Enhancing Static Visual Charts with Dynamic Effects

Min Lu, Noa Fish, Hui Huang, and Daniel Cohen-Or

Abstract—For centuries, knowledge sharing and exchange of ideas have relied upon the usage of visual charts and diagrams designed to be viewed in hard-copy form. To emphasize and draw attention to certain aspects of the data, static cues like color and geometric shapes were utilized with great success. Nowadays, digital displays are ubiquitous in the visualization of any form of data, lifting the confines of static presentations. In this work, we propose taking a natural step forward, and incorporate data-driven dynamic enhancements into otherwise static visualization schemes, for the purpose of element emphasis and attention guidance. Given a chart or a diagram, and their underlying data, we perform a simple analysis to determine elements and attributes of importance. According to their characteristics, a suitable dynamic effect is applied directly onto the displayed data, creating an illusion of a visualization brought to life. We experiment with three versatile effects, namely, *marching ants*, *geometry deformation* and *blinking*, and provide practical details regarding their mode of operation and extent of interaction with existing visual channels. We examine the impact and effectiveness of our enhancements via two user studies designed to assess personal preference as well as gauge the influence of visual dynamic effects on human perception in terms of fast, yet accurate visual understanding.

Index Terms—Visual encoding, Visual charts, Dynamic effects, Visual enhancement

1 Introduction

The age of information has seen a dramatic influx of readily available data in any conceivable field and in vastly different forms. The quest for knowledge has led to active exchange of ideas, calling for effective and intuitive ways to arrange and ultimately visualize relevant data. It is said that a picture is worth a thousand words, and, similarly, a well-constructed chart, scheme or diagram, often gets the point across faster and more clearly than verbal communication forms.

Across the centuries, technological advancements have continuously spurred the creation of new means to present data to improve information sharing. Despite becoming increasingly more elaborate, lacking appropriate technology, visualization schemes had mainly been designed to be displayed in hard copy form (*e.g.*, print). As personal computers, digital displays and smart phones have evolved and emerged onto the consumer market, hard copies made way for soft ones, changing the way we absorb and share information. Nowadays, visualization charts are, more often than not, displayed on a dynamic screen, suggesting that traditional schemes can be augmented with dynamic elements to increase their effectiveness and impact.

When creating a visualization to display pieces of information, one may wish to emphasize certain aspects of the data more than others. This is commonly achieved with color plays or geometric cues, whether intrinsic such as magnitude and proportion, or extrinsic such as pointers. Often, when the data is composed of multiple layers of information and different attributes ought to be portrayed, employing the aforementioned tools to convey each and every attribute may lead to over-saturation and visual clutter.

Psychological and cognitive studies have shown that the human eye is particularly attuned to movement and motion, even more so than color transitions or changes in pattern or texture [9, 31]. These findings suggest that the incorporation of dynamic elements within static environments as aspect emphasizers is a potentially beneficial venture.

- *Min Lu and Hui Huang are with Shenzhen University. E-mail: {minlu, huihuang}@szu.edu.cn*
- *Noa Fish is with Tel Aviv University, E-mail: noafish@post.tau.ac.il*
- *Dainel Cohen-Or is with Tel Aviv University and Shenzhen University, E-mail: dcor@tau.ac.il*
- *To whom correspondence should be addressed, email: huihuang@szu.edu.cn*

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In this paper, we present the idea of data-driven dynamic visual enhancements, where otherwise static visualization schemes are adorned with dynamic additions for the purpose of attribute emphasis, clarification or attention guidance. Given an existing visualization depicting characteristically static data (*i.e.*, non temporal data), we perform an analysis to locate the data elements that stand out, along with the attributes that set them apart, and apply a suitable effect onto the displayed elements. Such enhancements help draw the attention of the viewer to the most important details, and are easy to design in a tasteful and minimal manner to prevent user frustration. They are particularly advantageous when commonly used tools have already been exhausted, or when one wishes to highlight aspects pertaining to motion (*e.g.*, directionality, traversal).

Here, we choose to utilize three different types of dynamic enhancements - *marching ants*, *geometry deformation* and *blinking*, as these cater to a wide range of applications, but other kinetic effects can be used. *Marching ants* is a natural choice not only for schemes where direction is a core attribute (*e.g.* route chart), but also for general element emphasis and attention direction. *Geometry deformation* provides an intuitive solution for cluster-based schemes where certain elements stand out, and *blinking* excels at indicating order between elements.

Our enhancements and their contributions are evaluated via two user studies. The first is an extensive controlled experiment where static and dynamic versions of the same visualization schemes are shown to different participants, who are asked to answer a few questions correctly and in a timely fashion. Our findings indicate that dynamic effect additions act as constructive markers for data emphasis and contribute to faster understanding of the displayed information, but are still subtle enough so as not to cause irritation. The second is a larger-scale open-end survey designed to gauge personal preferences of viewers, prompted to state their choice between the static and dynamic versions of the presented visualization.

2 Related Work

The strength of dynamic visual cues in attention and memorization guidance has long been established [9, 25], but previous work on dynamic cuing has mainly focused on its integration within a specific setting and context (*e.g.*, algorithm visualization), or on manual customization. In this work, we aim to continue the trend and expand its impact by proposing a general methodology to static chart enhancement using dynamic effects.

Dynamic Visual Cuing Throughout history, static visual cues such as color, shape, orientation, position and regularity of placement, have been widely explored and utilized for many tasks. Among them, the task of visual encoding has continuously benefited from successful applications of these cues [11, 28]. With the emergence of digital displays, dynamic visual cues incorporating motion and movement were introduced, and subsequently recognized for their potential to attract and guide attention [31].

The application and evaluation of dynamic visual cues has resulted in polarized opinions. On one hand, the perception of dynamic visual cuing has drawn substantial research interest in both the fields of psychology and visualization, and has been positively connected to attention attraction and efficient memorization. Nakayama et al. [21] find that coherent motion facilitates group perception among individual elements. Driver et al. [6] clarify that the oscillation in different coherent patterns is what excels at separating the visual elements into groups. Bartram et al. [1, 2] characterize motion as a display dimension with substantial potential for its perceptual efficiency and interpretative richness. Huber et al. [15] study the perceptual properties of motion: flicker, direction and velocity, and optimize motion configurations for efficient perception. Hsueh et al. [14] conjecture that motion helps users complete comparison tasks in multidimensional visualizations faster and with reduced cognitive workload.

