**A project report submitted in partial fulfilment for the degree of**

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Flow Stitch

Cross Stitch Pattern Generator

Lili Veszeli

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# Abstract

The process of designing a cross stitch pattern can be made faster and more flexible using a computer program instead of paper. The goal of this project is to create a Windows application that allows users to generate a cross stitch pattern based on an image. This report reviews the literature available on image downsampling algorithms, posterization, and user interface design. A solution was developed using WPF. Bicubic downsampling and colour quantization was used to create the pattern. The colours are converted to real life DMC thread colours. The pattern can be edited, and the palette colours can be changed. The program includes other features such as preview generation and laying symbols on top of the pattern to distinguish colours easier. The project was successful. A fully functional cross stitch editor was developed with all the required features.

# Attestation

I understand the nature of plagiarism, and I am aware of the University’s policy on this.

I certify that this document reports original work by me during my University project.

Signature: Lili Veszeli

Date: 06/05/2021

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# Introduction

## Background and Context

This project combines modern technology and cross stitching. Cross stitching is a form of embroidery. Lots of creative hobbies can benefit from technology. For example, it is not possible to undo strokes on drawings done on paper or apply effects to them. This is the case for cross stitch patterns too that were traditionally designed on paper. If a mistake happens, the entire pattern has to be redrawn. Designing the pattern digitally allows for more flexibility and can even improve it with the help of image processing algorithms. It also makes it easier to duplicate and share with friends.

There are a few existing cross stitch applications, however they are expensive or have limited features. The project tries to address this issue with creating a middle ground.

## Objectives and Achievements

The objective of this project is to create a usable Windows application that can produce a simple cross stitch pattern based on an image. The program should be able to load, downsample, and quantize an image. The resulting pattern should be able to be edited and saved using a clean and aesthetic user interface.

The project was a success. All the objectives were achieved and exceeded. As a developer, it gave me invaluable experience and skills. As a person, it gave me confidence that even if something seems impossible it can be achieved by small steps.

## Overview of Report

**Chapter 2** reviews literature of relevant image processing techniques and user interface design. Furthermore, it explores the limited existing literature of cross stitch applications.

**Chapter 3** presents possible techniques, application platforms, and languages for the program. Project management methodologies are weighted, and requirements are introduced. Accessibility issues are also considered.

**Chapter 4** discusses the advantages and disadvantages of the application of the MVVM pattern for this project. Important use cases are outlined. Finally, the inspiration behind and decisions about the user interface design is explained.

**Chapter 5** details the implementation of the different steps that create the pattern in this program. It discusses the theory, and advantages and disadvantages behind the decisions.

**Chapter 6** describes different testing strategies that can be used to test the program and features a test script.

**Chapter 7** evaluates the success of the project and reflects on personal development. Future improvements and additions are also discussed.

# Background and Related Work

## Introduction

The popularity of arts and crafts is increasing among all age groups. Textile based hobbies, like knitting and embroidery are the 2nd most popular craft in the UK (Mintel, 2020). This statistic suggests that there is a market for an arts and crafts program. The objective of the project is to create a software that converts a picture into a cross stitch pattern. The user will be able to edit the pattern and customize it using different features of the program. This chapter reviews relevant literature about the topics in the project. It explains the basics of cross stitch, to gain an understanding of the fundamentals, and existing software. Another theme is about different methods for image downsampling, which will help to create the pattern. Different application platforms are evaluated, and UI design practices are explored.

## Cross Stitch History and Basics

For the purposes of this project a brief introduction to cross stitch is essential in order to understand how to implement the process digitally. Cross stitching is a type of embroidery stitch art (Setiabudi et al., 2017). A picture is created using colourful thread and little cross shaped stitches on fabric. Usually, two strands of cotton thread are used (Dyer, 1997). The stitching is done on fabric that has small holes: aida or evenweave (see Figure 1). The colour range of the threads can be vast, the most widely used is made by DMC. There are only a few types of stitches since the final result should look uniform. The simple cross is used most of the time, however, a half stitch, quarter stitch, three-quarter stitch and backstitching is also used occasionally (Atkinson & Roberts, 1999). Considering the different types of stitches used in this art form is important because they bear a close resemblance to the way that images are displayed on a computer screen because they both appear to be made of little squares (pixels).

A picture containing food, sushi

Description automatically generated

*Figure 1 - Example of a cross stitch on aida (RTO, n.d.).*

This art-form originated in Asia, and the oldest cross stitch dates back to 850 B.C. It became more popular in the Victorian era. Then, in 1980 cross stitch re-emerged again, and became how we know it today. It is one of the most popular type of needlework throughout the world (Leslie, 2007). It is a soothing and therapeutic hobby, and could help improve mental health (Hohmann, 2020).

A pattern is needed to make a counted cross stitch (see Figure 2). A pattern consists of a grid with colourful squares (Biedl et al., 2005). The squares signal the position and colour of the stitch, like in Figure 3 (Atkinson & Roberts, 1999). The size of a pattern is measured by the number of stitches across and down.

Diagram

Description automatically generated

*Figure 2 - Simple cross stitch pattern (Fitzgerald, 2017)*

*Diagram

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*Figure 3 – The way a pattern is converted to stitches (Biedl et al., 2005)*

## Image Processing

Digital image processing means manipulation of an image with a computer. The cross stitch program will do exactly this: manipulating a photo into a pixelated version by compressing it. This section overviews some techniques and previous solutions to help with achieving the desired effect. Image compression is an application area of image processing. An image has to be resampled in order to upscale it, downscale it or rotate it. Downsampling is a widely used image operation. It is used to reduce the storage requirements (Youssef, 1999). However, it will not be used in this project for that reason, but to get the pixelated look.

An image is stored in a bitmap. It is defined by the number of pixels and the information contained in them. Image scaling means to “re-sample a two-dimensional function on a new sampling grid” (Parthipan, 2017). Several algorithms can be used in image scaling. The simplest and fastest one is the nearest neighbour method, where the value of the new point becomes the value of the closest input point. Another method is linear interpolation, where the new point is interpolated between the two closest old points. Bilinear interpolation calculates the new point from the weighted average of the four closest input points. These might produce undesired effects like aliasing. A more sophisticated algorithm is bicubic interpolation. It samples the closest 4 by 4 pixels, so 16 pixels, and interpolates between them. This is the standard for most image editing software (Patil, 2018; Parker et al., 1983).

One of the simplest and most efficient downsampling algorithm is the box filter. It is a linear filter algorithm. This is considered to be used in the basic version of the program. The way it works is that each pixel in the target image is the average of the pixel values in a square from the source image. It is easier to understand with a diagram, see *Figure 4*.

A picture containing table

Description automatically generated

*Figure 4- Box filter (Parthipan, 2017).*

This is a simple way of converting a picture into bigger squares like on a pattern, but this algorithm can easily miss important details, and the resulting image/pattern might not be recognizable. Other research tries to solve this problem by using more complex algorithms.

### Detail Preserving Resampling

The algorithm by Gertsner et al. (2012) converts high resolution images into pixel art style ones with reduced colour palettes. It converts faces and other detailed images much more accurately than a regular downsampling algorithm. Pixel art is very close to a cross stitch pattern, it almost looks identical without the grid, so this article can provide great ideas to approach the problem.

Each pixel needs to be carefully placed, so that it accurately represents the original image. Areas such as the eyes and mouth are especially difficult to get right, however, it is achievable by using “superpixels”, see *Figure 5*. The algorithm uses an iterative process. First, the superpixels are initialized in a grid, and then each original pixel is assigned to the closest superpixel. The palette is also set to an average colour. Then, the iteration starts, the superpixels are refined and associated with colours in the palette, then palette is also refined, and expanded (Gertsner et al., 2012). Unfortunately, it does not allow users to pick the palette colours, so that has to be solved in another way in the program.

A picture containing text

Description automatically generated

*Figure 5 - Superpixels and final result (Gertsner et al., 2012).*

### Posterization

Posterization reduces the number of tones used in an image. There is no gradient between the areas and usually vivid colours are used (Afifi, 2018; Kwon & Chien, 2011), see *Figure 6*. This algorithm can be useful for the program since it also needs to reduce the number of colours from the original image.

First, the algorithm of Afifi (2018) removes small details from the image, then applies bilateral filtering. After the image is prepared for quantization (the process to reduce the number of colours in an image to a limited palette) (Orchard & Bouman, 1991), the pixels are sorted into ‘bright’, ‘grey’, and ‘dark’ categories using fuzzy logic.

A picture containing wall, person, clothing, suit

Description automatically generatedA picture containing text, suit

Description automatically generated

*Figure 6 - Posterized image (Kwon & Chien, 2011).*

## Application Platforms for Consideration

### .NET Framework

A suitable application platform needs to be selected for the software. This desktop application will be Windows based, so the Microsoft .NET Framework will be used. Figure 7 illustrates the .NET stack. This technology supports running Windows and Web apps (Microsoft Docs., 2020a). Both WPF and Windows Forms are part of the framework, however, they are best suited for different types of applications (Misra, 2016). Both of these platforms are evaluated and considered for the project below.

Graphical user interface, application

Description automatically generated

Figure 7 - *.NET Framework (Soumyasch, 2007).*

### Windows Forms

Windows Forms was released by Microsoft in 2002 as part of the .NET framework. This greatly influenced how Windows applications are written, explains Griffiths and Adams (2003). Before Windows Forms developers could only use Win32 to make Windows applications, this is lower level and does not have a GUI (Graphical User Interface). By increasing the level of abstraction, a higher-level object-oriented API was created. This makes it much simpler to develop an application, allowing to concentrate on the task rather than the low-level details. In Visual Studio developers can make use of the Windows Form Designer, where they can drag and drop controls into the UI. WinForms is event driven meaning when the user interacts with the interface, for example, clicking a button, an event occurs. The application processes these events with the help of event handlers, which are programmed in C# or other high-level languages (Microsoft Docs., 2017b).

### WPF

WPF (Windows Presentation Foundation) is a Graphical User Interface framework (Misra, 2016). It was released in 2006 with the new .NET 3.0 framework (Xu, 2010). The expectations for user interfaces were increasing, so new technology was needed, according to Nathan (2010). The user interface needed to be separated from the implementation, so that programmers and designers could work on the application without relying on one another. As an answer to this Microsoft released WPF. The user interface design is done in XAML (Extensible Application Markup Language), completely independent of the code. XAML is an XML based markup language designed for WPF (Microsoft Docs., 2016). This way the development is more efficient, and the cost is reduced. It is also easy to understand for designers. It is much more powerful than Windows Forms since it supports documents, multimedia, 2D and 3D graphics and animation (Xu, 2010). Before it would have required several different technologies to make an application containing all these. WPF is built on Direct3D, so it can provide high performance graphics.

### Comparison

The decision about which platform to use depends on the requirements of the application. WPF allows sophisticated UI design, while in WinForms the UI is not as customizable. UI is an important part of the program, so extensive customizability is preferred. WPF supports multimedia and graphics, while WinForms would need a third-party control to do the same. The cross stitch program mainly deals with images, so support for that is essential. WinForms uses less memory than WPF, however, memory is not a primary concern. WPF might have a steeper learning curve, and has less documentation, but it still proves to be the right choice for developing the application (Misra, 2016; Microsoft Docs., 2019).

