

A Unified Framework for Multi-class Scatterplot Colorization

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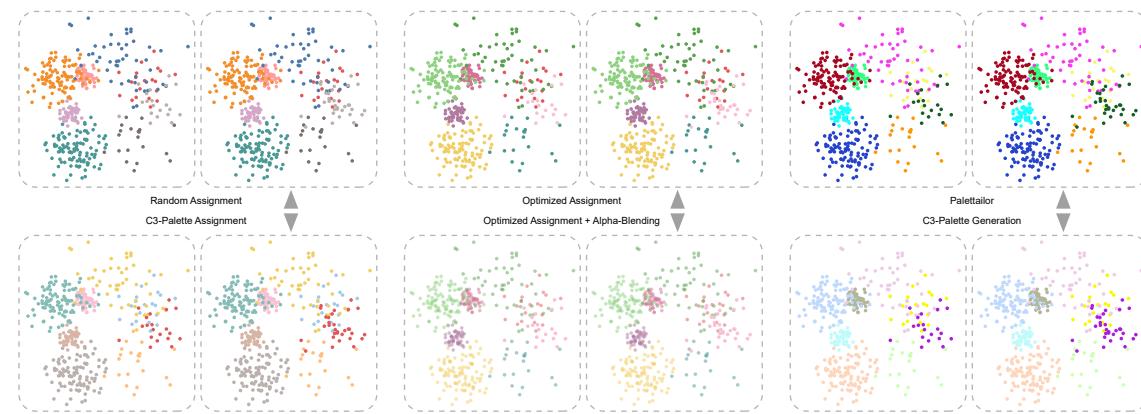


Fig. 1. Results for different conditions of two categorical scatterplots comparison: (left top) Random Assignment; (left bottom) C3-Palette Assignment; (center top) Optimized Assignment [54]; (center bottom) Applying Alpha-Blending on Optimized Assignment, all the classes' alpha are set to 0.5 except the changed class; (right top) Palettailor [37]; (right bottom) C3-Palette Generation. Our system unifies the palette assignment and palette generation to single or multiple scatterplots in a data-aware manner.

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CCS Concepts: • Computer systems organization → Embedded systems; Redundancy; Robotics; • Networks → Network reliability.

Additional Key Words and Phrases: datasets, neural networks, gaze detection, text tagging

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58 1 INTRODUCTION

60 ACM's consolidated article template, introduced in 2017, provides a consistent L^AT_EX style for use across ACM publications,
 61 and incorporates accessibility and metadata-extraction functionality necessary for future Digital Library endeavors.
 62 Numerous ACM and SIG-specific L^AT_EX templates have been examined, and their unique features incorporated into this
 63 single new template.

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 66 publication. If you have published with ACM before, this document provides insight and instruction into more recent
 67 changes to the article template.

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 70 for any stage of publication, from review to final "camera-ready" copy, to the author's own version, with *very* few
 71 changes to the source.

73 2 CO-SALIENCY BASED COLOR DESIGN

75 Given multiple labeled scatterplots with the same class labels (or a subset thereof), each scatterplot X^j has M classes
 76 and n_j data items $\{x_1^j, \dots, x_{n_j}^j\}$, where each x_t^j has a label $l(x_t^j)$ and the i -th class (with n_i^j data points) consists of
 77 $\{x_{i,1}^j, \dots, x_{i,n_i^j}^j\}, i \in \{1, \dots, m\}$. All visualizations use the same background color c_b and the same color mapping
 78 scheme $\tau : L \mapsto c$. Our goal is to find the best mapping τ that supports effective comparison of multiple categorical
 79 scatterplots.

82 In line with the design requirements of natural image comparison and categorial data visualization [19, 30, 37], our
 83 problem is formulated based on the following three design requirements:

- 84 (i) **DR1:** highlighting the most concerned classes between visualizations as much as possible for an efficient
 85 comparison;
- 86 (ii) **DR2:** maximizing the visual discrimination between classes in individual visualizations for an efficient exploration
 87 of multi-class data; and
- 88 (iii) **DR3:** providing flexible interactions for the exploration of relationships among the compared datasets.

90 Although visual comparison is an essential part of interactive data analysis, most of the existing colorization tech-
 91 niques [20, 37] attempt to meet DR2. The key challenge in meeting DR1 is that we need a proper model to characterize the
 92 most salient features in multiple visualizations. To address this issue, we propose a categorical visualization co-saliency
 93 model that calculates the saliency of each data item in the context of other similar visualizations. Integrating this model
 94 into the objective of state-of-the-art color mapping selection or generation frameworks [37, 54], we can generate proper
 95 color mappings to highlight salient differences between juxtaposed categorical visualizations.

