Toward an Interactive Voronoi Treemap for Manual Arrangement and Grouping

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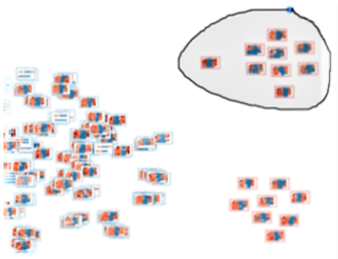

(a) Pilot interface (Sec. 2)

	Interactive A&G							Static idioms											
	[PKF 16a]	[RHC 04]	[SCH05]	[LZC 20]	[BFH05]	[WWI07]	[GAC 03]	[HB05]	[CPC09]	[GHK10]	[SSKB14]	[GNCM 15]	[Bed03]	[Bed03]	[Wat05,AHL13]	[ZL15]	[GSWD17]	[BD05]	
	D&D&Lasso	Periph. storage	Storage Bin	Piles	Dynapad	Bubble cluster	Photo manager	Vizster	Bubble set	Gmap	Node-Link-Grp	Grid based	Quantum TM	Bubblemap	Jigsaw/Gosper	Circular TM	Bubble TM	Voronoi TM	
DR1	x	x	x	x	x	x	v	x	v	v	v	v	v	v	v	v	v	v	Avoid occlusion, show content
DR2	x	x	x	x	x	x	v	x	x	x	x	v	v	v	v	v	v	v	Explicit, compact, contiguous
DR3	x	x	x	x	x	x	x	x	x	x	x	x	x	v	v	x	x	v	Use space, space-filling
DR4	v	v	v	v	v	v	x	v	v	v	v	x	x	x	x	v	v	v	Free positioning

(b) Related work and Design Requirements (Sec. 3)

(c) Interactive Voronoi Treemap (Sec. 5)

Figure 1: *(a) Arrangement and grouping (A&G) pilot interface from which we derived Design Requirements (DR). Each image shows activity (red) and sleep (blue) slots of a patient for each day of the week. Occlusion (DR1), non-explicit groups (DR2), and non-optimal use of space (DR3) are the main limitations of this interface. (b) Among all the related works, only the Voronoi Treemap idiom enriched with A&G interactions can match all the DR. (c) We developed a quiz game with the proposed interactive Voronoi treemap to foster interest in fine art. Images can be freely arranged and grouped (DR4) by drag-and-drop; color-coded weighted Voronoi cells serve to encode groups explicitely (DR2), and pictures are spread uniformly within these cells using Centroidal Voronoi Tesselation to fill space (DR3) while their size is automatically tuned to avoid occlusion (DR1). (A) At first, no image is categorized. (B) After several A&G actions (Sec. 4), mismatches are shown on demand in shades of red. (C) Eventually, the user correctly groups the pictures by style.*

Abstract

Interactive spatial arrangement and grouping (A&G) of images is a critical step of the sense-making process. We argue that to support A&G tasks, a visual encoding idiom should avoid clutter, show groups explicitly, and maximize the use of space while allowing free positioning. None of the existing interactive idioms supporting A&G tasks optimizes all these criteria at once. We propose and implement an interactive Voronoi treemap for A&G that fulfills all these requirements. The cells representing groups or objects can be dragged or clicked to arrange objects and groups and to create, merge, split, expand, or collapse groups. We present a usage scenario for an art quiz game and a comparative analysis of our approach to the recent Piling.js library for a categorization task of HiC data images. We discuss limitations and future work.

CCS Concepts

• ***Human-centered computing*** → ***Treemaps; Visualization design and evaluation methods;***

1. Introduction

In the physical world, humans spatially arrange objects by increasing size or group them by shape or known use for instance. They put them into boxes, use color stickers, or group them into clusters [Kir95]. Arrangement and grouping (A&G) of objects map some of their ordered (size...) and categorical (shape, function...) attributes to their spatial location and enriched appearance (boxes, color stickers...) respectively. A&G make faster the search of objects similar to a given one, like apples sorted in different baskets (grouping), or books indexed alphabetically (arrangement) and by topic (grouping) in a library. A&G help get an overview of objects' diversity, count them, find the typical ones or spot the outliers [HW12]. Arrangement by moving two objects side-by-side supports visual comparison which helps form homogeneous groups

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based on some attribute. And grouping helps focus on smaller subsets easier to scan and increases perceptual acuity of small differences between those similar objects to further arrange or group them locally [Kir95]. A&G can help form a mental map of objects at hand as available resources to use and to plan further actions, like gathering and organizing ingredients on a table to realize a cooking recipe. A&G tasks are also at the heart of the sense-making process for instance when solving a jigsaw puzzle, or when exploring new data images in search of categories of patterns that an automatic classifier could be trained on.