## User Interface

A user interface allows the user to interact with the program (Galitz, 2007). It is part of the field of Human Computer Interaction. This topic needs to be researched in order to be able to design a good UI for the program. A good UI means one that has a well-functioning input and output mechanism and lets the user accomplish tasks without putting any obstacles in their way (Gunderloy, 2006).

The most widely used type of UI is a Graphical User Interface (GUI). The first successful system using it was released by Apple in 1984. It includes lots of visible clues (buttons, windows, mouse) and real-world analogies (like dragging a file into a trash can meaning deleting it) (MacDonald, 2008).

The main aim for it is to be intuitive and logical. It is also important to be consistent within the application and with other popular software (like Word). The reason for this is that users already learnt the layout and menu organization of them, and it would slow them down by having to learn a completely new UI (Gunderloy, 2006). The UI of the cross stitch program will be similar to widely used drawing programs like Photoshop (see Figure 8) or Paint Tool SAI, since it is also a type of art program.

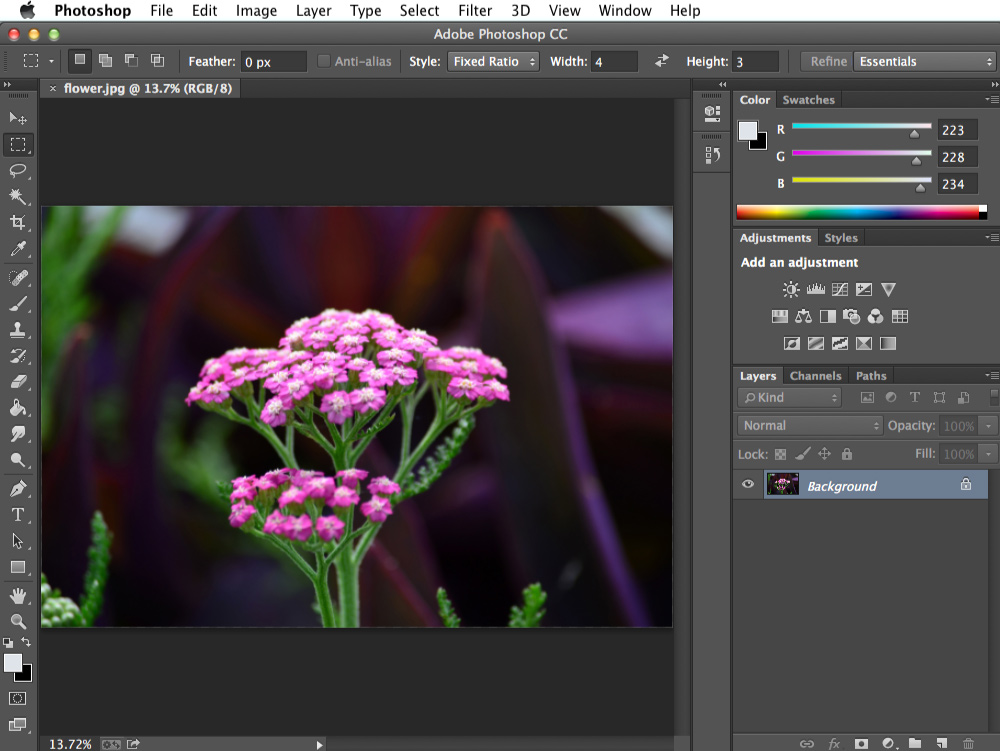


Figure 8 - Photoshop User Interface (GCFGlobal, n.d.)

Another general principle for UI design is to be aesthetically pleasing. This is an important aspect of the project. It can be achieved by using colour and graphics effectively. It also helps to convey messages clearly.

Limiting the ability to make mistakes can greatly improve usability. The UI needs to be forgiving and always have an option to undo an action. Finally, a simple design helps to not confuse new users by not overwhelming them with an overcrowded interface. Limiting the number of things the user has to remember also helps to reduce memory work (Galitz, 2007).

Identifying the user base is also vital for the success of a program (MacDonald, 2008). More influential factors for the project are the users’ familiarity with the computer, frequency of use, gender, and age. The users of a cross stitch software will mostly be discretionary users, so it will only be used if the benefit of using it exceeds the effort learning it, according to Galitz (2007).

Failing to use the principles will make the UI inefficient and people will have difficulty doing their job. They might even stop using the program.

### Colour

Colour can be really powerful. It can convey emotions without saying anything (Barševska & Rakele, 2019). It is not a surprise that it has a great impact on the mood and behaviours of users. It provides structure and meaning to the screen. Research proved that colour in user interfaces improves performance and aids memory (Galitz, 2007). However, some combinations can strain the eye, so it is important to study colour theory to make the right decisions. There are different ways of selecting a good colour scheme. Based on colour theory, there are the following main combinations (see all of them in Figure 9):

* Monochromatic, which uses one colour with different hues.
* Complementary, which combines contrasting colours (red, green). It is difficult to harmoniously combine them in a UI.
* Split complementary, where a primary colour is used with two analogous colours to its complement.
* Triad combines three colours on the colour wheel with equal distance from each other.

Graphical user interface

Description automatically generated

Graphical user interface

Description automatically generated Graphical user interface

Description automatically generated

Graphical user interface, application, website

Description automatically generated

Figure 9 - Colour combinations (Barševska & Rakele, 2019).

It is recommended to start designing the UI in black and white first. This helps focusing on the layout and simplifies the process. When the design is ready, then start adding colours as needed, but only with meaningful purposes. However, no more than five colours should be used. Avoiding pure black is encouraged since it looks unnatural. Keeping in mind the common meaning of colours will help the design. For example, red usually has meanings like stop and danger, so it shouldn’t be used for an OK button (Barševska & Rakele, 2019).

## Existing Cross Stitch Software

This section provides an overview of existing cross stitch pattern making software. Knowing what is currently available will help inform this project. There are a number of cross stitch pattern making software on the market with varied quality and features. The most popular and advanced one is WinStitch/MacStitch (2019). This is a commercial software, and it is regularly updated. Another example is PC Stitch (2016), which was the preferred software until it stopped getting updates. Both can be quite expensive for a hobbyist, so a good alternative can be free, open-source software. These generally have less features and not as clean UI (user interface); however, they can still create a pattern. These include XStitch (Chestnut Pens, 2020) and CStitch (Klein, 2017).

All of the above software can convert a picture into a pattern. WinStitch has a wide range of features and a professional looking UI, so it is a good source of ideas for this project. Some features proving very useful are the ability to select the size of the pattern before generating it, as well as the number of colours used. These types of features are ones that will need to be considered in the design phase of this project. WinStitch uses real thread colours in the pattern, this makes it very practical for the user to buy supplies. See on Figure 10 that the thread colours are as close as possible to the original painting, and how detailed the pattern is. There are also a lot of options to edit the pattern, from changing thread colours to drawing on it. The biggest differences between the free and commercial applications are the number of features and how the user interface looks. WinStitch’s UI is very sleek and intuitive, while CStitch’s is quite antiquated and sometimes hard to use. One of the aims here is to design an attractive UI with all suitable features without having too many options that may overwhelm the user. The intention for this project is to be a good middle ground for users, available at a lower price while still maintaining quality.



Figure 10 *- Painting and cross stitch. Pattern created in WinStitch (Batho, 2014).*

## Summary

After reviewing and analysing past literature about relevant topics, I am more prepared to design and implement the application. A simple resampling algorithm can be used for the basic implementation and fast performance, however, a more advanced one is preferred to preserve detail. WPF enables developers to build a robust application with advanced graphics and highly customized UI. This is ideal based on the requirements of the project, therefore WPF will be used instead of Windows Forms. The UI needs to be simple, so that novice users can interact with it easily, and optimal colour palettes need to be considered for a harmonious look.

# Project Planning

## Introduction

This chapter explores methodologies for project development and discusses possible tools and programming languages. Furthermore, the requirements are explained. And finally, it investigates legal and ethical issues in software development and considers possible problems in this project.

## Methodology

For a successful outcome it is important to decide the methodology used for the project management. There are a few things to take into consideration before deciding. The developer is only one person in this project so there is no team to be able to help; this means that some techniques from well-known methodologies cannot be used that were created for teams. There are limited resources and a limited time frame, so good time management is crucial. Requirements might change along the line, so the approach needs to be flexible enough to allow that.

The waterfall model is a sequential life-cycle where the phases are clearly defined (See Figure 11). The next phase cannot be started if the previous one is not completed. The features are also fixed. It is usually used for bigger projects. The advantage is that all requirements are clear before the start of the development and everything is well documented, however if a problem is discovered after a phase is finished it cannot be easily fixed (Balaji & Murugaiyan ,2012).

Diagram

Description automatically generated

Figure 11 -Waterfall method (Hughey, 2009).

Agile is an iterative development methodology. There is no extensive design upfront and it allows for changes. The pros of Agile is that the client can see what the program is like during development and change it according to their requirements, this ensures their satisfaction at the end of the project. The cons are that it can be more difficult to understand than Waterfall, there can be a lack of documentation, and it can be inefficient for large organizations.

The Agile method’s main characteristic is that it is more flexible than older methodologies like Waterfall (Tordrup Heeager, 2014). This is useful in modern software development, since the features often change and evolve during the project. Based on this aspect it would be a good fit for this project. The high-level requirements have been decided, and the details are explored during development. It is likely that they could change in the future, which Agile can accommodate for. Another important aspect is effective time management, since time is one of the biggest constraints of the project. Timeboxing is an Agile technique that divides the development into iterations. Each iteration is one or two weeks, which fits in perfectly with the schedule of the supervisory meetings. This also allows a step-by-step approach to development, which makes it less overwhelming and divides up the workload to smaller parts. In Agile, testing is done after each iteration to make sure that the new features work together with the product (See Figure 12). This ensures that the software is functional by the time it is finished, unlike in the waterfall method where the testing is done at the end of the life cycle.

Diagram

Description automatically generated

Figure 12 - Iterative Agile methodology (Hazevytch, 2020).

The Kanban method is also useful. A board can be created on Trello.com, which visualises tasks. With the help of this it is easier to see which features need to be implemented and which were already done. It can also motivate the developer to see how much work has already been done. The tasks can be prioritised and put into different categories.

Communication with customer, like supervisor.

## Requirements

Requirements were gathered during the planning phase of the project. These requirements are based on existing cross stitch software, and on what I would want an application to have as a cross stitcher.

The requirements are prioritized using Moscow. This method sorts features into priority order in an easy to understand way (Waters, 2009). The priorities can change at the end of each timebox based on needs. The most important features are listed first.

### Must

* A Windows application that can create a pixelated downsampled image.
* Basic UI for the application.
* A grid over the pattern.
* The ability to save the pattern.

### Should

• The ability to convert an image into different size of patterns.

• A more advanced UI.

• Saving the pattern as a PDF.

• The ability to edit the pattern once it was generated.

• The ability to reduce the number of colours used in the pattern (quantization).

### Could

• The ability to use real thread colours in the pattern.

• The ability to pan and zoom in on the pattern while editing.

### Won’t

• Using different types of stitches, like back stitches and French knots.