On the other hand, little attention has been given to the usage of dynamic cuing in visualizations. One notable exception is animation, *i.e.*, dynamic cuing over the time dimension. Fisher et al. [7] discuss the challenges and drawbacks of animation in visualization, and highlight that when the user is meant to compare the *before* to the *after*, animation is less likely to be of use. Tversky et al. [26] claim that animation is usually comprehended in a discrete manner and is hard to perceive accurately, such that it may hinder visual analytics.

Different from animation which necessitates frame-by-frame analysis along the time dimension, here, the proposed dynamic effects aim to enhance static attributes of visual elements, which either calls for looped dynamic cuing over the frames (*e.g.*, *marching ants*), or only requires in-frame inspection of elements and their differences (*e.g.*, *geometry deformation, blinking*). The dynamic effects play the role of attracting attention to the enhanced information, while encoding data attributes in a straightforward manner. Several previous works have applied dynamic cuing (mainly motion) to attract attention and encode static information [24]. For example, during examination of information in a visual analytics system, motion may help with visual search and notification [1], detecting and identifying patterns [29], or group information [6, 21]. In algorithm visualization, cuing (flashing) is used to indicate that two elements have exchanged value [23]. In flow visualization, animated motion shows the direction and speed of flow patterns [27], and animated glyphs for multidimensional datasets [18]. However, the aforementioned are ad-hoc and application-specific therefore they cater to specific settings, while in this work, a general dynamic cuing methodology is proposed.

Dynamic Activation The growing awareness for the importance of live illustrations and charts (*e.g.*, scientific publications [10]) has attracted some research effort directed at dynamic activation. Generally, we identify two approach types to activating dynamics in graphics. The first conveys dynamic motion of objects with static sketches, which usually outputs the static graphics with a minimalistic addition of dynamics, such as arrows in mechanical systems [12], afterglow static effects in user interfaces to indicate transitions [3], and physics-inspired rigs that propagate the primary motion of elements to produce plausible secondary motion [30].

The other approach is better suited for the e-display era, aiming to electronically mimic dynamic effects. Draco [16] is a sketch-based interface that allows users to add a set of animation effects to illustrations. As a follow up, Kazi et al. [17] propose seven motion amplifiers to craft animated illustrations containing exaggerated dynamics of stylized 2D animations. Borrowing the key concept from the traditional 2D brush model, the *motion brush* replaces the static brush image with a 3D animated scene comprised of geometry, appearance information and motion [20].

These dynamic activation techniques are primarily intended for illustrations and artistic purposes, and are generated via manual editing based on designer preference and experience. They are therefore not necessarily suitable for data representation and information encoding.

Table 1: Schema of Dynamics

Dynamic Type	Object	Information	Manner
Marching Ants	Individual	Directional Numerical Semantic	vs. Texture
Geometry Deformation	Group	Spatial Numerical	vs. Size Displacement
Blinking	Group	Ordinal Numerical	vs. Color

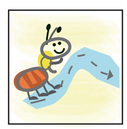
Our proposed dynamic enhancement approach is data-driven and designed to organically represent and emphasize attributes of the data.

3 Dynamic Visual Effects

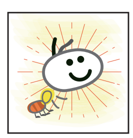
In the field of visualization, information is mapped to elements that carry visual features. Common and widely used visual features include color, size, etc., and these generally serve their purpose faithfully. As a complement to these tools, we propose dynamic visual effects as a form of kinetic visual encoding geared toward information and attribute enhancement.

Before we begin constructing these dynamic enhancements, we must consider three factors - *Objects* (where), *Information* (what) and *Manner* (how). *Objects* are the visual elements that are chosen for dynamic enhancement. *Information* pertains to the data attributes highlighted by the dynamic additions. Finally, *Manner* determines the physical aspect of the dynamic element, the way it interacts with the static visual channel and to what extent.

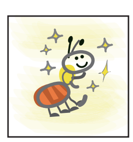
In order to cater to common combinations of these three factors, we explore three dynamic effects: *marching ants*, *geometry deformation* and *blinking*, and summarize the most favorable options for each factor per animation type, in Table 1.



Marching Ants (*MA*): Various graphic user interfaces utilize *MA* (*e.g.*, shifting dashed line) to mark element selection. We borrow this concept and extend it to a dynamic effect where patterns shift along a path at a certain speed, creating an illusion of ants marching. Tapping into our daily experiences, *MA* provides direct perception of direction and speed, and, with appropriate design considerations, is also capable of conveying semantic meaning (see Figure 2). With *MA* added as a layer on top of existing visual elements, it is essentially orthogonal to them and is non-disruptive, except for when the underlying elements are already endowed with a more visually complex appearance.



Geometry Deformation (*GD*): *GD* applies potentially exaggerated spatial modifications to the shape or placement of visual elements, at a certain pace. The joint transformation of individual elements can implicitly convey the existence of groups and relationships among parties. Beyond indication of such properties, numerical information can be encoded by adjusting the extent of applied deformation, from subtle to extreme. Since *GD* shifts or rescales elements, it may interfere with existing visual channels that utilize element size and location to express certain attributes.



Blinking (*BL*): Here, *BL* refers to a set of effects that apply repetitive changes to elements, such as brightness, saturation, color and border emphasis. These effects deliberately operate at a low rate, which is less than continuous (50 frames per second) [13], so as to attract attention to the discontinuous change. Activating blinking effects in coherent phases creates a sense of cohort among elements belonging to the same phase [15]. An effect applied directly onto the element may cause interference via color distortion, as opposed to one applied around the element (border).

