PatternPursuit: Pattern Generation using Libraries Built on Graphic Decomposition

Joana Rovira Martins, João Miguel Cunha, Pedro Martins, Ana Boavida
CISUC/LASI – Centre for Informatics and Systems of the University of Coimbra,
Department of Informatics Engineering, University of Coimbra
{jmmartins, jmacunha, pjmm, aboavida}@dei.uc.pt

Abstract

During the creative process, visual exploration can facilitate brainstorming. Today's designers tend to rely on digital references, often biased by digital culture, which may limit the exploration of diverse sources. This paper focuses on a specific design product: graphic patterns. We present *PatternPursuit*, an ideation system that allows designers to explore recognised pre-digital design work on a conceptual and visual level and, using its visual elements, produce graphic patterns for wrapping paper. The system employs Interactive Evolutionary Computation, Natural Language Processing and Computer Vision techniques to establish a connection between user introduced concepts and the design pieces available in the system knowledge base and thus develop graphic patterns. We conducted a study with design experts to assess the quality of the solutions produced by the system and understand aspects related to originality, the influence of the references on the produced patterns and the impact of the constituent elements and composition on the design process. The results show that the system offers an alternative approach to creating novel wrapping papers that maintains a connection to the style of the reference designer. We have explored the importance of integrating historical design practices with contemporary tools to promote creativity and diversity in design outcomes.

Introduction

Creativity can be unpredictable, lacking a consensually accepted method within scientific research (Boden 2004). The inherent unpredictability often leads individuals to seek inspiration, engaging in lengthy processes to achieve the coveted epiphany. Defining limits and objectives, as well as visual exploration during the creative process, which motivates our most intuitive characteristics (Rolo 2015), can help structure thinking and the creation of new ideas. The process of designing graphic patterns can be viewed as an interesting task, allowing the exploration of infinite and versatile visual solutions within a controlled environment with rigid limits. These restrictions, both in terms of unit dimensions and functionality, considering the repetitive nature of patterns, challenge designers to find a balance between visual impact and functionality, stimulating ideation. In addition to this intersection between form and function, the process of making a pattern has an iterative nature, in which the unit is worked on first and then the overall pattern. Moreover, graphic patterns can be viewed from two different perspectives: as decorative elements with various application possibilities; but also as representations of a specific concept, resorting to multiple semiotic aspects.

In our technology-laden contemporary era, although the technical learning curve for post-digital designers has decreased, over the years, their creative thinking process has become more complex, with a tendency for designers to access only digital references (Lupton and Phillips 2008). This factor promotes a superficial exploration of references, given that our online behaviour is often used to influence the content shown, presenting increasingly specific choices adapted to what we have previously given our attention to (Weller 2019). According to Albert et al. (2004), the lack of inclusion of references in the design environment results in less use of old works as inspiration. Cultural awareness is essential for designers, and traditional sources can provide valuable knowledge to expand the solution possibilities (Shaughnessy 2005; Kunkhet and Chudasri 2022). By taking advantage of previous references, designers can explore different styles and techniques, referencing works from the past, which conceptually increases the value of their work and expands their conceptual space.

This paper presents *PatternPursuit*, a system that allows the development of innovative graphic patterns through collaboration between the computer and designers and interaction with pre-digital design work. This research aims to pose questions about originality and influence (Elgammal and Saleh 2015), i.e. the ability to produce creative results based only on elements of a single reference and to understand the degree of recognition of the initial references. Additionally, this research aims to foster a bridge between pre- and post-digital design, promoting the emergence of new design paradigms and processes that move away from current digital design movements. The aim of this research is that through semantic exploration and decomposition of pre-digital works, to transform them into a set of enriching design materials, it will be possible to create, among which, wrapping paper. Wrapping paper, often depicting graphic patterns, not only maintains a medium widely used by pre-digital designers (paper) but also offers a scale comparable to reference works. The approach implemented fosters a deeper understanding of the decisions of the reference designer, making it easier to analyse their most outstanding conceptual and visual characteristics. In this sense, this study aims to understand which aspect is more decisive in the final design, whether the constituent elements, which have been taken from design pieces previously defined as valuable, or the compositional work in their processing to obtain the final result.

As a case study, we used the work of Sebastião Rodrigues,[1] a pioneer in Portuguese graphic design, as a foundational exploration. Despite his modernist and universally orientated approach to design, his visual language is deeply rooted in Portuguese cultural content and references (Baltazar, Bártolo, and Rosa 2021; Cabral and Silva 1995; Fior 2005; Rolo 2015). As Rodrigues has a vast and versatile portfolio, presenting a variety of techniques, we can consider using his work as a proof of concept so that this system can later be prepared to deal with the work of other designers. Furthermore, this choice guarantees that, since the visual elements to be decomposed have already contributed to quality work, a possible lack of value in the created wrapping paper will not mainly be caused by the elements used.

Related Work

In this paper, we present an ideation and pattern creation system for wrapping paper that uses Interactive Evolutionary Computation, Natural Language Processing and Computer Vision techniques. As such, this section presents related work from the following topics: Graphic Pattern Analysis and Generation, Interactive Evolutionary Computation and Co-Creative Systems.

Graphic Pattern Analysis and Generation

Patterns have algorithmic compositions, even those that were designed hundreds of years ago followed rules of composition that can be applied by software (Reas and McWilliams 2010). Through the field of computational design, it is possible to develop a range of versatile patterns, from the most complex visual structure to the most minimalist (Reas and McWilliams 2010). Developing graphic patterns ends up being demanding, as it is not enough to draw freely, as there is the rigour of unit limits (Day 2013). By unit, we mean the matrix that makes up the graphic pattern. For this reason, approaches have been developed to analyse their structures (Valiente et al. 2004; Gomis et al. 2003), as well as generating patterns (Ostromoukhov 1998; Kunkhet and Chudasri 2022). Some plug-ins available for Adobe Photoshop and Adobe Illustrator make it possible to edit graphic design work using patterns (Gomis et al. 2003).