98 2.1 Co-saliency for Multi-class Scatterplots

100 Following the definition of image co-saliency [30], we model the class co-saliency with two factors: class importance
 101 between scatterplots and class contrast within scatterplots. The class importance describes how much each class
 102 should stand out from the visualizatioin. While the class contrast measures the distinctness from neighboring classes

and the background, which is similar to perceptual class separability [8, 54]. Hence, we define two types of class contrasts: contrast with neighboring classes and contrast to the background. Analogous to bottom-up image co-saliency models [17, 30], the co-saliency of the i th class is defined as the product between class importance and class contrast score to emphasize the target class, and the co-saliency for M classes:

$$E_{CoS} = \sum_i \left(\sum_j \frac{1}{n_i^j} (\lambda \alpha_i^j + (1 - \lambda) \beta_i^j) \right) \exp(\theta_i) \quad (1)$$

where θ_i is the importance of the i th class, α_i^j is the contrast with neighboring classes of the i th class in the j th scatterplot, β_i^j is the contrast to the background, and λ is a weight between them. To better support DR1, we apply an exponential function to enlarge the weight of class importance, thus makes the target class easy to get a discriminable color from the optimization process.

Class Contrast. Given the j th scatterplot, we define the local class contrast with both point distinctness and point contrast with background [54] based on the neighbors calculated by α -Shape [37]. For each data point \mathbf{x}_t^j , we define its point distinctness as:

$$\gamma(\mathbf{x}_t^j) = \frac{1}{|\Omega_t^j|} \sum_{\mathbf{x}_p^j \in \Omega_t^j} \frac{\Delta\epsilon(\tau(l(\mathbf{x}_t^j)), \tau(l(\mathbf{x}_p^j)))}{d(\mathbf{x}_t^j, \mathbf{x}_p^j)}, \quad (2)$$

where Ω_t^j is set of nearest neighbors of \mathbf{x}_t^j , $\tau(l(\mathbf{x}_p^j))$ is the color of \mathbf{x}_p^j , $\Delta\epsilon$ is the CIELAB color distance [48] and d is the Euclidean distance. For the i th class, its point distinctness is the sum of all points with the same class label in the scatterplot:

$$\alpha_i^j = \frac{1}{n_i^j} \sum_p^{n_j} \gamma(\mathbf{x}_p^j) \delta(l(\mathbf{x}_p^j), i) \quad (3)$$

where $\delta(l(\mathbf{x}_p^j), i)$ is one if the class label $l(\mathbf{x}_p^j)$ is i and else zero. Similar to [54], we define non-separability as the difference value between \mathbf{x}_t^j with data points belonging to the different classes and same class, thus the contrast to the background can be defined as:

$$\rho(\mathbf{x}_t^j) = \frac{1}{|\Omega_t^j|} \sum_{\mathbf{x}_p^j \in \Omega_t^j} \frac{(1 - 2\delta(l(\mathbf{x}_t^j), l(\mathbf{x}_p^j))) \Delta\epsilon(\tau(l(\mathbf{x}_t^j)), \mathbf{c}_b)}{d(\mathbf{x}_t^j, \mathbf{x}_p^j)}, \quad (4)$$

the contrast to the background of the i th class is defined as follows:

$$\beta_i^j = \frac{f(\theta_i)}{n_i^j} \sum_p^{n_j} \exp(\rho(\mathbf{x}_p^j)) \delta(l(\mathbf{x}_p^j), i) \quad (5)$$

where we use a piecewise function to weight the background contrast:

$$f(\theta_i) = \begin{cases} 1 & \text{if } \theta_i > \kappa \\ -1 & \text{else} \end{cases} \quad (6)$$

κ is a user-specified threshold with the default zero. The reason for the two different weighting schemes is that classes with less or no importance might be treated as the background by viewers [55]. To suppress the saliency of such classes, we introduce a negative importance for them. Since $\rho(\mathbf{x}_t^j)$ might be a negative value, we apply an exponential function to transfer it to positive.

Class Importance. Class importance reflects whether a class should be highlight or not. It can be specified by user or by some measures. In our paper, we use class change degree to represent the importance of each class as default.

To quantify how users perceive class structure changes, we measure the difference between class distributions in two scatterplots with the Earth Mover's Distance (EMD) [44], a perceptual metric. Suppose the i th class with two sets of points $\mathbf{X}_i^1 = \{\mathbf{x}_{i,1}^1, \dots, \mathbf{x}_{i,n_i^1}^1\}$ and $\mathbf{X}_i^2 = \{\mathbf{x}_{i,1}^2, \dots, \mathbf{x}_{i,n_i^2}^2\}$. Taking the Euclidian distance between two points as the cost, we need to minimize the total matching cost

$$H(\mathbf{X}_i^1, \mathbf{X}_i^2) = \min_{\chi} \sum_t d(\mathbf{x}_{i,t}^1, \mathbf{x}_{i,\chi(t)}^2),$$

which constrains an one-to-one mapping χ between points (see an illustration in Fig. 2). This is the classic bipartite matching problem, which can be solved by the Hungarian method [34]. When the number of points of two sets is not equal, we further take the difference between the number of points into account. In doing so, the class change degree is defined as:

$$\theta_i = \frac{H(\mathbf{X}_i^1, \mathbf{X}_i^2)}{\min\{n_i^1, n_i^2\}} + \nu \frac{\|n_i^1 - n_i^2\|}{\max\{n_i^1, n_i^2\}} \quad (8)$$

where both terms range within $[0,1]$ and ν is 1.0 as the default.

