Variable Image Patterns

Eduarda Duarte
Department of Informatics Engineering, University of Coimbra, Coimbra, Portugal
eduarda@student.dei.uc.pt

Tiago Martins
CISUC – Department of Informatics Engineering, University of Coimbra, Coimbra, Portugal
tiagofm@dei.uc.pt

Artur Rebelo
CISUC – Department of Informatics Engineering, University of Coimbra, Coimbra, Portugal
arturr@dei.uc.pt

ABSTRACT

Modularity has served as a key in design and art to help reimagine new visual artifacts. Modular systems achieve this by presenting a simpler way to describe a mechanism, by breaking it into smaller and more, manageable parts. This way, they provide an easy way to get different combinations and possible results. With recent developments in technology and the rise of programming languages for art and design, we can portray this concept in a new mode. In this paper, we propose a modular computational system that focuses on a generative design standpoint to create images using tiles capable of changing their shape to form different styles and patterns.

Our goal is to build a generative system that adapts to different visual scenarios and purposes. We achieve this by implementing programmable tiles and by allowing the user to combine different values for the given settings. The presented system can be employed to generate stylized images or set an interactive mirror for new media art installations. It can also be used to adapt images to printing purposes or specific displays, produce laser cuts, artifacts for a graphic identity, or even build modular typefaces.

CCS CONCEPTS

• **Information systems** → Information systems applications; Multimedia information systems; • **Applied computing** → Arts and humanities.

KEYWORDS

Generative Design, Image Processing, Modular Design, Pattern Design

ACM Reference Format:
Eduarda Duarte, Tiago Martins, and Artur Rebelo. 2021. Variable Image Patterns. In *10th International Conference on Digital and Interactive Arts (ARTECH 2021), October 13–15, 2021, Aveiro, Portugal, Portugal.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3483529.3483658

1 INTRODUCTION

Modular systems have played an important role in graphic design and art. They have been used to produce unpredictable results by looking at familiar systems from a new angle [1]. To the creative process, modularity presents itself as a special kind of constraint in which modules are fixed elements used within a larger system. The number of possible combinations and results becomes exponential and the level of complexity of a final composition can be easily higher. It is possible to find design processes that translate this concept to build typefaces, images, and identities from blocks or modules.

Recently, advances in new media and its technologies contributed to the development of programming languages for art and design. Following this, the demand for dynamic and generative design has increased, opening new opportunities for both designers and artists to become creators of tools. The rising popularity of creative coding enabled the development of these custom tools, opening a new way to use modular systems to simplify and solve complex problems [2].

Systems as these are used in some design projects to generate visual compositions according to a specific problem whose requirements transform into the system's rules. They can range from stylizing images in the same way and linking them under a theme, like the graphic identity created by the studio R2, for the AGI Open Congress held in Porto in 2010 [3], to presenting a dichotomy between different perceptions of the same image, like Dutch Clouds, by Karel Martens [4]. Other projects use these systems to develop modular typefaces that can adapt to an environment like the project Typographic Music by Dina Silanteva [5], and the typeface TwoPoint by Muir McNeil [6]. Additionally, new media art projects have also been building and applying similar modular digital tools within an artistic approach: projects like Interactive Flip-Dot Display by studio Think Create [7], and Iris by studio Hybe [8]. These systems offer a new way to interpret and decompose the reflection or the interaction of the user to generate and show a new image.

In this paper, we experiment through generative design and image processing to achieve novel visual languages. In particular, we explore the computational creation of images using programmable tiles capable of changing their shape to achieve different patterns [9]. The variation in the shape and size of each tile helps to create the illusion of different shades of gray. By feeding the system with an image, the system translates it into a grid of tiles that adapt to match the shades of different regions of the image. This tricks the eye to perceive the input image, now stylized as a digital mosaic. The way this was made possible was through the creation of a system that allows its users to interact with it by giving it an image or even their webcam input. Additionally, it lets them choose different parameters to obtain customized images or videos which, ultimately, grants a way to quickly visualize a different range of results.

The remainder of this paper is organized as follows. Section 2 describes our generative system. Section 3 overviews different applications of this system. Finally, Section 4 presents the conclusions and directions for future work.