• Representation of how the pattern will look once finished (preview).

• Blended thread colours, which gives more colours.

## Potential Solutions and Tools and Techniques

There are several potential ways of creating a program like this, one of them is developing a desktop application. It would reach a greater user base if it could run on several operating systems, however because of time limitations it will be developed for only Windows since this is the most widely used operating system (Shanhong, 2021). Another option is creating a mobile application; however, this would not be sufficient since enough screen space is needed to be able to edit the pattern.

A web application could be considered too. This way the user does not have to download anything. The main obstacle with that is that it would not be possible to do in the time frame due to no experience in that field and the steep learning curve. Another downside is that an internet connection would be also required while using the program.

### Application platforms

There are various platforms to consider, each with their own pros and cons.

The Win32 API is the most performant of all of them. It has direct access to hardware. It uses C or C++, which is the language I have the most familiarity with. It is an unmanaged environment (directly executed by the operating system), unlike .NET. It does not offer an editor, so the UI has to be created in code using Windows functions. It is a great option for applications that need the highest efficiency and low-level control, but this project does not require that. It also has a steeper learning curve than APIs with an inbuilt UI editor (Microsoft Docs., 2020a).

UWP (Universal Windows Platform) is the newest API from the ones considered. It works on all platforms as long as it uses windows 10 or newer. XAML is used for the UI and C# or C++ for the code behind. It is suitable for sophisticated UI and graphics-intensive scenarios (Microsoft Docs., 2020b). A con is that there are not as much documentation available as for WPF or Winforms, since it is relatively new. It would also be important for the application to work on older versions of Windows too, since a lot of the potential users might not have the newest operating system.

WPF and Winforms were discussed in detail in section 2.4. The advantage of both is that they have an inbuilt GUI designer, which speeds up the UI development process, and they support Windows 7 and later versions (Microsoft Docs., 2020a). WPF supports high quality 2D graphics, like images, geometry, and shapes. It also supports the use of pixel shaders (version 3.0), which allows for the implementation of effects. Takes advantage of the GPU and minimizes CPU usage. A useful feature of WPF is data binding; this enables a connection between a UI control and the data it displays. If the data changes, the UI reflects that automatically. Winforms does not have these previous features, so WPF is selected as a platform for development.

### Programming languages

The programming language used in the project could be C#, C++ or Visual Basic.NET based on which application platform is chosen.

C++ is a general-purpose programming language designed by Bjarne Stroustrup (2007). He first developed “C with Classes” as an extension of C, and then using his experiences gained from that project created C++. It is a low-level, strictly typed language. It allows direct access to the memory, which makes it very efficient. It is best suited for performance critical programs. A downside could be that the memory has to be managed manually, unlike in the two other languages. I am most familiar with C++ so being able to use it in the project would be an advantage. WPF supports C++ in theory, however, the UI editor cannot be used. This would undermine the main point of using WPF. UWP and Win32 supports C++.

C# was developed by Microsoft as part of .NET in 2002. It is a strictly typed, object-oriented language, higher level than C++ (Microsoft Docs., 2021). It provides automatic memory management called garbage collection. This ensures there are no memory leaks, and programmer do not have to deal with memory management (Bates, 2004). This also means that memory is harder to access. It can only be accessed inside blocks marked with the unsafe keyword. Memory cannot be explicitly freed, only garbage collection can do it. Once there are no references to an object it is collected. It is similar to C++ but there is still a slight difference, which adds some difficulty to the development. It is supported by WPF and UWP.

Visual Basic.NET is an object-oriented language. It is similar to C# in the sense that they are both higher level managed languages and are built on the .NET framework (Bell, 2002). It also uses automatic garbage collection. It is considered to be easier to learn than C-type languages because it is more similar to normal English. However, because of previous experience in C based languages it would not necessarily be easier for me, and making a change to VB would just slow down development considerably. WPF supports both C# and VB, they are functionally equivalent.

### Other languages/Data languages

#### XAML

XAML is an XML based markup language developed by Microsoft in 2008. It is used in several .NET technologies, like WPF and Silverlight. It is also used in UWP. In all the mentioned technologies it is used for creating the user interface. Everything can be done in code behind that is done in XAML, however the advantages of using it is that it is more concise and readable (Microsoft Docs., 2017c). The separation of the UI and code behind encourages clean architecture. The UI can be modified without changing the application logic. It is easy to learn, even graphic designers can use it. A disadvantage of it is that it cannot contain logic, so all event handlers need to be declared in code. In WPF the XAML can be automatically generated based on the UI editor, and it can be written manually too (Microsoft Docs., 2020b). Case sensitive.

#### HLSL

WPF uses HLSL (High Level Shader Language) for its effects. Custom shaders can be written in HLSL, which makes image processing faster. HLSL is a graphics programming language developed by Microsoft in 2003. It was introduced with DirectX 9 and Shader version 2.0. Before HLSL shaders were developed in a low-level language similar to assembly. Registers had to be managed by the programmer. HLSL was made to simplify and abstract shader development (St-Laurent, 2005). The syntax is similar to C languages but it has its own data types. The advantage of using shaders is that the calculations are done parallelly on the GPU, not using CPU, making the program much faster. Data is sent over from the CPU side and it is rendered using a pipeline. The main parts of the graphics pipeline are vertex shaders, geometry shaders and pixel shaders (Li & Xu, 2009). GLSL (OpenGL Shading Language) could also be used for programming shaders, however WPF does not support it.

### Other tools

#### IDE

Visual Studio is an integrated development environment created by Microsoft. It is a code editor that supports programmers in development. It helps reducing mistakes and increases speed. Its features include IntelliSense code completion, code refactoring, integrated debugger, and syntax highlighting for easier coding (Muşlu et al, 2012). Both native and managed code can be written. It supports several languages including C++, C# and VB. The Community edition is free for everyone and the Enterprise versions is accessible for free for students. The .Net framework was built to work with visual studio, so it provides a comprehensive set of tools for development with .Net. The downside of it is that it takes up a lot of memory on the computer. Visual Studio Code could be another option for an IDE. It supports a lot more languages than Visual Studio, however it does not have key features like the UI editor, which is important for the development.

#### Version control

GitHub is a cloud-based repository hosting service and code sharing platform (Loeliger & McCullough, 2012). It is essential to back up work while developing a project and GitHub helps exactly with that while offering a lot more features too. The code can be managed and tracked using Git based version control. Git was developed by Linus Torvalds. The way it is used is that first a repository is created and then uploaded on the server. This can be accessed from any computer with the log in details. The repository can be public or private. All changes are recorded, and the older versions of the project can be accessed too. If a mistake was made the code can be rolled back to a previous state. Changes can be committed without internet connection. It can be also used for cooperation (Spinellis, 2012). Users can browse its largest collection of open source software (Borges et al, 2016). Feliciano et al (2016) found that using GitHub benefits students in several ways, for example it familiarizes us with a popular industry tool.

GitHub can be used in different ways. A fast way is using it from the command line; however, it can be difficult to remember commands. It can also be linked to Visual Studio, but this proved to be unstable and unreliable at times. The best and easiest way was found to be using the GitHub Desktop application. It is helpful for students because it visualizes the process and features a clean user interface (See Figure 13).

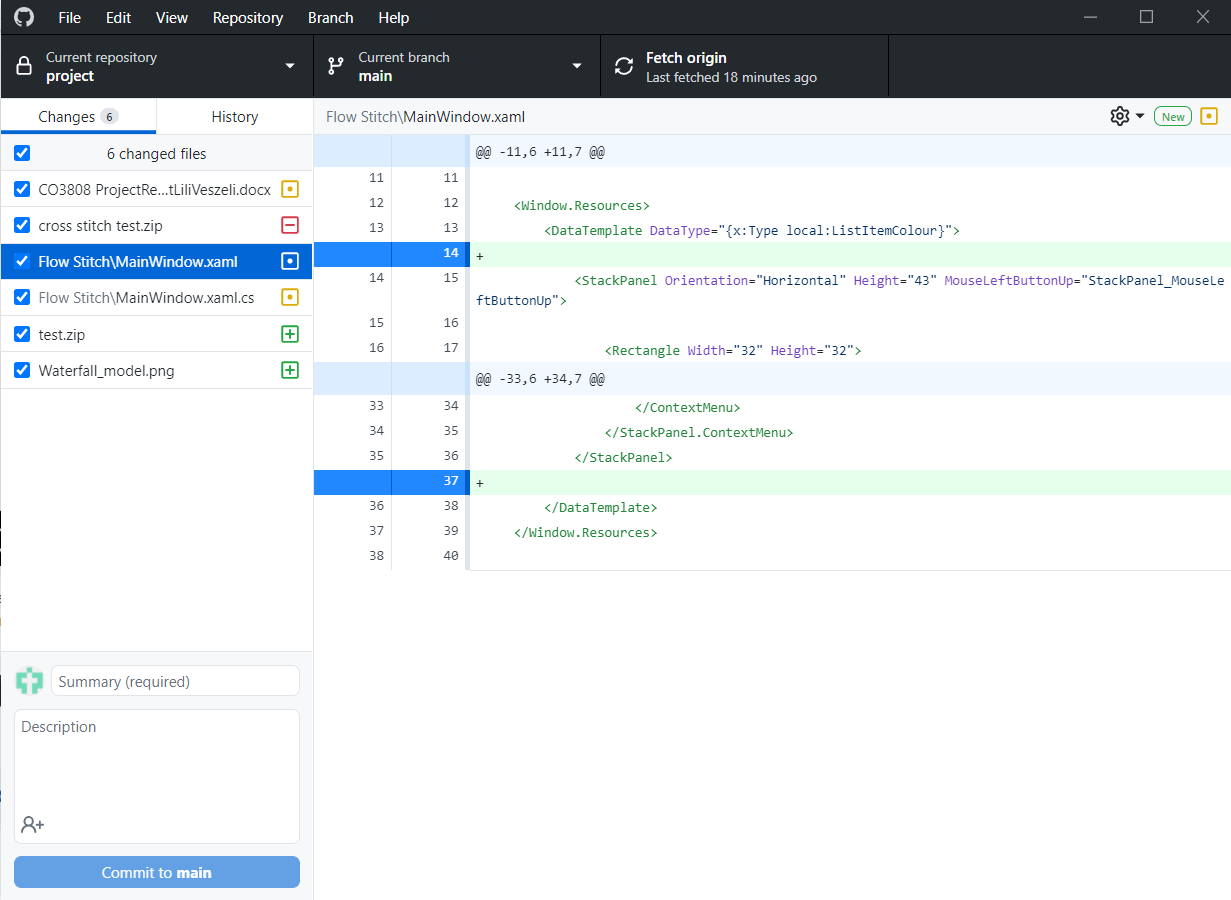


Figure 13 - GitHub Desktop.

## Legal, Social, and Ethical Issues

### Ethical Issues

The role of ethics in software design has increased recently. The issues can be categorized into privacy, accuracy, property, and accessibility (Thomson & Scmoldt, 2001). Improper access to private information causes privacy concerns. This application does not utilize any personal data from the user, so privacy issues do not arise. Accuracy and property issues are also irrelevant.