3.1 Marching Ants

MA is defined by five design dimensions - *ant*, *path*, *boundary*, *marching speed* and *spacing* (see Figure 1). *Ant* is the mobile element in the

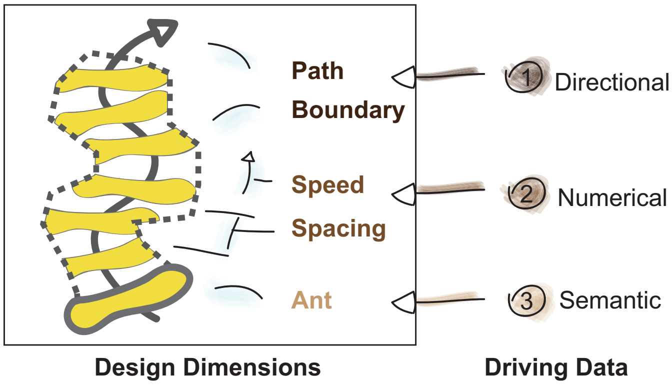


Fig. 1: Marching Ants: a *Marching Ants* effect is determined by five design dimensions, which can be encoded to indicate numerical, directional and semantic messages.

dynamic effect, and, while it originates from the well known traveling dashed line, it can take on any physical form and be used to convey semantic meanings. *Path* defines the route taken by the *ant*. It provides an intuitive perception of direction, but a notion of directionality is not a necessity for the application of *MA*. For instance, one can apply *MA* along a spiraling path inside a circle to create a dynamic texture effect without requiring any directionality information. *Boundary* limits the marching ground of the *ant*, and along with *path*, delineates the area of operation of the *MA* effect. The *speed* of movement and *spacing* between ants creates an impression of pace and density, and can be leveraged to encode numerical information pertaining to the underlying elements.

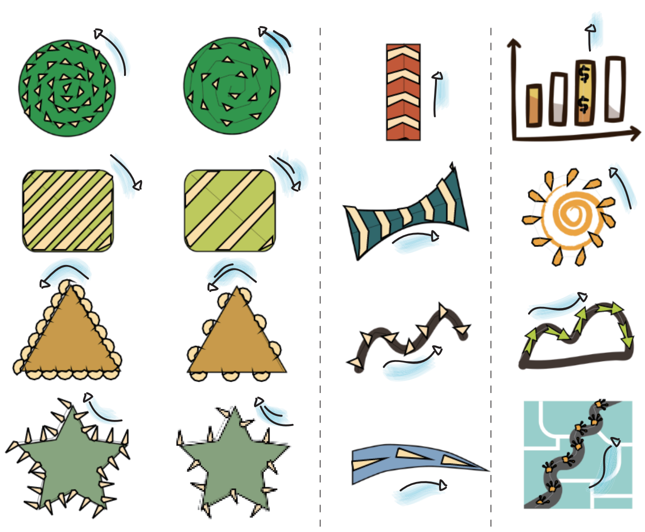


Fig. 2: Variation of Marching Ants: with various choices in design dimensions, *Marching Ants* demonstrates a rich expressive potential.

The five design dimensions of *MA* create a rich space of variation that provides a multitude of creative options for this effect, thereby demonstrating its expressive power. As exemplified in Figure 2, *MA* can be flexibly layered over existing visual elements, and indicate numerical (a) and directional (b) information, as well as convey semantic meaning (c). By placing a path within an enclosed area (a), appealing dynamic effects can be created for element emphasis purposes, and by tuning the *speed* of the ants, and their *spacing*, one can better influence viewer perception and guide attention, while simultaneously representing numerical attributes. Naturally, *MA* is particularly suitable for cases where the data is inherently directional, as the direction of marching over an element is intuitively interpreted as its own underlying direction (b). Finally, the design choices of the *ant* itself provide creative freedom that has value beyond fun and personal taste. As can be seen in (c), semantic properties can be visualized simply by a clever selection of graphics (*e.g.*, '$' sign at the top right), decreasing or even completely eliminating the need for extra clarifications.

3.2 Geometry Deformation

GD is a dynamic effect that enhances the spatial structure of visual elements. While related to distortion-oriented presentation techniques (*e.g.*, focus+context [19]), instead of allowing interactive actions that modify the visualization and its components, *GD* is automatically embedded within the visualization and is driven by the data, inducing varying degrees of deformation.

In order to seamlessly apply the notion of dynamics to information encoding, *GD* is simplified from a rich distortion presentation space [4] to a common non-linear drop-off deformation [8]. As Figure 3 shows, *GD* is defined by four design dimensions. *Context* - preserved or deformed, determines whether elements that do not take part in the effect itself remain unaffected (preserved) or are rather subjected to similar machinations as those that do (deformed). *Focal point* marks the center of the deformation effect, and *bandwidth* defines the maximum reach of the deformation, from the *focal point*. Finally, *speed* controls the rate of deformation and can therefore convey numerical attributes of the underlying data elements.

Figure 4 summarizes the possibilities afforded by the four design dimensions. Two original schemes (a,b) undergo *GD* with a small *bandwidth* (c,d), vs. a large *bandwidth* (e,f). *Context* preservation is exemplified in (e,f), vs. deformed in (g,h). Allowing context to be deformed lends an overall more organic look and feel to the visualization, and is suitable when the spatial relationship is implicit. For instance, *GD* applied on the matrix in (b) with *context* deformation generated the result in (h), where matrix cells neighboring the deformed element are affected by the deformation, promoting better spatial perception than that given by (f), where *context* was preserved. On the other hand, in cases where the spatial relations between elements are explicitly visualized, as in (a), sufficient visual cues exist to guide viewer perception, and maintaining preservation of *context* results in a clearer scheme (e). The change in *bandwidth* and *speed* is driven by the numerical information of the spatial structure. For example, in (a), the size of the clique (yellow nodes) drives the deformation, such that a larger size induces a faster deformation with a larger bandwidth.