ARTECH 2021, October 13–15, 2021, Aveiro, Portugal, Portugal

ACM ISBN 978-1-4503-8420-9/21/10.
https://doi.org/10.1145/3483529.3483658

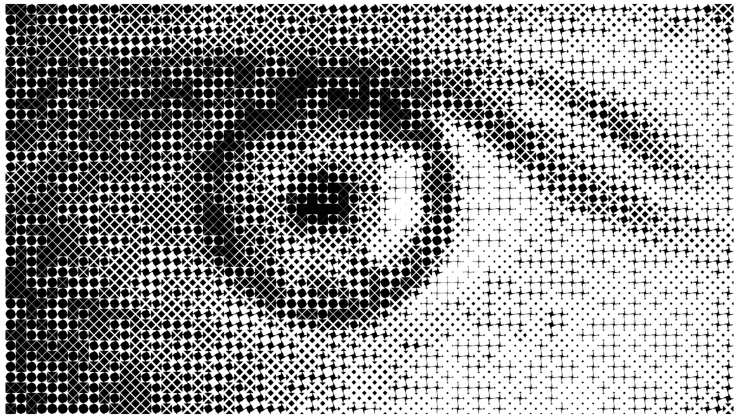

Figure 1: Image generated with the presented system.

2 GENERATOR

In pursuance of our goals, we developed a computational generative system to create monochromatic images made of modular tiles of varying shapes. These tiles are arranged on a grid, forming visual patterns that give the illusion of different but continuous tones. This method allows us to create unique representations of input images (see Figure 1) by choosing different tiles and by applying different values for other parameters. These parameters can range between modifications to the tiles style and behavior or even filter applications to the original image to refine the result. The process is inspired by non-photorealistic techniques, like projects that simulate decorative mosaics [10] and projects related to monochrome art [11]. We will now detail the explanation of our approach.

2.1 Approach

We begin by explaining the approach by understanding the general concept. The system dynamically changes the shape of each tile to vary its amount of black and white. This variation is made based on the brightness value of a given region of an input image. The output pattern appears to have different tones when viewed from a distance though they are monochromatic, which allows the viewer to recognize the original image. This idea is similar to a halftoning method which converts the different image tones into dots of varying size [12]. Furthermore, with the halftone method, different elements can be used besides the circled dot, creating different results [13]. It is typically used in printing and even in digital representation with pixels since this method allows itself to be readapted to different formats. The use of this methodology intends to represent images in a photorealistic way. However, the presented system differs from this goal by highlighting and giving relevance to the individual elements that compose the image. This is achieved by turning them into programmable tiles that can interpret parts of an image in different ways.

The process of generating an output image in the system can be summarized as follows. First, the system needs an input image. It is important to note that this input image can be a static one, a frame of a video, or a captured image from a webcam. Since the system is fast enough, it can present generated sequences of frames, which can be later exported as videos. Other variations can translate into interpreting real-time user interactions or movements into real-time drawings that can serve as the input images.

The system then resizes the input image to the target pattern resolution and a simple formula is applied to obtain the value of luminance for each pixel. To represent the array of pixels of the resized image, it creates a grid of tiles. The previously calculated brightness of each pixel, which can vary from 0 to 255, is mapped to a new range of 0 to 1. The resulting value determines the weight and shape of the corresponding tile, where the black area of each tile is proportional to the level of darkness of the corresponding region of the input image. As a result, low brightness values make the tiles change to a heavier shape, while high brightness values make the tiles change to a lighter shape, which eventually can be inverted if desired. It is possible to limit and alter the maximum and minimum brightness levels making the result have a wider or narrower tonal range.

Besides this, instead of mapping the brightness value directly and linearly, other functions can be used to either achieve different curves of the tonal range, to produce smooth tile transitions, or to make them interactive. For example, when treating a sequence of images, we may want the tiles to progressively grow or shrink instead of doing it right away. This is achieved by choosing a function to transition from a value to another progressively through a certain amount of time.

Several tiles were implemented (see Figure 2). Each one has its shape and way to change itself based on the desired tone. All tiles can adapt their shape to represent a darker or lighter tone. This adaptation can be made through a combination of changes in the shape's scale, translations, or other shape morphs that influence the distribution between black and white and that allow the tile to have a unique pattern. This lets us explore an even wider range of patterns. For example, there may be several tiles that use a black square to portray the darkest possible tone, but while one may only vary by scaling down both horizontally and vertically as the tone gets lighter, another may scale only vertically, morphing to a rectangular to represent lighter tones.