### Accessibility

Accessibility for people with special needs is an important issue in today’s society (Kavcic, 2005). It is often taken for granted that a user can read information displayed on the screen, can hear sounds and can use the keyboard and mouse. However, not all of the potential users are capable of these. Supporting alternative input devices and allowing keyboard only access can help people with mobility issues, who cannot operate a mouse. Resizable text and good contrast between colours can support people with visibility problems. Flashing elements should be avoided. For hearing considerations, any audio has to be represented visually, like with subtitles. This project does not have any audio components, so it is no applicable.

#### Colour blindness

Some colours in the application and pattern might be hard to distinguish for colour blind people. 1 in 12 man has a colour-vision deficiency. Green and red are usually the most problematic, but other colours containing them can be affected too. A solution would be using a colour blind friendly colour palette (Rigden, 1999). However, these palettes can drastically decrease the number of colours available, especially if real thread colours are used. Another solution is using symbols to illustrate colours during editing, this way all colours can be used.

### Legal Issues

A legal issue could be libraries used that need license for distribution. All libraries used are open source (allowing the code to be freely used, modified, and shared), however they still have licenses. AForge has a GNU General Public License, version 3 (GPLv3). This is the most restrictive open source license: the source must be made public, and the software must be released under the same license. Csv helper uses Apache License 2.0; with this license the source code does not have to be public, the software can use any license, and modifications need to be documented. Other libraries use the MIT license, which is the most permissive one: the source does not have to be public, it can use any license, and changes do not need to be documented. The license needs to be added as a text file to the root directory of the project (Raicea, 2017).

License texts are in Appendix 3 – Software Licenses.

## Summary

In this section, Waterfall and Agile methodologies were considered, proving Agile techniques to be more appropriate. Further on, several APIs were compared resulting in WPF being the most suitable. Additional tools were explored with their advantages and disadvantages. And legal and ethical issues were discussed, highlighting important design considerations for inclusivity.

# Design

## Introduction

This chapter explores a useful design pattern for WPF applications, which helps to make the code cleaner and the testing easier. Furthermore, it outlines the essential use case scenarios for the system design; and discusses the ideas behind the user interface design.

## Software design

Design patterns are a solution to common programming problems (Johnson & Vlissides, 1995). It is like a template that can be applied to different scenarios. An architectural pattern is similar to a design pattern, but it applies to the overall system structure (Avgeriou & Zdun, 2005).

### MVVM Pattern

Model-View-ViewModel (WVVM) is an architectural pattern often used in WPF applications. The pattern was published by John Gossman, an architect of WPF, in 2005 (Sharma, 2019). It is based on Martin Fowler’s Presentation Model pattern. It is similar to the widely used MVC (Model-View-Controller) pattern in the way that both separate the UI from the presentation logic (Microsoft Docs., 2012). One of the advantages of using this pattern is that it prevents tight coupling between the UI controls and the code behind. Tight coupling can cause difficulties when trying to update the user interface. The whole UI can be redesigned without any changes in the code if using MVVM. It is also easier to test the program using unit testing. Furthermore, it enables data binding, which is a powerful feature for displaying data in WPF. The code is also cleaner and easier to understand for future developers. A disadvantage of the pattern is that debugging is difficult when using data binding. Additionally, using the pattern for a simple UI can be excessive, and for a complex UI it could prove difficult to design.

There are three key components in the pattern: model, view, and view model. Figure 14 shows the relationship between them.

Graphical user interface, application

Description automatically generated

Figure 14 - Model-View-ViewModel components.

The view represents what can be seen on the screen, the user interface in this case. It is defined only with XAML in WPF. It should not contain any business logic, but it can handle some basic user interaction. The view model is connected to it by databinding.

The model is the data of the application. It could be phone numbers, addresses, etc. The business logic is separate from the model.

The view model is an intermediary between the two. The user can modify the with the help of the view model. It retrieves the data from the model and sends it to the view in an easily usable form. It also implements commands that the user can invoke from the view. In order for this two-way databinding to work, the INotifyPropertyChanged interface has to be implemented. This raises the PropertyChanged event, which updates the data in the view (Microsoft Docs., 2012).

In this project the model is the list of thread colours. The view is the palette displayed in the UI. The two are connected with data binding. The model view does the updates with the help of the INotifyPropertyChanged interface.

## System Design

To be able to implement the application it is essential to know the different actions and use cases that the user would want to do.

### Pattern Creation

* First, the user will be able to open a new picture. The height of the pattern and the maximum number of thread colours will have to be input. Then the picture will be chosen using the Windows file dialog.
* Then the chosen image will be downsampled and quantized.
* The quantized colours will be converted to the closest real thread colours. These colours will be displayed in a palette next to the pattern.
* The pattern will be able to be saved as a high resolution image.
* The pattern will be able to be saved with symbols that represent the different colours.

### Pattern Editing

* The user will be able to edit the output pattern by clicking on individual stitches. The stitches will change their colour to the current drawing colour if clicked (initially black).
* The user will also be able to erase stitches by clicking on the eraser button and then clicking on one of the stitches. This will make them white.
* A new drawing colour will be able to be chosen when clicking on the colour wheel or the pencil button. If the colour wheel is clicked, then an RGB colour picker window will open up and the desired colour will be able to be selected. This will be then converted to a thread colour. If the pencil button is clicked, then a list of the thread colours will open in a new window and one can be chosen.
* The colours in the palette will be able to be selected too to draw with by clicking on them.
* The palette colours will be able to be changed by right clicking them and selecting the corresponding option from the context menu. The new colour will be selected with the colour picker, converted to DMC colour, and all the stitches will be changed to it.
* Colours will be able to be deleted from the palette too with the context menu. This will delete it from the palette list and requantizes the pattern using the reduced number of colours.
* The pattern will be able to be previewed. This will show how a finished cross stitch would look like based on the pattern.

### User Interface

* The undo/redo functionality will be available. This will restore the previous state of the pattern. It will be able to be accessed from the top menu or by pressing the Ctrl+Z and Ctrl+Y key combinations.
* The user will be able to pan and zoom while editing the pattern. This is especially important for bigger patterns.
* Information about the application will be able to be found by pressing the About button in the top menu.

## User Interface Design

The aim of designing the user interface for the program is to make it as clean and intuitive as possible. It is also important to be aesthetically pleasing. The design is based on other popular creative applications and existing cross stitch programs. The familiarity with these existing programs gives an idea to the user how to use this program too. The first storyboard was largely based on Paint Tool SAI’s user interface (See Figure 15), and the idea for the way to display the thread colours was from WinStitch (See Figure 16). The storyboard and the final UI design can be seen on Figure 17 and Figure 18.

Graphical user interface, application, Word

Description automatically generated

Figure 15 - Paint Tool Sai UI.

A picture containing text, tape, electronics, display

Description automatically generated

Figure 16 - WinStitch UI.

A drawing on a white board

Description automatically generated with low confidence

Figure 17 - Initial Flow Stitch storyboard.

Graphical user interface

Description automatically generated

Figure 18 - Flow Stitch final UI.

Flow Stitch’s user interface is much less busy than the programs it was inspired by; this is because it has less features. However, this also makes it easier to navigate for new users while still being a functional pattern maker. The menu bar is quite standard, it works the same as Word or other drawing programs: a new picture can be opened and saved, and the application can be exited. Under the Edit item the buttons for undo/redo functionality can be found. This allows for the user to make mistakes and restore the pattern. It can be also used with key commands. Finally, under the About part in the menu, some information can be found about the program. Then there is a side panel containing all the editing tools and data about the pattern. The palette resembles the one used in WinStitch, however, it is a bit bigger for better visibility. The organization of the drawing tools are similar to how it is done in SAI. The main drawing area has the pattern in its pixelized and quantized form. This can be zoomed in and panned.

According to the original storyboard, a colour wheel would have been in the side panel too. This had to be taken out of the main UI since WPF did not have a control for it, and no libraries offered that functionality. Instead, the colour picker opens in a new window, which was achieved by the WpfColorPicker library made by Dsafa on GitHub (dsafa.WpfColorPicker, n.d.).

Some changes were made during development based on my supervisor’s recommendations. For example, the pattern was centred instead of being on the right, and the palette was made wider to allow for the full colour name to be read. Features were also added, like the properties plane to provide more information about the pattern, and a splash screen that shows as the program starts up.

## Summary

The advantages and disadvantages of the MVVM pattern were discussed and how it can apply to the project. It is useful for the colour palette; however, it won’t be implemented for the full application because the rest of the interface is quite simple. In system design important features and use cases were outlined in detail, which will help the implementation go smoother. The decisions behind the user interface design were reviewed; and the changes along the development were demonstrated.

# Implementation

## Introduction

This chapter discusses the various processes involved in creating the application. The different steps are introduced that are required to make the pattern. WPF is used as the application platform combined with several libraries. The input image goes through phases of downsampling, colour quantization and colour conversion to create the editable pattern. Additional features are also explained: the use of symbols, and preview generation in two ways, one of which involves shaders.

## Pattern Creation

### Downsampling

To achieve a pixelated look the image needs to be downsampled. Different methods for downsampling were discussed in section 2.3. A method that preserves the most details is best to use in this case. The more adjacent pixels it takes into consideration the more accurate it is. Bicubic downsampling preserves more detail than bilinear or nearest neighbour method, so it is used in the application. It considers the closest 4 by 4 area. Other more complex algorithms could be used too, like the Lanczos algorithm, however that would also increase processing time, making it impractical for the software (Parsania & Virparia, 2016). Figure 19 demonstrates the width and weight of the filters.

Diagram, engineering drawing

Description automatically generated

Figure 19 Graphs of the downsampling methods.

The GDI+ is a graphics device interface, it enables windows applications to use graphics. It allows for the interpolation mode to be set, which influences how images are scaled. It includes nearest neighbour, bilinear and bicubic interpolation. Additionally, it also offers a high quality bicubic filtering, which produces the highest quality shrunk image in the library (Microsoft Docs., 2018).

The desired height for the pattern can be input when opening an image. This decides the percentage the image has to be downscaled by. A function is used to calculate the new dimensions of the image and then it is downsampled to that size.

The downsampling produced an unwanted artefact on the final image. A long black line could be seen on the left side and on top of the image. After researching, the issue could be easily solved. What happened was the algorithm tried to sample pixels from outside the image, which resulted in the black edges. The image needed to be wrapped, so it would not sample non-existent pixels.

### Colour Quantization

When the downsampling is done, the number of colours in the pattern needs to be reduced. This is necessary because there is only a limited number of thread colours. Furthermore, there is a practical reason too: to reduce cost for the cross stitcher; it is impractical having to buy 100 different threads for a smaller pattern, when it could be done with only 20 colours. This step is called colour quantization. It calculates the statistical distribution of colours in an image, and the most frequent colours a kept. It is difficult to get a good perceived image quality. There are some common errors/artefacts like loss of colour variety and contrast. The result colours are mapped onto the original image (Verevka, 1995). Some examples are shown in Figure 20.

A picture containing grass, outdoor, mammal, standing

Description automatically generated A picture containing sunset, outdoor, mountain, nature

Description automatically generated

A picture containing grass, outdoor, mammal, dry

Description automatically generated A picture containing nature, sunset, night sky

Description automatically generated

A picture containing outdoor, snow

Description automatically generated A picture containing sunset, orange, background

Description automatically generated

Figure 20 – Original vs. downsampled only vs. downsampled and quantized images (maximum 20 colours).

