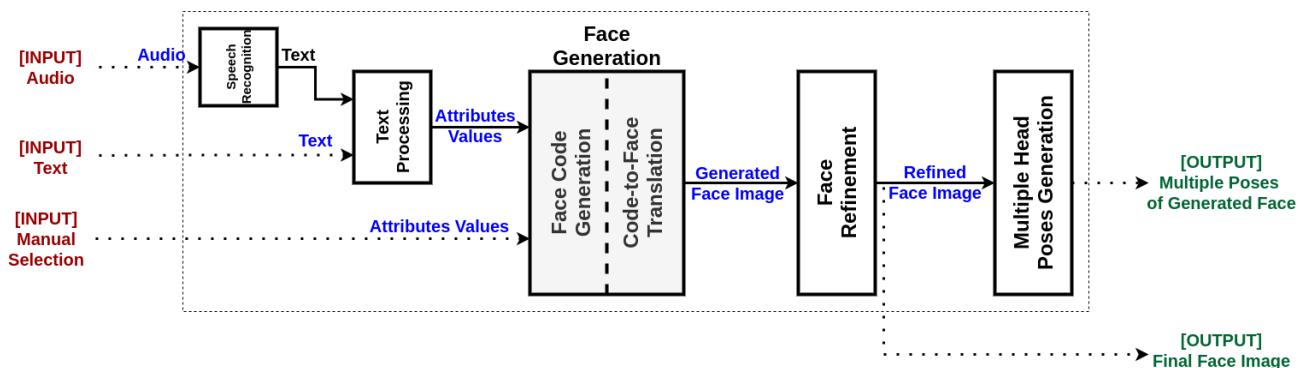


Figure 4.1: Block diagram of complete system architecture

We discuss each module in more details in the subsequent sections. Also, these modules are organized into a web application for easier usage, as shown in Figure 4.2. The application is divided into :

- **Web (Frontend)** : which contains the user interface and, also, the *speech recognizer*. The speech recognizer is moved to the frontend to reduce the network communication overhead between the web application and the server, as transmitting text is easier than transmitting speech. Moreover, the speech recognizer doesn't require high computational power, so it can be embedded in the web application.
- **Server (Backend)** : which is separated into two servers. First server contains the *text processor* and the *generative model* and serves the requests of face generation and refinement. Second server contains the *pose generator* and serves the requests of face rotation.

The two servers can communicate with each other to exchange the generated face portraits through TCP sockets. Meanwhile, the web application communicates and sends requests to the servers through HTTP REST API.

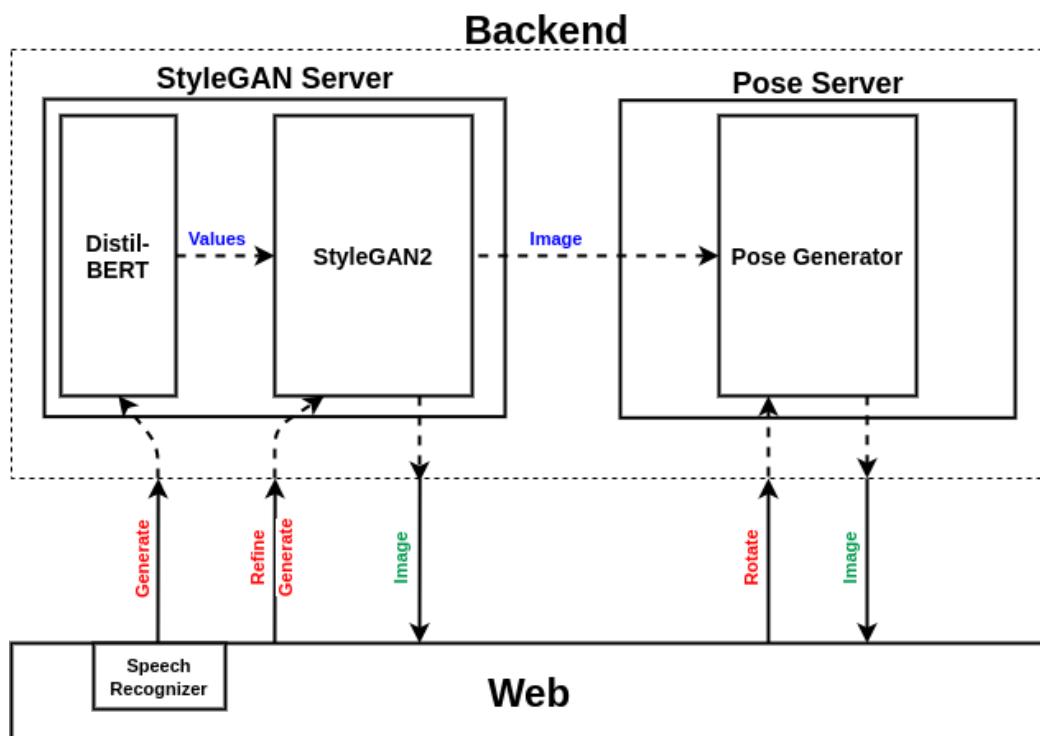


Figure 4.2: Block diagram of application design

## 4.3 Module 1 : Speech Recognition

This is the first module in our pipeline, its responsibility is to get the textual description of the image from speech. It takes the speech as input then processes it to get its textual content to be used to extract the facial features used to generate the image.

### 4.3.1 Functional Description

Our aim is to add functionality that the user can enter a speech description of the image to generate it, so we used an automatic speech recognition model based on DeepSpeech2 [20], we used the Spectograms features from the audio and applied some preprocessing to those features before training. The target of the speech model is to detect the English spoken words and get their textual meaning so that it can be used to generate the Face Image and output the desired described Face.

- **Input :**

- Speech audio wave.

- **Output :**

- The spoken words on the input audio (textual description).

### 4.3.2 Modular Decomposition

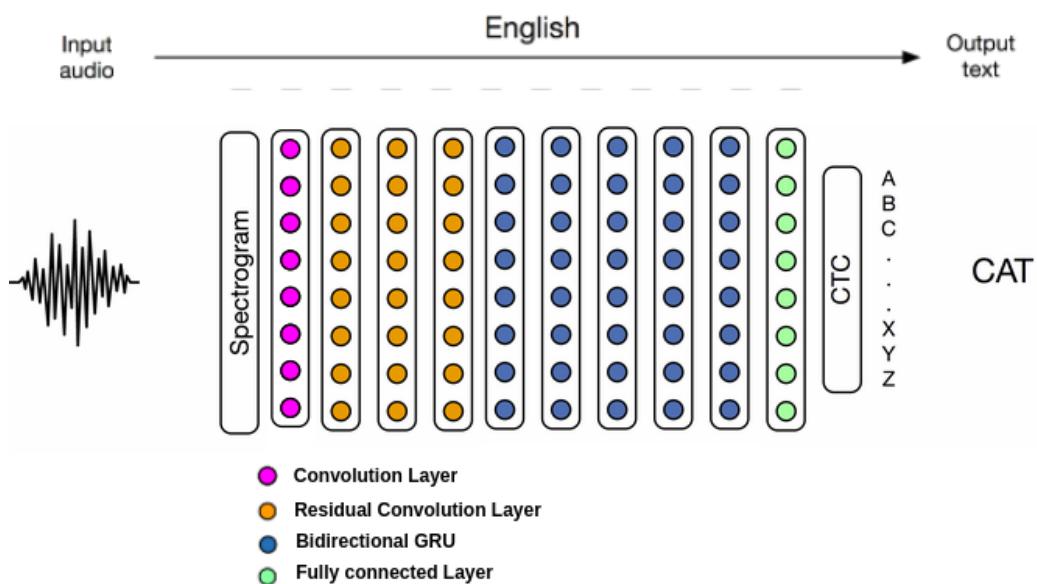


Figure 4.3: Modified DeepSpeech2 network architecture.

As mentioned, we use DeepSpeech2 with connectionist temporal classification (CTC) losses as a base to our speech recognition model. The model takes as input features from the audio in the form of spectrograms compressed by frequency and time masking to separate the spectrograms in time and frequency domains.

The model architecture (shown in figure 4.3) consists of one convolutional layer followed by 3

residual CNNs and 5 bidirectional gated recurrent units GRUs.

The first convolution layer used to compress the audio information in low dimension space, The residual CNN consists of layer normalization over the time axis of the speech then 2 convolution layers summed with the original input to the resCNN.

The bidirectional RNN uses 512 hidden units used to predict the input character at each time step, The last layer is a fully connected layer to out the final predicted character for each input spectrogram.

Connectionist Temporal Classification (CTC) loss function is used to align each character and its location in the audio input file, By summing the probabilities of possible alignments of the input to target and producing a loss value which is differentiable with respect to the model inputs and functions weights. After that those weights are updated using Adam optimizer to minimize this loss value until convergence.

$$L(x, y; \theta) = -\log \sum_{l \in Align(x, y)} \prod_t^{T'} pctc(l_t|x; \theta) \quad (3)$$

The best aligned character is selected using greedy beam search from all available character to the corresponding input.

The model Was trained and tested on LibriSpeech ASR corpus which consists of 100 hours for training and test set, "clean" speech for testing. We calculate the word error rate (WER) and character error rate (CER) for the test data to evaluate the model performance.

#### 4.3.3 Design Constraints

As our application is a real time interactive app, It's a must for the speech recognition model to be very fast to be able to process the input quickly so that we gain the users satisfaction. It was a constraint as we couldn't use larger model with more accurate results, as it will increase the processing time which is against our needs.

## 4.4 Module 2 : Text Processing

This module is the first stage in our pipeline that adds the feature of face generation from bare textual descriptions, not just manual manipulators. It's responsible for understanding the input textual description and converting it into facial features logits, where each logit describes how much the generated face should be saturated with. This task is done for 34 different facial attributes where each of them may or may not be entangled with other attributes, such as gender and beard attributes. Attributes may be on different levels as well, some of them are continuous, such as age, some are discrete, such as wearing sunglasses. see figure 4.4 as an example.

**A fat female with brown eyes. Her hair is red and not long.  
She is wearing eyeglasses.**

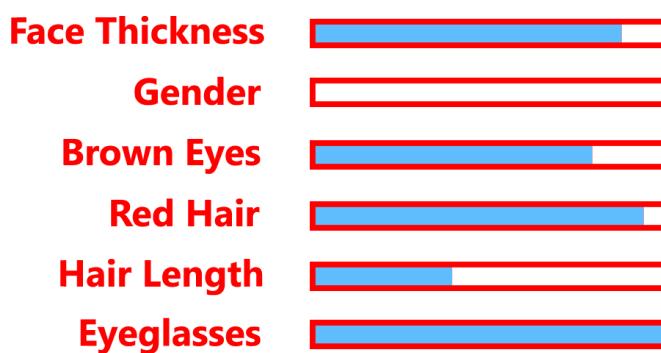


Figure 4.4: Attributes Scores Example

### 4.4.1 Functional Description

This module takes the input text and tries to

1. extract mentioned facial attributes.
2. extract a score for each mentioned facial attribute referring to the level of saturation of this facial attribute.
3. extract other non-mentioned attributes.

Table 4.1 show the list of supported facial attributes along with their types (whether continuous or binary).

Table 4.1: The list of supported facial attributes with their types.

Group	Attribute	Type
Eyebrows	Bushy Eyebrows	Binary
Hair Color	Black Hair Red Hair Blonde Hair Brown Hair Gray Hair	Binary Binary Binary Binary Binary
Hair Style	Curly-Straight Hair Receding Hairline Baldness Bangs Hair Length	Continuous Binary Binary Binary Continuous
Facial Hair	Beard	Continuous
Race	Asian Race Skin Color	Binary Continuous
General Facial Attributes	Face Thickness Gender Age Lips Size Nose Size Ears Size Double Chin High Cheekbones Pointy Nose Rosy Cheeks	Continuous Binary Continuous Continuous Continuous Continuous Binary Binary Binary Binary
Eyes	Black Eyes Green Eyes Blue Eyes Brown Eyes Eye Size Eye Bags	Binary Binary Binary Binary Continuous Binary
Makeup	Makeup Saturation Lipstick	Continuous Binary
Eyeglasses	Sight Glasses Sun Glasses	Binary Binary

#### 4.4.2 Modular Decomposition

This module is considered as an NLP task that can be tackled using classical approaches, such as Text Parsing and Tagging, and Deep Learning approaches. The final design for this module is to use the power of Deep Learning approaches especially transformers to analyze and understand the text. This is because that the classical approaches failed in such a task as there are a lot of sequence dependencies on the textual description that may arise such as restricting the age of the described person to the range of low-to-medium beard levels and gender attribute, except in the case of age attribute is mentioned explicitly or implicitly in the text, for example "a boy", "a boy with a beard" and "a boy almost in his thirties", the

first description should be understood as a child or teenager, while other descriptions refer to a middle-aged man. A lot of other dependencies that may arise that make the classical approaches not feasible and makes the deep learning solutions a must to tackle such a task.

The biggest challenge in the Deep Learning approaches is that there are no available datasets mapping textual descriptions to facial features. That's what led us to use synthesize our own dataset that must be much likely to be human-generated. This what made the module to be split into two sub-modules as shown in figure 4.5. First one is the Dataset Synthesis sub-module and the Deep Learning Sequence Model to be trained on the synthesized dataset.

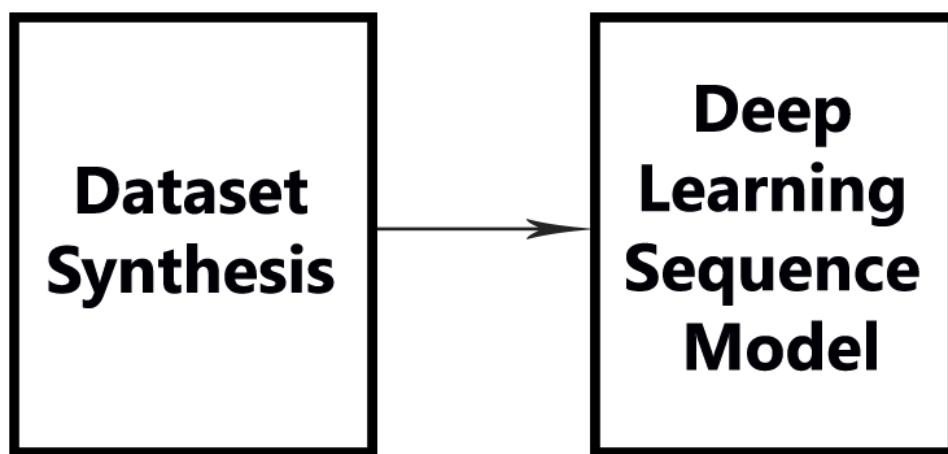


Figure 4.5: Text Processing Pipeline

#### 4.4.2.1 Dataset Synthesis Sub-module

This sub-module is the most critical one, as it should be as likely as possible to be human-generated. The approach we used to do so consists of three main stages as shown in figure 4.6 in the reverse order of what needed in the training phase.