While some tiles are only simple forms like squares, triangles, or circles that vary in scale, others are more complex geometries or inspired by drawing techniques like cross-hatching or stippling.

Figure 2: Some of the tiles implemented in the presented system to create images.

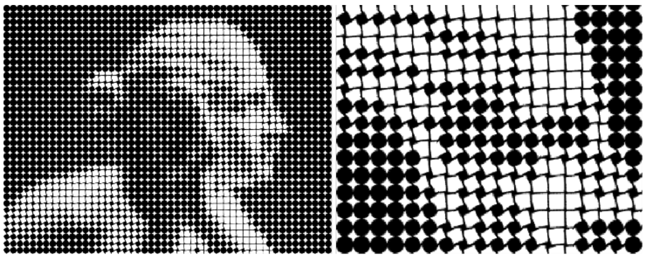

Figure 3: Generated image (left) and close-up of the image, displaying one of the available tiles (right).

Plus, having the tool built as a modular system, makes it easy to rapidly expand the list of available tiles by constantly creating and adding new ones. This idea also opens the possibility of adding an option for the user to customize or even create his tiles in future work. Another currently available option lets the user choose and combine more than one type of tile to be used in the same composition, giving it a less predictable output. By choosing more than one tile, the selection can be randomly distributed across the grid, using image segmentation or following a sequence. A challenge presents itself within this, in which we need to visually calibrate the area of black and white of all tiles to be approximately the same when representing the same tone. Otherwise, the fina illusion would not be as successful in presenting smooth continuous tones.

Currently, the system uses a square grid with a configurabl resolution to place the tiles. The number of columns, rows, and margins that make up this grid is customizable. The higher the resolution of the tiles' grid, the greater the detail it can reproduce. This enables the creation of images for diffe ent needs. For example, an image such as a landscape with smaller details requires a higher resolution to represent these details in a way that they stay recognizable.

The position of the tiles on a given grid, the way they morph their shape, and their monochromatic restriction, are the factors that constitute the fix d elements of a set state of the modular system. The advantages of a system like this are that we can pick up the modules and group, switch, stack, remove them as whatever we want if they respect these restrictions. The novelty appears in the fact that each tile, or module, can respond in diffe ent ways to a given value. In this case, it is given the brightness value of the region of the image they are associated with, to which they respond by lowering or increasing the amount of black (See Figure 3). The results are dynamic monochromatic mosaic images.

Though the system only uses a square grid, other grids can be implemented and used to achieve diffe ent types of patterns, offerin another layer of options, such as a hexagonal or a triangular grid, which result in a diffe ent aesthetic. With these changes, the tiles would also have to be able to fi correctly into the new grids, possibly using a line clipping algorithm, or by having a list of tiles made specifica ly for each list. What was explained until now presents the base of the concept developed for the system. However, more parameters were added to stylize the tiles: changing their color and its background color, the image size (in pixels per inch), maximum and minimum values allowed for the tile. Another set of important parameters, that needed to be added, is a group of filters to process the original values of the image, like contrast, brightness, or noise introduction [14]. This would allow the user to better manipulate the final pattern and its quality.