Analysing the units that compose a given pattern is an important step towards understanding which geometric transformations are appropriate for each unit. In this sense, Albert et al. (2004) developed a methodology for analysing units to detect their basic shape, which makes it possible to redesign the pattern from which the unit was taken, ensuring its continuity. The system has an architecture with two modules: one comprises two databases, one for acquisition and the other for pattern design; the second implements two tools for analysing and editing. Given this, the images are initially stored in the acquisition database and the analysis tool is executed to obtain the integral elements of the unit in vector form. In addition, the structure of the model is obtained and, together with the integral elements, is added to the Pattern Design Database. Finally, the pattern structuring is performed using an experimental Adobe Illustrator plug-in (Gomis et al. 2003).

Ostromoukhov (1998) presents mathematical tools for creating ornamental patterns, using Islamic patterns as a starting point. The system begins by analysing the design given by the designer, which will identify its repetitions. An analytical representation is then developed to obtain a unit that can serve as input for the pattern. The final pattern is obtained after various geometric transformations.

Having Persian floral patterns as inspiration, Hamekasi and Samavati (2012) developed a system that automatically generates patterns based on circle arcs and characteristic tangents. The composition of the circles is initially defined by the user, making it possible to establish the boundaries that will position the base spirals of the floral pattern. To do this, the system analyses the circle packing, finds the largest empty circle within the accessible limits and then invokes the elements close to that circle. Once the basic structure of the pattern has been defined, the ornaments are added.

The project developed by Kunkhet and Chudasri (2022) is based on generating patterns for tiles from traditional fabrics. Two methods of pattern generation are presented. The first consists of the structuring of patterns using an extract of a traditional fabric. In the second method, the architecture of the unit is analysed and then goes through a process of mapping and simplification. After this initial treatment of the unit, the pattern is developed.

Anderson et al. (2008) developed the *evoDesign* system which uses a genetic algorithm to develop tiles or, in other words, units to be used as decorative patterns on walls or floors. The tile contains simple graphic elements such as coloured horizontal and vertical stripes, circles, squares and rectangles. The user can evolve the tile by assessing its ability to meet the objective, considering each element mentioned, and manipulating its number, size, location, colour, and transparency.

Interactive Evolutionary Computation

Evolutionary Algorithms (EAs) are based on Darwin's Theory of Natural Selection (1831) and are considered stochastic direct search algorithms based on a population. One approach is Genetic Algorithms, which are based on the evolution of individuals belonging to a population whose aim is to survive and be used to build other possible solutions (Eiben and Smith 2015). Their quality is defined by a fitness function that assesses the individual's ability to fulfil an objective. These models are then implemented when there is a specific goal to achieve, allowing the quality of the results to be assessed (Bartz-Beielstein et al. 2014; Eiben and Smith 2015). However, when the objective or the quality criteria are subjective, as is the case when they depend on human perception and are influenced by prefer-

[1] Sebastião Rodrigues (Lisbon, 1929 - 1997) (Rolo 2015).

ences and past experiences, it is preferable to implement approaches that include the user as an evaluator in the evolution process (Parmee, Abraham, and Machwe 2008). This type of approach is called Interactive Evolutionary Computation (IEC).

The inclusion in the design process of approaches characterised by the generation of results is an asset since, as Martins (2021) points out, the randomness present in these systems enables an unpredictability of results that can promote the designer's creativity. This is because designers are presented with new possible solutions that can lead them down unexplored paths. The IEC is versatile in responding to problems, especially visual ones, and resulting in different kinds of output, such as anthropomorphic symbols that represent emotions (Dorris et al. 2004), symbols that match user preferences (Hiroyasu et al. 2008), typographic posters (Rebelo et al. 2018), visual blends that represent abstract concepts (Cunha 2022) and data visualisation artefacts (Maçãs 2021).

Co-creative Systems

Digital creativity support tools allow designers to explore new ideas, and sometimes through stimuli provided by intelligent systems that enable real-time collaboration. In recent years, there have been several examples of works in the area of computational creativity applied to design, dealing with problems such as the generation of posters or book covers, as is the case with the EvoDesigner system (Lopes, Correia, and Machado 2022).

Another application domain of computational creativity is co-creative sketching systems (Karimi et al. 2019b). Among these, we can highlight Drawing Apprentice (Davis et al. 2015), CICADA—a Collaborative, Interactive Context-Aware Drawing Agent (Ibarrola, Lawton, and Grace 2023), and Arny system, which is based on emotional feedback to respond to the human collaborator (Abdellahi, Maher, and Siddiqui 2020).

Drawing Apprentice starts by analysing the sketch presented by the user to identify drawn objects and then select a complementary object to display on the screen. The computational agent defines its creative actions based on the user's creative behaviour (Davis et al. 2015). CICADA, on the other hand, starts from a partial sketch provided by the user and develops it, adding or modifying features, also bearing in mind the target object. This process happens by employing a vector-based method of synthesis by optimisation (Ibarrola, Lawton, and Grace 2023).

The project developed by Karimi et al. (2019b), Creative Sketching Apprentice (CSA), is also an example of a co-creative design system and aims to support the design process. Through visual and conceptual similarity, the object to be included in the sketch is chosen and drawn on the screen by the computational agent; however, unlike Drawing Apprentice, this system uses a computational model of conceptual change rather than looking for solutions within the same conceptual category (Karimi et al. 2019a). The authors of the CSA consider this conceptual shift to be a strategy that allows designers to perceive their design ideas from different perspectives (Karimi et al. 2019b; 2019a).

Considering the existing work in the three fields related to this research, *PatternPursuit* represents a different approach, especially to graphic pattern generation. While existing systems focus on analysing and generating patterns, *PatternPursuit* stands out for its ability to explore concepts where there is no clear definition of them. This approach gives users greater control over the result. Moreover, this unconventional and collaborative process allows the exploration of the various layers of the work, motivating the creation of novel possibilities and serving as an ideation tool.