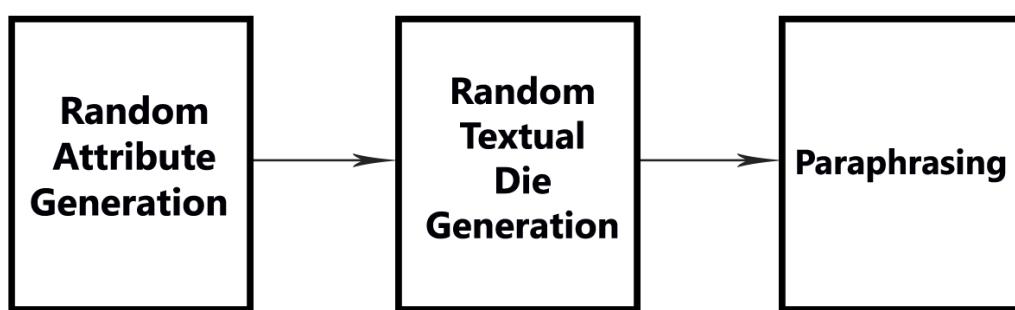


Figure 4.6: Dataset Synthesis Pipeline

##### 1. Random Attribute Generation

In this stage, we generate any random attribute scores for all 34 attributes. Each attribute is generated with its pre-defined range of scores with one of random different

modes

- Full Random Mode: All attributes will be mentioned in the text with random scores.
- Half-Length Random Mode: 50% of attributes will be mentioned in the text with random scores, while other 50% will not be mentioned.
- Short Random Mode: 20% of attributes will be mentioned in the text with random scores, while other 80% will not be mentioned.
- Very-Short Random Mode: 10% of attributes will be mentioned in the text with random scores, while other 90% will not be mentioned.

Mentioned Attributes are generated with some restrictions to make their scores consistent with others, such as

- Females, babies and children cannot have facial hair.
- Females cannot be bald.
- Males and babies cannot put makeup or lipstick.
- Bald people cannot have any hair attribute mentioned, such as hair color or hair style.
- One hair color at most can be mentioned (i.e. no person can have both yellow and red hair).
- One eye color at most can be mentioned (i.e. no person can have both blue and black eyes).
- People with bangs cannot have receding hairline and vice versa.
- One Eyeglasses type at most can be mentioned (i.e. no person wear both sun and sight glasses).

## 2. Random Textual Die Generation

In this sub-module, a textual description is generated in a textual die using the random scores of facial attributes. Attributes are categorized using different categories, such as

- First Categorization is based on the facial part that is described, such as all hair attributes (Black Hair, Blonde Hair, Gray Hair, Red Hair, Brown Hair, Straight Hair, Hair Length) can be combined in a single description of the hair (e.g. a woman with long, brown and curly hair).
- Second Categorization is based on the grammatical way that the attribute can be described with. Each attribute can be of one or more of types below
  - With Attributes: attributes that can be described using with statement (e.g. a man with brown hair and blue eyes.)
  - Has Attributes: attributes that can be described using has statement (e.g. a man who has brown hair and blue eyes.)
  - Puts Attributes: attributes that can be described using put statement (e.g. a woman is putting heavy makeup.)

- Wears Attributes: attributes that can be described using wear statement (e.g. a woman is wearing a glasses.)
- Full Statement Attributes: attributes that can be described using a full statement (e.g. His hair is brown. His Eyes is blue)
- Adjective Attributes: attributes that can be described using adjectives (e.g. a blond old man.)

Each mentioned attribute can have a form of different forms, such as

- Positive Attributes using Synonyms: describing an attribute with one of its synonyms randomly (e.g. “a man with a thick face.” can be described as a “a chubby man.”).
- Positive Attributes using Antonyms and Negation: describing an attribute with the negation of one of its antonyms randomly (e.g. “a man with a thick face.” can be described as a “He is not thin” or “a man with non-thin face.” and so forth).
- Negative Attributes using Antonyms: describing a negative attribute with one of its antonyms randomly (e.g. “a man with no thick face.” can be described as a “a thin man.”).
- Negative Attributes using Synonyms and Negation: describing a negative attribute with the negation of one of its synonyms randomly (e.g. “a man with no thick face.” can be described as a “He is not chubby” or “a man with non-thick face.” and so forth).

Each mentioned attribute chooses one of its categories and one of its forms randomly and reserve a slot in the textual die represented in figure 4.7 .

A Adjective  
An Attributes      Gender With      With  
Without      Without      Without  
Attributes      Attributes      Attributes      Other Statements

Figure 4.7: Textual Die where each attribute chooses a random slot for itself

### 3. Paraphrasing

As we use deep learning approaches, using the textual die to train a model is just making the model learn the die itself, not to generalize and extract the attributes from any other textual description. So, in this sub-module, we tried different approaches to restructure and paraphrase the textual die generated in the previous step, so that the generated description is more likely to be human-generated and to be general. To do so, we tried two approaches as a paraphraser

- First Approach: Training a Sequence-To-Sequence model using the “entailment” class in Stanford Natural Language Inference Dataset (SNLI) to re-structure any

English statement to any other English statement based on the diversity of expressing ways in the English Language

- Second Approach: Using a random cycle of machine translators (e.g. translates the die in the sequence “English To Arabic To Spanish To Italian To English” or in the sequence “English To Chinese To English”). Using the power of different linguistic ways in different languages makes the paraphrased description more generic.

#### 4.4.2.2 Deep Learning Sequence Model

The main task of Text Processing module is to map input textual description to corresponding attributes scores, so It's a multi-class multi-label NLP problem. Therefore, in this submodule we trained different deep learning architectures on the previously generated dataset. We tried

- LSTM Architecture: 2 BiLSTMs followed by a linear layer.
- Transformers Architecture: DistilBert-base-uncased, Bert-base-uncased, Albert-base-v2, Roberta-base

Where transformers architectures out-performed, so the final choice was DistilBert-base-uncased, as it's the lightest one out of them with accuracy hit +99% on validation.

#### 4.4.3 Design Constraints

The design constraints of this module are enumerated as follows :

- Human-like Dataset Synthesis: The biggest challenge of this module is that there's no available dataset to tackle such a task. So, we needed to synthesize our own dataset that should be as generic and human-generated as possible, so that what made the paraphraser performance really matters.
- Conditional entailment of different facial attributes: as different facial attribute may affect each other, so the dataset should be generated in a robust way so that it can train the deep learning model to detect such relations, such as entanglement between beard, gender and age.
- Accuracy matters: as this is one of the early modules in the pipeline, the results of all other modules depend on its performance and accuracy. So, lack of accuracy in this module will be catastrophic for the whole pipeline.

## 4.5 Module 3 : Face Code Generation

Here, we discuss the face code generation from numerical values of facial attributes. This is the most important and innovative module in our system and the first stage of *face generation*. It's **worth noting** that we use both of the terms "*feature*" and "*attribute*" to refer to a facial attribute, like hair color or nose size.

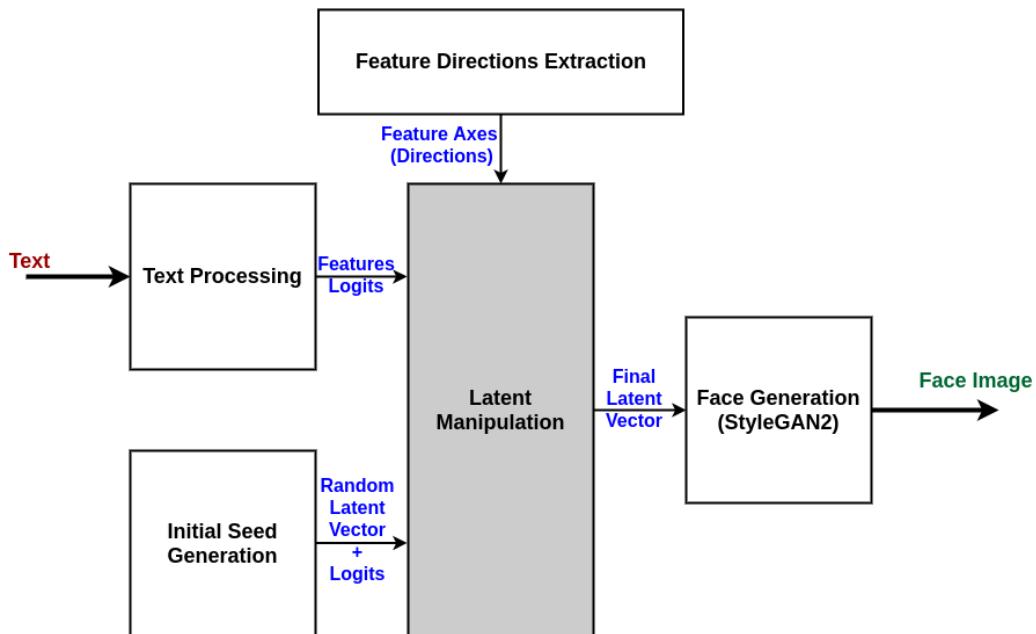


Figure 4.8: Detailed block diagram of the three core modules workflow

### 4.5.1 Functional Description

Figure 4.8 shows a block diagram of the interaction between the 3 core modules. We can see that the code generation module is the main driver of our face generation process. Generally, it converts the numerical attributes values (a.k.a. *logits*) into a face embedding vector that matches the design of the latent space of the face generator (*StyleGAN2*). Basically, it starts from an initial vector and uses the *required feature values* and *extracted feature directions* to transform this vector into the final latent vector, which is passed to the generative model.

- **Input :**
  - Numerical values of facial features (logits).
- **Output :**
  - Low dimensional face embedding vector (latent vector).

### 4.5.2 Modular Decomposition

As figure 4.8 tells, the code generation module can be torn down into 3 sub-modules, which are **latent manipulation**, **initial seed generation** and **feature directions extraction**. Each sub-module is discussed in details to show how they integrate to each other to achieve the desired goal.

#### 4.5.2.1 Feature Directions Generation

Since, we use StyleGAN2 [5] as our generative model, we have a full  $512D$  latent space that is used to encode the whole face attributes. The changes in this latent space maps to the generated face image and similar features occupies the same area in the latent space. Consequently, we have to come up with a way to extract the axes (*hyperplanes*) in this latent space to define each of our 32 facial features. These feature directions are, then, used to manipulate the latent vector, in order to map to the required face image.

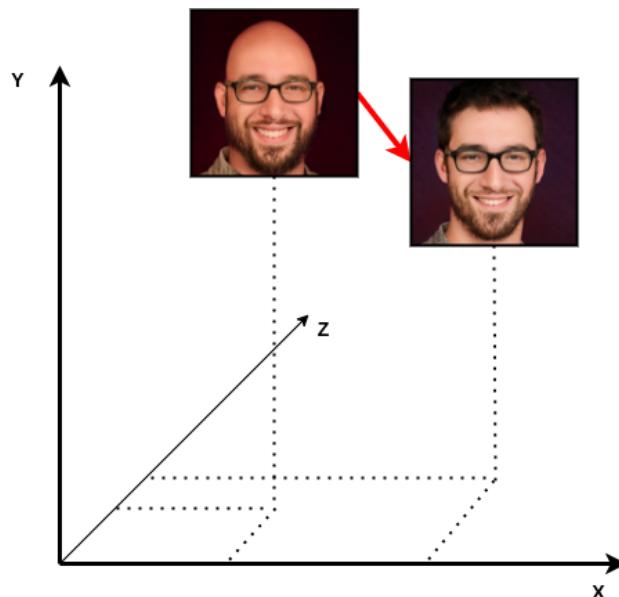


Figure 4.9: Illustration of feature directions in latent space

Figure 4.9 further illustrates the idea of feature directions in the latent space. Here, we plot two face images in a  $3D$  latent space. We can see that the difference between the two images is the presence and absence of hair, thus the red arrow represents the *baldness* feature direction in that  $3D$  latent space (moving along this particular vector causes hair density to change).

Our method of extracting the feature directions (*hyperplanes*) consists of 3 steps :

- 1. Code-Image Pairs Generation and Classification :** First, we use StyleGAN2 to generate a large number of synthetic faces from random latent vectors. After so, we cluster the synthetic images (along with their latent vectors) according to each feature. The clustering can be based on discrete categories (like *hair color* or *race*) or continuous values (like *hair length* or *nose size*). We randomize the synthetic images in each clustering process to have better generalization and to cope with potential generation noise. For classification and regression, we use one of three possible methods, which are **manual labelling**, **classical image processing techniques** and **neural networks**. Thus, the output of this process is different groups of synthetic images sharing common facial features, along with their latent vectors.
- 2. Feature Directions Fitting :** Now, we have a set of latent vectors (x) and their corresponding feature values (Y). It's required to find a set of feature directions that satisfies

the mapping between feature vectors and values. This problem can be formulated as :

$$Y = A_f \cdot X \quad (4)$$

Where  $A_f$  is the axis (direction) of feature  $f$ .

We can obtain the solution to this equation in a closed form. However, due to the noise in both generation and classification, along with the non-linear nature of the problem, we opt to use *ML* methods, specifically **Logistic Regression** and **SVM** to get an *approximate solution*. Meanwhile, we cannot see any difference between the two methods, as they yield almost the same results.

Finally, the generated feature directions are normalized to unit vectors :

$$A_{unit} = \frac{A}{\|A\|} \quad (5)$$

3. **Directions Orthogonalization** : Facial features entanglement is one of the most difficult challenges of face generation. Some attributes in the human face tend to be extremely entangled by nature. For example, Asians rarely have curly hair, a woman cannot have beard and a man cannot put on makeup. Since StyleGAN2 is trained and tuned on **FFHQ** dataset [4], which contains real human faces, it is normal to notice some entanglement between some features. Consequently, the feature directions have to be further disentangled by using *orthogonalization*. The orthogonalization process is done iteratively, starting from the most accurate feature directions. We orthogonalize other feature directions on the accurate ones, so that we have completely independent feature directions, where tuning one direction doesn't affect the others. The directions are orthogonalized as follows :

$$A_{proj} = (A \cdot B_{unit})B_{unit} \quad (6)$$

$$A_{orthogonal} = A - A_{proj} \quad (7)$$

Figure 4.10 visually illustrates the *directions orthogonalization* process on 2D vectors.

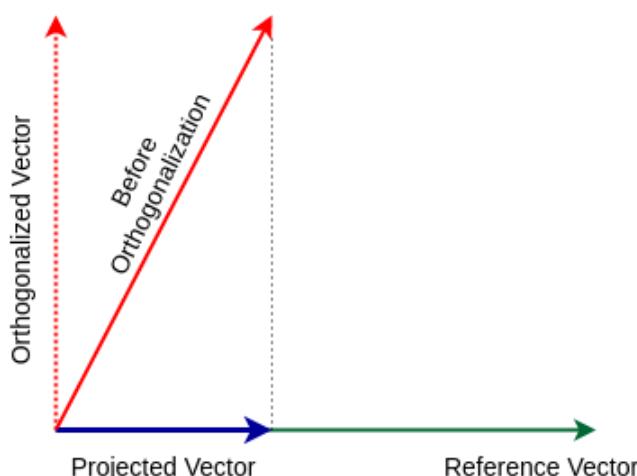


Figure 4.10: Illustration of orthogonalization relative to a reference vector

To ensure convergence to reasonable set of feature directions, we use a threshold margin to stop the orthogonalization process, which is from 85 to 95 degrees (5 degrees on each side of normal angle).