Thus, *manual* A&G is fundamental for the analyst to generate base knowledge of the objects at hand and thus for data-encoded-as-image objects as well [SSS*14]. Groups of objects and their derived ground truth labels that will serve to train automatic classifiers [BZSA18] cannot come from automatic approaches but from the user manually forging and curating these groups from the ground up to match her mental model — where the actual ground truth comes from. In this work, we focus on supporting these *manual* A&G tasks. We propose that a 2-level Voronoi treemap [BD05] visual encoding idiom enriched with specific interactions could better support such critical tasks than existing techniques. Here is why.

2. Design challenges for visual A&G

Aiming to support a domain expert for grouping images of actigraphy data [PMA*19] by visual similarity of sleep and activity patterns (Figure 1a), we initially proposed a graphical interface to drag images to form groups by proximity, similar to the one used for a visualization study [PKF*16]. Our interface supported **free positioning** to optimize expressiveness of the visual encoding of user's mental map as arrangement and groupings of images. A lasso allowed selecting images to drag them together to make arrangements faster, or to assign them to a color-coded group all at once.

This interface proved painful for the user in several ways. Images cluttered rapidly when dragged with the lasso, hiding one another. The user wanted to see the content of the groups for visual comparison, but it was time-consuming to remove clutter manually, so there was a need for **showing group content** and an automatic way to **avoid occlusion and clutter**. Assigning images to groups with the lasso took additional actions, and groups were not clearly identifiable without the color encoding, calling for the use of **explicit groupings and arrangements**. At last, dragging images let empty space while at the same time the user wanted to see larger images but without occlusion, calling for a more **optimal use of available space**. The pain points of this initial experience led to the following Design Requirements (DR) to support A&G tasks, that we further corroborate with results from state-of-the-art analyses and studies:

DR1: Avoid occlusion and show groups content Itoh *et al.* [IMMS09] recommend avoiding occlusion as it prevents readability of the objects for selection and side-by-side comparison required to take A&G decisions.

DR2: Make explicit groupings and arrangements relates to the Gestalt principles of grouping perception [PBN03]. Bauer *et al.* [BFH05] distinguish implicit (subjective) from *explicit* (objective) groupings: Groupings by proximity are implicit, existing only in the user's mind. Groupings by common region, element connectedness, or similarity, are encoded in the machine either as visually distinct containers, connections between objects, or colors respectively. Explicit grouping is preferable as it bears no ambiguity on where a group starts or ends. Other studies [SSKB14, JRHT14] show that contiguous groups with explicit adjacency between groups and objects, typical of area charts, are better than node-link diagrams or disconnected groups to support group-related tasks. Bruls *et al.* [BHvW00] propose that compact cells in treemaps are easier to detect and point at. From these studies, we conclude that an idiom better supports A&G tasks if it encodes groups as **expicit, contiguous compact adjacent areas** with the same color.

DR3: Maximize use of space Itoh *et al.* [IMMS09] and Bederson [Bed03] recommend optimizing the use of available screen space using a **space-filling** idiom. That also means to avoid unnecessary empty space, hence to maximize data pixels and minimize non-data ones as recommended by Tufte [Tuf01].

DR4: Allow free positioning Arrangement of objects and groups shall come through free positioning [BFH05] rather than constrained positioning (*e.g.* grid layout [Bed03]) to better let the user express her mental model of objects A&G. This follows from the maximum expressiveness criterion for visual encoding [Mac86]: encode all and only the desired information.

As we shall see, free positioning (DR4) seems to prevent at least one of the other requirements (DR1,2,3) in existing A&G techniques. Therefore, the main challenge is to find an idiom that fulfills these four design requirements altogether.

3. Related works

Figure 1b shows summary characteristics of existing interactive idioms (pale blue, left side) supporting A&G tasks and static idioms (pale red, right side) never used to support such tasks so far.