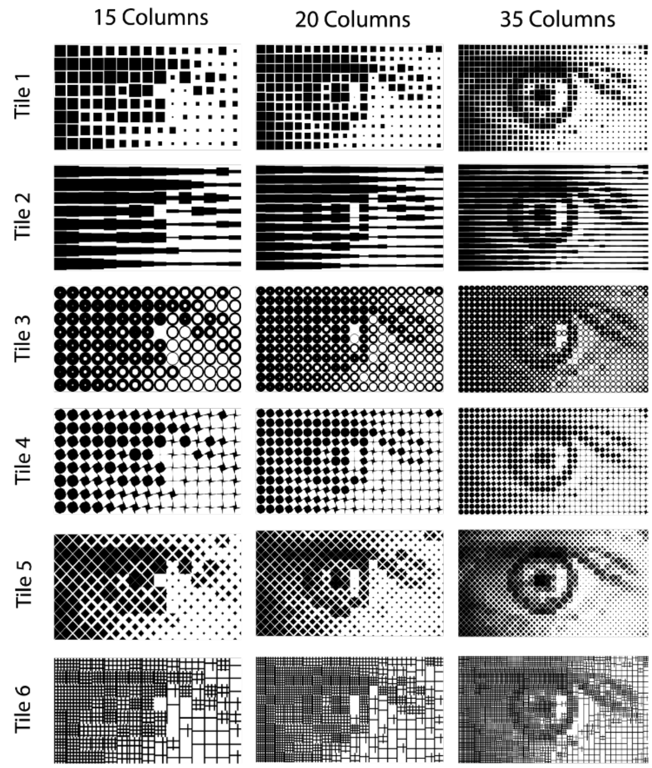

Figure 4: Table with some of the results showing tile varia-tion (vertically) and grid size variation (horizontally).

2.2 Results

To compare results and better expose possibilities given by some parameters, a table is presented (see Figure 4) where the horizontal axis represents an increase of the grid resolution and the vertical axis presents a variation of the tiles used. This list represents only a sample of the available tiles and variations of the parameters. By looking at the table, we can see how easy it is for an image to transform into new contexts and styles. As it exists now, some modules portray the tones with more contrast than others, this is due to the variations on each drawing of the tile, that affect the quantity of black and white.

The outputs can be exported as a rasterized image (PNG) or a vector image (SVG). Since the user can adjust the image resolution as well as the grid resolution, the results can either be exported with high, medium, or low quality. These adjustments help to control the result to better suit different situations and purposes, for example printing a big poster or just making a small avatar for a website.

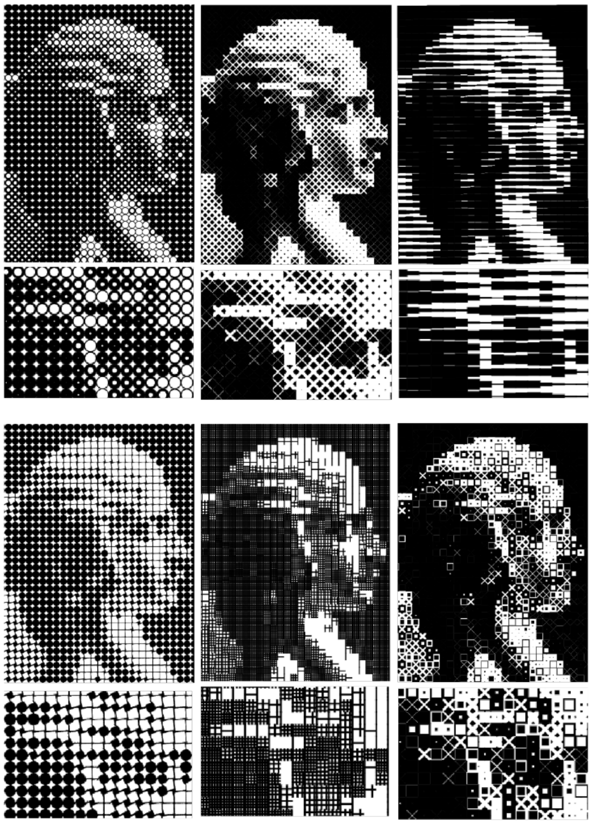

Figure 5: Images generated using different variable tiles. In the last example, more than one tile is selected.

In this way, they can be used for different static and graphical purposes, but that is not the limit of the system. It is simple to re-adapt it to fit any display or to translate it to any visual context.

The possible applications of a framework as such go through representing any type of visual artifact, from still filtered image mosaics to video animations, modular visual installations, generating modular typefaces. The possibilities are endless, which is the goal of creating a customizable tool with so many options.

In the next section, we present the system through a different lens by referring to different forms of manipulating it. We also showcase different usages to which the system could contribute or elevate a project in design or even new media art.

3 APPLICATION

Although one of the goals is to describe the system, it is also of interest to explain the implication of its different forms of usage. This chapter, therefore, contains considerations regarding the application of such a system, whether we are talking about the parametrization of different functionalities and how it affects the results, or whether we are talking about what contexts it can be used in. Therefore, it is important to study both perspectives to obtain the outcome closest to the desired.