#### 4.5.2.2 Initial Seed Generation

In order to avoid noise and discontinuities in the latent space, we generate an initial random latent vector. This is done by generating a random  $512D$  vector and then passing it through the *mapping network* of StyleGAN2, which is not invertible. This initial vector is, then, manipulated by sequential navigation along each feature direction (axis) with certain amounts. To get these amounts, we should know the component of the initial vector along each feature direction. We do that by simply performing a dot product between the initial vector and the unit vector of each feature direction. Thus, we have an initial latent vector and the numerical attributes values, it presents.

#### 4.5.2.3 Latent Manipulation

This sub-module ingests all the inputs and produces the required latent vector (*face embedding*) that describes all of the required facial attributes. The inputs to this latent manipulation sub-module are *initial random vector* along with its logits, *text logits* and *feature directions*. The latent manipulation, simply, wants to realize the following transformation on the *initial random vector* :

$$E_{final} = E_{initial} + (l_{text} - l_{rand})D \quad (8)$$

Where  $E_{final}$  is the final latent (*embedding*) vector of dimensions  $1X512$ ,  $E_{initial}$  is the initial random vector of dimensions  $1X512$ ,  $l_{text}$  is the text logits vector of dimensions  $1X32$  (remember that we consider 32 facial features),  $l_{rand}$  is the logits vector of the initial random vector of dimensions  $1X32$  and  $D$  is the feature directions matrix of dimensions  $32X512$ . The transformation includes calculating the difference between the required logits and the random logits and, then, use this difference to move the initial random vector along the feature directions to reach the final latent vector.

It might seem straight forward to perform this transformation. Unfortunately, it's not feasible to perform the transformation using direct matrix multiplication, mainly due to heavy *entanglement* between direction vectors even after *orthogonalization*. Also, the latent space of StyleGAN2 can be very noisy in certain regions, so transformations have to be done carefully.

Consequently, the processing in this sub-module is done iteratively as follows :

- Both random and text logits are scaled from 0 to 1, which cannot have significant effect, when navigating using unit directions. Consequently, the inputs logits are scaled with the directions scale, which is obtained empirically to be from  $-4$  to  $4$ , as shown in figure 4.11.
- The next step is to get the *difference* between *text logits* and *random logits*, which is of dimensions  $1X32$ . We call that **differentiated logits**. It's worth noting here that the input text usually contains a *subset* of the facial features. Consequently, *not all* the text logits

are set to specific values. So, when doing the *differentiation*, we set the differentiated logits of the *unmentioned facial features* to 0. So, it can be summarized as follows :

$$l_{diff} = \begin{cases} l_{text} - l_{rand} & l_{text} \neq None \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

- Loop over each direction in feature directions :

- Multiply the *differentiated logit* corresponding to the *current feature* with its *direction*.
- Add the product to the current latent vector (starting with the *initial random vector*).  
The following equation summarizes these steps :

$$E_{next} = E_{prev} + l_{diff}[j] * D[j] \quad (10)$$

- Finally, to ensure that every transformation is independent of the subsequent transformations and that they are applied sequentially, we re-compute the *produced latent vector logits* and re-differentiate it with the *text logits*. This is done on every iteration of the latent manipulation process.

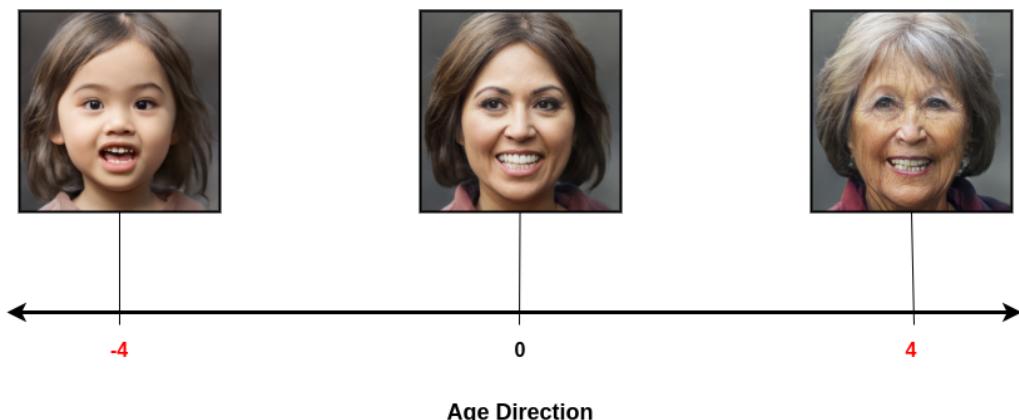


Figure 4.11: Illustration of directions scale using age direction

By applying the previous process, the *numerical value* of facial features extracted from text or manually entered by the user can be converted into a complete face embedding (*latent vector*) matching the required facial attributes. This vector can be passed to StyleGAN2 to translate it to a complete human face image.

### 4.5.3 Design Constraints

The design constraints of this module are enumerated as follows :

1. **Facial attributes entanglement** is the main challenge of the face code generation module. Naturally, human face attributes are related to each other. For example, Asians barely have curly hair, no woman cannot have beard and most women have long hair and wear makeup. We mentioned before that StyleGAN2 is trained and refined on FFHQ

dataset, which contains real human faces. Consequently, it's normal to see heavy entanglement between features in the latent space. Due to this *entanglement*, we have to perform extra computations to get decent results.

2. **Random initialization** of the latent vector can cause some issues with the final output, as the vector can be initialized in a noisy area of the latent vector. We try to *limit* the initialization of latent vector to a certain set of random vectors to avoid this effect. This method significantly reduces the *random initialization effect*, however it's not fully cured.
3. **Directions accuracy** can be a challenge as well. Some factors can negatively affect the feature directions accuracy. These factors include **synthetic image clustering** (whether *classification* or *regression*) and **directions fitting** process. We already discussed our solutions to this problem.

#### 4.5.4 Synthetic Image Clustering

As we mentioned before, it's required to cluster the generated synthetic images, in order to be able to fit the feature directions. The *clustering* process can be performed through *classification* or *regression*. For example, features like hair and skin colors should be classified (grouped) into discrete categories, however features like hair length and mouth size should be assigned a continuous value. We do this task using one of three different methods :

1. **Manual labelling** is the first idea to come to our minds. It's straight forward to manually classify a group of faces according to a certain feature. This method is used with some features, however it's very cumbersome and only works for classification.
2. **Classical image processing techniques** are, also, used to classify images based on some features. Mainly, we use these techniques to detect *colors* like eye color and hair color. We use *morphological operators* and *classical segmentation* to detect *the eye* or *the hair* and then retrieve its color.
3. **Deep learning techniques** (*neural networks*) are used to perform regression on the rest of the features. We basically use *facial landmark detection* pretrained networks to detect the important facial landmarks, which is, then, used to calculate *sizes* and *distances*.

## 4.6 Module 4 : Code-to-Face Translation

Here, we discuss the process of converting the face embedding (*latent vector*) to a complete face image using StyleGAN2 (our chosen generative model). We discuss our reasons for choosing this particular architecture and how we use it.

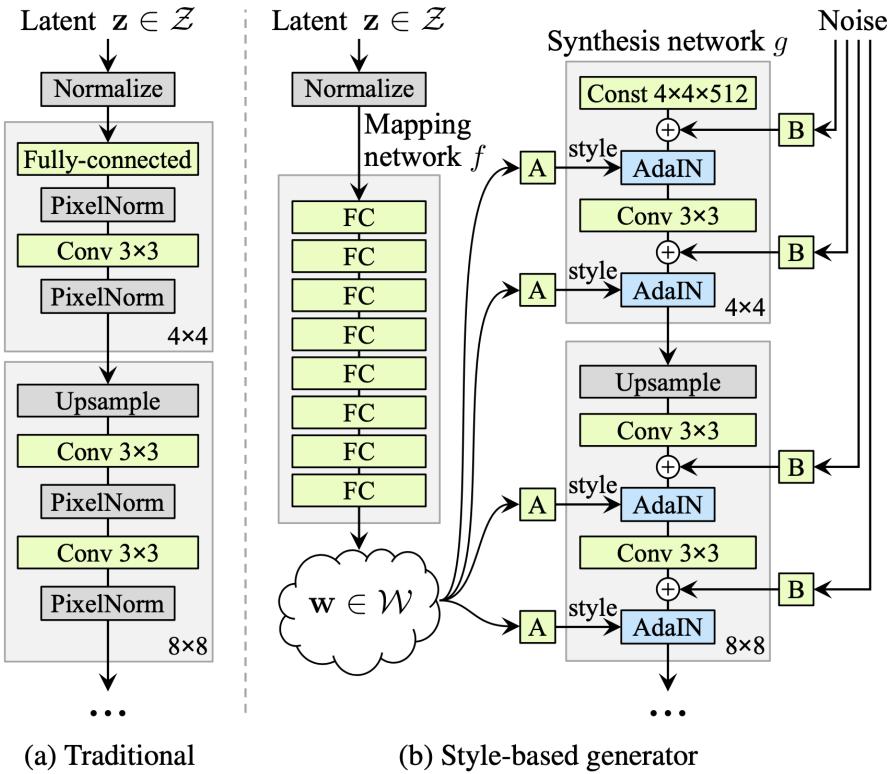


Figure 4.12: Style-based GAN architecture against traditional GAN

### 4.6.1 Functional Description

This module utilizes the power of *style-based* generative models, specifically StyleGAN2 [5], to translate the required *latent vector* to a complete *human face image*. *Style-based GANs* (sometimes called *latent-based GANs*) can exert artistic control over the generated content (images, videos, text ..., etc). Consequently, we can tune it to fit our need and, iteratively, design it along with *code generation* 4.5 and *text processing* 4.4, in order to have a complete end-to-end pipeline for *text-to-face generation*.

- **Input :**
  - Low dimensional face embedding vector (latent vector).
- **Output :**
  - Complete human face image (portrait).

### 4.6.2 Modular Decomposition

As mentioned before, we opt to use *Style-based GANs* to be able to artistically control the output and designed the whole pipeline for *text-to-face generation*. Moreover, we choose

StyleGAN2, because it's one of the most popular and robust Style-based GANs in research literature. Also, it's relatively lightweight compared to other GANs used for the same purposes, but most importantly, StyleGAN2 excels at human face generation based on latent space. Figure 4.12 shows the original architecture of StyleGAN and how it is compared to traditional GANs. StyleGAN generator has two networks as follows :

- **Mapping network** creates nonlinear transformation to the input latent vector  $z$  ( $512D$ ). This transformation is not invertible and results in a  $512D$  latent vector  $w$ . This latent vector  $w$  is expanded into several  $512D$  vector using affine transformation, which gives the *extended latent vector*  $w+$ . The extended latent vector  $w+$  dimensions depend on the dimensions of the output image.
- **Synthesis network** generates the synthetic image from *normally-distributed noise* guided by the extended latent vector  $w+$ .

StyleGAN2 [5] is a newer version that follows the same architecture, but with some modifications to further improve the control over latent space and the quality of the outputs.

So, let's discuss how we adapted StyleGAN2 to our work :

- To provide a high fidelity results, we target  $1024 \times 1024$  synthetic images. To achieve this, we have to use an extended latent vector  $w+$  of dimensions  $18 \times 512$ , meaning we repeat the latent vector  $w$  18 times with *affine transformation* for each.
- To further improve feature directions disentanglement, we fine-tune StyleGAN2 using a subset of FFHQ dataset with increasing the weight of *perceptual path regularization* in the loss function. *Perceptual path regularization* in StyleGAN2 loss encourages the smooth mapping between latent and image spaces. So, when increasing it in certain directions, it highly penalizes the deviation between latent and image spaces in these directions giving more organized latent space. To avoid using the whole dataset, we use StyleGAN2 *adaptive discriminator augmentation (ADA)* [22] training methodology.
- Finally, we opt to remove the *mapping network* of StyleGAN2 generator and only use the *synthesis network*. This is mainly because :
  - The mapping network doesn't satisfy the *path length regularization*, so there is no smooth mapping between latent space  $z$  and image space (only with latent space  $w$ ). This is discussed in the original paper [5] and our experiments support that.
  - The mapping network is not invertible, unlike the synthesis network. So, we cannot reverse the transformation from image space to latent space  $z$ . That's why we only work with latent space  $w$  to test the consistency of the results.
  - Removing the mapping network reduces the computations and the memory footprint, which is crucial in our case.

After the previous modifications, the output model can directly translate the face embedding vector (*latent space*) into a complete human face portrait.

Notice that using this methodology of **code-to-face translation** along with **code generation** makes the sequential navigation in the latent space is *easily invertible*, which eases the

generation and the refinement (discussed in 4.7) of the synthetic face and gives the system versatility and fault tolerance. Figure 4.13 illustrates the idea of *invertibility* of sequential edits on a 2D latent space example. Here, we show a simplified 2D latent space with 3 feature direction.  $AB$  vector represents the *hair color* direction and  $BC$  vector represents the *gender* direction. Point  $A$  starts with a *blonde girl*, moving along  $AB$  vector results in a *girl with black hair* at point  $B$ . Then, moving along  $BC$  vector gives us a *man with black hair* at point  $c$ . Consequently, moving along  $CA$  vector, which is the opposite of the resultant of  $AB$  and  $BC$ , gives us the original face, thus inverting the sequential changes.

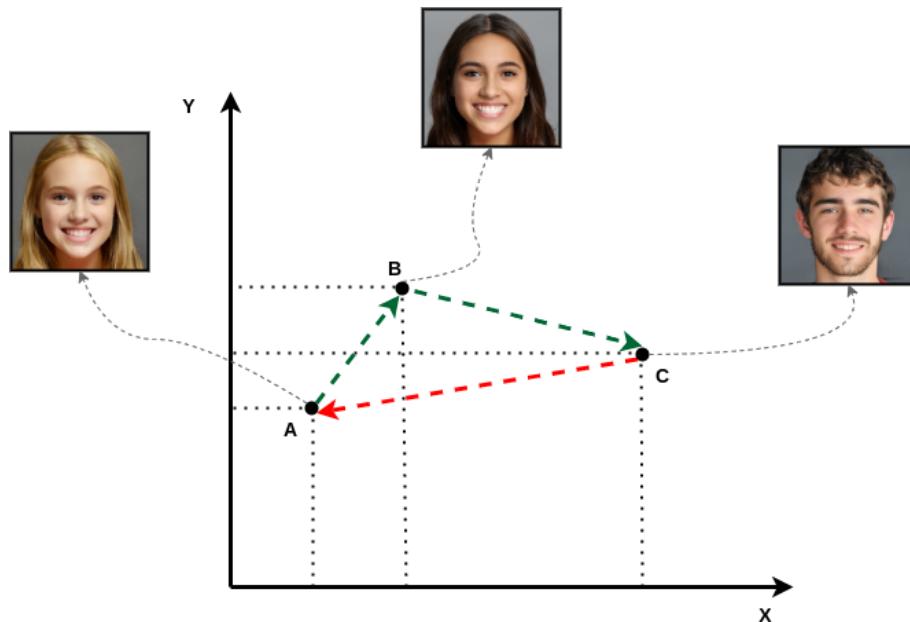


Figure 4.13: Illustration of sequential navigation and invertibility in a 2D latent space

#### 4.6.3 Design Constraints

The basic design constraints for this module can be enumerated as follows :

1. **Network size** is surely one of our challenges. StyleGAN2 has a large memory footprint, as the case with most *deep generative models*. This constrains its training and deployment. We managed to remove the *mapping network*, which gives us a chance to use the full *synthesis network*.
2. **Faces dataset** is, also, a constraint, because real images of human faces contains entanglement between facial features (*as discussed before*). So, we have to exert extra effort in the **code generation** module to solve some of this entanglement, emerging from real human faces datasets.