An attempt was made to write my own colour quantization function, however, several mature existing libraries were discovered after research, so a decision was made to use a library. The most widely recommended one was nQuant (nQuant, n.d.), however it did not have the functionality to quantize images to a specific number of colours. This is an essential feature, since the user inputs the maximum number of colours in the pattern, which cannot be surpassed. Fortunately, another library, AForge (AForge.NET, n.d.), was found that possessed this feature. An issue with it was that sometimes it returns less colours than the input value, especially if it is a bigger number. However, it is not always possible to get that exact number of colours, it largely depends on the source image. Another issue was that it made some pictures less saturated. To get more control over the quantization process, it could be implemented manually; however, this would require a longer time frame and extensive research.

The resulted colours from the quantization are put in an array; they will be converted into real life thread colours in the next step.

### DMC Thread Colours

Dollfus-Mieg et Compagnie is a French textile company created in 1746 (DMC, n.d.). They make one of the most widely used embroidery threads in the world. It has the largest colour range (482) compared to other threads like Anchor; and it is made from Egyptian cotton (Bare, 2018).

These thread colours are used in the program. The RGB value, name, and number for each thread is stored in a csv file. These are read into a list at the start of the program using the CsvHelper library (CsvHelper, n.d.). A DMC class was created specifically for these colours (See Listing 1). The list is storing this DMC type.

//class to store DMC thread colour properties

public class DMC

{

public string Floss { get; set; } //identifying number of colour

public string Description { get; set; } //name of colour

//RGB values of colour

public int Red { get; set; }

public int Green { get; set; }

public int Blue { get; set; }

}

Listing 1 – [DMCColours.cs] DMC class.

The final quantized colours of the image are converted into real life DMC thread colours. The colours are first converted to Lab colour space, since that is a better representation of how humans perceive colour, so there is a better chance to get a good thread colour match. The Lab colour space is represented in three dimensions, as illustrated on Figure 21. There is one dimension for lightness (*L*, where *L*=0 is white and L=100 is black), one for indicating the value between red and green (*a*, where the lower *a* is the greener the colour), and finally one that shows thee value between yellow and blue (*b*, where the lower the value the bluer the colour). It includes all perceivable colours by the human eye, which means that it exceeds the RGB colour space (See Figure 22) (Rathorel et al, 2012). It is derived from CIEXYZ, which was an earlier colour space model.

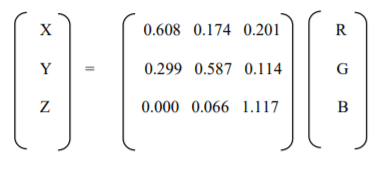
Diagram

Description automatically generatedChart, radar chart

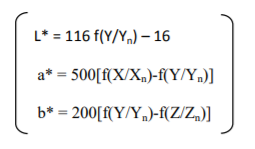
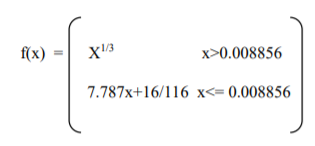
Description automatically generated

Figure 21 – Modell of the Lab colour space. Figure 22 - Colour coverage of Lab.

To do this conversion, first the RGB values have to be converted to CIEXYZ values the following way:

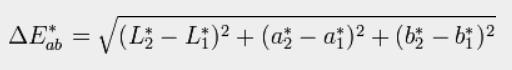


Then they are converted to Lab:



where

The Color Mine library (ColorMine, n.d.) was used to convert the RGB colours to Lab colours. Another method for it would have been writing the conversion myself, which would not have been too complicated, however, Color Mine also has an inbuilt colour comparison function. This function comes useful for the next step. To get the closest DMC colour to the new Lab colour palette the distance between the palette colours and all DMC colours are calculated. The smaller the distance, the closest the colour match is. If simply the Euclidean distance would be calculated between RGB values, then the results would not be the expected colour matches. RGB is convenient to use with electric systems but it does not show colours how humans perceive it. To get a more accurate result, the distance between two Lab colours needs to be calculated, which is called delta E (ColorMine.org, n.d.). It is done in the following way:



The DMC colour with the smallest delta E distance from the palette colour will be assigned to the pattern. The palette list is generated in the left UI panel. The image is requantized with the new DMC palette (See Figure 23). Some RGB colours don’t have a close respective DMC colour because of the limited number of thread colours, especially blue and purple hues.

A picture containing sunset, orange, background

Description automatically generated A picture containing sunset

Description automatically generated

Figure 23 - Quantized image vs. quantized image converted to DMC colours (maximum 20 colours).

Even after using the Lab colour space, there still seemed to be an inaccuracy with the colour matching, specifically with blue colours. The blue part of the colours needed to be more prominent to be recognized. This inaccuracy happened most likely because of the limited number of available blue coloured threads. The thread colours are human made colour, so it is reasonable to use heuristic to get a closer match. The blue value had to be tweaked using the heuristic in Listing 2.

//getting a closer blue colour because of lack of bright blue threads

var b = myPalette.Colors[i].B;

if (myPalette.Colors[i].B > 180 && myPalette.Colors[i].G < 100 && myPalette.Colors[i].R < 100)

{

b = (byte)(160 + (20 \* (b - 160)) / (256 - 160));

}

Listing 2 - Heuristic used for more accurate colour matching.

## Pattern Editing

The pattern can be edited by drawing on it, and by changing or deleting a thread colour.

Each pixel in the pattern represents a stitch. When a stitch is clicked it changes to the current drawing colour. To make this happen, the screen position of the mouse is converted to its position on the pattern. The coordinates of the mouse are passed to code behind when the click event happens. Using those coordinates the stitch is located and the colour is changed. If it is a new colour it is added to the palette. If the eraser item was used when the click happened, it changes the colour to white and removes a thread colour from the palette if necessary.

The palette in the UI is bound to the list storing the thread colours in the pattern. Data binding is a powerful feature of WPF, which makes flexible representation of data possible. It is the process of establishing a connection between the data and UI. This makes any changes in the data reflect automatically on the UI, and the other way around.

The palette colours are a collection of data, so it needs to be stored in a special type of list called ObservableCollection. This makes it possible for INotifyPropertyChanged to update the values (Microsoft Docs., 2021).

The palette can also be edited, colours can be deleted and changed. When changing a colour, all the pixels with the same colour in the pattern are changed too. If a colour is deleted, the pattern is requantized with the remaining palette.

## Pattern Symbols

Traditionally, small symbols are added on top of the coloured rectangles in a cross stitch pattern to make the colours easier to differentiate. Each colour has different symbol. This was an important feature to add to make the pattern usable.

First, it was difficult to decide the approach. One way would have been to upscale the pattern and put the symbols in the same image, another way is to put the symbols on top of the pattern without upscaling it.

After finding ImageDrawings, the decision was made to place the symbols on top of the pattern. With the help of ImageDrawings several images can be put on top of each other. First, an ImageGroup is created, and children can be added to it. Then a new ImageDrawing is created with the ImageGroup as its source. Finally, the new ImageDrawing is set as the source of the image control displaying the pattern (Microsoft Docs., 2017a). The symbols need to be put on top of each stitch. The correct positions were calculated based on the width and height of the image and the number of stitches in the pattern. The pattern can be saved with the symbols: it is rendered to a bitmap and upscaled based on the size of the pattern. An example of the pattern with symbols can be seen on Figure 24.

A picture containing window, tiled

Description automatically generated

Figure 24 - Pattern with symbols.

## Preview

A preview of the pattern helps to visualise how the finished cross stitch would look based on the current pattern. Instead of rectangles, small x-shaped images are drawn in the according colours on aida canvas. An example can be seen on Figure 25.

Background pattern

Description automatically generated with medium confidence

Figure 25 – Preview of pattern.

The preview generation was done in two different ways: colour blending in C# and in pixel shader.

### Multiplicative Colour Blending

Colour blending is used when it needs to be determined how two layers are blended with each other. Pixel blending combines the RGB colours of the source image and the given colour. There are different types of blending, which all use different equations. For making the preview, multiplicative blending is used. This is a darkening effect, so if a source pixel is blended with white, then it stays the same, however, it gets darker when blended with darker colours. This blending mode is used because the source image is a white cross stitch, so the colours can only make it darker. It works similar to painting/dying fabrics in real life. The blending equation used is as follows:

int red = SourceColor.R \* stitchColor.R / 255;

int blue = SourceColor.B \* stitchColor.B / 255;

int green = SourceColor.G \* stitchColor.G / 255;

Listing 3 - Multiplicative blending equation.

First, this blending equation was used with bitmap’s GetPixel and SetPixel methods. The pattern was looped through, getting each stitch’s colour, and blending the cross stitch with it. These methods are slow, and this seriously impacted performance.

A faster way was needed to access the pixels. The above described process can be done using pointers, which speeds up the image processing significantly. The memory location of the pixels is directly accessed. A class is used to make the syntax simpler resulting in a very similar equation to the first method. However, the speed could still be increased, especially for larger images, that is where shaders can be useful.

### Shaders in WPF

WPF can apply inbuilt effects to a control, like blur or drop shadow. Custom shaders can also be written in HLSL. The advantage of using shaders in the program is that it makes the image processing significantly faster because the calculations are done on the GPU side parallelly. WPF only supports Shader model 3.0 pixel shaders, which means that some registers are limited (only 16 sampler registers, which WPF restricts further to 8) (Microsoft Docs., n.d. b). The final colour of a pixel is decided in the pixel shader.

Multiplicative blending can be also done in a pixel shader. It is done by multiplying the original pixel colours by the passed colour. In this project, the original pixels come from the base white cross stitch image and it is multiplied by the colour of the stitches in the pattern. A custom shader effect has to be made to do this operation. The process described is based on Ritscher’s (2012) book. First, an unmanaged pixel shader was created. It needs to be in an .fx file, which has to be compiled into a .ps file, which is used in the program. There are several ways to make a precompiled shader, it was done with DirectX SDK command prompt in this case. The shader itself is quite simple for this program, see Listing 4, however, setting up the communication between the GPU and the CPU/program was more complex.

//texture passed

sampler2D implicitInputSampler : register(S0);

//constant passed

float4 colorFilter : register(C0);

float4 main(float2 uv : TEXCOORD) : COLOR

{

//sampling input texture

float4 color = tex2D(implicitInputSampler, uv);

//multiplicative bleneding with input colour

//return that colour

return color \* colorFilter;

}

Listing 4 - Colour tint pixel shader.

The shader needs a wrapper class. The ShaderEffects base class wraps the HLSL shader and makes it possible to apply it to XAML elements by communicating with the GPU. A managed PixelShader class needs to be initialized, and it is associated with the .ps file. The ShaderEffects class injects the shader into the WPF graphics pipeline.

The pixels also need to be passed from the image to the shader. They can be passed by a sampler using a GPU register. Input image data is usually stored in the S registers (Viswan, n.d.). In the example code, it is stored in the first S register slot, denoted by ‘S0’. It is important to know where the passed data is stored because it needs to be represented correctly on the WPF side too. Dependency properties are created for this purpose in the ShaderEffects class, and they must be associated with the correct register input.