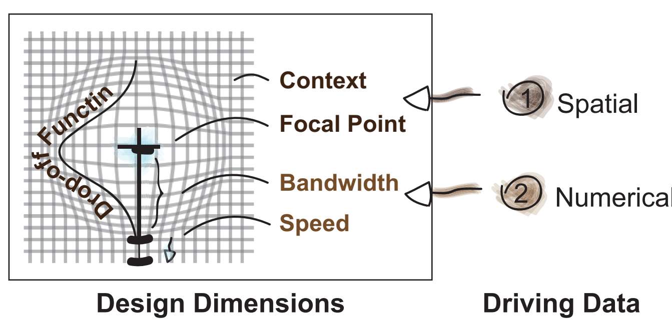


Fig. 3: Geometry Deformation: a *Geometry Deformation* effect is determined by four design dimensions, which can encode the spatial structure and numerical information of the structure.

3.3 Blinking

In *BL*, a visual effect is applied repetitively to elements in an on/off pattern. It is reminiscent of cue techniques for object highlighting [19], but, while these are typically utilized in interactive visual systems whenever the data satisfies a certain criteria, *e.g.*, searching, filtering, etc., in our case, *BL* effects are driven by the inherent attributes of the data, and are set up to encode that information visually. Moreover, applying a *BL* effect in phases facilitates the perception of element

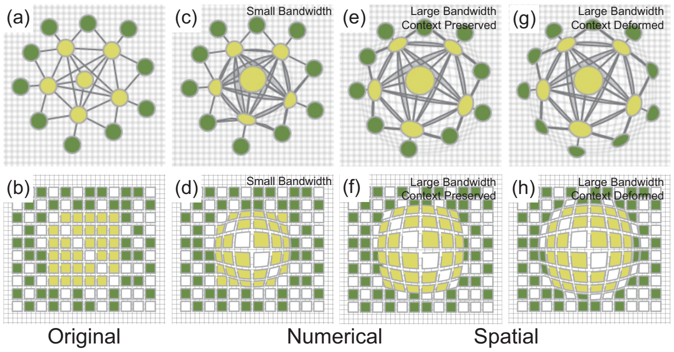


Fig. 4: Variation of Geometry Deformation: different design choices of context preserved or not, extent of bandwidth and speed, when enhancing the existence of cliques and their magnitude in a node-link diagram and matrix.

division into groups, where elements belonging to the same phase intuitively appear to form one group, sharing common attributes. For example, in a tree-based visualization, applying a *BL* effect over the nodes level by level, indicates the hierarchical structure of the tree.

As Figure 5 illustrates, a *BL* effect is defined by four design dimensions, *i.e.*, *visual proxy*, *offset*, *cycle length* and *repetitions*. *Visual proxy* is the visual design of the blinking effect, *e.g.*, change in brightness, appearance of borders, etc. *Offset* defines the lag between two consecutive effect applications. For attentional blinking, the offset between two applications is suggested to be larger than 500 ms [22], otherwise two targets presented in rapid succession, the second target cannot be detected or identified. *Cycle length* sets the on/off switching ratio of the effect, and is normally suggested to be no less than 120 ms [15]. Lastly, *repetitions* determines the total number of effect applications. The runtime duration of the entire effect is given by *repetitions* × (*cycle length* + *offset*).

The *BL* visual proxy supports the application of rich designs, for which any highlighting cue can be considered. Figure 6 presents a few representative designs. We identify two important considerations - space requirement and visual interference, and note their mutual contradiction. Space requirement is determined by the placement of the applied effect, such that a completely internal operation requires no additional space, and a completely external operation requires the largest amount of added space around the element. On the other hand, an effect layered over an element results in increased visual clutter and disruption to existing features (*e.g.*, color, pattern, border), that is avoided when application is external. Naturally, one must consider the type of scheme at hand, for instance, applying external proxies to a treemap, which is an inherently compact scheme, is problematic due to space restrictions, but a circle packing diagram enjoys a sparse layout that is able to support that.

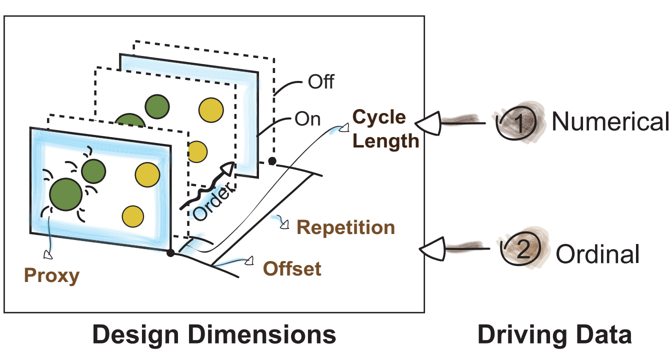


Fig. 5: Blinking: a *Blinking* effect is defined by four design dimensions which are driven by the ordinal and numerical information.

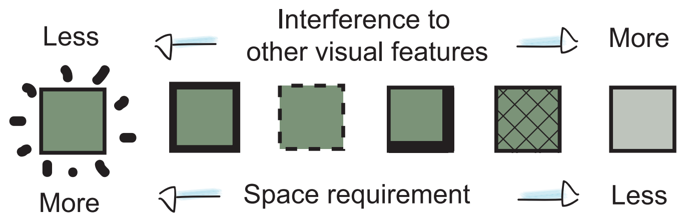


Fig. 6: Variation of Blinking Visual Proxy: distribution of representative visual proxies by considering the interference to other visual features and required space.

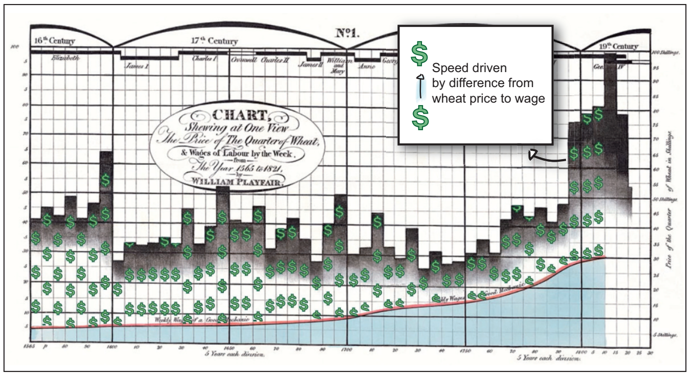
4 Examples

In this section, we present a few examples for static visualizations that were enhanced with our dynamic effects. Apart from textual details and explanatory figures which are given here, we urge the reader to visit our project page (https://2018study.github.io/activateviz/) where all our examples are available to be viewed in their dynamic form.