## 4.7 Module 5 : Face Refinement

Figure 4.13 shows that StyleGAN2 latent space can be used to perform *directed manipulation* by using the feature directions extract in **code generation** 4.5. We discussed how we use this technique for *conditional sampling* from latent space by starting from an initial seed and editing it until we reach the desired latent vector. Now let's discuss our methodology of applying the same technique is *directed manipulation* of one or more features to be used in *face refinement*.

### 4.7.1 Functional Description

This module basically gives the users a chance to further refine the generated face portrait to their liking. The user can refine the generated face using the same facial features used in **face generation**, along with some additional features related to *face morphology*, which are hard to describe in words. We adapt the techniques used in *face generation* to perform *face refinement*.

- **Input :**
  - Generated human face image (portrait).
- **Output :**
  - Refined human face image (portrait).

### 4.7.2 Modular Decomposition

We utilize the same technique used *face generation* to perform *directed manipulation* of one or more features. This is exactly what is required by *face refinement*. Consequently, we opt to stick with our *face generation* pipeline, due to the following reasons :

- Latent manipulation in StyleGAN2 yields better results than most attribute-editing GANs.
- We use the same network, which significantly reduces the memory footprint.
- Since StyleGAN2 has an artistic control over its output, we can expand the number of target facial features, which improves the system scalability.

Using latent space navigation, we can easily perform *directed manipulation* on a subset of the facial features, which is required for *face refinement*. The *directed manipulation* over a single facial feature can be formulated as :

$$E_{refined} = E_{old} + \delta_{feature} * d_{feature} \quad (11)$$

Where  $E_{refined}$  is the refined latent vector,  $E_{old}$  is the old latent vector,  $\delta_{feature}$  is the change offset of the facial feature and  $d_{feature}$  is the feature direction.

Subsequently, we pass the *refined latent vector* through the *synthesis network* of StyleGAN2 to produce the new refined face portrait.

Finally, more feature directions are generated for the purpose of *face refinement*, which are hard to describe in words. These features are more related to *face morphology* and listed as follows :

- Distance between eyes.
- Distance between eyes and eyebrows.
- Distance between nose and mouth.
- Eyes opening.
- Mouth opening.
- Smiling or not.

These feature directions are obtained using the same technique described in 4.5, however all of these features are clustered using regression techniques. Overall, we use both facial features used in *face generation* and the new facial features (which sum up to 38 features) to refine the generated face.

#### 4.7.3 Design Constraints

The only constraint, imposed on this module, is the difficulty to generate the feature directions. The new features describe spare facial attributes related to morphology, so it's hard to regress them. We use *facial landmark detection* techniques to detect the distances, in order to fit the feature directions. We couldn't further expand the morphological feature directions, due to *limited resources* and *time constraints*. Our *recommendation* is that using the facial landmarks detection can actually further expand the morphological features, so it's worth spending more time on it.

## 4.8 Module 6 : Multiple Head Poses Generation

In the previous section we discussed how Face Refinement can be done by changing Facial attributes. One of the important attributes is changing the yaw angle of the generated face to a specific angle. This module is designed specifically for this purpose.

### 4.8.1 Functional Description

This module is responsible of changing the yaw pose of the generated Face by providing a specific yaw angle.

- **Input :**
  - 2D Image for the generated Face.
  - Target yaw angle  $\Theta$
- **Output :**
  - 2D Image for the generated Face rotated with angle  $\Theta$

### 4.8.2 Modular Decomposition

The Multiple Head Poses Generation is performed on three main steps.

#### 4.8.2.1 3D Face Fitting

The first step is generating a 3D Morphable Model (3DMM) from the input 2D Image. The resulting 3DMM is parametrized with the following parameters:

- $\bar{S}$ : The mean 3D Face Mesh
- $A_{exp}$ : The Eigen vectors responsible for Face Expression
- $A_{id}$ : The Eigen vectors responsible for the Face Identity
- $\alpha_{exp}$ : The Face Expression parameters
- $\alpha_{id}$ : The Face Identity parameters.
- $R$ : The Euler angles representing the Face Rotation in the 3D space
- $t_{2d}$ : Face translation matrix in the 2D space
- $f$ : Face scale parameter in the 2D space

Thus the resulting 3D Model is represented as follows:

$$S = \bar{S} + A_{id}\alpha_{id} + A_{exp}\alpha_{exp}$$

To project a 3d vertex of the model to the 2d space, The following equation is used:

$$V_{2d} = f * Pr * R(\bar{S} + A_{id}\alpha_{id} + A_{exp}\alpha_{exp}) + t_{2d}$$

Where  $Pr$  is the projection matrix.

In order to construct the 3D model the  $R, alpha_{exp}, alpha_{id}, T_{2d}, f$  parameters need to be predicted from the input 2D image. We use a CNN with MobileNet architecture which we trained on AFLW dataset to regress the 3D Parameters by optimizing a parameter distance cost function which consists of the mean squared error between the actual parameters and the predicted parameters. The AFLW dataset consists of facial images and their corresponding 3DMM parameters.

At the end of the first stage we have a 3D model for the input image.

#### 4.8.2.2 Rotating and Rendering the 3D model

The second stage consists of rotating the resulted 3D model with the target angle in the 3D space and projecting it to the 2D Image. Pytorch's Neural Renderer is used to project the 3D Face Model into a 2D image. The texture information for the 3D model is taken from the input 2D Image by projecting each vertex into the 2D space and getting the corresponding pixel value.

At the end of this stage we have a 2D Image that has the face model rotated and projected. But the 2D Image for the Face has missing parts which don't exist in the 3D Model such as the hair and teeth. In addition to the occluded parts of the face in the input 2D Image.

#### 4.8.2.3 Face Inpainting

In this stage, Face Inpainting is performed for the resulted 2D Image from the previous step to fill the missing gaps. The model for Face Inpainting is CycleGAN which takes an Input as the Image with gaps and predicts the final 2D Image with the complete face. The CycleGAN model is trained on a generated dataset which is generated by:

- Generating 3D Model for the face.
- Rotating the 3D Model with a random angle.
- Project the 3D Model to 2D space.
- Generating 3D Model for the 2D Image generated from the previous step.
- Rotating back the Image with the previous angle to the initial pose
- Projecting the Image to 2D Space yielding a pair of complete face image and face image with gaps.

At the end of this stage, The result will be a 2D Image consists of the input face rotated with the input yaw angle.

#### 4.8.3 Design Constraints

In order to design a Pose Generation system suitable for practice and to be integrated with the final application, Some Design constrained has been taken.

- **Models sizes:** Models sizes in this module were constrained to be small to fit into our deployment server which consists of 11 GB Nvidia 1080 ti GPU and 16GB ram.
- **Models speed:** Models speed in this module were constrained to be fast so it can be run on CPU. So we made use of MobileNet CNN architecture which is lightweight and fast when it is run on CPU.
- **Output Image Size:** As GAN-based models can take around one month of training on a single GPU when it is trained on images of the 1080x1080 Resolution, We made the output image of our module to be 256x256 in order to make the training feasible given our limited computational power and to make the module fits in memory with the other modules in the system.

## 4.9 Module 7 : Web Application

As we described above, our users need the UI of the project to be as easy and familiar to them as possible, because they will use it in critical situations, such as a parent describes the criminal who kidnapped his/her child. So, we tried to make the both Frontend Design and Backend Endpoints to be very simple and isolated from the complex techniques used in the background.

### 4.9.1 Functional Description

Our Application allows the user to get his/her intended face based on different generation modes that he/she can navigate through in the main page. Our generation modes are

- Generation from Voice Description.
- Generation from Textual Description.
- Generation using Manual Manipulators.

After each mode, the user is allowed to do extra sequential refinements using manual manipulators and to generate 8 different head poses of the final refined face.

### 4.9.2 Modular Decomposition

As shown in figure 4.2, we can decompose this module into two sub-modules, frontend design (*user interface*) and backend API (*server*).

#### 4.9.2.1 Frontend Design

We used VueJS as our frontend framework with Axios as a request handler. Our frontend design consists of 6 pages

- Main Page

This Page is just a page with single list of generation modes.

- Generation From Voice Description Page

This Page is a page with two different assets (voice and textual input) for the user to describe a face. After generation, it allows the user to refine the generated face or generate head poses.

- Generation From Textual Description Page

This Page is a page with one asset (textual input) for the user to describe a face. After generation, it allows the user to refine the generated face or generate head poses.

- Generation/Refinement Using Manual Manipulators Page

This page allows the user to generate a new face or refine an actually-generated face using manual manipulators.

- Head Poses Page

This page generates eight different head poses for extra identification.

- Help and Demo Page

This Page is a help aid for the user to know how to use the application and to support the user with some extra information about the project, such as :

- Why is Retratista important?
- Statistics.
- Project Features.
- How To Use?
- Result Samples.
- Team.

#### 4.9.2.2 Backend API

The application backend (shown in 4.2) is an *HTTP REST API* that offers 4 endpoints for all system functionalities. It is composed of 2 servers communicating through *TCP* ports :

- **StyleGAN Server** : which offers the face generation from description and face refinement functionalities.
- **Pose Server** : which offers the face rotation functionality.

The *API* endpoints are listed as follows :

- **Face Generation from Text** :

- **Request** : textual description (user input or from speech).
- **Response** : face image (portrait) & numerical attributes values.

- **Face Generation from Values** :

- **Request** : numerical attributes values (user input).
- **Response** : face image (portrait) & numerical attributes values.

- **Face Refinement** :

- **Request** : updates of numerical attributes values (user input).
- **Response** : refined face image (portrait) & numerical attributes values.

- **Face Poses Generation** :

- **Request** : angle of rotation (user input).
- **Response** : rotated face image (portrait).

#### 4.9.3 Design Constraints

As described above, the main constraints on this module are :

- Simplicity of User Interface.
- Isolation of Complex Techniques used in background.

## 4.10 Other Approaches

At the beginning of our project, we tried to automate the whole pipeline in an *end-to-end* deep learning approach starting from the textual input to the generated face. The pipeline is shown in figure 4.14.

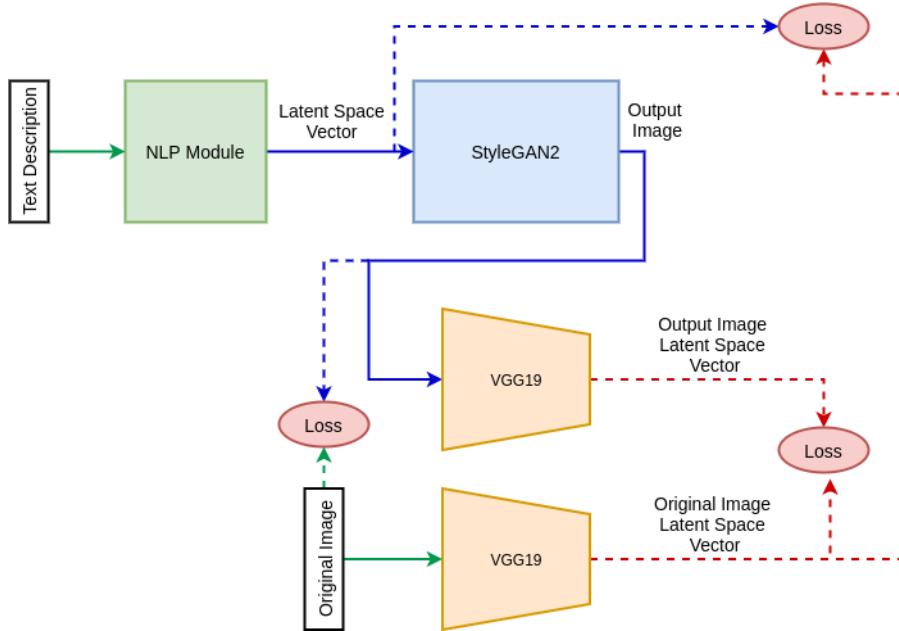


Figure 4.14: Old Approach

### 4.10.1 Face Generator Module

We used the same latent-based generative model, which is StyleGAN2 with no modifications. We aimed to use the generator pretrained weights to start the *end-to-end* training process, which tunes the generator weights along with the whole system.

### 4.10.2 NLP Module

This module translates the text directly to the StyleGAN2 latent vector  $z$  that encodes all described facial features. We used a simple *Recurrent Neural Network* (RNN) architecture that consists of 2 recurrent layers followed by a fully connected layer. This is trained on a semi-synthesized dataset of text, latent vector and face image triplets.

### 4.10.3 Dataset and Training

Our dataset generation and the training process goes as follows :

- We started by using *Face2Text* dataset that consists of 4000 records of textual descriptions of images in the *CelebA* dataset.
- This dataset is very small, so we needed to make it larger :
  - We used FaceNet [23] to encode the whole *CelebA* dataset, as FaceNet is one of the best facial features extractors.

- We used *K-Nearest Neighbors* (KNN) to get the closest 10 matches of each celebrity in *Face2Text* dataset from *CelebA* dataset.
- Then, we manually picked the best 5 matching faces out of the 10 faces got from KNN. Therefore, we have a dataset of 20,000 text-face pairs.
- We separately trained a strong feature extractor (VGG19) to map from face images to latent vector, which we called *image-to-latent projector*.
- Finally, we used the image-to-latent projector to generate the latent vector corresponding to the dataset faces.
- Thus, we had the final dataset triplets of text, latent vector and face image.
- Consequently, we trained our architecture 4.14 in an *end-to-end* manner using the generated dataset. Mainly, we trained our NLP module and tuned StyleGAN2 using a combined loss that consists of the summation of 3 parts :
  1. Mean squared error (*MSE*) loss between the output latent vector from NLP module and the project latent vector from the original image.
  2. Reconstruction loss between the output image from StyleGAN2 generator using the output latent vector and the original image.
  3. Mean squared error (*MSE*) loss between the projected latent vector of StyleGAN2 generator output and the projected latent vector of the original image. This acts as a *perceptual loss* and it's the most important part of our combined loss, as it ensures *cycle consistency*.

#### 4.10.4 Results

Unfortunately, the previous architecture did not yield good results, due to many reasons :

- The dataset was not robust and various enough to train such a huge network.
- We did not have enough computational resources to correctly and efficiently train this network for a long time.
- The latent space  $z$  of StyleGAN2 is very sensitive, so the NLP module has to be much more complex to be able to handle the latent vector generation. This was unfeasible given our resources.

Consequently, we opt to re-design our system in the staged manner, mentioned above, so that most of the system modules can use unsupervised learning or even no learning at all.

## 5 System Testing and Verification

In this chapter, we discuss how the system is tested both on module level and integration level. We discuss our *performance metrics* and show the results of the system both *quantitatively* and *qualitatively*. We, also, show how our system performs compared to the baselines. Finally, we include the complexity analysis of our system for both time and memory.

### 5.1 Testing Setup

The testing environment of the whole system is basically targeting 4 main properties :

1. The quality of the output face images compared to the real human face images.
2. The ability of the system to capture the included facial features in the input description and how they actually map to the output.
3. The smooth and consistent mapping between the edits, imposed on the input description, and the changes of the output face image.
4. The Independence (*disentanglement*) between the different facial features.

