DIY Bertin Matrix

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Abstract
In this paper, we relate the iterative fabrication of a physical Bertin Matrix. Jacques Bertin designed and refined such devices over 10 years (1970–1980) and five iterations of what he called Dominos 1–5. For the purpose of an exhibit dedicated to Bertin's work during VIS 2014 in Paris, we designed an improved version of such device by leveraging modern fabrication possibilities and in particular a laser cutter. We describe the process, iterations and improvements of our matrix, and report lessons we learnt.

Author Keywords
Physical visualization, Physical matrix, Bertin matrix, Bertin exhibit.

Context and Motivations
The project of building a reproduction of Bertin matrices was in the context of the Bertin exhibit [5] (Figure 1) which was set up during the IEEE VIS 2014 conference in Paris.

For Jacques Bertin, many data analysis questions start with a two-dimensional numerical table: one dimension as rows, the other as columns. In Semiology of Graphics [3], he gives a taxonomy of data dimensions, of which one criteria is whether a dimension is reorderable. For example, if a dimension is time, one usually wants to preserve its natural order: it is not reorderable.

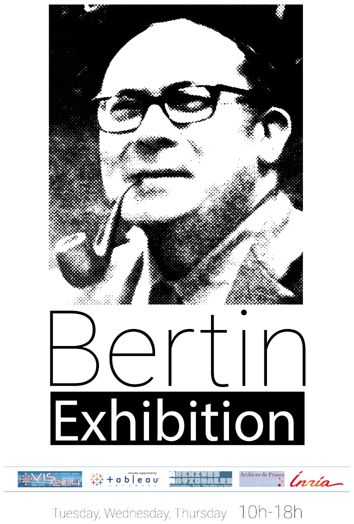

Figure 1: The Bertin exhibit took place during VIS 2014 in Paris.

Figure 3: Manipulation of a physical matrix, Serge Bonin.

When both dimensions are reorderable, the appropriate visualization is a matrix, i. e. a table where cell values are encoded visually. For Bertin, the matrix was the most general and clearly the most important visual construction.

The key idea behind the methods he used for more than 15 years [2, 4] (in the 70's–80's) is that visual representations should be rearrangeable to reveal patterns: *"this point is fundamental. It is the internal mobility of the image that characterizes the modern Graphique. We do not "draw" an image once for all. We "build" it and rebuild it (we manipulate it) until all hidden relationships have been perceived."* While he did not have access to computers at this time, he already figured out that interaction was at the heart of visualization.

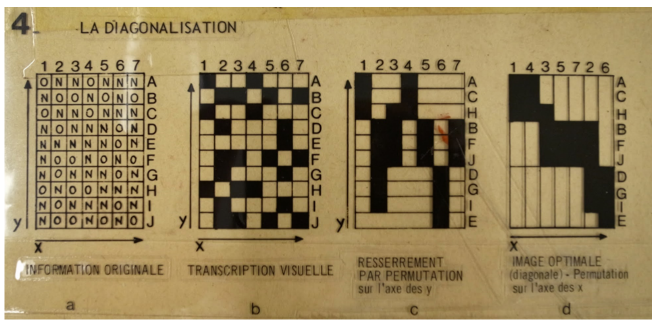

Figure 2: Bertin's famous "Towns" dataset.

Figure 2 shows the famous "Towns" dataset from Bertin that illustrates the method. He first built a table, here a binary one, with towns in rows and characteristics in columns (a); then, he encoded each cell according to its value, yes being black and no being white (b); then he reordered rows by visual similarity (c); and finally he reorders columns (d). At the very end, he annotated the table and analyzed the results, correlations, and groups.

Reordering was clearly the most crucial but also the most time-consuming part of the matrix visualization process. In 1968, Bertin and his colleagues started to design a mechanical device that would facilitate reordering: the reorderable matrix.

Resurrecting the Reorderable Matrix

The reorderable matrix, illustrated in Figure 3, consisted in separate plastic cells, and a rod mechanism for reordering them across either rows and columns. The device underwent successive refinements up to the 80s, was sold to other French labs, and even used in schools.