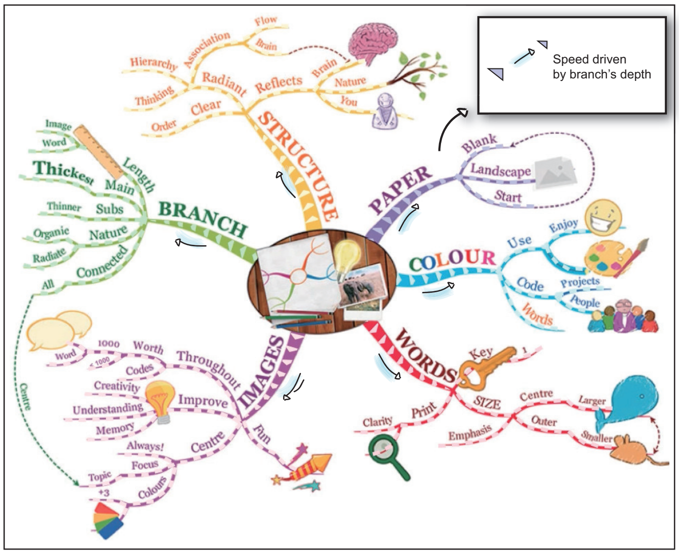
Playfair's Wheat Chart Infographics can be enhanced with dynamic effects highlighting implicit information to make the visualization speak for itself. Figure 7(a) shows an example of a visualization by William Playfair, hand-drawn in 1822 and enhanced in 2018 with a *marching ants* effect. The original, elegant yet static, chart visualizes the price of wheat (bars) and weekly wages of labor (curve) over 250 years. Playfair intended his chart to convey the fact that "never at any former period was wheat so cheap, in proportion to mechanical labor, as it is at the present time". However, in the static visualization, the dominant visual cues suggest that the price of wheat varies while wages remain stable. To remedy that, in this example, the *MA* effect is placed over the space stretching between 'wheat' and 'wage', with a '$' sign serving as the ant to represent the economic effort to reach from 'wage' to 'wheat'. The speed of the ant is driven by the ratio between 'wage' and price of 'wheat', such that the faster it marches, the smaller the effort is. The fastest moving element indicates that during the 18th century the proportion of 'wheat' price to mechanical labor was the smallest, emphasizing Playfair's original visualization intentions.

Mind Map A mind map is a diagram designed to showcase the hierarchical relationships among elements that represent pieces of a whole. Starting from a central concept, additional concepts and subconcepts branch out. Visually, the branches are typically curved to balance the map as a spider layout, which may hinder the perception of hierarchical structures (*e.g.*, branch depth). In Figure 7(b), *MA* is laid over a mind map, and the depth of branch attribute determines the speed of the ants. The deeper the branch, the faster its overlaid ants will march. In this case, *MA* creates an intuitive visual representation of flow that is able to stand out despite the saliency of the rich graphics and text.

Basic Charts Conventional charts are a tried-and-true tool that makes good use of static visual cues to display information. Here, we demonstrate ways to extend static charts to dynamic ones using dynamic effects, to promote better understanding or provide more information. Figure 8 contains six examples of basic static charts that were enhanced with our three experimental effects. In (a), two types of common charts are enhanced with *MA* to convey numerical information. Chart 1 is a boxplot with an added *MA* effect running up and down the top and bottom boxes of each plot in different speeds, in order to model the compactness of the distribution. Chart 2 is a circos enhanced with *MA* over top its ribbons. The speed of the ants in this case corresponds to the capacity of each ribbon, such that a larger capacity induces a faster movement. While the capacity is also visualized by the width of the ribbon, minute differences between ribbons are easier to discern by comparing ant speed rather than ribbon width. In (b), we enhance two different graph visualizations with *GD* effects to emphasize the existence of cliques and their magnitudes. In both the node-link diagram and the matrix, the cliques are recovered from the underlying



(a)



(b)

Fig. 7: Dynamic Effects Enhanced Infographics: (a) Marching Ants on Playfair's Visualization, where the speed of ants is driven by the ratio from wage to wheat price; (b) Marching Ants on a Mindmap, where the ants' speed is driven by the branch's depth.

data and are considered as the focal regions for the operation of *GD*. The deformation bandwidth is driven by numerical attributes of the cliques, *e.g.*, clique size. This creates a visual connection between the perception of clique size and the illusion of pumping/contraction. In this case, the advantage of the dynamic effect over its static counterpart, is its ability to clearly emphasize the important attributes of the data, by virtually making them pop out of the arguably messy layout of the diagram. Finally, in (c), two tree visualizations are enhanced with *BL* effects to convey hierarchical order. Given a hierarchy-based data, nodes in the tree are wrapped with a blinking visual proxy whose blinking offset is driven by the level (depth) of the node in the tree. The blinking effect creates an illusion of unity among nodes in the same level as they fade in and out, thereby providing viewers with an explicit in-order traversal of the data.

5 Evaluation

Dynamic enhancement effects form a rich design space full of possibilities. This variation makes it difficult to estimate the general contribution of these effects as a group, to the creation of clearer visualization schemes. Nevertheless, to assess the impact and effectiveness of dynamic enhancements to visualization charts, we perform two types of user studies. The first is a controlled experiment designed to carefully evaluate the strengths of our effects and their contribution to faster and more accurate understanding and assimilation of visual data. The second is an open-end survey geared toward general personal preference appraisal. The details of both experiments can be found in our project page.

5.1 Controlled Experiment

Our controlled experiment is designed to evaluate the contribution of dynamic enhancements to static visualizations, and to assess the potential of these enhancements to facilitate faster and more accurate visual understanding.