We create our testing strategy to assess these 4 properties on the output face images. Also, we compare our results against the following baselines :

- StyleGAN2 [5] : We compare our results with the original *StyleGAN2* to check the output quality.
- Faces à la Carte [11] : This is the only previous research work that attempted *Text-to-Face Generation*.
- Image2StyleGAN [6] : Our feature directions extraction methodology is inspired by this work, which is based on the first version of *StyleGAN*.

### 5.2 Testing Plan and Strategy

To assess the 4 previously-mentioned properties, multiple metrics are used, which are listed as follows :

1. **Fréchet Inception Distance (FID)** [24] : This metric is an improvement over the traditional *inception score* to be able to measure the similarities between a set of real and synthetic images. Basically, *inception score* measures the ability of Inception V3 network [25] to classify a synthetic image into 1000 classes. However, *FID* measures the distance between synthetic and real images. This is done by extracting  $2048D$  feature vector from each image using the Inception V3 network and then calculating the *Fréchet* distance using :

$$d^2 = \|\mathbf{u}_1 - \mathbf{u}_2\|^2 + \text{Trace}(\mathbf{C}_1 + \mathbf{C}_2 - 2 * \sqrt{\mathbf{C}_1 * \mathbf{C}_2}) \quad (12)$$

Where  $\mathbf{u}$  is the feature-wise mean vector and  $\mathbf{C}$  is the covariance matrix of the feature vector.

2. **Learned Perceptual Image Patch Similarity (LPIPS)** [26] : This metric measures the smoothness of the mapping between the latent space edits and the output image changes. This metric takes as an input, two synthetic images. It uses a pretrained neural network to project them to a latent space. Then, it calculates the difference between the two latent vectors, along with the perceptual distance between the two images. Finally, it uses the two distances to calculate the final score. This metric is used in StyleGAN2 paper to assess the *perceptual path length*.
3. **Edit Consistency Score** : We use this metric to ensure that the final facial attributes values are consistent with the input values after the *latent manipulation* process. This metric is simply calculated by projecting the final latent vector over all feature directions and compare it to the input values.
4. **Directions Disentanglement Score** : The disentanglement between feature directions are assessed by using the *angles* between each pairs of directions. Angles of values 85 to 95 degrees usually indicates low entanglement. The angles between two directions is calculated by taking the *inverse cosine* of the dot product between their unit vectors :

$$\theta_{1,2} = \arccos(d1_{unit} \cdot d2_{unit}) \quad (13)$$

## 5.2.1 Module Testing

### 5.2.1.1 Speech Recognition

Our final speech module is tested on *LibriSpeech ASR* corpus, *test-clean-speech* dataset. We use *character error rate* (CER) and *word error rate* (WER) to evaluate the accuracy of the model after 30 epoch of training. Table 5.1 show the results of our model.

Table 5.1: Speech recognition results.

CER	0.25
WER	0.65
CTC Losses	0.7

### 5.2.1.2 Text Processing

Our Final Design for Text Processing module is considered as a multi-label multi-class classification using DistelBERT base uncased, so we finetuned then tested it on a testing dataset of 100,000 records based on the metrics shown in table 5.2. The metrics proved that it will work very well (almost perfect) in inference time.

We tried different architectures such as ALBERT, BERT-base-uncased, ROBERTA-base. All of them converged on almost the same metrics mentioned above from DistelBERT. On the other hand, DistelBERT is the lightest out of them as shown in table 5.3 of average runtime. So, DistelBERT was the optimal choice to use.

Table 5.2: DistelBERT Testing Metrics.

Metric	Value
Accuracy	0.995
Precision	0.988
Recall	0.991
F1-Score	0.989

Table 5.3: Runtime for different architectures.

Architecture	Runtime
DistelBERT	0.0072 sec
ALBERT	0.0143 sec
BERT-base-uncased	0.0127 sec
ROBERTA-base	0.0125 sec

### 5.2.1.3 Code Generation

To test the quality of the generated feature directions that are used for *code generation*. We use two methods, which are **directions disentanglement scores** and **visual result** of moving along directions.

Table 5.4 shows the angles between the directions of a subset of features. Remember that angles in range 85 to 95 degrees indicate low entanglement. Consequently, we can infer that the numbers, provided by the table, are reasonable. For example, the angle between *gray hair* and *age* directions is 79.6 degrees, because old people normally have gray hair. Also, men are *not* likely to wear makeup, so the angle between *makeup* and *gender* directions is 107.7 degrees, same for *beard* with men.

Moreover, figure 5.1 shows the *visual results* of moving along some feature directions. We use these results to qualitatively measure the accuracy of the extracted feature directions.

Table 5.4: Angles (measured in degrees) between different feature directions using a subset of the considered facial features (closer to 90 degrees is better).

Angles	Age	Gender	Beard	Gray Hair
Age	0.0	92.4	85.8	79.6
Gender	92.4	0.0	80.0	88.6
Makeup	88.0	107.7	100.5	94.5
Hair Length	89.7	95.9	90.6	96.6

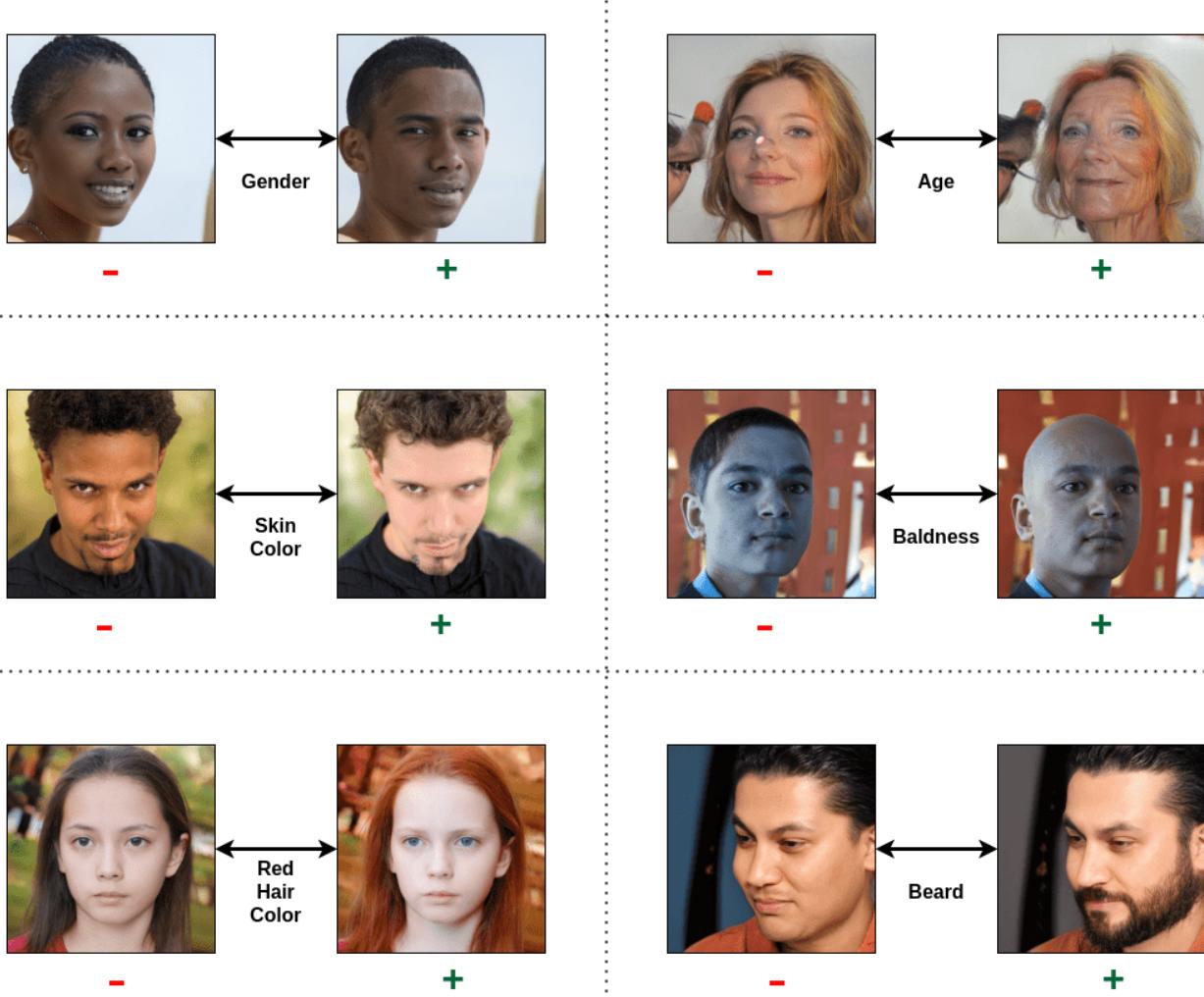


Figure 5.1: The results of moving along some extracted feature directions.

#### 5.2.1.4 Code-to-Face Translation

This module is basically tested using integration with **code generation**, which is shown in the **integration** test. However, we perform testing on this module separately using **edit consistency score** of the facial attributes values of the output image and the input values.

As figure 5.2 shows, the system can convert a random vector (*on the left*) to the final latent vector (*on the right*) driven by the input values (*on top*). Also, we can see the consistency between the required values and the values corresponding to the generated face.

Also, table 5.5 shows the relation between *LPIPS* score (between the intial and output images) and the number of directions, navigated during face generation. We can see that the score increases, as the number of navigated directions increases. This is mainly because the output face image is far from the initial face image. However, we can see that some *anomalies* can occur, like the case of the input text "*Woman with lipstick and rosy cheeks*", which navigates along only 3 directions, but gives a high *LPIPS* score.

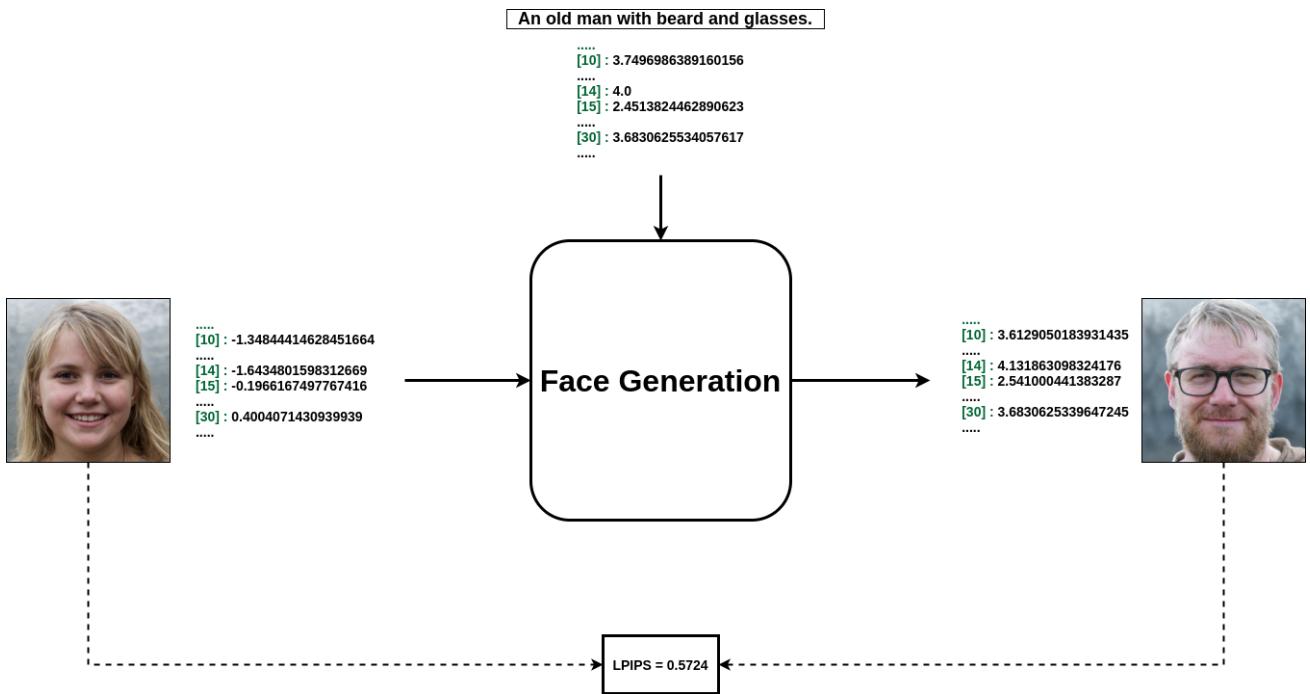


Figure 5.2: An example of the consistency in reaching the required facial attributes starting from initial random vector.

Table 5.5: LPIPS values against the number of navigated directions for sample text (lower is better).

Input Text	Number of Navigated Directions	LPIPS
Female with chubby face	2	0.3905
Woman with long wavy hair	3	0.4412
Old black man with glasses	4	0.5023
Woman with lipstick and rosy cheeks	3	0.5107
Young black man with long hair and beard	5	0.5733
Old man with chubby face and glasses	4	0.4905

### 5.2.1.5 Face Refinement

Since, we adapt StyleGAN2 for the refinement process, so this module testing is almost the same as **code-to-face generation** module. However, we focus more on the visuals of the *sequential navigation*, along with the new features related to the face morphology. Figure 5.3 shows the results of sequential navigation given an original synthetic face image. We tried to maintain the independence of sequential direction navigation as much as possible to keep the results visually acceptable. For example, in the first row, we convert from a "*young man with hear and no beard*" into an "*old bald man with beard*" by sequential navigation using *age*, *beard* and *baldness* directions. This yields much better visual results than many recent *attribute-editing GANs*.