The current stitch colour needs to be passed too. It is passed as an input parameter with the constant registers (denoted with C). These values can be changed during initialization, but not during the execution of the shader. A dependency property is also used for the stitch colour on the WPF side. The new colour can be set in code each time before executing the shader.

An instance of the custom effect is created if used in code behind. Finally, the white cross stitch is converted into a control and the effect is applied to it.

The preview contains several small images, each blended separately with the specific colour. The coloured stitches are added to an ImageGroup, the same way it was done with the symbols. However, the image needs to be rendered so that the shader effect shows up when adding it to the group.

A difficulty in creating the custom shader was that there are limited resources on setting up the shader in code behind rather than in XAML. However, this was needed because the images are created dynamically.

## Undo/Redo Functionality

The undo/redo functionality stores the different states of the pattern. This makes it possible for the user to go back to previous versions of the pattern. This feature can be implemented in different ways. The two main methods considered were storing the bitmap containing the different versions of the pattern in a list, and remembering the actions taken to get to the state and reverse them. These two are similar to the memento pattern and command pattern respectively. The first option is simple to implement, however it can take up a large amount of memory. The second option is very efficient, but some actions could be difficult to invert, it is also more involved to program it (Kyriakides, 2019).

The program uses the first option because the patterns stored are small in size, so it doesn’t cause a problem with taking up too much memory, especially if there is a maximum undo limit. Furthermore, when a colour is changed the only way to invert the action is to remember the previous colour. This makes the command pattern less suitable.

A bitmap of the pattern is stored every time a change is made. An index keeps track of which state the pattern is in the list. Redoable states are removed if a new action is done after an undo command. The undo/redo functionality can be invoked by buttons and also by keyboard shortcuts.

## Summary

The important and more challenging features were discussed. This project involved a wide range of different technologies, and it successfully managed to make it work together.

# Testing

## Introduction

This chapter introduces various testing methodologies, and evaluates the use of both manual and automated testing approaches for the project. It also demonstrates how the application was tested.

## The Importance of Testing / General

Nowadays many different fields depend on software. The expectations are much higher since the quality of the software can be critical in many real life scenarios and the financial stakes can be high if it fails according to Mili & Tchier (2015). Software testing can assure software quality. The aim of testing is to make sure that the program does what it is intended to do. Testing also increases user confidence, ensures customer satisfaction, and lowers maintenance cost. There are different strategies to testing, each one tests different aspects of the program explains Singh & Singh (2012). They can be divided into functional (unit, integration, acceptance), and non-functional (security, performance, usability) tests. The way testing works generally is, the software is executed with desired inputs, and the outputs are compared with the expected ones. If the two do not match, then there is a bug. A good test case is one that has a high probability of finding errors (Singh & Singh, 2012).

## Unit Testing

Unit testing tests the individual parts of the software, stated by Singh (2011), it is done at the lowest level. It is usually performed by the developers. Testing boundaries is often done in unit testing because it has a higher probability of detecting faults. It can also be automated, which speeds up the process and can cover more code areas; a good tool for that is NUnit. However, it has limitations: it is impossible to evaluate every execution path, and there is a limit to how many test scenarios can be made. Furthermore, parts of the software working independently of each other does not mean that the whole product is functional. Integration testing is needed too, which is testing that separately developed modules work together as expected, like two or more units (Singh, 2011).

## Automation Testing

Automation testing can generate the test data automatically for the software. It is more efficient, cost-effective, and reliable if done correctly, however, it is not a straightforward process as written by Singh (2011). Test data can be generated by static evaluation (like syntax and semantic analysis tools) or dynamically by executing the program (for example, performance testing or functional testing). Any functional testing can be automated. A test automation pyramid is often used in agile projects (See Figure 26).

Diagram

Description automatically generated

Figure 26 - Ideal test automation pyramid (Palamarchuk, 2015).

The testing could go on forever, so criteria need to be set for when it is considered adequate. This can be different based on the program, but an example is “Every path of the code should be executed at least once” (Singh, 2011). This sets the standard to measure the thoroughness of testing.

The advantages of automation testing are that it is faster than manual testing, has a wider coverage of the code, it is reliable, consistent, more accurate, and saves time and cost. The disadvantages are that it can be expensive and manual testing is still needed sometimes because it might miss insights that a human could draw (Singh, 2011). Furthermore, automated tests cannot evolve and cannot notice new problems that the developer did not program them to do according to Bach (Eesti Infotehnoloogia Kolledž, 2011).

Automation testing could be used on the project, especially automated unit testing. The application might need to be refactored to fit the tools better. Automation testing is more suited to large projects and where the tests need to be repeated a lot. This is a relatively small program so fully automating the testing most likely would not be worth it because of time constraints and the expense of some tools. It is possible to test it thoroughly manually.

## Testing Scripts

The following test script (see Table 1) introduces the bugs found and fixed during exploratory testing throughout the development process. The rumble strip heuristic by James Bach (Eesti Infotehnoloogia Kolledž, 2011) was used, which means that strange behaviours of the program are investigated in case they lead to a bigger problem.

Table 1 - Test Results.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Test input / action** | **Expected outcome** | **Actual outcome** | **Steps taken to resolve it.** | **Current state** |
| Testing the input validation in the new image window. | | | | |
| Input 10000 for height. | Pattern is displayed. | Out of memory exception. | Set a realistic upper boundary for the height. (5000) | Checkmark with solid fill |
| Input 1 for height. | Pattern with 1 pixel is displayed. | Pattern with 1 pixel is displayed. | - | Checkmark with solid fill |
| Input -1 for height | Message saying to input a height bigger than 0. | Program crashed. | Needed to add an extra check for height. Displays the message now. | Checkmark with solid fill |
| Input 0 for height. | Message saying to input a height bigger than 0. | Message saying to input a height bigger than 0. | - | Checkmark with solid fill |  |  |  |  |
| Input 5000 for height. | Message saying to input a height smaller than 5000. | Nothing happens. No message | When displaying the error message, the check needed to be changed to >= from >. The message is displayed now. | Checkmark with solid fill |
| Input “dog” for height. | Message saying to input an integer value bigger than 0 for height. | Message saying to input an integer value bigger than 0 for height. | - | Checkmark with solid fill |
| Input 1 for max number of colours. | Pattern displayed containing only one colour. | AForge library throws error. | It turns out that the smallest number of colours the quantization library accepts is 2 (and the largest is 256). Needed to put extra checks in place. | Checkmark with solid fill |
| Input 0 for max number of colours. | Message saying to input a number between 2 and 256 for number of colours. | Message saying to input a number between 2 and 256 for number of colours. | - | Checkmark with solid fill |
| Input “dog” for max number of colours. | Message saying to input a number between 2 and 256 for number of colours. | Message saying to input a number between 2 and 256 for number of colours. | - | Checkmark with solid fill |
| Input -1 for max number of colours. | Message saying to input a number between 2 and 256 for number of colours. | Message saying to input a number between 2 and 256 for number of colours. | - | Checkmark with solid fill |
| No input for either fields. | Message saying to input a value. | Message saying to input a value. | - | Checkmark with solid fill |
| Clicking Cancel after inputting valid values. | Nothing happens. | Open file dialog appears. | Made the new window return a boolean to the main window. If OK is clicked it returns true and displays the file dialog. If false, it does nothing. | Checkmark with solid fill |
| Loading an image with the open file dialog. | Can only open image files, like .png or .jpg | Can only open image files, like .png or .jpg | - | Checkmark with solid fill |
| Testing the pattern and palette creation process. | | | | |
| Opening an image. | Displayed pattern height is the same as the input height. | Displayed pattern height is the same as the input height. | - | Checkmark with solid fill |
| Opening an image. | Displayed pattern’s number of colours does not exceed the max number of colours. | Displayed pattern’s number of colours does not exceed the max number of colours. | - | Checkmark with solid fill |
| Opening an image. | The proportion of the image stays the same after downsampling. | The proportion of the image stays the same after downsampling. | - | Checkmark with solid fill |
| Opening an image. | The palette has no duplicate colours. | The palette has duplicate colours. | This happened because of the quantization library. Duplicate colours had to be deleted from the list before making the palette. | Checkmark with solid fill |
| Opening an image. | Displayed pattern colours and palette colours match. | Displayed pattern colours and palette colours do not match. | Had to redo the palette after requantizing the image with the DMC colours. | Checkmark with solid fill |
| Testing the palette editing features. | | | | |
| Changing the colour of a thread in the palette. | Changes all stitches from the old colour to the new colour. | Changes all stitches from the old colour to the new colour. | - | Checkmark with solid fill |
| Changing a colour in the palette to another colour that already exists in the palette. | One of the instances are removed from the palette, leaving no duplicates. | One of the instances are removed from the palette, leaving no duplicates. | - | Checkmark with solid fill |
| Deleting a colour from the palette. | The pattern is requantized with the remaining colours. | The pattern is requantized with the remaining colours. | - | Checkmark with solid fill |
| Trying to delete the last colour from the palette. | Message saying that you cannot delete all colours. | Message saying that you cannot delete all colours. | - | Checkmark with solid fill |
| Testing image editing features. | | | | |
| Left click on the pattern. | The stich/pixel clicked changes colour to the current colour. | The stich/pixel clicked changes colour to the current colour. | - | Checkmark with solid fill |
| Left click on the pattern using a new colour. | The stich/pixel clicked changes to the new colour, and it is added to the palette. | The stich/pixel clicked changes to the new colour, and it is added to the palette. | - | Checkmark with solid fill |
| Left click on the pattern using the eraser. | The stich/pixel clicked changes to white and it is not added to the palette. | The stich/pixel clicked changes to white and it is not added to the palette. | - | Checkmark with solid fill |
| Left click on the pattern using the eraser, fully erasing a colour. | The stich/pixel clicked changes to white and the erased colour is removed from the palette. | The stich/pixel clicked changes to white and the erased colour is removed from the palette. | - | Checkmark with solid fill |
| Left click on one of the colours in the palette. | The current colour changes to that colour. | The current colour changes to that colour. | - | Checkmark with solid fill |
| Left click on the pencil button. | A list of DMC colours opens. | A list of DMC colours opens. | - | Checkmark with solid fill |
| Click on one of the DMC colours in that list. | The current colour changes to it, and it is added to the palette if it was used on the pattern. | The current colour changes to it, and it is added to the palette if it was used on the pattern. | - | Checkmark with solid fill |
| Left click on the colour wheel. | The colour picker opens. | The colour picker opens. | - | Checkmark with solid fill |
| A colour is chosen from the colour picker. | The current colour changes to that but converted to the closest DMC colour. (and it is added to the palette if it was used on the pattern.) | The current colour changes to that but converted to the closest DMC colour. (and it is added to the palette if it was used on the pattern.) | - | Checkmark with solid fill |
| The number of colours in the palette changes. | The number or colours is updated in the properties. | The number or colours is updated in the properties. | - | Checkmark with solid fill |
| Testing pattern options | | | | |
| Left clicking the generate symbols button. | Another window opens with the pattern with symbols. | Another window opens with the pattern with symbols. | - | Checkmark with solid fill |
| Clicking the save button in the symbols window. | The save file dialog opens and the pattern can be saved with the symbols in a high resolution. | The save file dialog opens and the pattern can be saved with the symbols in a high resolution. | - | Checkmark with solid fill |
| Left clicking on the preview button. | Another window opens with the preview of the pattern. (takes longer for bigger patterns) | Another window opens with the preview of the pattern. (takes longer for bigger patterns) | - | Checkmark with solid fill |
| Clicking the save button in the preview window. | The save file dialog opens and the preview can be saved. | The save file dialog opens and the preview can be saved. | - | Checkmark with solid fill |
| Preview or symbol button clicked, and the pattern has erased stitches. | At the position of the erased stitches there are not any symbols or crosses. | At the position of the erased stitches there are not any symbols or crosses. | - | Checkmark with solid fill |
| Testing undo/redo feature | | | | |
| Undo/redo button is clicked when no image is loaded. | Nothing happens. | Nothing happens. | - | Checkmark with solid fill |
| Undo/redo button is clicked when image is loaded but there are no actions to undo/redo. | Nothing happens. | Nothing happens. | - | Checkmark with solid fill |
| Undo button is clicked when image is loaded and there are actions to undo. | An action is undone. | An action is undone. | - | Checkmark with solid fill |
| Redo button is clicked when image is loaded and there are actions to redo. | An action is redone. | An action is redone. | - | Checkmark with solid fill |
| An action is undone, another action is done, redo button clicked. | Nothing happens because redo history is deleted. Logically would not make sense to allow to redo when another action was already done. | Nothing happens because redo history is deleted. Logically would not make sense to allow to redo when another action was already done. | - | Checkmark with solid fill |
| A colour is added to the palette, undo clicked. | Colour is deleted from the palette and pattern. | Colour is deleted from the palette and pattern. | - | Checkmark with solid fill |
| The same scenario as above, and then redo is clicked. | The colour is added back to the palette and pattern. | The colour is added back to the palette and pattern. | - | Checkmark with solid fill |
| All the previous cases but using Ctrl+Z and Ctrl+Y instead of undo and redo buttons. | The same results. | The same results. | - | Checkmark with solid fill |
| Testing miscellaneous features | | | | |
| Clicking Exit | The program closes. | The program closes. | - | Checkmark with solid fill |
| Clicking About Flow Stitch. | A window opens showing the Flow stitch logo and some information. | A window opens showing the Flow stitch logo and some information. | - | Checkmark with solid fill |
| Scrolling mouse wheel on the pattern. | Pattern is zoomed in and out. | Pattern is zoomed in and out. But the zooming is not always towards the mouse position. | - | Paragraph Squiggle outline |
| Right clicking on the pattern. | Pattern can be panned. | Pattern can be panned. | - | Checkmark with solid fill |