PatternPursuit

The *PatternPursuit* system generates graphic patterns based on the pre-digital work of the graphic designer Sebastião Rodrigues. Sebastião Rodrigues was a Portuguese designer who was a contemporary in the reinvention of international graphic languages, both at the design and market levels (Baltazar, Bártolo, and Rosa 2021). In addition to their often decorative uses, graphic patterns can also serve as illustrations when produced to represent a given concept. *PatternPursuit* explores this representation potential by combining user introduced concepts with the work of Sebastião Rodrigues. This intersection produces a visual summary using patterns that convey a message of typical uniqueness, almost as if they were caricatures, in this case, Portuguese caricatures, filtered through user concepts.

The current version of *PatternPursuit* is structured into five distinct modules (see Fig. 1): (i) the text handling; (ii) image selection; (iii) image decomposition; (iv) unit generation; and (v) pattern generation. The system's workflow across these modules is implemented in Python and Processing. This section describes the functionalities of each module.

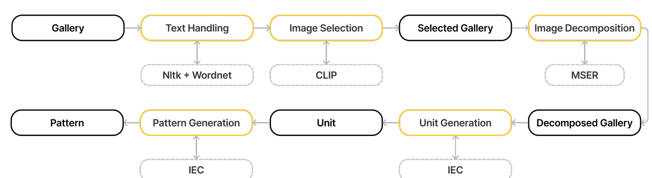

Figure 1: System workflow, showing the approaches used in each module.

Text Handling and Image Selection

The main aim of these two modules is to establish a semantic link between a concept given by the user and the gallery of design pieces available to the system, which, in this case, is composed of Sebastião Rodrigues' work. The system starts by analysing the user's text input, which consists of a word or list of words, and processing it to ensure it is appropriate to be used by the system. Afterwards, using NLTK (Bird, Loper, and Klein 2009), a Python open-source library of Natural Language Processing, and Wordnet (Princeton University 2010), a lexical database, the system searches for hypernyms, hyponyms, and synonyms, in order to create a semantic space around the word given by the user, which will enable conceptual search through the works in the Gallery. This information is also treated to guarantee that there are no unnecessary characters and is then compared to the works in the gallery using the CLIP model (Radford et al. 2021). Implementing CLIP allows an automatic and more conceptual selection of works, considering the level of similarity between the words in the semantic space defined by the user and the characteristics of the images in the gallery. This model employs a ViT-L/14 Transformer for image encoding and a masked self-attention Transformer for text encoding. It was trained to maximise the similarity between image and text pairs through contrastive loss (Radford et al. 2021). According to the resulting similarity probability level, the works are selected to move on to the next module, with the minimum probability being 0.65. To ensure that no work is repeated, for instance by having two words associated with a high probability, the system checks whether each image already exists in the new repository. If so, it replaces the selected keyword if its probability is higher than the current one.

Once the works have been selected based on the input word(s), a new set of works is presented to the user. Each work is presented together with the input word, the semantically selected word and the corresponding image, mediated by the similarity value obtained with CLIP. The user also has access to the concepts present in the defined semantic space. To provide a higher level of explainability, we used Llama 2, an open-source large language model that has been pre-trained and adjusted with 7 billion parameters (Touvron et al. 2023). This approach allows the user to obtain an explanatory text on the relationship between the input word and the related word used by the system, based on the definition of the latter. This approach was implemented using a standardised prompt[2] as input for the model, defined through empirical exploration.

From the presented images, the user is able to select the ones they want to explore further and, ultimately, use them to produce patterns. These images are given as input to the next module.

Image Decomposition

This module is responsible for decomposing the images into elements. These elements can be typography, regular or irregular shapes, textures, lines, etc. Decomposition promotes the exploration of the different layers in design works, allowing designers to almost reverse the creative process and access information that may otherwise be unclear. An important aspect of this research is the fact that the main material used is analogue and had to be digitised, which means that the quality of the input images is lower than digital ones. To overcome this problem, the first step in this module is to treat the quality of the images. Using the open-source OpenCV library, the image is first converted into RGB colour space, reshaped into a vector and subjected to K-Means clustering to obtain the dominant colours (Dhanachandra, Manglem, and Chanu 2015). This approach serves to reduce possible grain due to the digitisation of the work.

After applying the techniques to improve image quality, the image is subjected to an object detection process. As we are working with an extensive range of works with different characteristics and techniques, it was necessary to combine different techniques to maximise the number of elements detected. To this end, the image is subjected to binary inverse thresholding using the Otsu method and a variant thresholding approach (Otsu 1979). To identify regions of interest in the segmented images, the MSER (Maximally Stable Extremal Regions) detector is used in both approaches. This detector is capable of locating stable and distinct regions (Matas et al. 2004). In addition, the analysis is extended to the different colour channels, considering primary and secondary colours. All the regions detected in the various approaches implemented are aggregated into a single set of regions.

The final part of this module consists of detecting the contours of the region in the original image and applying a clipping mask so that it has a transparent background. To filter out irrelevant elements, the system applies a set of criteria, considering regions that adhere to predefined area constraints and bounding box dimensions. To determine the appropriate limits for the area and bounding box dimensions, we calculated the area of a small sample of acceptable regions. This calculated average served as a benchmark for defining the permissible size parameters, ensuring that only regions with comparable characteristics are retained for further exploration. Additionally, another criterion is the ratio between the area of a region and the area of the enclosing bounding box. Essentially, the system prioritises regions with a larger area covered by the bounding box, indicating a more substantial presence within the element. However, even if these elements are not good enough to pass the set conditions, there is a 10 per cent chance of including them anyway. This allows the user to work with some abstract elements that may prove interesting to use in the final pattern. Once the requirements described have been checked, the element goes through a filtering process, ensuring no other structurally similar element exists. This comparison is made using the Image Similarity Measures approach with the Structural Similarity Index (SSIM) evaluation metric (Müller et al. 2020). Another requirement was that each image has a maximum of 100 associated elements as final results. This is due to two factors: (1) to avoid images with too many elements taking too long to be analysed; (2) to slightly reduce the number of elements the user can work with, so that they can explore all the combination possibilities in a reasonable amount of interaction time.