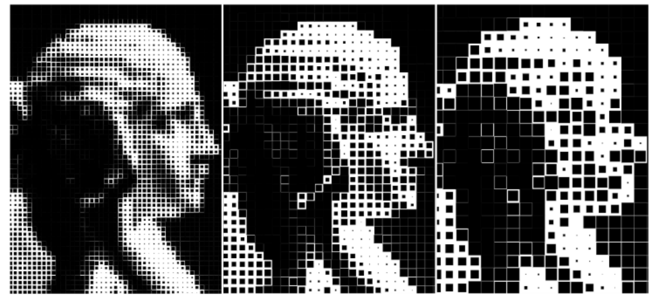

Figure 6: Images generated using different grid resolution.

3.1 Parametrization

Each parameter that was mentioned has a strong effect on the results, hence it is important to showcase their differences and how they can be applied to better decide in which situations one can take advantage of them.

Firstly, by varying the tile the user can change the stylization of the image (see Figure 5). The choice of the tile can also add context to the image. This said context can come from an abstract concept: the tile can be a dynamic logo or symbol, therefore, connecting all the images composed with this tile to a graphic identity or idea..., or it can also come from a physical limitation, for example, the resolution of a screen in which the tiles must be made of rectangles because that is the screen's unit. The tiles are the component that allows the system to encapsulate the capacities of representing visual coherence (by applying the same one to different images) and diversity (by applying different tiles). As mentioned before, more than one tile can be selected to be used in the same composition (see Figure 5).

Secondly, by varying the pattern resolution the resulting image can have different levels of detail. The higher the resolution, the closer the output is to the input, meaning the image becomes more recognizable. This is useful when handling images with more than one element. The lower the resolution, the less recognizable the image gets in comparison to its original, by ignoring and erasing a lot of detail that could be essential. This also means the attention will be dragged to the tiles themselves and their form. This last format works better with images of simpler composition (see Figure 6).

Different images produce, therefore, different success levels of readability. If an image, such as a landscape, has a lot of small details, it would need more grid resolution to be recognized as such, than a simpler composed image by, for example, an object against a white background.

There is another added layer of possibilities by varying the tile and background colors. This offers more aesthetic options and new opportunities to create more contexts (such as visual identities) by combining different shapes of tiles and now, colors (see Figure 7).

Although still monochromatic, the color option opens possibilities, for the future, to overlap different images with different colors, and to work with different values besides brightness.

The system can also be used to either achieve visual diversity or visual coherence. This means that it can generate different patterns using the same image by exchanging parameters, such as used tiles

Figure 7: Images generated with different colors (top) and close-up of the tiles (bottom).

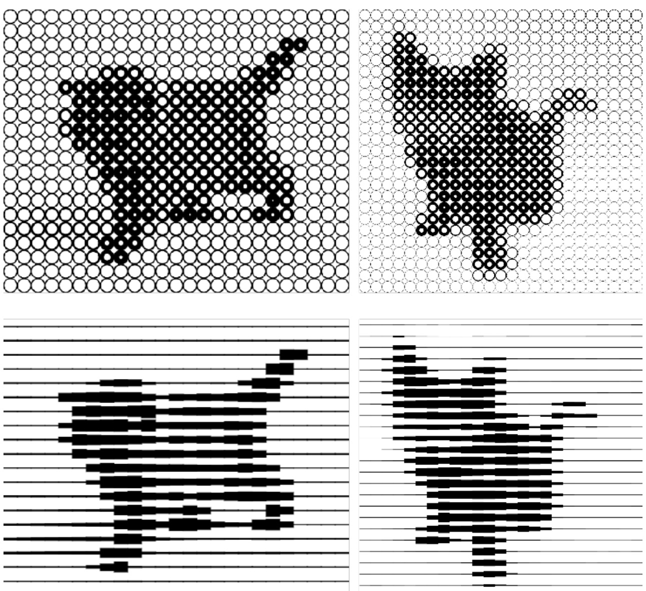

Figure 8: Images portraying diversity (vertically) and visual coherence (horizontally).

and grid size, therefore achieving diversity. However, it can also achieve coherence by giving the same parameters to diffe ent input images, making the results share the same style (see Figure 8). As it is, the system can represent any tone in an image, but this does not mean it represents them all. This is also limited by the imposed resolution that we want to work with. Nonetheless, given a high resolution, the system will smoothly portray the tonal values. This will aff ct the perception of the whole image.