Regarding interactive idioms, **free positioning** interfaces like our pilot study and others [PKF*16], use proximity so they lack explicit grouping and adjacency, do not avoid occlusion, and let empty space. **Container-based** techniques [SCH05, RHC*04] use containers where objects can be dropped, while **pile-based and blob** idioms [BFH05, WWI07, LZC*20] represent groups as piles, and objects can be grouped by contact, freely positioned or arranged on a grid. None of them optimizes the use of space or prevents occlusion. **Grid-based** interfaces for photo management [GAC*03] use explicit grouping and adjacency of objects and groups, but they do not allow free positioning. In short, no existing interactive idiom fulfills all the requirements.

Regarding static idioms, **grid-based** space-filling approaches have been used to automatically group images of various sizes [GNCM*15].They use explicit contiguous groupings and arrangements avoiding occlusion, but do not allow free positioning. **Mixed idioms** like Vizster [HB05], Bubble Sets [CPC09], GMap [GHK10] and Node-Link-Group [SSKB14] allows free positioning, but they can generate non-compact groups and are not space-filling. **Treemaps** encode hierarchical data into nested cells of area proportional to their content. In most cases [Bed03, Wat05, AHL*13], rectangle or regular-polygon-based treemaps are space-filling but also grid-based which prevents free positioning. Quantum, Circular, and Bubble treemaps [Bed03, ZL15, GSWD17] are not space-filling idioms.

Finally, we discover that the Voronoi treemap idiom [BD05] is the only one to fulfill all our design requirements. Our proposal is to enrich it with the interactions needed to support manual A&G tasks.

4. An Interactive Voronoi Treemap to support A&G tasks

General set up We propose to use a two-level *Voronoi treemap* idiom with parent and child (leaf) cells representing groups and objects respectively. Groups are cells of a power diagram with area optimized with Nocaj and Brandes technique [NB12] to be proportional to their number of objects. Such group cells do not overlap (DR1) and form compact convex contiguous containers further color-coded (categorical scale) that explicitly identify all objects in a group (DR2). Objects are thumbnail *images* positioned at the center of gravity of their unweighted Voronoi *cell* using Centroidal Voronoi Tesselation (CVT) [DFG99]. CVT ensures uniform spreading of the images in the available space formed by their group cells (DR3) so all object cells have approximately the same area, size, and aspect ratio across all groups. CVT allows more free positioning and arrangement of the objects and groups (DR4) than a grid layout. The base size σ of all images is automatically tuned to avoid image overlap (DR1) as the average distance between the centroids of pairs of adjacent Voronoi cells (Delaunay neighbors). The adjacency of groups and of objects is explicit through Voronoi edges (DR2). Initially, all images are displayed within a single group of grey color, the root cell, with a square shape forming the outer boundary of the workspace.

Interaction design solutions In order to support A&G tasks, we enrich the treemap with interactions aiming to support the grouping (T1) of single or multiple objects, the arrangement (T2) of objects and of groups, and the presentation (T3) of objects and groups. Figure 2 illustrates these interactions which use only three controls: the mouse pointer position, the primary (left) mouse button, and the mouse scroll-wheel.

Users can **resize all images** (T3/IDS1) at once with the scroll wheel, as a proportion of the base size σ to adjust the level of occlusion (DR1). Users can **arrange an object freely** (T2/IDS2) (DR4) by dragging its image, and **get details of an object** (T3/IDS3) by a click on that image. When no available group matches with an object, users can **create a group with an object** (T1/IDS4) by dragging its image outside of the root cell. A group is automatically deleted when its last object is added to another group. Users can **add a single object to an existing group** (T1/IDS5) by dropping the object in the cell of that group. The object eventually gets the color of the group after 1 second, and all the group cell areas and positions are updated (CVT). When multiple images have to be added to the same group, users can **make this group the target group** (T1/IDS6) by double-clicking on its Voronoi cell. Users can **teleport an object to the target group** (T1/IDS7) by starting a drag of its image, or **add multiple objects to the target group** (T1/IDS8) by drawing a selection line across their images, starting it as a drag of the Voronoi cell of the first object. On mouse release, all these objects are teleported to the target group in the selection order. Users can **merge two adjacent groups** (T1/IDS12) by drawing (IDS8) a zigzag "stitching" pattern across their shared boundary. Users can **split a group** (T1/IDS13) by using a selection line (IDS8) if no target group is active. Users can **choose the representative image of a group** (T1/IDS9) by double-clicking on any non-representative image of that group. This image becomes the new group's representative and gets a thicker outline. Users can **collapse or expand a group** (T3/IDS10) to save space when collapsed, or show group content (DR1) when expanded (default). One or several objects can be added (IDS5, IDS7, IDS8) to a collapsed group too.Users can **arrange a group freely** (T2/IDS11) (DR4) by dragging its representative image. During the move, all images are hidden except the representative one (IDS9).