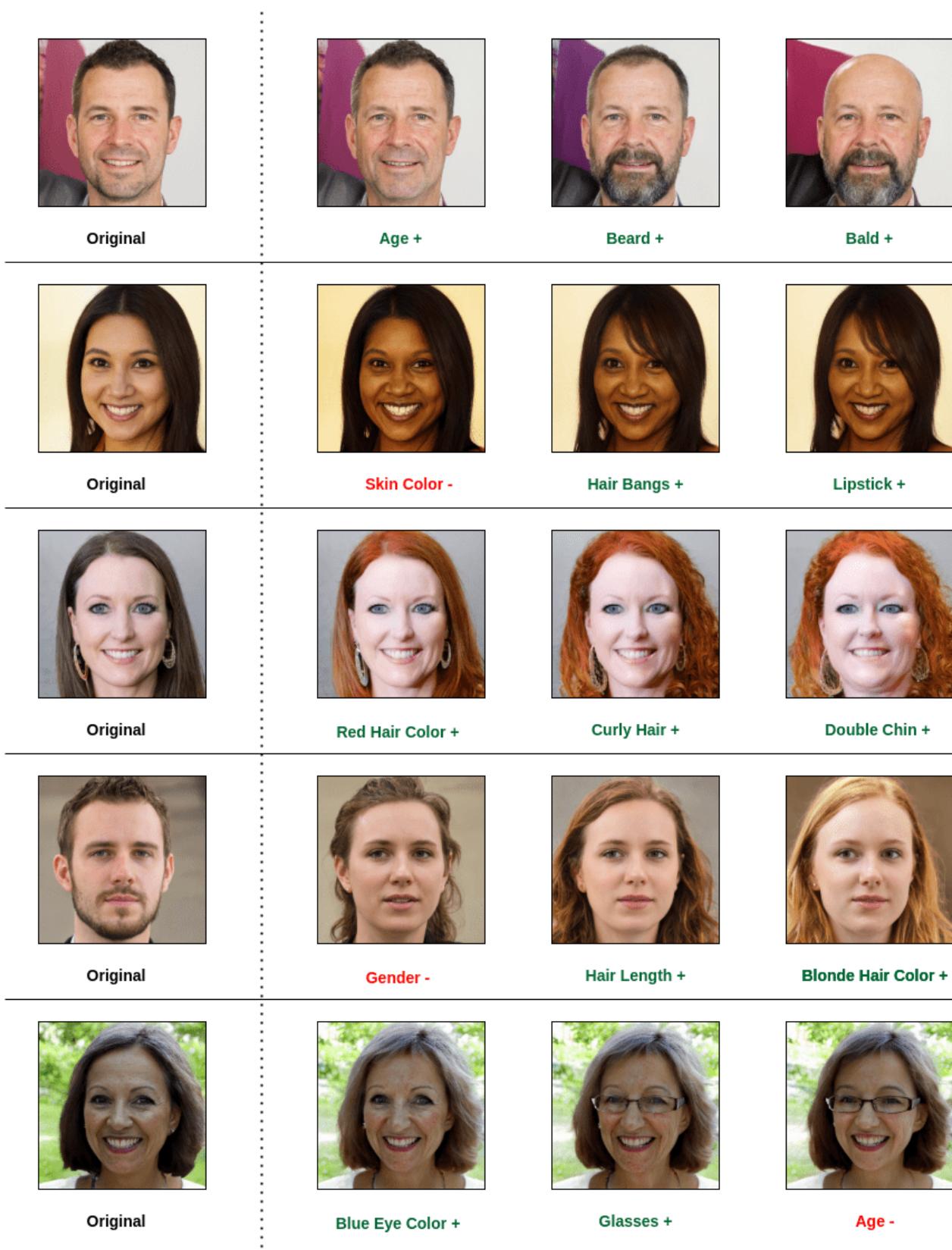


Figure 5.3: The results of sequential navigation along certain feature directions.

#### 5.2.1.6 Multiple Head Poses Generation

In order to test the Multiple Head Pose Generation module, 2 Tests are performed :

Table 5.6: NME mean and std for test data of AFLW and AFLW2000 dataset. NME is calculated for a various range of poses for 3DMMs

Pose Range	NME on <b>AFLW</b>	NME on <b>AFLW2000</b>
[0-30]	7.65±5.41	5.668±2.88
[30-60]	9.11±6.47	7.05±4.04
[30-90]	10.04±8.33	8.28±4.42
<b>[0-90]</b>	<b>8.93±0.98</b>	<b>7.002±1.06</b>

- **Quantitative Testing:** Calculating a metric on a Dataset to evaluate the performance of the 3D Fitting sub-module. The dataset used are AFLW (21 annotated facial landmarks) and AFLW2000 (68 annotated facial landmarks) datasets which contains Human faces and their corresponding Parameters for the 3DMM. The used metric is the Normalized Mean Error (NME) which is the standard metric for evaluating 3D Fitting models. NME is calculated for the single 3DMM as follows:

$$NME = \frac{1}{N} \sum_{k=1}^N \frac{l2norm(x_k - y_k)}{d}$$

Where d is the distance in the 3D model between the 2 eyes of the face. Results of NME metric are reported in table 5.6

- **Qualitative Testing:** In addition to the Quantitative evaluation for the module, A Quantitative evaluation is performed by generating and visually evaluating results for Images outputted from our previous modules. Doing this asserts that the generated images have a user-friendly quality and doesn't mess up with the quality of the image generated in the previous steps. In figure 5.4 we provide an example of some input face images generated from the previous modules. Qualitative results for the 3 input examples are displayed in figure 5.5, figure 5.6, figure 5.7



Figure 5.4: Example of input faces from previous stage.

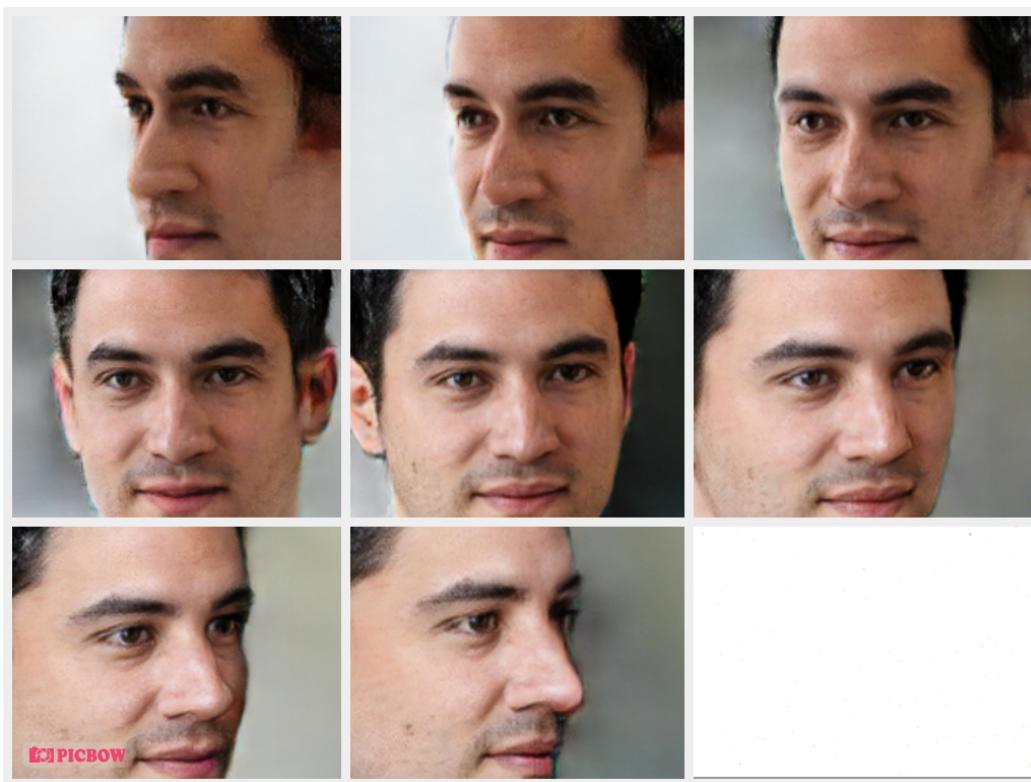


Figure 5.5: Example of output 8 poses for the first input face

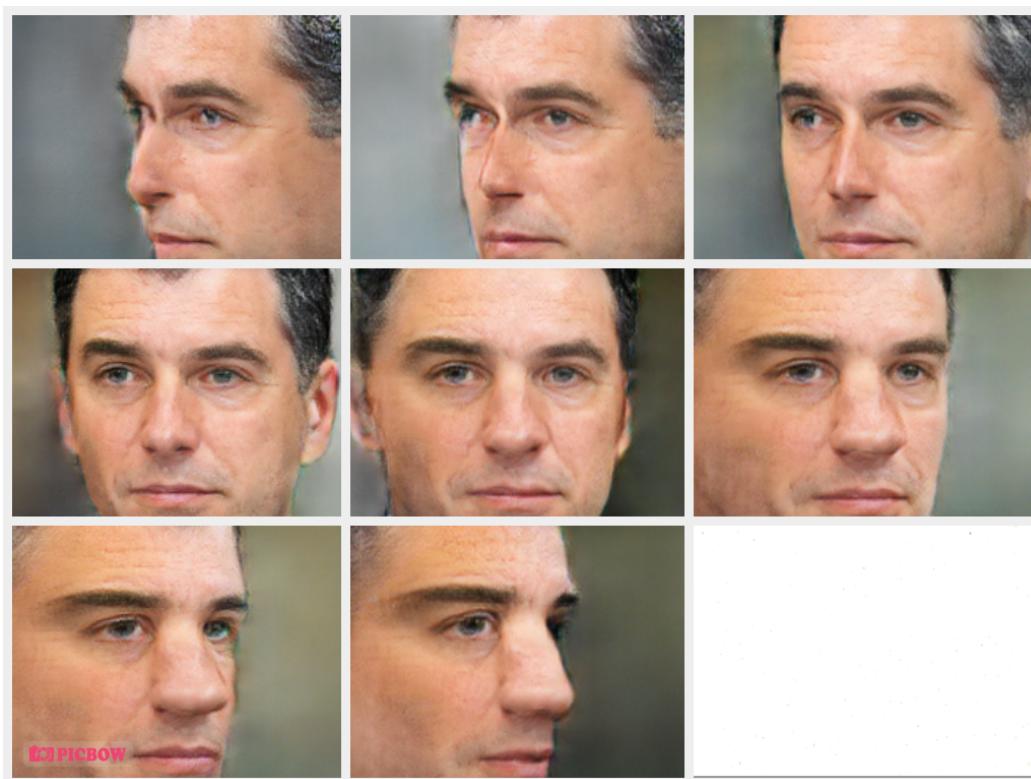


Figure 5.6: Example of output 8 poses for the second input face.

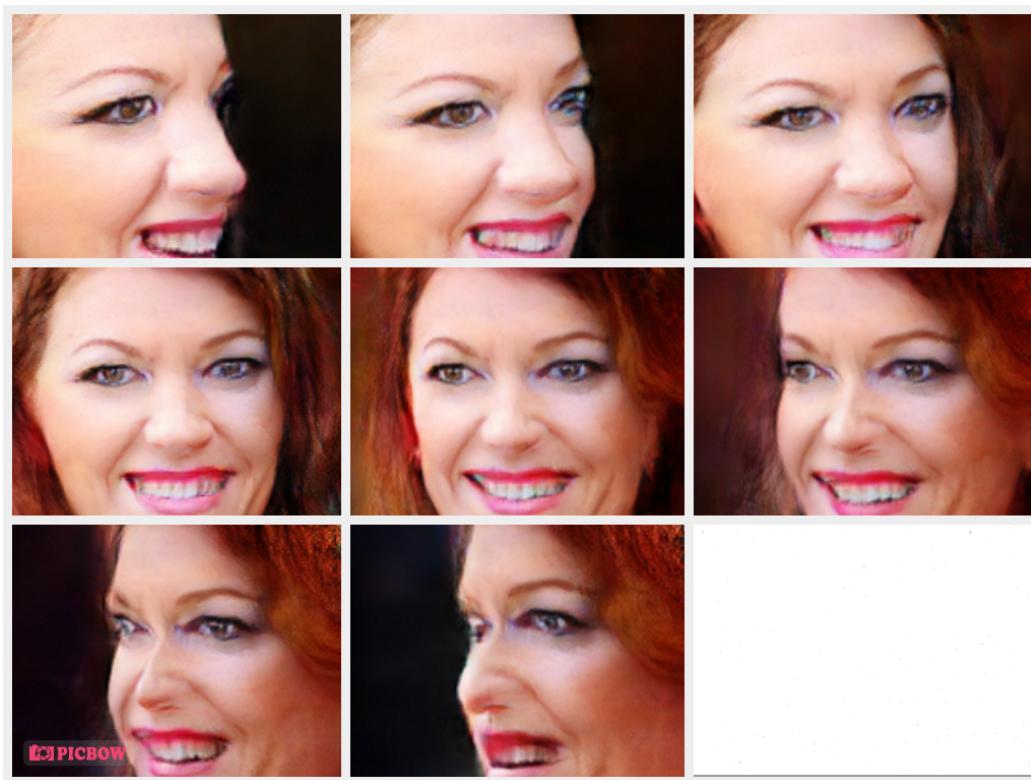


Figure 5.7: Example of output 8 poses for the third input face.

### 5.2.2 Integration Testing

The integration of the whole system into a web application is tested qualitatively and quantitatively. In this section, we show the visual results of our system in an *end-to-end* manner. However, we show the quantitative metrics in the comparison with previous work.

Figures 5.8 and 5.9 show correct results of **face generation** in an *end-to-end* manner using our final *web application*, which contains our complete pipeline. We can see that the results samples are of high accuracy and fidelity. However, of course, the system is *not* 100% accurate. From our extensive testing to the system, we notice *4types* of failures, described visually in figure 5.10. These failures are listed as follows :

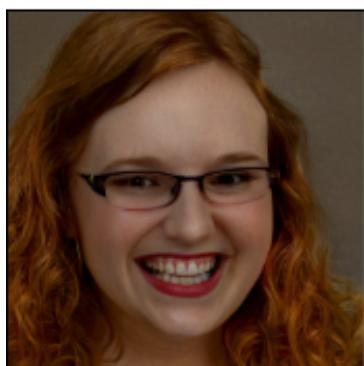
1. Failures due to **contradicting facial features**. As in the *top-left* image, as *rosy cheeks* are very hard to capture with *black skin color*.
2. Failures due to **excessive navigation on directions**. As in the *top-right* image, which is very unclear and of low quality with many visual artifacts.
3. Failures due to **random initialization**. As in the *bottom-left* image, where sometimes bad initial latent vector can cause the output to be visually inconsistent with many visual artifacts.
4. Failures due to **sequential latent manipulation**. As in the *bottom-right* image, where navigation on one direction (*wavy hair*) cancel the navigation on another direction (*short hair*).



**Young bald man with  
beard and glasses.**



**Young girl with blonde  
hair and blue eyes.**



**Young woman with  
brown wavy hair. She is  
putting on lipstick and  
wearing glasses.**



**Old black man with grey  
hair.**

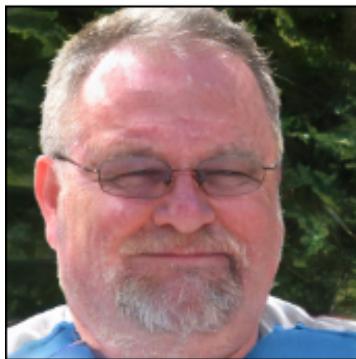
Figure 5.8: Samples of correctly generated face portrait from textual description.



A bald Asian man with beard. He is wearing glasses.



A white woman with short brown hair. She has hair bangs and is wearing glasses.



An old chubby man with double chin and rosy cheeks. He is wearing glasses and has receding hairline.

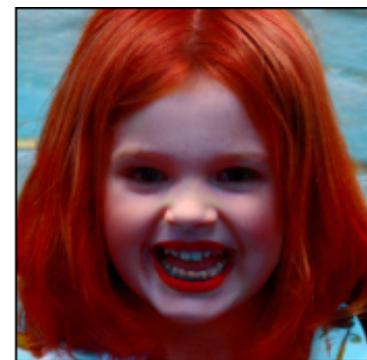


A young woman with blonde hair and rosy cheeks. She is putting on slight makeup and her hair is short.

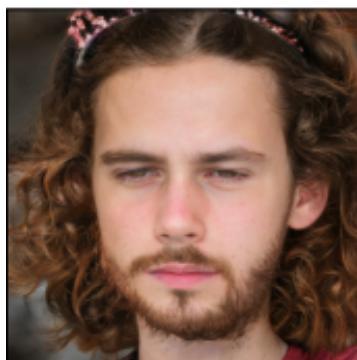
Figure 5.9: Samples of correctly generated face portrait from textual description.