## User Testing

This testing method involves real users interacting with the application. They are asked to do typical tasks or explore it freely. Their interaction with program is observed. The test aims to find out how easy and intuitive it is to use the application. The evaluations were done remotely due to the Covid situation. The test was done synchronously, which means that the facilitator and evaluator communicate in real time (Bastien, 2010). The feedback of the testers was that it was easy to use the application, but some features could have more explanation. The main difficulty in my opinion was that neither of them had any experience in cross stitching, so that contributed to the smaller obstacle in understanding. Some recommendations for improving the user interface were to highlight the tool that is currently used, to add tool tips for the drawing tools, and change some error messages to warnings. They also had some great ideas for additions to the software, for example, the option to highlight certain colours in the pattern, and to display RGB values of the thread colours. These features could be added in the future.

Some bugs were also discovered and were fixed, see Table 2.

Table 2 - User testing results.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Action** | **Expected outcome** | **Actual outcome** | **Steps taken to resolve it.** | **Current state** |
| Clicking the tool buttons before opening an image. | Nothing. | The program crashed (the bitmap was empty). | It is checked if an image is loaded before the action is done by the tool. If there is no image nothing happens. | Checkmark with solid fill |
| Loading a medium sized pattern with symbols. | Pattern displayed with symbols. | Out of memory exception. | A certain sized pattern with symbols was rendered too big, so the dimensions needed to be reduced. | Checkmark with solid fill |

## Evaluation

All the features of the program were tested and the discovered bugs that prevent proper functionality were fixed. More exhaustive testing could be done, for example, to test a more complex sequence of actions. Different types of testing could be conducted too, like performance testing and unit testing. User testing was extremely helpful because it helped uncover problems that, as the developer, I did not notice because of the familiarity of the program. More people doing user testing could uncover more bugs too. Given a second time around, I would plan out the testing strategy more carefully and start testing sooner. I would also ask my friends earlier to user test the program, because they seemed to be too busy towards the end of the year.

## Summary

The importance of testing and the main methods for it were discussed. The project was tested using exploratory testing during development and user testing after it was in its final version. The steps taken to fix the bugs found were detailed and they were reduced according to my best capability.

# Evaluation, Conclusions and Future Work

## Project Objectives

The objective of this project was to produce a program that can generate a cross-stitch pattern based on an image, which can be edited and saved. The aim of the program was to be easy to use for hobbyists and to be aesthetically pleasing.

The technical objectives were reached and even exceeded. The design objectives can be improved.

## Self-Evaluation

The experience of delivering a longer project with time-constraints was very valuable both for developing my technical skills and improving as person. Since I have not done anything like this before it pushed me in a lot of ways. I think one of the main take-away from this experience is that I need more confidence in myself. It was difficult to start to do things alone without knowing if I am doing them right, but when I managed to start the application, I realized it is not as hard as I expected. I felt relieved and was able to achieve and even exceed my goals. I could not have done this without the help of my project supervisor.

I became much better at individual work and research. I learnt to understand code that was not written by my lecturers and modified it to be able to be used in my application. My debugging skills and my understanding of shaders are way better, which proved useful in other modules too. I was wary of C# before, but now I am more confident in using it, even wish some features were available in C++.

I achieved much more than I expected. I learnt WPF and XAML alone. And was able to do things I would have never imagined without help.

## Project Evaluation

I exceeded the objectives of the project based on the Moscow requirements in my technical plan. I implemented all must have features except the grid, which was deemed unnecessary because the stitches were easy to see without it. All the should haves have been implemented, except saving it as a PDF, which was proven to be low priority and maybe unnecessary, since it can be saved as a picture. All the could haves have been implemented. Even the preview feature from the won’t have list was implemented which was a surprise for me, since I did not expect to get that far. Especially because the shader was quite involved.

In terms of the UI design, I feel like I could not quite achieve what I expected to. WPF UI design turned out to be more difficult than expected. Making a basic UI is easy enough, but making it look beautiful is very hard. I think I managed to make the UI simple and easy to use. The colours are also aesthetic. I decided on a simple pastel design, since most cross-stitch patterns have a similar mood so it would suit them well.

All in all, using WPF proved to be a good decision. All the desired features were able to be implemented. The start was difficult, since there is not just a single right way to do things in WPF. A lot of decisions had to be made at the start, which delayed the development. However, once they were made, the rest of the development process was much quicker. I found plenty of resources on Stack Overflow, which would not have been possible with UWP for example. The UI could also be created quickly without too much difficulty. A problem was encountered with memory management when creating the preview, which could have been avoided if there was more control over the memory, like in Win32.

If I would do it again, I would research WPF even more before starting. I would implement the MVVM pattern fully and do more extensive testing. To have more control over the memory and UI, and have faster image processing, a lower level API could be used like DirectX. However, this would only be possible if the time frame were longer since it requires more work to add the same features an in a higher level API.

## Applicability of Findings to the Commercial World

The finished application can be used by cross stitchers. It is a great alternative to expensive programs and provides a good range of features. An everyday user can easily make a usable and nice pattern.

It could be sold commercially, maybe with more added features. Alternatively, if it is released as a free open-source program, then parts of it could be reused and could help others who are trying to make similar applications.).

## Conclusions

I am satisfied with the project. All features were added that were expected to be added in this timeframe. However, there is always room for improvement. I acquired a good base understanding of WPF, which adds to my skillset. I experienced working on a longer project, which helps with expectations about future development projects.

## Future Work

The application is a functional pattern generator, however compared to the leading programs there is possibility for a lot of improvement.

### Improvement of existing features

Some of the already implemented features could be more polished. For example, when the pattern is first generated, the exact number of colours might differ from the input value. This is due to the colour quantization library used. However, colours can be added or removed afterwards.

The colours also sometimes appear to be duller than expected. This could be because of the conversion of RGB colours to the DMC thread colours. Now the RGB colours are converted to Lab space and then matched to the closest DMC colour. This is the best way for colour matching; however, another algorithm could make the process more sophisticated and choose colours closer to what a person would match them to.

The preview takes longer to load for bigger patterns. For example, a pattern with height bigger than 400 would take a few minutes to generate. This would be dramatically reduced by using shaders for big patterns too (which is already used for smaller ones), however it takes up too much memory and the system runs out of GDI objects.

The downsampling of the image could be improved. Based on the paper written by Gertsner et al. (2012), a smart detail preserving algorithm can be used to downsample images. This could be especially useful for cross stitch patterns, since the details are the most important parts that make the image recognizable, and the backgrounds are usually plain and unimportant.

### Additional Features

As for additional features, based on existing top applications (WinSticth), colour blending could be added. This generates more colours by blending existing thread colours together, resulting in a wider variety and closer colour matches to the original picture. At the moment only the simple cross stitch type is supported. This is the case for most free/smaller programs, however more stitch types could be added in the future, like French knots and backstitches.

An additional useful feature could be printing the DMC colour list together with the pattern. The list containing the colours would have to be exported together with the pattern when saving it. An option to save work in progress could be added. This way the user can continue to work on a pattern later even after closing the application. Similarly to other applications, more brands of threads could be added, like Anchor, and the user could choose which type they want to use.

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# Appendix 1 – Project Proposal

## Computing Degree Project Proposal

|  |  |
| --- | --- |
| **Student Name: Lili Veszeli** |  |
| **Course: Computer Games Development** |  |
| **Project Title: Cross Stitch Pattern Generator** |  |

## Project Context

I would like to create a computer software that could convert a picture to a cross stitch pattern. There are other software like this available online for free or for a price. (Chestnut Pens, 2020; Klein, 2017) This would be an interesting project that involves all the techniques I learnt at university.

## Specific Objectives

* Generate a pattern based on a picture
* Choose desired number of colours
* Choose size of pattern
* Edit pattern (for example change colour or draw on it)
* Save the pattern at the end

## Potential Ethical or Legal Issues

Copyright issues. The software might be too similar to one previously created. However it would not be illegal to do it for an educational purpose (Copyright, Designs and Patents Act 1988).

Some users could abuse the software to make patterns from copyrighted images/characters and sell them, which would be illegal.

Some users could make patterns with disturbing content, which might be seen by children if the patterns are sold.

## Resources

Computer – available at university and also own laptop

Visual Studio – available.