The images generated demonstrate the ability of the system to create an illusion of a range of continuous tones and, consequently, patterns with the underneath image being recognizable by combining all these factors. As said before, this capacity to recognize the image is enhanced when the grid has a higher resolution, however,

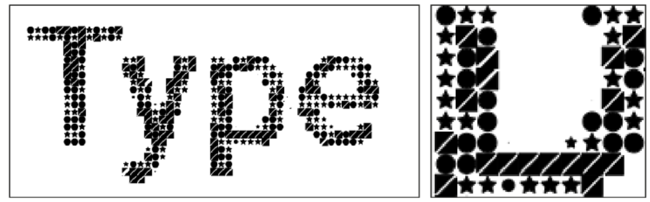

Figure 9: Image generated from a screenshot of the word "Type" using Roboto font (left) and close-up (right).

the tiles will not be so easily perceived as individual elements (unless seen up close or zoomed in). In the case of wanting to display or share the results, for example, on social media, this becomes important. Since the image may be displayed on a phone screen, this means there will be bounds and limits to where we can perceive the image and the tile. Nonetheless, both represent paths that serve diffe ent goals.

3.2 Usage

Besides knowing how to manipulate the system, it is also relevant to think about the situations it could be used in. By being modular and generative, the system allows itself to be re-adapted and approached in diffe ent forms.

Regarding the area of Graphic Design, a framework like this can be used to produce artifacts for a visual identity that relies on modularity, therefore achieving visual coherence faster. The tile can be a symbol, a logo, or any other reference that helps to transform and link a random artifact to the identity. For example, it can generate posters, banners for an event or even produce personalized gifts for the visitors. It can also be used to compose visuals to perfectly fi into a specifi display. In a more exploratory approach, it can be used to produce fun visuals, from avatars to gifs or even transformed drawings.

Another option is using it to transform type so it can blend with other artifacts using the same visual language. As it is now, the system can transform type only when represented in images, as seen in Figure 9. This is not ideal for smaller grid sizes, where a lot of information necessary for readability is lost. This brings a future possibility of adapting the system to better deal with typography, handling type skeletons built specificall for the system, and generating modular types that can be exported as actual fonts.

Apart from this, the system can also enroll in New Media Art. Since captured images and videos are just sequences of frames and since the system is fast, it allows rendering transformed videos in real-time. This opens space to use the system to create installations or interactive mirrors. By displaying the visuals in a bigger display and using, for example, a Kinect, we can reprogram the tiles to respond to certain movements, proximity. or other types of interaction, generating new visuals that turn into an immersive experience. These visuals may or may not be more abstract, depending on the desired outcome. As an example, instead of just translating the image's brightness values, the system may be programmed to only portray detected movement, using its speed as input for the tiles' weight instead (Figure 10).

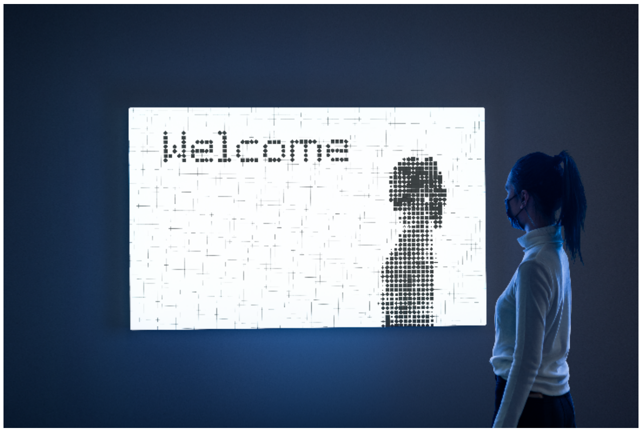

Figure 10: Mockup of an interactive mirror installation using the presented system.

Figure 11: Mockup of a drawing application built using the presented system.

Another example can be imagined as an interactive drawing tool (see Figure 11), in which the user picks the tile and color and creates whatever composition he desires. The weight that the tile takes can be the pressure the user applies when using a tablet or even the speed to which he draws. Ultimately, we can mix any of these ideas and create an interactive body drawing experience.