In terms of the interface (see Fig. 2), the user is presented with the original work and the decomposed elements. This approach allows the user to understand where the elements presented come from, as well as maintain the information provided in the previous module about the selected words and their respective information. In this way, the user has access to the process carried out by the system so far, promoting trust in the machine.

[2]"Give me, in British English, a short explanation of how the word 'inputword' is related to the word 'keyword', following the definition of the word 'keyword'."

Figure 2: Decomposition page. Left: the original works, the concept introduced, and the word semantically selected. Right: the decomposed elements.

Unit and Pattern Generation

These two modules consist of two similar evolutionary processes for generating units and graphic patterns, and they have two agents each: an evaluator (user) and a solution generator (system). This approach is inspired by the standard Evolutionary Algorithm, in which a population of individuals, represented by units and patterns, goes through successive generations of evolution. The main objective is to explore the vast design space of these elements' compositions and converge on creative solutions. In this section, we explain the fundamental components of the genetic algorithms implemented, highlighting the functionalities of both modules.

After the decomposition, the elements extracted serve as input to the evolution of the pattern unit. To obtain the best possible results in the development of the final pattern, it was necessary to define a set of restrictive rules that would make the combination of the units richer. As mentioned by Wong (1993), the singular form contributes to constructing the plural form. Depending on the internal and/or external variation, the result will be different. In other words, the units could touch, overlap, join or remain separate. Following this reasoning, we established that the unit would be based on a square grid and that the selected elements had to take up as much space as possible when aligned. For this to happen, we created a relationship between the number of elements, the number chosen by the user (between 1 and 6), their size, the relative scale between them and the size of the square. To guarantee that the elements are positioned evenly on the grid when there are three or more elements, the following rules were defined: 1/3 must be positioned in the right half (with a 50 per cent chance of being in the first or third quadrants); 1/3 must be positioned in the left half (with a 50 per cent chance of being in the second or fourth quadrants); 1/3 must be close to the edges so that interaction between units is more likely. An important detail to mention is that although the grid is a square, the elements are not restricted by its boundaries, since when exported, they are saved with a border around them to ensure that the elements are not cut off and can interact with the repeated unit to create more interesting results.

Geometric transformations turn out to be one of the bases for structuring a pattern (Reas and McWilliams 2010; Wong 1993). The most typical transformation is translation since the movement of objects in a structure becomes a fundamental aspect in the development of a pattern. Rotation and reflection are other common geometric transformations, giving them a variety of options about the other units. Scale or dilation is also a possible approach, but this is not easy to apply in practice, and there are few examples of this approach in everyday life (Reas and McWilliams 2010).

Another aspect of producing patterns is composition. According to Wong (1993), the simplest is a two-way continuity, which means that the unit is repeated depending on a line. This line does not have to be straight but can be adapted to a desired shape, for instance, by making a slight curve. From here, when this line is repeated in parallel, even if the two-way continuity structure is on the diagonal, the pattern formed is called four-way continuity. As different compositions exist (e.g. four-way or six-way continuity), to guarantee that all patterns would work well, we defined 16 structure versions, combining different geometric transformations such as translation (taking into account horizontal, vertical and diagonal axes), reflection (considering horizontal and vertical axis) and rotation (of 30º, 45º and 90º).

Considering that these modules aim to evolve the units and patterns, we chose to differentiate the size of the populations in each one. This can be explained by using an adaptation of the Diverge / Converge methodology as inspiration (Dubberly 2004). According to Dubberly (2004), many designers claim to break the problem down into parts by decomposing it, i.e. diverging, to analyse and then synthesise it. These steps allow the parts obtained to be reorganised and recombined when convergence occurs. Transferring this reasoning to the system (see Fig. 3), when users start interacting with the gallery and search for a word, they converge on a theme. However, as the search is semantic, the system expands the available options (divergence) and returns semantically related works (convergence). Once the user has selected and decomposed the works, they have all the components needed to evolve the units. In this sense, having a larger population is more effective, as it allows several compositions to be explored simultaneously because the number of elements can be significant (divergence). Then, once the unit(s) of the pattern are defined, the range of options becomes smaller, and there is no need to have more than three individuals. From here, the pattern evolves, with the aim being to converge on what will become the wrapping paper.

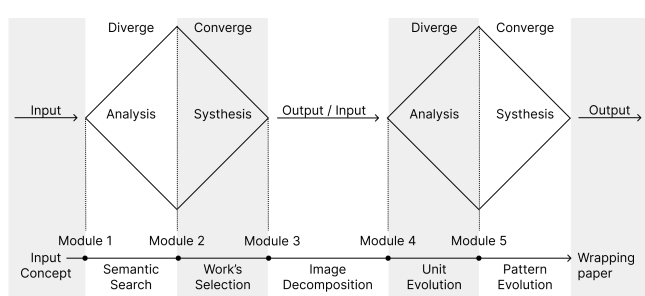

Figure 3: Adaptation of Diverge / Converge by Dubberly (2004).

Evolution Overview To generate both units and patterns, the system uses a genetic algorithm that initially generates a population and then evolves it based on the user's evaluation. This strategy preserves the characteristics of the units/patterns favoured by the user, influencing the trajectory of the evolving population.

The genotype of each candidate solution is a sequence of parameters set that encodes the unit's design and the pattern. In the case of the unit, this is influenced by the grid, the number of visual elements defined, the chosen elements, their resulting relative size, and the positions they adopt. The input elements are those resulting from the decomposition in module 3. Conversely, the pattern is influenced by the grid, the chosen visual element and the structure. In this case, the visual elements are obtained from the units exported by the user in module 4. Phenotypes represent a visual interpretation of the genotype, i.e. the component generated based on the parameters encoded by the genotype. The expression process involves creating a graphic unit/pattern that corresponds to what has been defined in the genotype.