5.1.1 Experiment Set-up

Test Visualizations Six representative visualization schemes were chosen to appear in our experiment (see Figure 8) - two for each of our three experimental effects (*marching ants*, *geometry deformation*, *blinking*). Boxplot and circos were chosen to be enhanced by *MA* since they comprise the majority of numerical visualizations where the numerical reading baselines are shifted or curled for the benefit of the overall layout. For *GD*, we selected a node-link diagram and a matrix as they are two of the most common diagrams for network visualization, with explicit or implicit visual link structures. For *BL*, a treemap and a circle packing diagram were chosen for their popularity as visualizers of ordinal information, showcasing either compact or less compact visual layouts.

Static vs. Dynamic Information Enhancement In order to evaluate our independent variable - extent of contribution of dynamic effects - we prepared two versions for each of the six visualizations, a reference and a controlled version. The reference version is completely static, but has been carefully designed and enhanced with appropriate static visual cues to highlight the same information that is highlighted by the effects added to the controlled (dynamic) version. Taking the node-link graph as an example, in its controlled version, a *GD* effect is applied to enhance the structural information of cliques. As compensation, in the reference version, nodes taking part in a clique are marked with a border whose thickness corresponds with the size of clique.

Test Questions For each visualization, three types of questions were asked in order to measure participant performance in analysis tasks of different levels, all pertaining to the enhanced information. The first question asks the participant to identify the maximum/minimum element (numerical/structural/ordinal, respective to the three effect types). The second question asks for a comparison between two elements, while the third for a sorting of multiple elements.

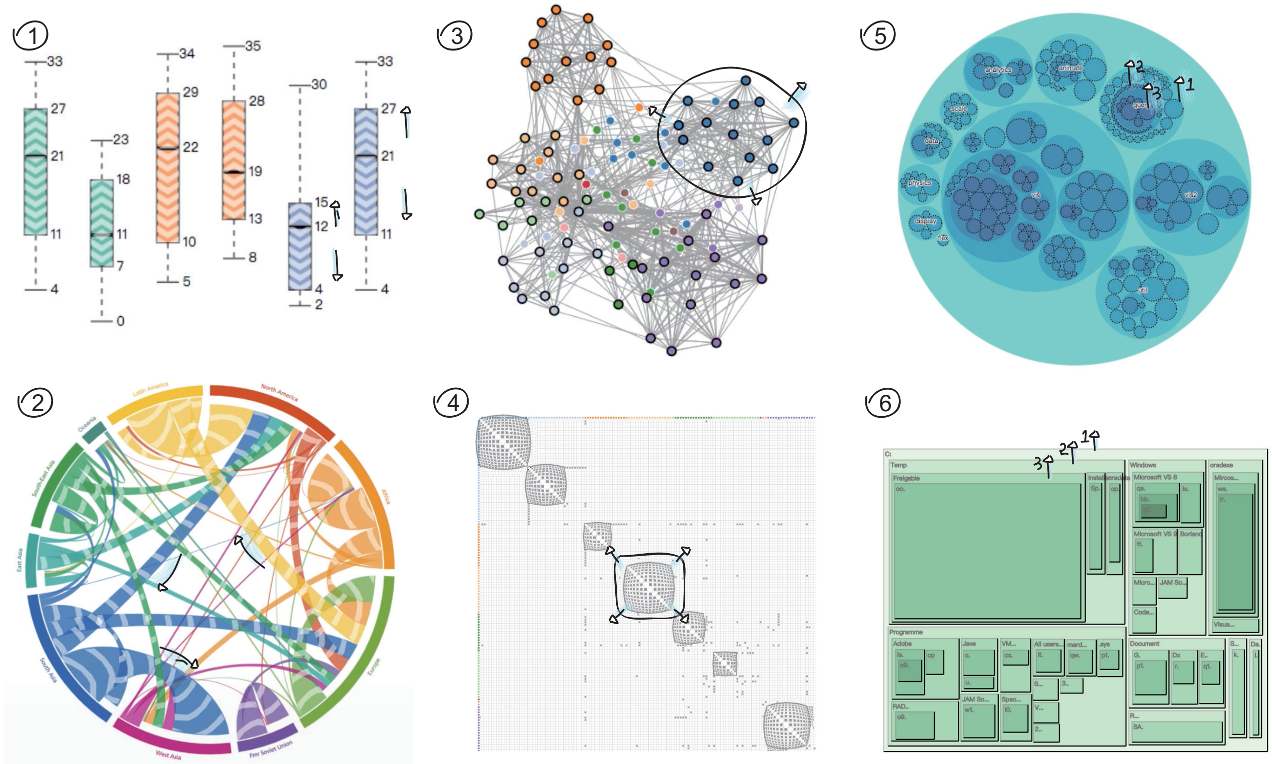
Test Measurement For each question, both time cost and accuracy were measured to gauge the influence of static/dynamic enhancements on user perception in terms of fast and accurate visual understanding.

5.1.2 Procedure

We recruited 14 participants between the ages of 25 to 35, all novices in data visualization, but predominantly with an academic background in Science/Engineering.

The participants were randomly divided into two groups, A and B, such that group A was given the six aforementioned visualization tests in alternation between static and dynamic, and group B was given its complement set. That is, each participant viewed and was tested on only one version of each visualization - either the static or the dynamic. All visualizations were displayed on a 22" HD display with a resolution of 1920×1080 pixels.

Each participant was accompanied by an evaluation assistant while taking the test. The assistant gave a brief introduction to data visualization, and explained the outline of the test and its expected time frame (approximately 15 minutes). Prior to each of the six tasks, a short clarification was given regarding the relevant type of chart or diagram. Next, the participant was presented with a screenshot of the tested visualization, covered with a semi-transparency mask to prevent bias from early exposure, along with a motivating background story to the displayed information. Any questions raised were answered by the assistant, and the participant was free to proceed to the three test questions. For each one, the participant was first given a preview of the



(a) (b) (c)

Fig. 8: Charts enhanced with dynamic effects: (a) *MA* driven by numerical attributes; (b) *GD* driven by the spatial structure of the data in the graph visualizations; (c) *BL* driven by the hierarchy of the data in the tree visualizations. Note that here the dynamic effects are represented by static cues. To view the original dynamic version, please visit the project homepage.

textual question alone so as to minimize reading comprehension issues. Having understood the question, the participant was free to proceed to the test itself, where the full-sized visualization scheme was clearly presented in the center of the screen, along with the current question at the bottom. Elapsed time from participant first viewing the actual test until giving an answer, was automatically recorded. Upon completion of all tasks, the assistant noted the accuracy scores and time costs for performance analysis.