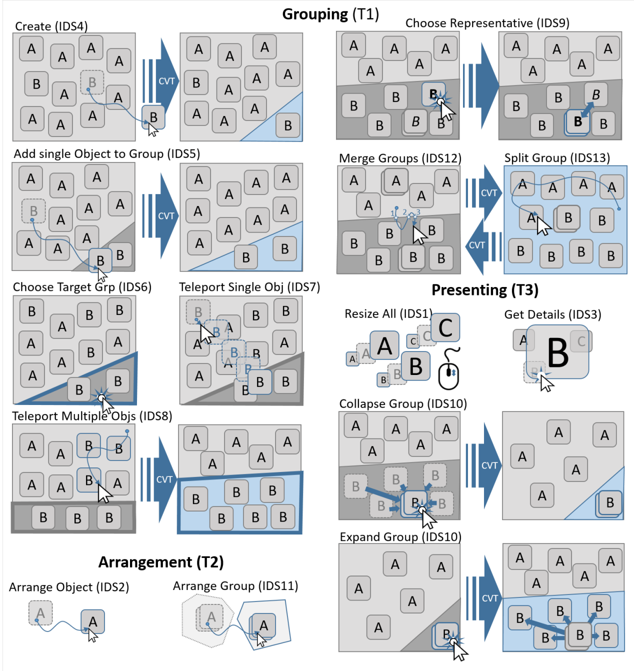

Figure 2: *Interactions for Grouping (T1), Arrangement (T2), and Presentation (T3) tasks (Sec. 4)*

Technical details When an object is dragged (IDS5), it is assigned to another group as soon as the position of the mouse pointer enters the power cell of that group [NB12]. The CVT [DFG99] always runs during drags to regularize the positions, after each action modifying group content (IDS2, IDS4, IDS5). Object positions are initialized at random. When a group is dragged (IDS11), we run a force-directed approach [AA20] with parameter $\beta = 45\%$ to preserve the stability of the layout and relative areas of the cells during that move, getting a more fluid update than with the standard technique of Nocaj and Brandes [NB12]. When the group is released, the standard technique is used again starting from the last positions and parameters of the force-directed one, to get more accurate areas. On release, we set the objects at the same initial position relative to the center of the new group cell as they were within the initial group cell, scaled up or down to fit within the new one; then we run CVT to spread them uniformly. As the number of visible images decreases/increases on group collapse/expand (IDS10), the size of their Voronoi cells increases/decreases, and so does the average σ of their adjacent pairwise distances. Hence all images are automatically resized filling in the empty space while maintaining minimal occlusion as per user-tuned proportion (IDS1). We use `D3.js` V4 to implement the interactive Voronoi treemap. In particular we use `d3-force`, an open-source `D3.js` module [For] for implementing the force-directed approach [AA20]. The Nocaj and Brandes [NB12] technique is implemented with the `d3-voronoi-map` module [Wei].

5. A quiz game for visitors of an Art Museum

We implemented a quiz game interface to foster interest in fine art and details of style from the lay public. The interactive Voronoi treemap displays 45 fine art items from 8 artists (Figure 1c). Only interactions IDS2,3,4,5 are enabled to ease the use by non-experts. In our scenario, the interface is displayed on a touch screen within the museum, and visitors are invited to group pictures by style. A score is displayed and help given on demand to show the mismatches. A study is planned to evaluate this interface with visitors of the *Mathaf Arab Museum of Modern Art* in Doha (https://www.mathaf.org.qa/) with pictures from their exhibitions.