The process begins with the generation of a population of individuals with random genetic information, composed of, in the case of units, visual elements and spatial organisation, in the case of patterns, unit and pattern structure. Subsequently, the individuals are evaluated by the user and selected, depending on their fitness, for recombination and mutation. This retention of the individuals with the best fitness, known as the elite, helps to preserve the structuring characteristics that will be transferred unchanged to the next generation. The recombination strategy is used to guarantee the diversity of the offspring by exchanging genetic information. The tournament selection mechanism is fundamental in choosing the parent pieces for the crossover in the recombination process. A set of pieces is shown at random and the fittest individual is selected as the parent. To introduce variability and avoid premature convergence, mutation operators are applied. Employing mutation introduces controlled randomness, allowing unknown design possibilities to be explored. This stochastic approach increases diversity and prevents the algorithm from converging prematurely.

Archive and Expansion Features The archive functionality in both modules acts as a repository so that users have the opportunity to save individuals they find interesting to explore later. This functionality has two main reasons for being included: (i) since it guarantees the preservation of solutions that may not be generated again, it ensures that exploratory paths of interest are not lost; (ii) it makes it possible to combine different individuals with different characteristics at any moment of interaction, both between individuals in the archive and between those in the main population and those in the archive.

Another key factor of this system is the expanded feature. Both modules allow the user to see an enlarged version of what they are developing, which helps them get a sense of the whole picture. In the unit case, the user can immediately access a rudimentary pattern version to understand how the elements will interact with each other. During the pattern's evolution, the user can access a larger version of the pattern to get closer to what will be applied in the final medium.

Experimentation

To critically analyse the system's components, methods and results, we carried out an expert evaluation, benefiting from the experience and expertise of the participants. This section describes the tests conducted, the results obtained and the conclusions.

Setup

Two test phases were conducted. These were semi-structured, the first consisting of five tasks and the second of three. In the first phase, four of the five tasks consisted of interacting with each of the system's modules, while the fifth consisted of answering a form with 17 questions. In this form, 13 experts were asked to evaluate the usefulness and effectiveness of each module, rate the final wrapping paper based on its originality/typicality and value, and assess the system's ability to serve as an ideation tool. In the second phase, the first two tasks involved interacting with the first two modules, and the third involved answering a form with seven questions. Four of the 13 experts involved in the first phase took part in the second, which aimed to assess the effectiveness of the Llama 2 integration (Touvron et al. 2023). To get an overview of the participants, characteristics such as age, gender, profession, and experience were analysed.

Age The average age of the participants was 41. Of the 13 experts, the majority (6) were aged between 30 and 39, followed by 4 participants aged between 40 and 49. Two experts were aged between 50 and 59 and one participant was aged 60 or over.

Gender Concerning gender, there was a slight male predominance, with 9 male and 4 female participants.

Profession All the participants were active professionals in the design field, with 5 being cross-media designers and 8 being graphic designers, 3 of whom were senior designers. Of these 13, 9 were also university professors, 7 of whom had a PhD, 2 were artistic/creative directors, and 1 was also an architect.

Years of Experience The participants' professional experience varied considerably, with an average of 18 years of experience in the design field. One participant had 9 or fewer years of experience, while 6 had between 10 and 19 years of experience. Another 4 participants had between 20 and 29 years of experience, and 2 participants had 30 or more years of experience.

Results

First phase The average results of the answers obtained reveal an overall positive evaluation of the system by the participants. Most of the experts showed familiarity with Sebastião Rodrigues' work, with the average score for this evaluation item being 4.3 from 1 to 5, with a mode and median of 4. This score suggests a prior recognition of the context in which the system is inserted, which can positively influence the understanding and evaluation of the functionalities implemented.

Considering the effectiveness of the image decomposition module, it received an average score of 3.9, with the mode and median being 4. This assessment indicates that the system was able to decompose the works adequately and effectively. Still, there may be areas where the accuracy or extent of the decomposition could be improved. The system sometimes includes visual elements that end up not being visually interesting.

The system's ability to allow personalised exploration of the units received an average score of 4.2, with a mode and median of 4. This score suggests that users felt empowered to manipulate and adjust the units according to their preferences and needs. The interface for creating units and patterns was evaluated with an average score of 4.1 and 4, respectively, with a mode of 5 and a median of 4 in both cases. This reflects a generally positive experience in terms of usability.

The use of the archive during unit and pattern creation was considered useful, receiving an average score of 4.9 and 4.5, respectively, with a mode and median of 5 in both cases. We can, therefore, conclude that access to the archive during the creation process was an asset. The difference in scores can be explained by the fact that in the process of exploring the unit, the archive ends up becoming more beneficial as it is a divergent stage, where the solution space and level of exploration are more significant. The Expanded mode during the creation of the unit and the pattern received an average score of 4.5 and 4.9, respectively, and a mode and median of 5 in both cases. This suggests that the Expanded mode provided a more comprehensive and detailed view, helping users to make decisions during the creation process. Since, in the unit module, the Expanded mode offers a rudimentary version of the pattern, ultimately not reflecting the unit's full potential, it may discourage experts from using the functionality or not finding it as useful. This can be solved by including various random formats so the user can analyse different structures whenever they want a more comprehensive view of the unit.

Considering the wrapping paper as the final destination for the patterns, the participants gave an average score of 4.4, with a mode and median of 4. Regarding the balance in the final pattern between novelty and reference to the original work, the average score was 3.5, with a mode and median of 4. These results suggest the value and tendency for a balance between novelty and recognising references. However, the average score of 3.2, with a mode and median of 4, for recognising Sebastião Rodrigues' authorship in the final patterns indicates less emphasis on the impact of the source of the elements used.