UI library for C++ - there are some free options, like JUCE (Robinson, 2013)

OpenCV – available

DirectX – if needed available

## Potential Commercial Considerations - Estimated costs and benefits

The software would be mainly used by people who enjoy cross stitching, which can be done any time. Hobbies including arts and crafts are becoming more popular (Kelly et al, 2020), a huge rise was experienced during lockdown (The Guardian, 2020). There are people who enjoy it from all generations, so I am confident that it will continue to be practiced and hence the program will be used. With the help of the application, it is possible to make patterns from pop culture, so it might help to make it more popular among young people.

Cost of programming the software: it will take around 30 weeks (academic year), so the salary for a programmer for that period would be approximately £12750.

The software would be sold for individuals for a low price, £10-15, because most similar applications start at £50, and I think a casual cross stitcher would be more likely to buy a product with a lower price.

All similar free applications have a bad quality UI, so by making the UI of my program clean and compelling it will be more attractive for users.

It would need to be advertised in some way, so that would add more to the costs depending which way it is advertised. If used Facebook advertisement, it would cost £300 for a month.

## Proposed Approach

Writing Technical Plan – 1 week

Researching how to load an image using C++ and code it – 1 week

Researching how to convert the pixels in the image to the squares in the pattern and code it – 5 weeks

Researching how to draw the grid over the squares and code it – 1 week

Researching how to edit the pattern and code it – 10 weeks

Researching how to make UI and code it – 3 weeks

Researching how to save file and code it – 1 week

Testing the application – 1 week (Testing would be involved every stage, but a more comprehensive testing period would be at the end)

Writing report - 4 weeks

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Appendix 2 – Technical Plan

## Computing Project Technical Plan

**Name:** Lili Veszeli

**Course:** Computer Games Development

**Supervisory Team:** Games Team

## Title

Cross Stitch Pattern Generator.

Summary

I will create a computer application that will generate a cross stitch pattern based on an image. The user would be able to modify the pattern, for example change colours, change stitch location, change overall size. The pattern can be saved and printed. I will also have to a make a User Interface.

The difficult part in this project will be figuring out how to edit the pattern, making sure that the pattern looks right and uses the correct colours. I will need to research different methods to create these features. Working with C# will also be challenging since I am more familiar with C++.

I will use the Waterfall model as my development methodology, since we have set deadlines and once we submitted the required material we cannot change it. Some tools from Agile will be used too, like Moscow; this can make sure that all the essential features will be complete (Waters, 2009). Testing will be done too to make sure the program works as expected.

## Deliverables

The main product of this project will be a Windows based computer software that will be able to generate a cross stitch pattern from a picture. Other deliverables will be the report and poster.

## Constraints

The most serious constraint is the deadlines. It might be the case that the application won’t have all the features because of the limited time available for development.

Another constraint could be lack of resources. I might not find specific enough resources about how to create different features for my project.

The methodology used in my project could be a constraint. Using the Agile methodology is not possible since we cannot change our project after submitting the proposal. This might not be flexible enough for the project.

## Key Problems

The main difficulties will be

* to figure out how to edit the generated cross stitch pattern. I am not familiar enough with WPF to know how it could be done, so I will need to research it more.
* to design an efficient and clean user interface. I will need to research examples for it and experiment with my UI.
* to figure out how to work with pixels in WPF.

## System and Work Outline

The project will be developed will be developed using WPF in C# and XAML. The UI component will be made using WPF’s built in drag and drop UI editor. This can be further customized with XAML. The behaviour of the UI and the backend will be programmed in C#. Visual Studio will be used for the development environment. GitHub will be used for version control and backup.

Features of the program using Moscow prioritization:

|  |
| --- |
| **Must have:** |
| * A Windows application that can convert a picture’s pixels to bigger squares. * Basic UI. * A grid over the picture/pattern. * The ability to save it and print it. |
| **Should have:** |
| * The ability to resize the pattern. * More advanced UI. * Saving it in a PDF. * The ability to edit the pattern. * The ability to reduce the number of colours used in the pattern. |
| **Could have:** |
| * The ability to use real thread colours. * Zoom in while editing. |
| **Won’t have (but Would like in the future):** |
| * Other types of stitches. * Representation of how the pattern will look once finished. * Blended colours. |

(Agile Business Consortium, 2019)

Regarding WPF, I will need to research how images could be loaded in, how to make a modern UI and how to manipulate graphics (Sells & Griffiths, 2007).

I will also need to research how to navigate Windows folders, save and print files (Microsoft Docs., 2020).

## Project Activities



## Risk Analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Severity** | **Likelihood** | **Action** |
| My computer breaks | Severe | Small | Get it fixed – would hinder development by a few days.  Alternatively, work in the games lab – good solution, but might be difficult because of the limited availability this year. |
| Not being able to implement every planned feature. | Low | High | To be able to demonstrate my program it only needs the most important features, which are highly likely to be implemented. Using Moscow will help to ensure this. |
| Loss of data | Severe | Low | Making copies of the project every time I add to it, and storing it on a cloud based server. |

## Options

As an alternative to the Waterfall method, Agile could be used. However, because the deadlines for the deliverables are already set it makes the development less flexible. Main features cannot be changed either. Since I know what kind of features I want, I won’t have to do major changes to the program. It is also harder to use agile techniques if developing alone. Because of these constraints the best suited project management methodology for this project is Waterfall (Balaji & Murugaiyan ,2012).

An alternative I considered to develop the program in was Windows forms. However, WPF is a more modern and more flexible version of Windows forms, with more customization options (“WPF vs. WinForms”, 2020*)*. In WPF the UI editor is in XAML, with a drag and drop menu.

Another option could be DirectX 11. It would need a Windows library to be able to make the UI and it would be unnecessarily complicated to make the pattern using shaders.

Windows is the target environment. This program can be used most effectively on a computer, in a mobile app version the user would not be able to use the features properly. Later on, the project could be expanded to macOS and Linux, but this is not part of the objectives now because of the time limitation.

## Potential Ethical or Legal Issues

Legal issues might arise regarding the copyright law (Copyright, Designs and Patents Act 1988). If the program turns out to be too similar to one previously made, it could be a problem. However, this can be avoided by writing original code, not copying code that isn’t allowed to be freely used, and designing my own UI and mechanics of the application.

## Commercial Analysis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Factor name** | **Description** | **Is this a cost or a benefit** | **Estimated Amount** | **Estimate of when paid** |
| Hardware | Computer to develop the project on. | Cost | Cost of my laptop - £900 | Start of the project |
| Software | Windows operating system | Cost | Cost of Windows 10 Pro - £220 | Start of the project |
| Salary | Salary for developing the program | Benefit | Salary for 30 weeks (academic year) based on average junior games developer salary - £12750  (Prospects, 2020) | Every month |
| Advertisement | Cost to advertise the product to the targeted audience | Cost | Facebook advertisement for 2 months –  £600 | End of project |
| Price | Price of the product | Benefit | £15 every time it is purchased | End of project |

## Employability Contribution

This project will help me get a better understanding of making software for the public. It will improve my skill at UI design and my coding abilities in C# and XAML. I will gain experience in programming a Windows application. After writing the report I will be better at written communication.

The project can be expanded with a lot more features and could be marketed.

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# Appendix 3 – Software Licenses

## MIT License

|  |  |
| --- | --- |
|  |  |
|  | Copyright (c) 2013 ColorMine.org |
|  |  |
|  | Permission is hereby granted, free of charge, to any person obtaining a copy |
|  | of this software and associated documentation files (the "Software"), to deal |
|  | in the Software without restriction, including without limitation the rights |
|  | to use, copy, modify, merge, publish, distribute, sublicense, and/or sell |
|  | copies of the Software, and to permit persons to whom the Software is |
|  | furnished to do so, subject to the following conditions: |
|  |  |
|  | The above copyright notice and this permission notice shall be included in |
|  | all copies or substantial portions of the Software. |
|  |  |
|  | THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR |
|  | IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, |
|  | FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE |
|  | AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER |
|  | LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, |
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(CsvHelper)

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|  |  |
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|  |  |
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|  | for making modifications to it. "Object code" means any non-source |
|  | form of a work. |
|  |  |
|  | A "Standard Interface" means an interface that either is an official |
|  | standard defined by a recognized standards body, or, in the case of |
|  | interfaces specified for a particular programming language, one that |
|  | is widely used among developers working in that language. |
|  |  |
|  | The "System Libraries" of an executable work include anything, other |
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|  | packaging a Major Component, but which is not part of that Major |
|  | Component, and (b) serves only to enable use of the work with that |
|  | Major Component, or to implement a Standard Interface for which an |
|  | implementation is available to the public in source code form. A |
|  | "Major Component", in this context, means a major essential component |
|  | (kernel, window system, and so on) of the specific operating system |
|  | (if any) on which the executable work runs, or a compiler used to |
|  | produce the work, or an object code interpreter used to run it. |
|  |  |
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|  | work) run the object code and to modify the work, including scripts to |
|  | control those activities. However, it does not include the work's |
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|  | the work, and the source code for shared libraries and dynamically |
|  | linked subprograms that the work is specifically designed to require, |
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|  | subprograms and other parts of the work. |
|  |  |
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|  | can regenerate automatically from other parts of the Corresponding |
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|  |  |
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|  |  |
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|  | long as you offer spare parts or customer support for that product |
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|  | medium customarily used for software interchange, for a price no |
|  | more than your reasonable cost of physically performing this |
|  | conveying of source, or (2) access to copy the |
|  | Corresponding Source from a network server at no charge. |
|  |  |
|  | c) Convey individual copies of the object code with a copy of the |
|  | written offer to provide the Corresponding Source. This |
|  | alternative is allowed only occasionally and noncommercially, and |
|  | only if you received the object code with such an offer, in accord |
|  | with subsection 6b. |
|  |  |
|  | d) Convey the object code by offering access from a designated |
|  | place (gratis or for a charge), and offer equivalent access to the |
|  | Corresponding Source in the same way through the same place at no |
|  | further charge. You need not require recipients to copy the |
|  | Corresponding Source along with the object code. If the place to |
|  | copy the object code is a network server, the Corresponding Source |
|  | may be on a different server (operated by you or a third party) |
|  | that supports equivalent copying facilities, provided you maintain |
|  | clear directions next to the object code saying where to find the |
|  | Corresponding Source. Regardless of what server hosts the |
|  | Corresponding Source, you remain obligated to ensure that it is |
|  | available for as long as needed to satisfy these requirements. |
|  |  |
|  | e) Convey the object code using peer-to-peer transmission, provided |
|  | you inform other peers where the object code and Corresponding |
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|  | charge under subsection 6d. |
|  |  |
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|  | from the Corresponding Source as a System Library, need not be |
|  | included in conveying the object code work. |
|  |  |
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|  | the only significant mode of use of the product. |
|  |  |
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|  | a modified version of its Corresponding Source. The information must |
|  | suffice to ensure that the continued functioning of the modified object |
|  | code is in no case prevented or interfered with solely because |
|  | modification has been made. |
|  |  |
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|  | specifically for use in, a User Product, and the conveying occurs as |
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|  | User Product is transferred to the recipient in perpetuity or for a |
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|  | by the Installation Information. But this requirement does not apply |
|  | if neither you nor any third party retains the ability to install |
|  | modified object code on the User Product (for example, the work has |
|  | been installed in ROM). |
|  |  |
|  | The requirement to provide Installation Information does not include a |
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|  |  |
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