6. Piling idiom versus Interactive Voronoi Treemap

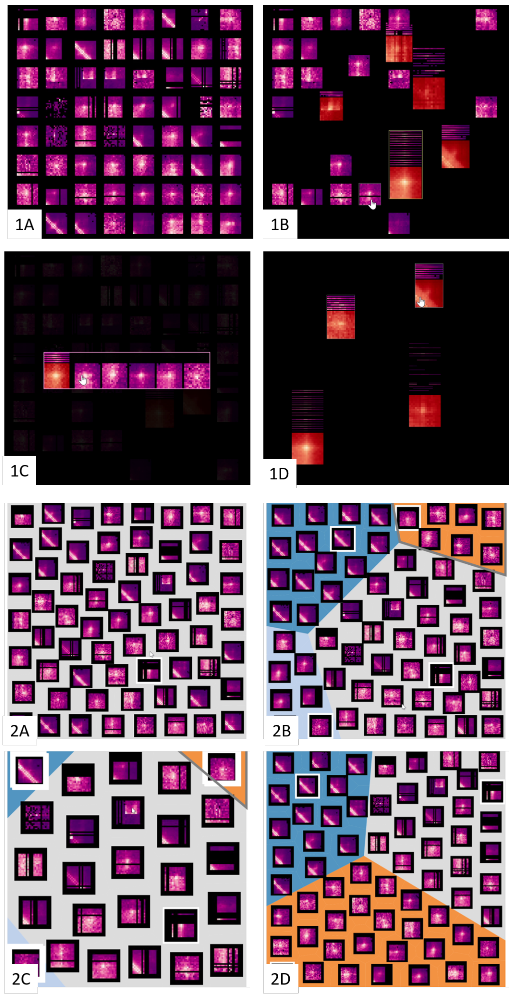

Figure 3: *Piling (1x) vs Interactive Voronoi Treemap (2x) (Sec. 6).*

The `Piling` framework is a javascript piling-based interface that supports A&G tasks [LZC*20]. We use HiC data provided on `piling.js.org/demos/?example=matrices`. We selected 64 images (Figure 3 1A) in `Piling` and use the same in our interactive Voronoi treemap (IVT) (Figure 3 2A). We use this example to illustrate the *qualitative* differences between IVT and the piling-based idiom. As for IVT, `Piling` groups can be arranged freely (DR4). But in `Piling`, groups are explicit but no adjacency is encoded (DR2 is partially fulfilled), objects can be initialized on a grid but there is no actual snap-to-grid grid preventing occlusion (Missing DR1) and the idiom is no space-filling (Missing DR3). There are two major weaknesses in piling that IVT can resolve:

Group content visibility (DR1) In `Piling`, when piles form, *the content of the groups is hidden* (1B) except by opening them (1C) in an overlaid frame; it disrupts the A&G flow and interferes with the user's mental map of the other groups and images. The frame is also not editable without de-piling the whole group. Hence, `Piling` is not ideal for A&G because forming initial groups from the ground up relies mostly on visual comparison by arrangements within and between these seed groups. In IVT, when we expand a group (2C → 2B), we simply increase the weight of its power diagram cells [AA20] which thus decreases the size of all images to optimize the use of space. With IVT, the mental map is better preserved and side-by-side comparisons within and between groups are still possible to decide about group creation or object-to-group assignment.

Use all available space (DR3) In `Piling`, *stacking up images generate empty space* where images are removed from (1B). In IVT, no empty space is created when objects are moved from one group to another (2A → 2B): a group cell area is always proportional to its number of objects, and CVT updates all objects position to spread them over the available space. When a group is collapsed in IVT, it creates a pile (2B → 2C), but the empty space is filled in by automatically increasing the size of the remaining images (2C).

7. Limitations and future work

Scalability On a standard 14-inch laptop display, the Voronoi treemap is limited to show a hundred images to let them readable all at one glance. To handle more images, we could display a subset of them for each group at a time (paging). As CVT is running in real-time during arrangements (IDS4,5), the interface becomes laggy with more than a hundred images. This could be avoided by running the CVT once images are dropped in the final position, at the price of transient occlusion of the still images by the dragged one.Although it is crucial to manually generate the seed groups, it is cumbersome to group more than a hundred images by hand, calling for progressive automation of the process [BZSA18]. We assume that at some point a group contains a sufficient number of objects to be meaningful and used to train an automatic model for classifying the remaining objects. At that point, groups can be collapsed to show only their representative image and save additional space to display other images.

Multi-level It would be natural to support multi-level A&G tasks typical of file management systems represented as folder trees [Bed03]. However, we did not yet determine how to design the interactions to move or copy objects up and down the hierarchy in such a multi-level Voronoi treemap.

User evaluation User studies are still needed to evaluate the benefits and limits of the interactive Voronoi treemap for A&G tasks.

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