A black man with rosy cheeks and blonde hair.



A young woman with red hair and rosy cheeks. She is putting on lipstick.



A young man with long hair and beard.



A young woman with short wavy hair.

Figure 5.10: Samples of incorrectly generated face portrait from textual description.

### 5.3 Testing Schedule

Our testing process is scheduled as follows :

- First, we conducted the initial testing on the 3 core modules, while being iteratively designed, until they converged to decent results.
- We, then, did the integration testing on these modules separately.
- After so, the rest of the system modules were designed and tested separately.
- Finally, the whole system was integrated into a single web application and complete testing of the whole system functionalities was conducted.

### 5.4 Comparative Results to Previous Work

First of all, it's worth mentioning that our system considers *more facial features* than all previous research that worked on latent manipulation. As mentioned before, we compare our results quantitatively with 3 baselines, using **FID score**, **average LPIPS** and **execution time**.

Table 5.7 and plot 5.11 show the comparison of our system to StyleGAN2 and Image2StyleGAN. We couldn't include Faces à la Carte in this comparison, as the authors didn't include it in

the paper. Also, we couldn't replicate their work, as they didn't provide any specific details about the implementation. We can see that as the number of test images increases, the overall quality of the images increases (*FID* score decreases). Our system performs better than Image2StyleGAN, but worse than the original StyleGAN2, because it is just image generation from random vector with no *latent manipulation* (fewer artifacts).

Table 5.7: FID scores comparison on different number of test images (lower is better).

Test Size	StyleGAN2	Image2StyleGAN	Retratista
50	129.15	179.58	151.58
100	104.29	150.54	132.54
200	95.25	136.45	114.45
300	92.44	134.04	113.04
400	86.37	121.59	100.59
500	80.09	119.02	99.02



Figure 5.11: Plot of FID score of different pipelines against different number of test images (lower is better).

Next, we compare our system with Faces à la Carte using the only metric, the authors provided, which *LPIPS*. We can see from table 5.8 that our system yields lower overall *LPIPS*, which is better. However, we have higher error margin than Faces à la Carte.

Table 5.8: LPIPS comparison with Faces à la Carte (lower is better).

Retratista	Faces à la Carte
0.595±0.008	0.634±0.005

Finally, table 5.9 shows the execution time of different core stages of our system. We can see that the overall *text-to-face generation* process takes only about 0.2 seconds on an

*Nvidia GTX 1080 ti.* However, the web application can take from 1 second up to multiple seconds to generate a face portrait (from any description) using the same GPU, depending on the *connectivity* with the server. Meanwhile, our *multiple head poses generation* module takes around 2 seconds to generate a single pose on the same GPU as well. Most of the application backend runs on *CUDA GPUs*. The whole system without **multiple head poses generation** module occupies around *5.5 GB* of *VRAM*. Meanwhile, this module occupies up to *3 GB*. So, in total, the whole system occupies between *8 to 9 GB* of *VRAM*.

Table 5.9: The execution time of different stages of the core of our system (measured in seconds).

Text Processing	Latent Manipulation	Face Generation
0.048	0.11	0.024

## 6 Conclusions and Future Work

Our system offers an innovative solution that leverages the power of *Deep Learning*, *Generative Adversarial Networks*, *Computer Vision* and *Natural Language Processing* to build an automated, fast and robust system for face generation and identification from various types of description. We push our pipeline to be as flexible and accurate as possible. Also we managed to overcome most of the challenges that faced us during building the system. Face generation and manipulation using voice, text and manual input are feasible in an automated way within few seconds. Moreover, our system considers a sufficient set of facial features to enable describing faces in an accurate way. Finally, our system is very flexible to add more facial features and further improve the results given enough resources and time.

### 6.1 Faced Challenges

Throughout the project, we faced many challenges. Basically, the challenges are related to *data scarcity*, *few related research work*, *architectural complexity* and *facial attributes*.

#### 6.1.1 Data Scarcity

One of the main challenges of our project is data scarcity. No open-source source datasets exist for *text-face* pairs, except only one dataset (**Face2Text**). We had to contact the authors, who kindly gave us an access for the dataset. Unfortunately, the dataset contains only 4000 text-face pairs, which are not enough at all to conduct experiments or build the system. Consequently, we built our system in stages, as mentioned before. However, the *text processing* module required a dataset, as it's completely supervised. Consequently, we built our face textual description from scratch, as discussed above 4.4.

#### 6.1.2 Few Related Research Work

Although the problem of image generation is popular in the research community, only one work actually targets human face generation from description, which is *Faces à la Carte* [11]. *Faces à la Carte* does not even provide enough information about the method implementation. Consequently, we had to come up with our own working pipeline to build the face generation from description. We gained a lot of insights from other research works related to image (face) manipulation and awesome StyleGAN2 follow-up papers.

#### 6.1.3 Architectural Complexity

Most of the architectures related to high quality image generation are very complex and slow at inference. This results in the difficulty of editing or tuning them to other purposes. Also, we have to keep our inference time as minimal as possible. So, we had to spend a lot of time trying to adapt only the relevant modules of these enormous architectures into our system to maintain both time and memory complexity.

#### 6.1.4 Facial Attributes and Entanglement

As mentioned before, the choice of facial attributes and the entanglement between them are the most difficult challenges of our project. We had to spend some time researching to select a set of facial attributes that correctly and sufficiently describes a human face. We came up with 32 facial features for face generation and 38 (32 + 6 new) facial features for refinement. However, we were left with the entanglement challenge, because all open-source faces datasets contain real human faces. Real human faces contain natural entanglement between facial attributes. This results in features entanglement in the latent space of our generative model, which makes the process of feature directions extraction very difficult. We tried to solve this entanglement problem with various techniques and reached good results. However, the problem is not 100% solved.

### 6.2 Gained Experience

Throughout our work on this project, we were exposed to numerous research works. We read lots of scientific research papers and articles, gained insights from many of them and adapted their techniques to our work. Also, we had the chance to work with multiple tools and technologies including, but not limited to, *Python*, *C/C++*, *JavaScript*, *PyTorch*, *OpenCV*, *REST APIs* and *Docker*. Moreover, we gained a lot of experience from integrating such complex architectures into a single software.

### 6.3 Conclusions

Through the project, we managed to build a complete system that provides an automated, fast and robust way to generate and identify human faces from bare description. We consider voice, text and manual descriptions. Also, we formulated our system into a web application with a simple web user interface, where the user can input his preferred face description to be generated within few seconds. Then, the user is able to refine the generated face and render it in multiple poses for more identification. While being automated and accurate, our system suffers from some downsides as well. The facial features entanglement can still affect the output face portraits in some cases. Also, we tried to consider as much facial features as possible, however there can be even more features to include.

### 6.4 Future Work

Our work is flexible to changes and can be extended in various ways. To tackle the problem of entanglement, StyleGAN2 synthesis network can be tuned using synthetic face images generated from **Epic's MetaHuman Creator**. This exposes the latent space to more generic faces with different facial features, which can help reducing entanglement and overlapping between feature clusters. Consequently, the set of facial features can be expanded to include more fine details about the human face. Following these methods, the system can be extended to generate fine-detailed human face portraits better than professional portraitists and within minimal time.

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# A Development Platforms and Tools

Our project is completely software, so we discuss the software tools and packages used to develop our system.

## A.1 Software Tools

### A.1.1 Ready-made Models

#### A.1.1.1 Facial Landmark Detection Model

The facial landmark detection model, used to extract some the feature directions, is completely ready-made. We used the open-source implementation of **High-resolution networks (HRNets) for facial landmark detection** [27] to do the landmark detection task, in order to get different facial distances and sizes.

#### A.1.1.2 Neural Face Renderer

We used a ready-made neural network model for rendering *3D* faces from *2D* images to perform face rotation. This model is an open-source *PyTorch* implementation for **Neural 3D Mesh Renderer** [28].

### A.1.2 Frameworks and Packages

#### A.1.2.1 PyTorch

An highly-optimized open-source *ML* library used to implement, train and deploy all *DL* models used in our system.

#### A.1.2.2 OpenCV

An open-source library for optimized image processing and computer vision applications. It's used in facial attributes classification in feature directions extraction.

#### A.1.2.3 Flask

An open-source *Python* framework, used to implement the server *API* endpoints.

#### A.1.2.4 Vuejs

An open-source *JavaScript* framework, used to implement the web user interface.

#### A.1.2.5 Docker

An open-source software used for containerization. It has been used throughout the project and through deployment for automation and to handle conflicting dependencies.

## B Use Cases

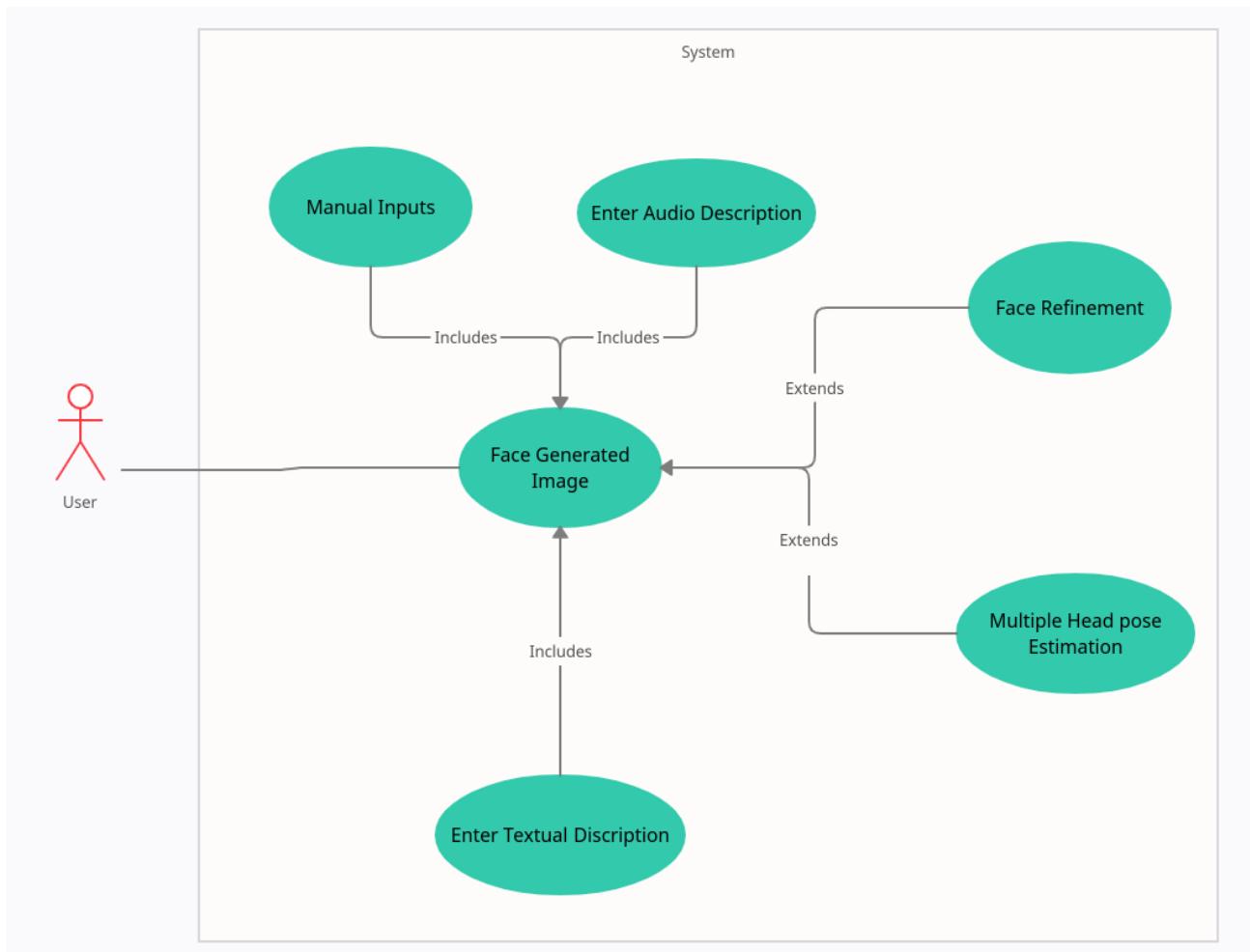


Figure B.1: UML diagram for our application.

As mentioned before, our application can be used in police station or any organization responsible for missing people like International Center for Missing and Exploited Children and many other organizations. Also, Archaeological and Historical Researchers will be willing to use our app as it will help them to identify the facial description on the mummies using images not only textual descriptions.

## C User Guide

### C.1 Main Page

In this page as shown in figure C.1, the user can

1. choose from a menu the generation mode that he or she wants.
2. navigate to the demo and help page from the bar in the header.

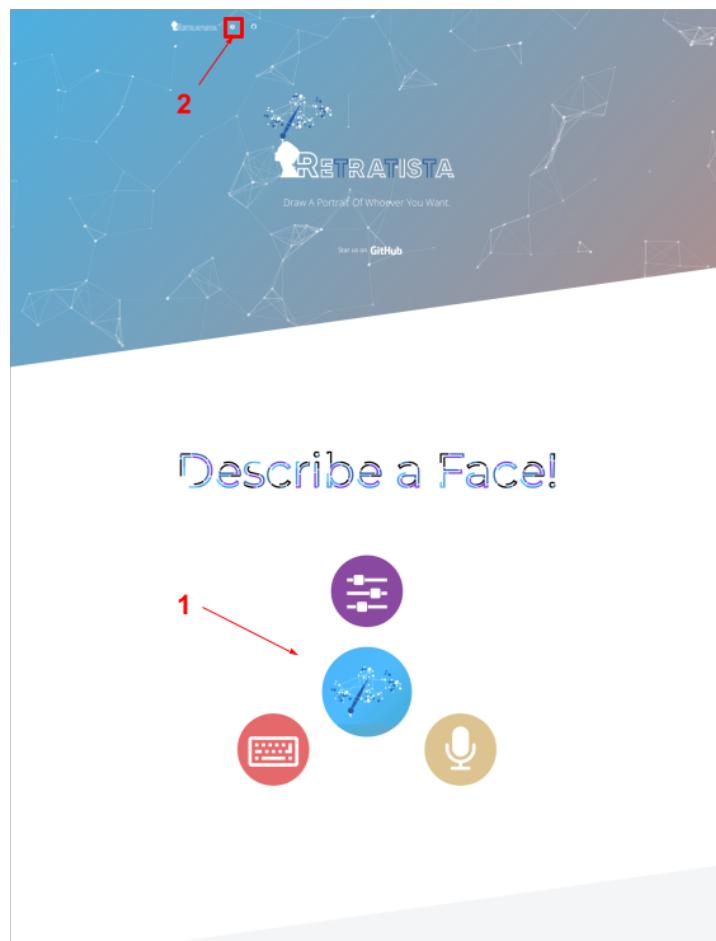


Figure C.1: Main Page

## C.2 Voice Description Page

In this page as shown in figure C.2, the user can

1. describe a face using his voice.
2. edit the description textually.
3. generate the described face.
4. route to refine page after generation.
5. route to head poses page after generation.