Bertin nicknamed his reorderable matrices "dominos". He designed and built five versions, each with a different size and visual encoding. He also explains the general workflow involved in using them. First, an initial numerical paper table was made. Then, cell values were converted into discrete steps on another table. The physical matrix was then assembled by choosing among a collection of physical cells that encode different ranges of values. Then, the matrix was reordered. This stage is the most fundamental one and was performed visually, using what Bertin called the "Painter's eye" [1]. Finally, meaningful groups were identified and named. The result was then photographied or photocopied, and the final image was used as a figure in the scientific publication or textbook.

Bertin's physical matrices underwent several computer adaptations and progressively ceased to be used [8]. While computers can dramatically accelerate the reordering process, physical matrices provide unique affordances that can be beneficial in educational or museum settings, and that may support a deeper engagement with data [6]. One drawback with Bertin's original physical matrices is that they were only accessible in a few labs and schools in

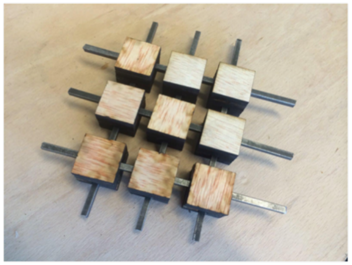

Figure 4: The first plywood prototype.

Figure 5: The second prototype, built using a 3d printer.

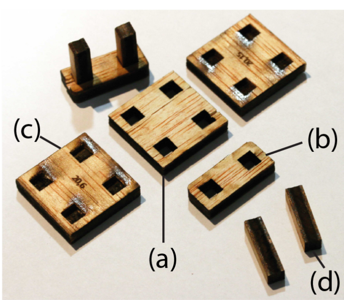

Figure 6: The wooden pieces of the last prototype: (a) central support, (b) rod guides, (c) encoded caps, (d) assembling bars.

France and thus could not be widely adopted.

Based on existing variations of dominos, we designed a new version using modern fabrication tools, keeping in mind that this modern version should feature new characteristics that the original ones did not have. In particular, we wanted the matrix to be i) low-cost, while the ones Bertin built were extremely expensive; ii) accessible to many people, while the original ones had to be ordered and built by industrials; and iii) easy to manipulate, while the original ones were difficult to operate and the pieces too small. Thus we provide a design that anyone in the world who has access to digital fabrication facilities can reuse at low cost.

Matrix Iterative Design

Our first attempt to make dominos consisted in making the different layers out of plywood using a laser cutter, and glueing parts together to obtain the final domino (see Figure 4). However, this process turned out to be unadapted since parts would often be misaligned, causing irregularities in the matrix and excessive friction of the rods.

We then tried to use 3D printing to achieve more consistency in the fabrication process, as illustrated in Figure 5. Yet, the printing time was about an hour per domino which we considered excessive.

We finally decided to switch back to laser cutting. We came up with a design allowing us to assemble the domino without using glue. It consists of 11 parts, illustrated in Figure 6: one central support, four guides to create the slide slots for the steel rods, two caps where encoding are engraved, and four bars to hold all the parts together. We created several version of each piece in order to assess the best configuration. The main parameter to optimize was the size of the holes in dominos where the rods fit. Indeed, a too small hole would make it difficult to remove and insert the rods, while a too large one would make the matrix too unstable. Finally, we opted for very small holes, ensuring a solid matrix but requiring to sand and sharpen all rods to ensure a smooth manipulation.

We finally added small magnets to be able to change the encoding of each domino (see Figure 7). This enables updates and modifications of the encoding of existing dominos to avoid building new ones. However, the cost of magnets is high and we decided to build only a few of them to illustrate this feature.

Final result

We fabricated a large-scale wooden replicate of Bertin's matrices shown Figure 9. It shows a subset of the World Value Survey [9], a series of questionnaires that assess people's moral values across countries and years. We selected countries with the most attendees at VIS 2014. We then computed the average country response for each question, and selected the questions yielding the highest variations in responses. The data table consisted of 19 indicators for 18 countries, resulting in 532 dominos plus 37 labels, the labels being basically larger dominos to identify rows and columns. In total, we cut and assembled 569 dominos.