5.1.3 Results

Figure 9 compares the overall time cost and accuracy, over the three questions, between the static and dynamic visualization versions, demonstrating the superior performance of the latter both in terms of accuracy and time efficiency. Generally, as a high-level analysis task that, the task of sorting multiple elements, has, as expected, incurred the highest time cost for both the static and dynamic visualization versions. Comparison tasks, however, required less time than the maximum/minimum targeting task. While performing comparison tasks, it was observed that participants were able to quickly narrow down their analysis scope from global to local using the visual markers for the compared elements. In terms of accuracy, in most cases, participants were able to name the correct answer in both versions. Outliers of lower accuracy were recorded in the maximum/minimum numerical targeting task in the static version of the boxplot chart, and the comparison task in the static version of the circos chart. Static visual cues such as size and length are sensitive to orientation and referencing anchors [5]. The nonalignment (*e.g.*, boxplot) or curling (*e.g.*, circos) of visual elements hinders the right perception of width, size, etc. *MA* maintains a more isotropic numerical encoding via speed, which can be uniformly perceived in all orientations. In that case, *MA* delivers numerical information more efficiently and correctly.

Figure 10 presents the time costs of each visualization type, for each of the three questions, and compares the results on static (blue) vs. dynamic (green). For the maximum/minimum targeting task, *BL* performs extremely well in the circle packing and treemap diagrams, while the corresponding static versions perform poorly in comparison. We reiterate that participants were unfamiliar with these types of visualizations, and therefore has cause to spend some time figuring out where to begin and how to trace the tree structure appearing in the 2D graphics. In contrast, the *BL* effect is able to guide its viewers to traverse the hierarchical data in an intuitive manner. For the comparison task, the time cost recorded for *BL* is rather substantial since participants usually observed the effect for several cycles (commonly two), and

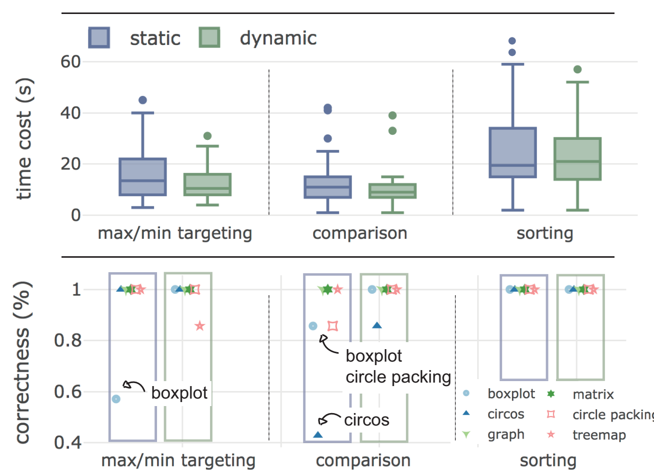


Fig. 9: Overall Performance: time cost and accuracy of static and dynamic visualizations over the three different tasks

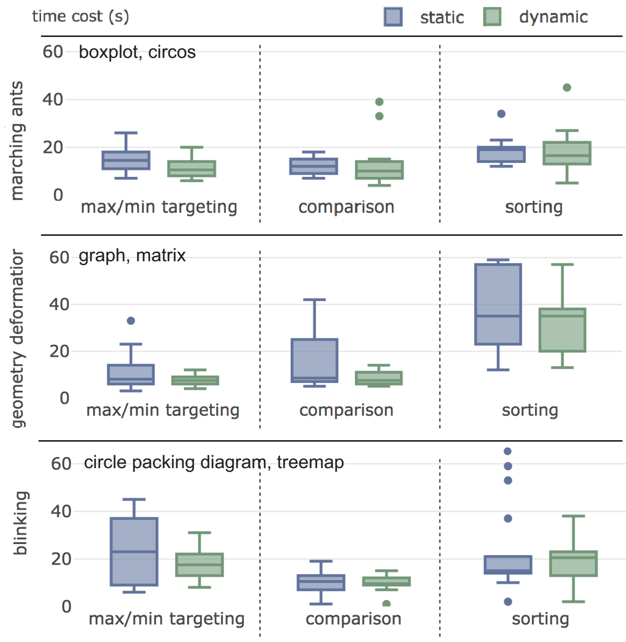


Fig. 10: Detailed time cost analysis of three dynamic effects over three questions

only then made their decision. Observing the recordings for the graph and matrix schemes, we note the large difference between static and dynamic, to the detriment of the first. It appears that participants failed to concentrate on the statically cued cliques embedded among the busy layout of the graph. Conversely, *GD* easily emphasizes cliques with its pumping effect, and is able to highlight differences between clique sizes by tuning the contraction extent accordingly. For the sorting task, we find that there is no significant advantage of *MA* over static cues in the boxplot and circos charts. Furthermore, we note it is more costly to perform the sorting task with *BL* rather than with static cues, since participants generally waited several cycles to target all the requested elements.

Having collected the findings above, we draw the following conclusions regarding the performance of dynamic in the context of chart understanding and analysis:

- Dynamic effects generally provide more effective support for analysis tasks when designed properly.
- *Marching ants* maintains more isotropic numerical encoding than static visual cues, such as length and width. This facilitates more efficient and accurate numerical targeting and comparison, especially in the case of an unaligned or distorted layout. For more complicated numerical analysis tasks, *e.g.*, sorting, there is no obvious advantage to *MA* over other static cuing.
- *Geometry Deformation* provides a more efficient enhancement to structure than static visual cuing when the visualization is cluttered, *e.g.*, a node-link diagram. It acts as an orthogonal visual channel to encode numerical information along with structure, which promotes a more stable performance in spatially related analysis tasks.
- *Blinking* acts as a powerful guide for chart reading, by providing an enhancement with a better order identification than static visual cuing (*e.g.*, color). When performing quantitative analysis, such as comparison or sorting, *BL* usually incurs several cycles from users wishing to target objects and perform analysis.