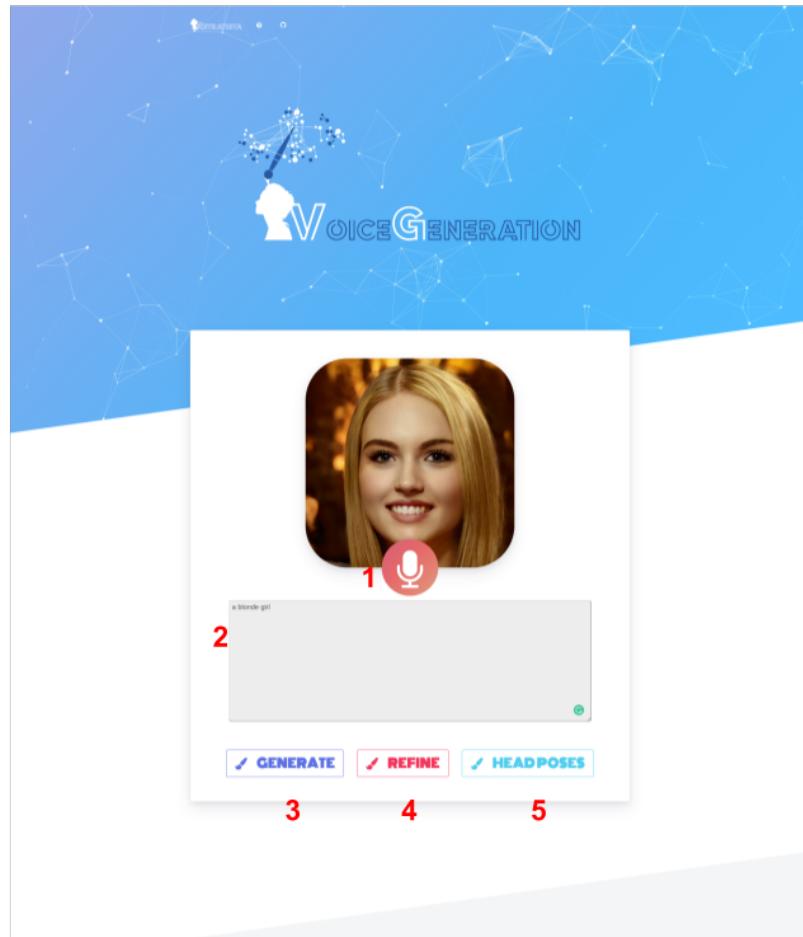


Figure C.2: Voice Description Page

### C.3 Text Description Page

In this page as shown in figure C.3, the user can

1. describe a face textually.
2. generate the described face.
3. route to refine page after generation.
4. route to head poses page after generation.

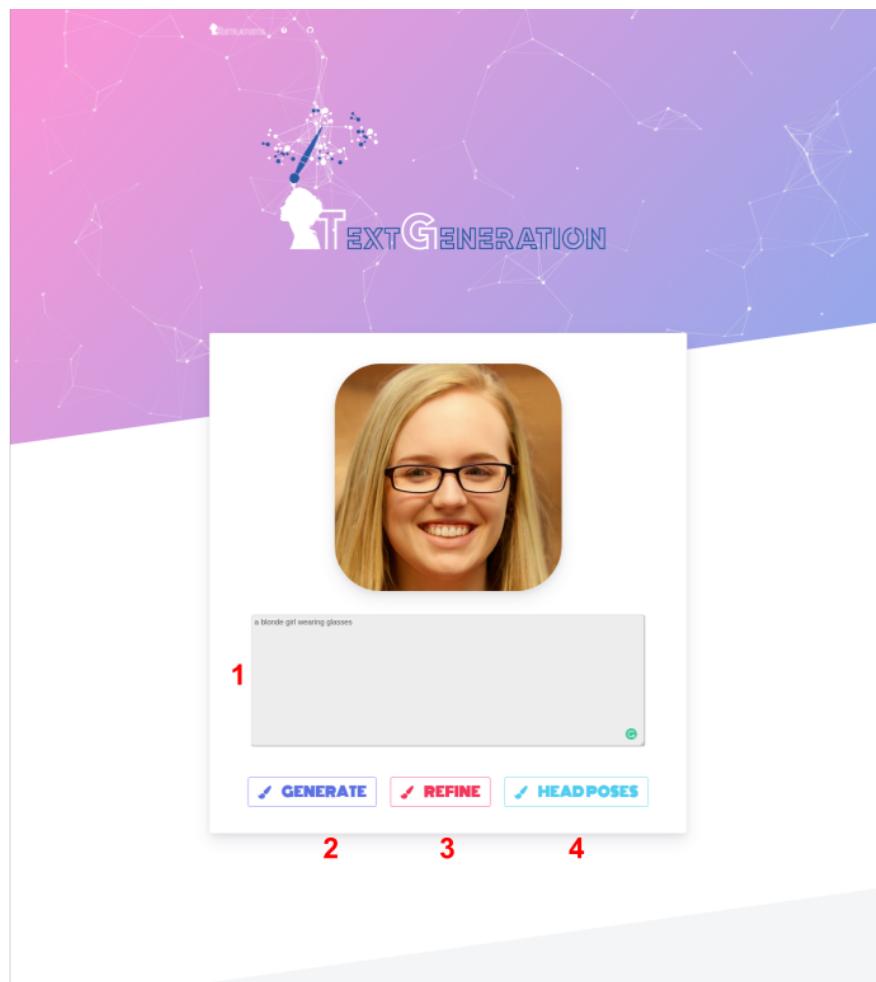


Figure C.3: Text Description Page

## C.4 Refine Page

In this page as shown in figure C.4 for refinement of age attribute, the user can

1. navigate in 39 different facial attributes to get the actual intended face.
2. route to head poses page after refinement.

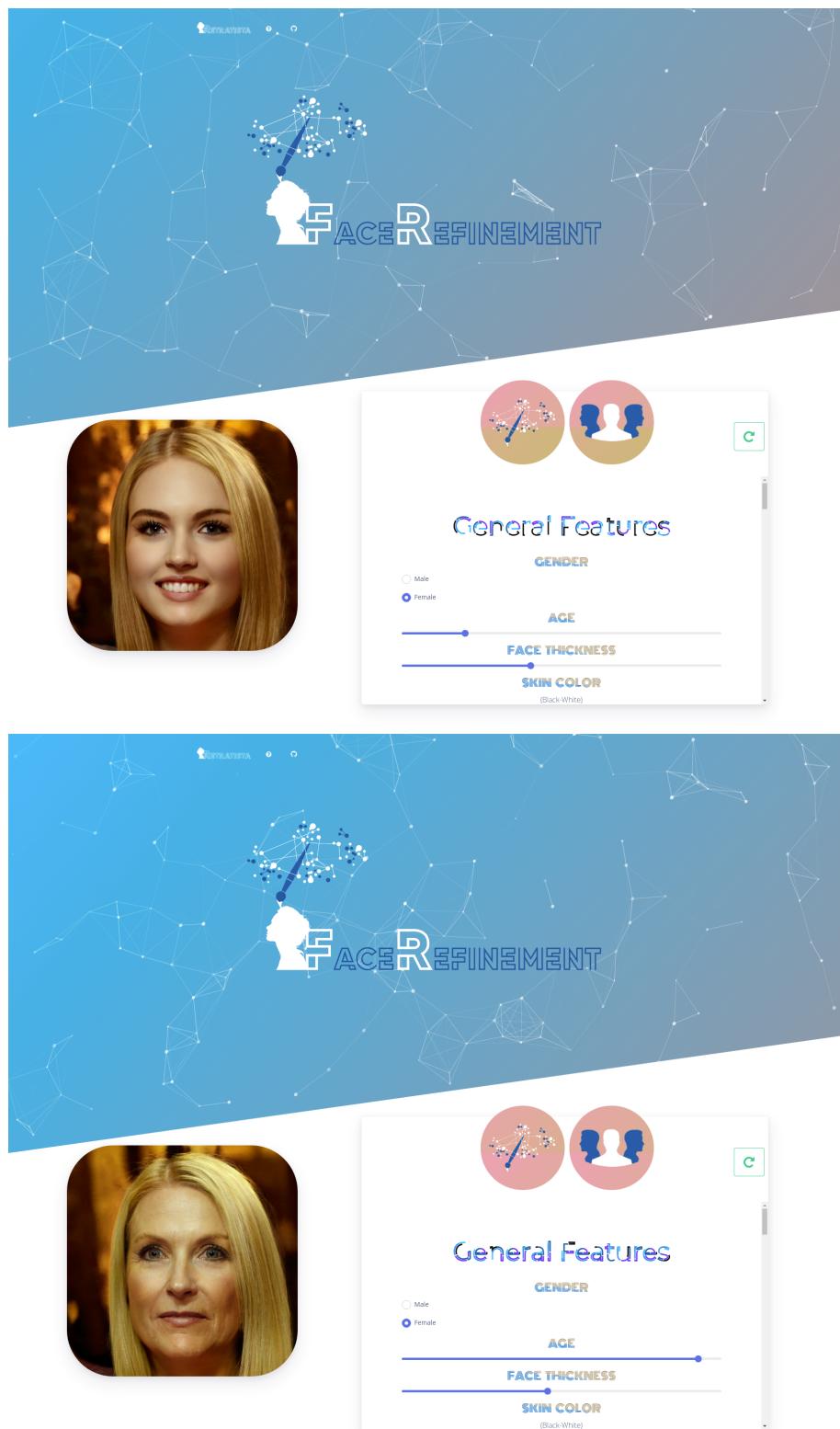


Figure C.4: Refine Page

## C.5 Head Pose Page

In this page as shown in figure C.5, the user gets 8 different head poses for the same person for extra identification.

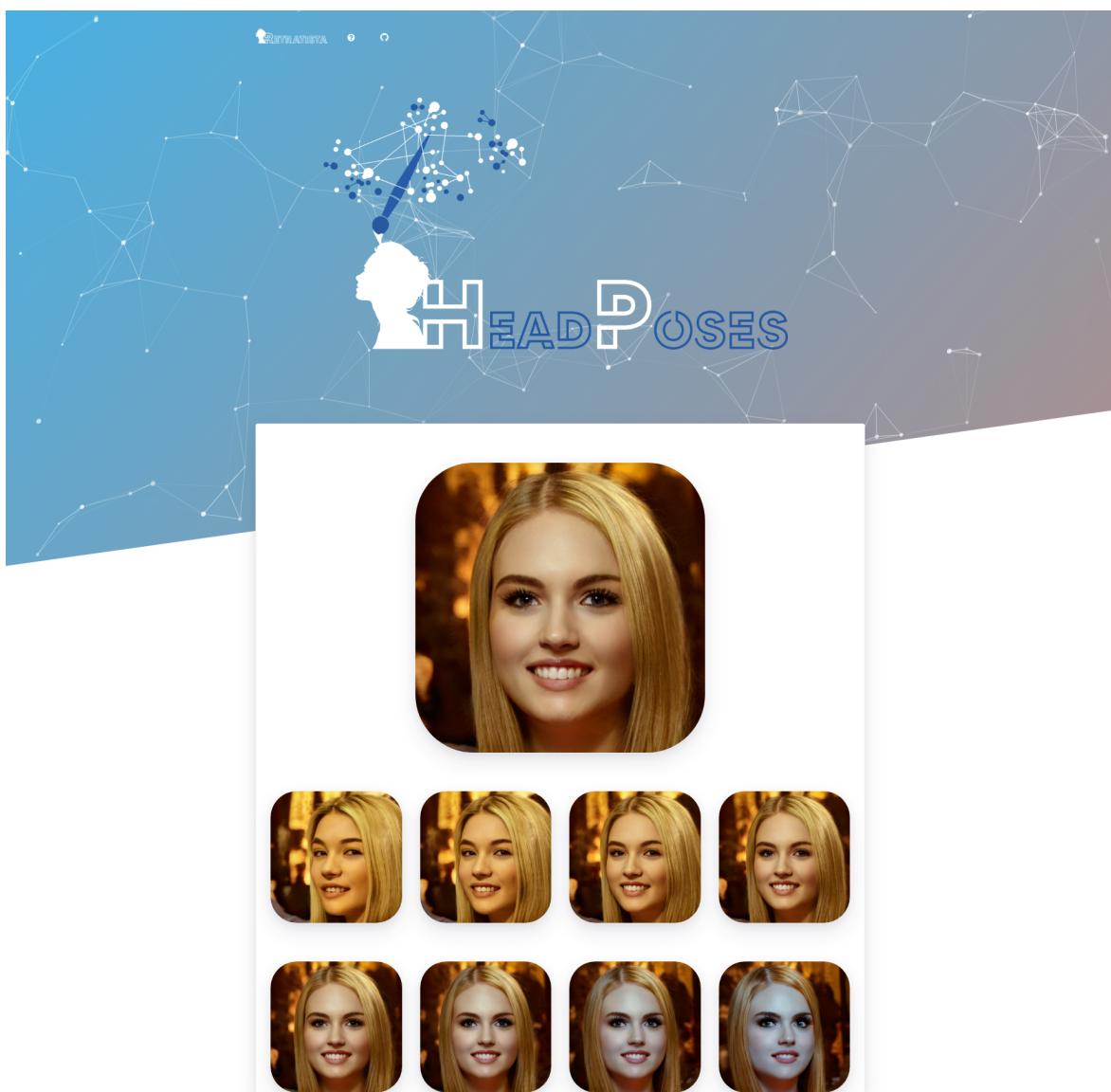


Figure C.5: Head Pose Page

## C.6 Demo Page

This Page is a help aid for the user to know how to use the application and to support the user with some extra information about the project, such as

- Why is Retratista important?
- Statistics
- Project Features
- How To Use?
- Result Samples
- Team

## D Feasibility Study

### D.1 Technical Feasibility

To conduct this project knowledge base in the field of image processing and mathematics is required, to build on the knowledge in artificial intelligence, the use of generative adversarial networks and supervised learning to build and improve the models. Also, experience in web design and launching to represent our product to any user or organization, so that they buy it. We used our devices to train the models besides the online free service, such as *Google Colab*. Additionally most of the developed models were guided by published research papers, therefore indicating and emphasizing the feasibility of the solution.

### D.2 Operational Feasibility

As mentioned before, we deal with two types of users. One uses the application for special purposes; finding missing people or identifying the image of some ancient king or queen, so they need to have at least one PC with VRAM 11GB or more, to be able to run the application which will cost around \$1500 to \$2000 or more depends on the number of PCs will be used and their specifications. For the other type of users we can deploy the app for free as a trial, then a little expense is asked from subscribed users so that the deployment cost is covered with profits.

### D.3 Legal Feasibility

The development of the project depends on publicly available libraries and software tools, like *PyTorch*, *OpenCV*, *Flask* and *VueJS*. All the pretrained models used are open sources and legal to be used for any product. All datasets used to train any written model are public for any commercial use or made by us. The devices used to train those models are our own or on *Google Colab*, which is also public for any use.

## D.4 SWOT Analysis

### D.4.1 Strength (S)

- Fast.
- Automated.
- Easy-to-use.
- Realistic results.
- Containing a sufficient set of features to describe a human face.

#### D.4.2 Weaknesses (W)

- Facial features entanglement.
- High *V**RAM* usage.
- Sometimes results can be inaccurate.

#### D.4.3 Opportunities (O)

- No competitors.
- Fast and automated.

#### D.4.4 Threats (T)

- Lack of datasets.
- High cost.