The wooden matrix was built by first loading the data into the Bertifier software [8] and exporting a 2D matrix visualization in SVG. The SVG file was turned into a digital fabrication design file. Sheets of plywood were laser-cut, laser-engraved and manually assembled (see Figure 8). Steel rods were bought in a DIY store and cut. The resulting matrix is a simplified version of the original, but also features a few innovations, such as the use of a magnet mechanism to switch encodings.

Overall, the matrix consists of 569 dominos, requiring

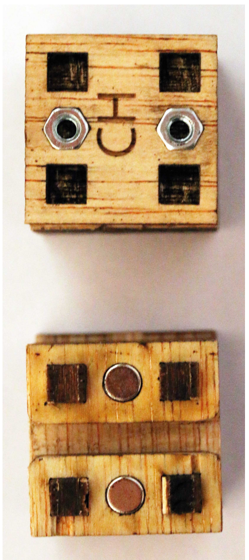

Figure 7: Extension to the last prototype: magnets make it possible to change dominos' encodings.

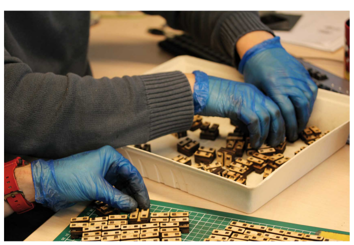

Figure 8: Assembling the wooden blocks to build dominos.

assembling 4414 wooden parts laser cut from 2.16m2/23.25sqft of plywood. Cutting the wooden pieces took approximately 15 hours and assembling them more than 50 hours. Its cost was approximately 20 Euros for the wood and 100 Euros for the rods. Using magnets makes the matrix become much more expensive.

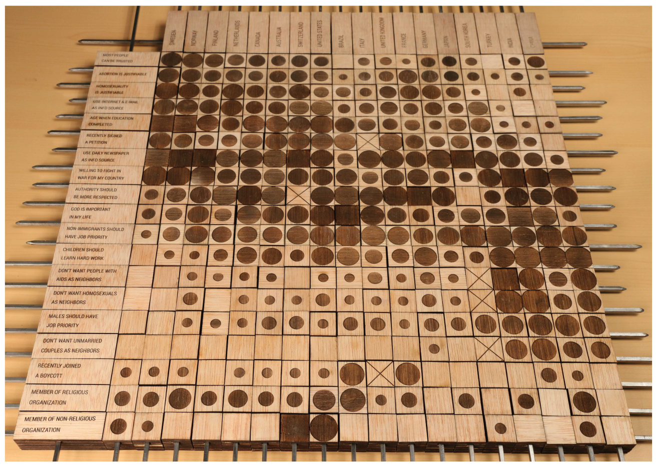

Figure 9: The final matrix, assembled and reordered. Dimensions: 50x52.5 + the rod extremities.

Lessons Learnt and Perspectives

The physical matrix was a real success during the exhibit. Visitors were encouraged to manipulate it, and so they did. We believe that the physical manipulation—interaction with the data—engaged visitors as the process is playful and rewarding. Moreover, it is not just data, and several visitors qualified the matrix as being a piece of art. The first lesson we learnt is that pre-computer era designs can be inspiring (see http://dataphys.org/list/ for a list of exciting physical visualizations).

Second, the reordering method has already been used for education in elementary schools in France in the 80's [7], and there is no reason why it should not come back. It could also be used in Infovis classes, as an introduction to visual mappings, data transformation, and interaction.

We worked in the INRIA digiscope fablab which started to experiment with tangible/physical visualization a few years ago. The Bertin Matrix is thus a great example of collaboration between the data visualization research field and digital fabrication processes in fablabs.

Finally, the DIY Bertin Matrix we exposed during the exhibit illustrates the benefits of providing both physical and directly manipulable data to visitors in the context of an exhibit. We observed collaboration behaviors, it created discussions and generated debates between visitors.

To make such devices accessible to a broad audience, we will release as open source the fabrication plans and all related material and documentation online by the time of the workshop at http://www.aviz.fr/diyMatrix.

Acknowledgements

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