5.2 Open-end Survey

Our second evaluation experiment is a larger scale survey designed to assess general personal preference of viewers, whether they are more partial to static or dynamic visualizations of different types, without delving deep into performing analysis tasks. To that end, we created an online survey via Google Forms that was distributed freely and attracted 288 (43% were female) participants between the ages of 15 to 50.

5.2.1 Survey Preparation

The survey is composed of two parts. The first contains 10 binary personal preference questions. Prior to each question, a brief introduction to a specific type of visual encoding (*e.g.*, boxplot) is given in two to three sentences, accompanied with an illustrating example when necessary. Following that, both a static and a dynamic version of the same visualization is presented, in random order. The participant is asked to select the chart which they find to be generally more appealing.

The second part aims to help shed light on the reasoning behind participants' choices, by prompting them to select possible motives from a multiple choice menu, and allowing them to leave comments and remarks freely. More details on the open-end survey can be found in the project page.

5.2.2 Results

Figure 11 summarizes the voting results of static (blue) vs. dynamic (green) visualization preferences. For most visualization types, the dynamic version collected more votes than the static version. Particularly, dynamic inforgraphics such as Charles Joseph Minard's Immigration Flow map and William Playfair's Wheat visualization received notably high scores, as did the dynamic version of circos of immigration flow. For those graphics with a "flow of data" story (*e.g.*, infographics), the enhancement with intuitive dynamic effects achieves a multiplier effect, such as strengthened information augmentation, efficient attention attraction, vivid data representation, etc. Several participants commented that "the flow map with animation is very impressive and intuitive", "the dynamic infographics is highly active and brings the untold story to life."

On the other hand, for more classical visualizations (*e.g.*, boxplot, treemap and matrix), there is a slight tendency among participants to prefer the static version to the dynamic one. One participant commented "the hierarchy of a treemap is better conveyed by nesting, the animation distracts my attention". Such a comment may clarify that, when participants are already familiar with a certain type of visualization, they may prefer to view it in its original, well-known form, rather than to experiment with alterations. Some participants react against the dynamic effects and blame them for distracting their attention from reading the charts. One participant commented "It is hard to focus on the information because of the dynamic effect". This suggests that the powerful attention guidance abilities of dynamic effects is a double-edged sword. On one side, dynamic effects effectively direct attention as desired. On the other, it may cause attention distraction and disrupt the reading of other visual encoding when the enhancement via dynamic effects is not well controlled. With digital displays becoming every day more mainstream, the incorporation of dynamic effects in visualization is inevitable. Just like upgrading from black&white to color print, dynamics is another intrinsic property of the real world as color is, thus the ability to perform dynamic decoding and visual attention control will become more intuitive.

In fact, the top three motives selected by participants as their selection reasoning supports our expectation of dynamic visual charts, *i.e.*, dynamics in visualization clarifies information well, draws attention and is interesting. For information clarification, one participant commented "dynamics is more suitable to integrate information in the visualization, especially when they are already visually cluttered". Several participants commented that *blinking* assisted them in following hierarchical order better (treemap and circle packing diagrams), which, in turn, helped them understand the visualization better. For attention attraction, almost all participants agreed that "dynamics attracts attention well". Some participants commented that "dynamics is more fun", and "dynamic visualizations are more impressive".

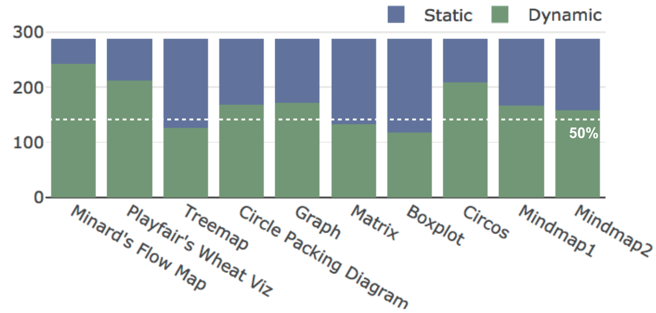


Fig. 11: Preference Voting for Static Visualization versus Dynamic Visualization

6 Conclusion

In this paper, we presented the concept of dynamic visual enhancement, where commonly static schemes are augmented with various dynamic effects. Our experimental findings indicate that the addition of these effects promotes a clearer visualization of the latent information in the underlying data, that aids in conveying the important aspects to the viewer, whether because these effects are natural attention guides, or because they are able to visualize information that is otherwise hard to convey with static means. While applying dynamic effects to inherently dynamic (temporal) data is trivial, our aim is rather to complement the visualization of static information with non-static effects in an informative and intuitive manner that will facilitate faster and clearer assimilation of data.

Our current setting produces effects that are data-driven and require no user input or intervention. However, as an extension, user control can be combined to allow fine-tuning of the generated effects, both in data aspects as well as more cosmetic choices. To support hard copy visualizations with an added "dynamic" value, one may devise effective ways to adapt schemes that were enhanced with dynamic effects, into a static version that carries tokens of dynamic origin, serving a similar purpose. Lastly, to cater to the widest possible audience and prevent user irritation, we would like to develop more types of dynamic effects characterized by increased visual subtlety that does not compromise emphasis and attention guidance abilities. Taking it further, a more challenging problem may consider the use of subliminal effects that attract and guide user attention unconsciously, and thereby unobtrusively.

The digital trend suggests that data consumption in hard copy form will continue to diminish, until virtually all visualization forms will be viewed on dynamic displays. We believe this will inevitably raise the appeal of added dynamics and ultimately encourage the development of additional effects to complement the ones we have presented here.

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