The ideation factor obtained an average score of 4.2, with a mode and median of 4, which shows the system's effectiveness in promoting new ideas and creativity. This can be justified by the fact that the system is made up of several modules that help the user understand and explore the reference work, opening up their solution space.

Most participants considered the initial semantic search relevant, although it received an average score of 3.5 with a mode and median of 3. This suggests that although the semantic approach works, there is still room to improve the accuracy and effectiveness of the results. Regarding the selection of works based on the resulting word, the score was positive at 3.9, with a mode and median of 4.

Second Phase To understand the negative tendency in semantic search and its relationship with images, possible reasons were identified. Firstly, given that WordNet provides a semantic space of words that are conceptually interconnected with the input word, as in the case of "blue", resulting in "amytal", a blue pill, experts have shown that they do not fully understand the relationship between the selected words. In addition, sometimes the experts did not immediately know what the resulting word meant, which caused some discomfort. This lack of understanding may be because English is the mother tongue of only one of the experts. Moreover, the relationship between the text and the image was sometimes not evident regarding more abstract concepts. This may be because we were cross-referencing a collection of works in Portuguese with a database in English.

Taking these aspects into account, a second test phase was then conducted, in which Llama 2 was used as a way of accessing the definition of the resulting word and a possible justification of the relationship between it and the searched word. This test showed that when users have access to more information, the perception of the semantic search result improves. In this parameter, the average score was 4.5, with a mode and median of 4 and 4.5, respectively. Regarding helping to establish the relationship between the text and the image, the average, the mode and median were 3.

General Discussion Considering the results obtained regarding the balance between novelty and reference and the level of recognition of Sebastião Rodrigues' work, we can say that they indicate a balance between both factors, although more inclined towards novelty. Establishing a bridge with the importance of the presence of typicality discussed by Ritchie (2007), the balance between novelty and "Rodriguesness", i.e. the typicality/level of recognition of the work present in the pattern, guarantees that they are recognisable in a specific context.

One possible reason for the results showing less emphasis on recognising references is that two types of objectives were detected when using the system. On the one hand, we observed that some users used the system intending to explore Sebastião Rodrigues' work, showing a reluctance to deviate from its themes. On the other hand, some users adopted a more exploratory stance, basing themselves on concepts they found interesting, regardless of whether they aligned with Rodrigues' themes. By grouping the experts into these two groups, taking into account the input words, it was possible to see that the first group scored higher on their level of knowledge of Sebastião Rodrigues' work, as well as on the relevance of semantic search, the text-image relationship and also on recognising the designer in the final pattern. This first group consisted of older participants (average age 46), more experienced (average of 21 years' experience) and predominantly specialised in Graphic Design. The second group included younger users (average age 36), less experienced (average age 14) and more specialised in Cross-Media Design. This data may suggest that the level of recognition can be influenced by the user's intention to honour the artist's legacy, their willingness to explore new possibilities, and their knowledge of the work.

When confronting the duality between the elements of reference and process in the Design area, it is essential to recognise the importance of both. Although the recognition of references could be more precise, it still has a positive evaluation, which shows that it is a determining factor in the final result. However, we can conclude that it tends to be the compositional process that transforms visual elements into something new. With its ability to catalyse transformation, the compositional process can be the most decisive element in creating graphic patterns. This finding highlights the interdependent nature of the creative process, where references and processes work together to produce results that transcend the individual parts.

Finally, we can conclude from the results that the *PatternPursuit* is an effective ideation tool. The approach to searching and selecting works centred on the semantic value of both components is more conceptual. It provides a deeper understanding, a more detailed analysis of the selected works, and a more personalised development of graphic patterns. The system makes it possible to develop creative solutions by exploring design work that has already been recognised as valuable, even when working with the same unit (see Fig. 4). Although novel, these results maintain a tangible link to the style of the reference designer.

Comparing *PatternPursuit* with other systems such as *Leonard.AI*[3], *Bing Image Creator*[4], *Stable Diffusion* (Rombach et al. 2022) and *DALL-E 2* (Ramesh et al. 2022), it stands out in several characteristics that directly affect the relevance of the graphic patterns generated. As seen in Fig. 5, *PatternPursuit* offers patterns with a well-defined modular structure. This means that the resulting patterns have a visual consistency, avoiding random or disconnected results that do not fit the definition of a visually recognisable pattern, as is the case with the above systems. Another advantage of *PatternPursuit* is its direct relationship with the reference work. Unlike the systems mentioned above, *PatternPursuit* not only provides the user with an exploration of works with assumed value but also guarantees a stylistic continuity and homage to the artist's work that other systems cannot replicate. *PatternPursuit* also demonstrates a more transparent creative process, allowing users to understand where the elements used to create the patterns come from. Whereas in other systems, we only have access to the result, *PatternPursuit* offers a level of control and understanding that allows users to monitor, adjust and influence the creative process more directly, contributing to a personalised exploration of the patterns. This ability to intervene results in more adapted and valuable patterns for users, unlike other systems that can offer more standardised and inflexible results.

Conclusions and Future Work

Human-computer co-creative systems are gaining prominence as tools for promoting creativity. Since there is a tendency to rely on highly biased digital references, exploring them becomes superficial. *PatternPursuit* responds to this need, taking advantage of both pre-digital design and the potential of contemporary computing.

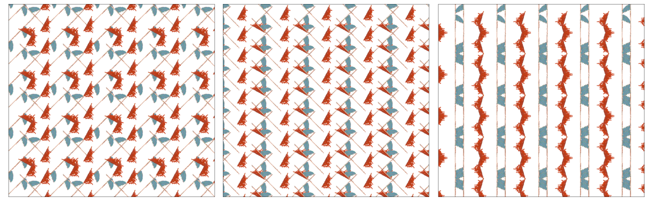

Figure 4: Wrapping paper created by a user with *PatternPursuit*, using the same unit, in which the concept introduced was "Freedom".