As a way to reach more people, a good interface could also be developed to support an online platform where the users could fully explore the system's functionalities. The advantage of this modular visual system is that it becomes simpler to separate and deal with different inputs and to represent them visually under an exponential number of different styles and sizes.

3.3 Audience

Until this point, the different uses of the system were explained, however, it is also relevant to explore the socio-cultural context in which the framework is placed. As previously hinted, the system was developed for designers and artists with experience using image editing tools and basic computer programming knowledge. Their intentions should be to generate, from varied inputs, different artifacts located between the visual, artistic, and digital world.

Additionally, the system was also envisioned to be able to adapt to different cultures and spaces. These range from physical and public spaces, like urban streets, museums, and galleries where, for example, an installation can be placed. It can also fit private and virtual spaces such as websites and social media, where generated results can be shared. The user may adapt the system to elevate the qualities of the space it is being used in. For example, changing the grid to fit a smaller display, using new tiles with a certain symbolism, or using a set of colors to fit the theme of an exhibition. The framework can be used in other possible and imaginable media contexts.

Finally, it is important to mention the people that encounter the generated artifacts. These can be the visitors of the built physical spaces such as installations or they can be the ones who find digital artifacts generated with the system, such as a post on a social network. This group accounts for an important part of the validation of the developed framework. While designers and artists provide a perspective of the product they are using, pointing to the effectiveness of the system, architecture, and bugs, the viewers' perspective centers on the quality of the artifacts. This provides validation of the proposed concept and gives pointers to improve the efficiency of the program.

3.4 Considerations

Having all of this in mind, it is important to highlight the importance of choosing the right values of each parameter to achieve an intended goal, unless an exploratory approach is taken. In both cases, one of the main advantages of this tool is its capacity to customize and stylize any images, even if they are not interesting or have a bad resolution in the beginning. In these cases, the output will ignore either of these aspects and give the image a new life. We can create new images from symbols or tiles and embrace them under a context or either make them unique or stand out from each other, as said before.

The vectorial format of the images generated by the system allows not only the creation of large format prints but also laser engravings or laser cuts on CNC machines. A bitmap format is also offered that can be used to achieve another large number of imaginable artifacts like for example, generating badges, posters, and other merch for an event, or even generate mosaic portraits or avatars for a web platform (working as a filter). It can be adapted to build a dynamic interactive installation that uses the image of the user as an input image, generating stop-motion animations or still frames that the user can save.

Lastly, all these applications can have their results automatically adapted to the desired size thanks to their modularity, which is helpful when printing in different sizes, or changing in other ways the format of an artifact.

4 CONCLUSIONS AND FUTURE WORK

We presented a generative design system that allows the creation of monochromatic images or videos made of varying shapes. These varying shapes, or tiles, can represent a tonal value and can be composed in different ways depending on a set of selected parameters to interpret an input image.

The presented system can be applied in different areas such as Graphic Design, type design, and New Media Art with different approaches and outcomes by redefining what is an input and by adapting how tiles respond to it.

From the generated results we can see the potential and advantages that such a tool can bring, from a rapid stylization and exploration of any image to obtain new results to a more calculated approach. This last one can be achieved by selecting the right criteria to reach an end, such as building a certain filter for a certain visual identity or picking the right size to use in posters, banners, or avatars. Any person can use the system to filter an image, but it can also be used by an entity to rapidly produce and communicate their visual contents. The results also hint at the range of potential future applications either by using the system to build different specific artifacts such as abstract animations, modular typefaces, or adapting it to other displays and uses, such as interactive installations. It can also be seen as a dynamic drawing and stylization tool.

Regarding future work, there will be a focus on exploring these numerous ways to expand the system. We can imagine more visual parameters, such as different interpretations to inputs using motion detection or other computer vision techniques to make different compositions. There will also be further development that enables the creation of animated patterns that could be interpreted as abstract imagery. This would allow us to apply the presented generative process to develop an interactive media art installation that could work as a digital mirror. We also intend to implement options for the user to customize and create his tiles. Additionally, other grids besides a square grid will be added and another possible future development regard experimenting with the creation of more complex color imagery, for example by layering different outputs, each one using a different color. This would result in having different ways to represent the image besides mapping its brightness. Lastly, experiments with the creation of lettering and fonts using the presented system will also take place with the goal of creating modular letters with varying weights and styles. Furthermore, this would contribute to generate and present both image and typography together in a visual coherence fashion, within the same style.