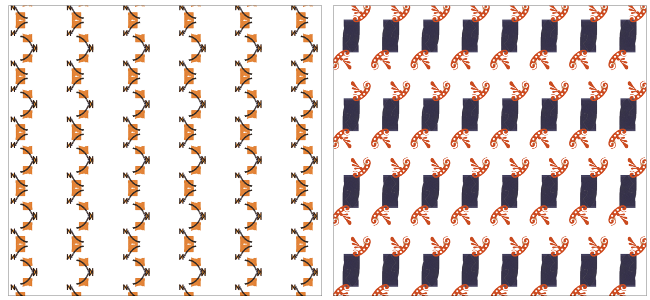

Figure 5: Wrapping paper created by users using *PatternPursuit*. On the left the concept introduced was "Sun" and on the right was "Portugal".

PatternPursuit has proved capable of generating creative and valuable graphic patterns through collaboration with designers. Given its exploratory nature, it has also proved useful in the ideation process, offering a wide range of creative possibilities while maintaining a tangible connection with the style of the reference designer. Its basis in Sebastião Rodrigues' work, a pioneer of Portuguese graphic design, provided a solid starting point for exploring new creative possibilities. However, given the approaches used, the system's applicability can be extended to various other designers. This research contributes to a deeper understanding of the design process, showing that although the composition process tends to be the most impactful, a set of references with graphic quality positively influences the final result.

Future work will involve (1) deconstructing the language barriers and making better use of Llama 2 to promote transparency; (2) improving the decomposition into elements using machine learning; (3) increasing the number of parameters the user can influence and the machine's decision-making power.

Acknowledgements

This work is funded by the FCT - Foundation for Science and Technology, I.P./MCTES through national funds (PIDDAC), within the scope of CISUC R&D Unit - UIDB/00326/2020 or project code UIDP/00326/2020; and also supported by the Portuguese Recovery and Resilience Plan (PRR) through project C645008882-00000055, Center for Responsible AI.

[3]https://leonardo.ai

[4]https://www.bing.com/images/create

References

Abdellahi, S.; Maher, M. L.; and Siddiqui, S. 2020. Arny: A co-creative system design based on emotional feedback. In *ICCC*, 81–84.

Albert, F.; Gomis, J. M.; Valor, M.; and Valiente, J. M. 2004. Methodology for Graphic Redesign Applied to Textile and Tile Pattern Design. In Orchard, B.; Yang, C.; and Ali, M., eds., *Innovations in Applied Artificial Intelligence*, Lecture Notes in Computer Science, 876–885. Berlin, Heidelberg: Springer.

Anderson, C.; Buchsbaum, D.; Potter, J.; and Bonabeau, E. 2008. Making Interactive Evolutionary Graphic Design Practical. In Kacprzyk, J.; Yu, T.; Davis, L.; Baydar, C.; and Roy, R., eds., *Evolutionary Computation in Practice*, volume 88. Berlin, Heidelberg: Springer Berlin Heidelberg. 125–141. Series Title: Studies in Computational Intelligence.

Baltazar, M. J.; Bártolo, J.; and Rosa, V. 2021. *Designers Portugueses (Vols. 3–Sebastião Rodrigues)*. Cardume.

Bartz-Beielstein, T.; Branke, J.; Mehnen, J.; and Mersmann, O. 2014. Evolutionary algorithms. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery* 4(3):178–195.

Bird, S.; Loper, E.; and Klein, E. 2009. *Natural Language Processing with Python*. O'Reilly Media Inc.

Boden, M. 2004. *The Creative Mind: Myths and Mechanisms (Second Edition)*. London: Routledge.

Cabral, M. d. C., and Silva, M. d. C. M. d. 1995. *Sebastião Rodrigues Designer.* Fundação Calouste Gulbenkian.

Cunha, J. M. 2022. *Generation of Concept-Representative Symbols*. Ph.D. Dissertation, Universidade de Coimbra.

Darwin, C. 1831. *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*, volume 11859. London: John Murray.

Davis, N.; Hsiao, C.-P.; Singh, K. Y.; Li, L.; Moningi, S.; and Magerko, B. 2015. Drawing apprentice: An enactive co-creative agent for artistic collaboration. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*, 185–186.

Day, L. F. 2013. *Pattern design*. Courier Corporation.

Dhanachandra, N.; Manglem, K.; and Chanu, Y. J. 2015. Image Segmentation Using K -means Clustering Algorithm and Subtractive Clustering Algorithm. *Procedia Computer Science* 54:764–771.

Dorris, N.; Carnahan, B.; Orsini, L.; and Kuntz, L. 2004. Interactive evolutionary design of anthropomorphic symbols. In *Proceedings of the 2004 Congress on Evolutionary Computation (IEEE Cat. No.04TH8753)*, volume 1, 433–440 Vol.1.

Dubberly, H. 2004. How do you design: A compendium of models. San Francisco, CA: Dubberly Design Office.

Eiben, A., and Smith, J. 2015. *Introduction to Evolutionary Computing*. Natural Computing Series. Berlin, Heidelberg: Springer Berlin Heidelberg.

Elgammal, A., and Saleh, B. 2015. Quantifying creativity in art networks. *arXiv preprint arXiv:1506.00711*.

Fior, R. 2005. *Sebastiäo Rodrigues and the development of modern graphic design in Portugal*. doctoral Thesis, The University of Reading. Department of Typography and Graphic Communication.

Gomis, J. M.; Valor, M.; Albert, F.; and Contero, M. 2003. Intregated system and methodology for supporting textile and tile pattern design. In *Smart Graphics: Third International Symposium on Smart Graphics, SG 2003 Heidelberg, Germany, July 2–4, 2003 Proceedings 3*, 69–78. Springer.

Hamekasi, N., and Samavati, F. 2012. Designing persian floral patterns using circle packing. In *GRAPP/IVAPP*, 135–142. Citeseer.

Hiroyasu, T.; Tanaka, M.; Ito, F.; and Miki, M. 2008. Discussion of a crossover method using a probabilistic model for interactive genetic algorithm. In *SCIS & ISIS SCIS & ISIS 2008*, 1055–1060. Japan Society for Fuzzy Theory and Intelligent Informatics.

Ibarrola, F.; Lawton, T.; and Grace, K. 2023. A collaborative, interactive and context-aware drawing agent for co-creative design. *IEEE Transactions on Visualization and Computer Graphics*.

Karimi, P.; Grace, K.; Davis, N.; and Maher, M. 2019a. Creative sketching apprentice: Supporting conceptual shifts in sketch ideation. In *J. Gero (eds) Design Computing and Cognition '18. Springer, Cham.*

Karimi, P.; Maher, M. L.; Davis, N.; and Grace, K. 2019b. Deep Learning in a Computational Model for Conceptual Shifts in a Co-Creative Design System. arXiv:1906.10188 [cs, stat].

Kunkhet, A., and Chudasri, D. 2022. Developing Design Approaches for Tile Pattern Designs Inspired by Traditional Textile Patterns. *Processes* 10(12):2744. Number: 12 Publisher: Multidisciplinary Digital Publishing Institute.

Lopes, D.; Correia, J.; and Machado, P. 2022. Evodesigner: Towards aiding creativity in graphic design. In *International Conference on Computational Intelligence in Music, Sound, Art and Design (Part of EvoStar)*, 162–178. Springer.

Lupton, E., and Phillips, J. C. 2008. *Graphic Design: The New Basics*. Princeton Architectural Press.

Martins, T. F. d. S. 2021. *Automated Evolution for Design*. doctoralThesis, Universidade de Coimbra.

Matas, J.; Chum, O.; Urban, M.; and Pajdla, T. 2004. Robust wide-baseline stereo from maximally stable extremal regions. *Image and Vision Computing* 22(10):761–767. British Machine Vision Computing 2002.

Maçãs, C. S. H. 2021. *Time-Series Visualization: Highlighting Patterns and Deviations*. doctoralThesis, Universidade de Coimbra.

Müller, M. U.; Ekhtiari, N.; Almeida, R. M.; and Rieke, C. 2020. Super-resolution of multispectral satellite images using convolutional neural networks. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* V-1-2020:33–40. Conference Name: XXIV ISPRS

Congress, Commission I (Volume V-1-2020) - 2020 edition Publisher: Copernicus GmbH.

Ostromoukhov, V. 1998. Mathematical tools for computer-generated ornamental patterns. In Hersch, R. D.; André, J.; and Brown, H., eds., *Electronic Publishing, Artistic Imaging, and Digital Typography*, Lecture Notes in Computer Science, 193–223. Berlin, Heidelberg: Springer.

Otsu, N. 1979. A Tlreshold Selection Method from Gray-Level Histograms. *IEEE Transactions on Systems, Man, and Cybernetics* 9(1):62—-66.

Parmee, I. C.; Abraham, J. A.; and Machwe, A. 2008. User-centric evolutionary computing: Melding human and machine capability to satisfy multiple criteria. In *Multiobjective Problem Solving from Nature: From Concepts to Applications*. Springer. 263–283.

Princeton University. 2010. About wordnet. WordNet. Princeton University. https://wordnet.princeton.edu [Accessed: 2024/01/18].

Radford, A.; Kim, J. W.; Hallacy, C.; Ramesh, A.; Goh, G.; Agarwal, S.; Sastry, G.; Askell, A.; Mishkin, P.; Clark, J.; Krueger, G.; and Sutskever, I. 2021. Learning Transferable Visual Models From Natural Language Supervision. arXiv:2103.00020 [cs].

Ramesh, A.; Dhariwal, P.; Nichol, A.; Chu, C.; and Chen, M. 2022. Hierarchical Text-Conditional Image Generation with CLIP Latents. arXiv:2204.06125 [cs].

Reas, C., and McWilliams, C. 2010. *Form+ Code: in design, art, and architecture*. Princeton Architecturel Press.

Rebelo, S.; Fonseca, C. M.; Bicker, J.; and Machado, P. 2018. Experiments in the development of typographical posters. In *6th Conference on Computation, Communication, Aesthetics and X*.

Ritchie, G. 2007. Some Empirical Criteria for Attributing Creativity to a Computer Program. *Minds and Machines* 17(1):67–99.

Rolo, E. d. J. R. 2015. *Olhar, jogo, espirito de serviço*. doctoral Thesis, Universidade de Lisboa. Faculdade de Arquitetura.

Rombach, R.; Blattmann, A.; Lorenz, D.; Esser, P.; and Ommer, B. 2022. High-Resolution Image Synthesis With Latent Diffusion Models. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, 10684–10695.

Shaughnessy, A. 2005. *How to be a Graphic Designer, Without Losing Your Soul*. Laurence King Publishing.

Touvron, H.; Martin, L.; Stone, K.; Albert, P.; Almahairi, A.; Babaei, Y.; Bashlykov, N.; Batra, S.; Bhargava, P.; Bhosale, S.; et al. 2023. Llama 2: Open foundation and fine-tuned chat models. *arXiv preprint arXiv:2307.09288*.

Valiente, J.; Albert, F.; Carretero, C.; and Gomis, J. 2004. Structural description of textile and tile pattern designs using image processing. In *Proceedings of the 17th International Conference on Pattern Recognition, 2004. ICPR 2004.*, volume 1, 498–503 Vol.1. ISSN: 1051-4651.

Weller, A. J. 2019. Design Thinking for a User-Centered Approach to Artificial Intelligence. *She Ji: The Journal of Design, Economics, and Innovation* 5(4):394–396.

Wong, W. 1993. *Principles of Form and Design*. John Wiley and Sons, Inc.