To conclude, we presented a framework that enables the creation of different visual artifacts made of variable tiles. It can be used not only in an artistic manner, but it can also serve as a rapid solution to build artifacts for a certain design problem. Ultimately, it allows the user to focus on the process of selecting the adequate settings for the parameters, redefining, therefore, the creative process.

ACKNOWLEDGMENTS

This work is funded by national funds through the FCT - Foundation for Science and Technology, I.P., within the scope of the project CISUC - UID/CEC/00326/2020 and by European Social Fund, through the Regional Operational Program Centro 2020.

REFERENCES

[1] Ellen Lupton and Jennifer C. Philips. 2008. *Graphic Design: The New Basics* (2nd ed.). Princeton Architectural Press.
[2] Frits Pil and Susan Cohen. 2006. Modularity: Implications for Imitation, Innovation, and Sustained Advantage. In *Academy of Management Review.* Vol. 31, No. 4, 995-1011. DOI: https://doi.org/10.5465/AMR.2006.22528166.
[3] R2. 2010. Graphic Identity for AGI Congress Held in Porto. (May 2021). Retrieved February 20, 2021 from https://www.r2design.pt/projects/agi-open-congress-porto-2010/.
[4] Martens-Martens. 2011. Dutch Clouds. (October 2020). Retrieved February 20, 2021 from https://martens-martens.com/dutchcloud.html.
[5] Dina Silanteva. 2011. Typographic Music. (May 2021). Retrieved February 20, 2021 from http://www.ddina.com/index.php?/2011/typographic-music/2/.
[6] Muir McNeil. N.d. TwoPoint. Retrieved February 20, 2021 from https://muirmcneil.com/project/twopoint/?section=about.
[7] Think Create. 2018. Interactive Flip-Dot Display. Retrieved April 1, 2021 from https://thinkcreate.us/portfolio-interactive-flip-dot-display.html.
[8] Alexandra Serrano. 2013. Interactive Pixel Installations. Retrieved April 1, 2021 from https://www.trendhunter.com/trends/iris-by-hybe.
[9] Branko Grunbaum, and G.C. Shepard. 1987. *Tilings and Patterns.* New York: W.H. Freeman.
[10] Alejo Hausner. 2001. Simulating Decorative Mosaics. In *SIGGRAPH01: Proceedings of the 28th annual conference on Computer graphics and interactive techniques.* August 2001. Association for Computing Machinery, New York, NY, USA, 573–580. DOI: https://doi.org/10.1145/383259.383327.
[11] Sergej Stoppel and Stefan Bruckner. 2019. LinesLab: A Flexible Low-Cost Approach for the Generation of Physical Monochrome Art. In *Computer Graphics Forum*, March 2019. Vol. 38, Issue 6. John Wiley & Sons. DOI: https://doi.org/10.1111/cgf.13609.
[12] Robert Ulichney. 1999. A Review of Halftoning Techniques. In *Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts V*, January 22-28, 2000, San Jose, CA, United States. Vol. 3963. Electronic Imaging, SPIE, Bellingham, Washington, USA. DOI: https://doi.org/10.1117/12.373419.
[13] Victor Ostromoukhov. 1999. Artistic Halftoning: between technology and art. In *Color Imaging: Device-Independent Color, Color Hardcopy, and Graphic Arts V*, January 22-28, 2000, San Jose, CA, United States. Vol. 3963. Electronic Imaging, SPIE, Bellingham, Washington, USA. DOI: https://doi.org/10.1117/12.373433.
[14] James Coady, Andre O'Riordan, Gerard Dooly, Thomas Newe, and Daniel Toal. 2019. An Overview Of Popular Digital Image Processing Filtering Operations. In *2019 13Th International Conference On Sensing Technology (ICST)* , December 2-4, 2019, Sydney, NSW, Australia. IEEE, New York, NY, USA. DOI: https://doi.org/10.1109/ICST46873.2019.9047683/.