2.2 Co-Saliency based Color Mapping

On the basis of the co-saliency model, we meet DR1 and DR2 in two ways: co-saliency based color assignment and co-saliency based palette generation.

Co-saliency based Color Assignment. Given a good color palette with P colors ($P \geq M$), the optimal color mapping can be obtained by taking the co-saliency model in Eq. 1 as the objective of the state-of-the-art color assignment method [54]. Starting from a random permutation of P colors, we use the simulated annealing algorithm [1] to find the optimal permutation with two randomized strategies to improve the solution. One is randomly exchanging two colors from the selected m colors and the other is replacing one color from the m selected colors with the one chosen from the unselected $P - M$ colors. With a few iterations, we can obtain a reasonable color mapping as shown in Fig. 1 bottom left.

However, this method has two major limitations: i) requiring users to try many palettes for selecting a good one; and ii) the design of most existing palettes is not oriented towards visual comparison so that even the best color assignment cannot provide prominent cues for this task. For example, all colors in the ColorBrewer 8-class Set1 [25] palette are highly discriminable, but it is hard to find a satisfactory solution. Fig. 3 shows an example, where the change of the red class is hard to identify at once even it is very distinctive. Thus, we prompt users to use our co-saliency based palette generation method.

Co-saliency based Palette Generation. The recently proposed data-aware palette generation method [37] automatically generates discriminable and preferable palettes by maximizing the combination of three palette quality measures: point distinctness, name difference, and color discrimination. By replacing the first measure with our co-saliency model, the palette generation is formulated as an optimization problem:

$$\arg \max_{\tau} E(\tau) = \omega_0 E_{CoS} + \omega_1 E_{ND} + \omega_2 E_{CD}. \quad (9)$$

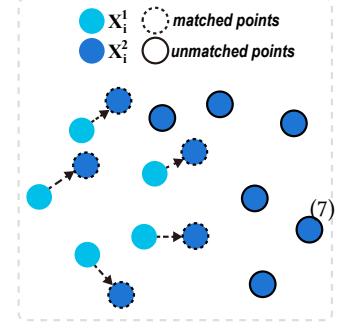


Fig. 2. An one-to-one mapping for computing the changes between two classes.

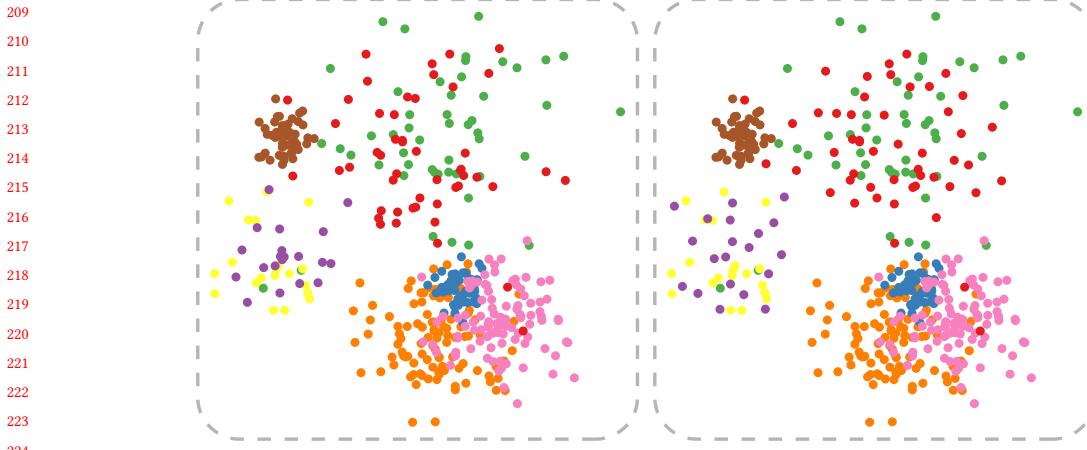


Fig. 3. Visualizing the same data sets as shown in Fig. 4 with the ColorBrewer palette and our assignment method.

which consists of a co-saliency term E_{CoS} (see Eq. 1), a name difference term E_{ND} and a color discrimination term E_{CD} , balanced by ω_0 , ω_1 and ω_2 . For more detail about E_{ND} and E_{CD} , we refer readers to [37]. By using the same optimization method as Lu et al. [37], we can generate desired colors in real time.

2.3 Parameter Effect

Besides different weights for different terms in palette generation [37], our co-saliency model involves three parameters: the weight λ between two contrasts, the threshold for the class importance κ , and ν that is related to the definition of the class change degree which is used as our default class importance. Since ν is fixed in our experiments and the class importance can be specified by user, we mainly discuss the effects of λ and κ .

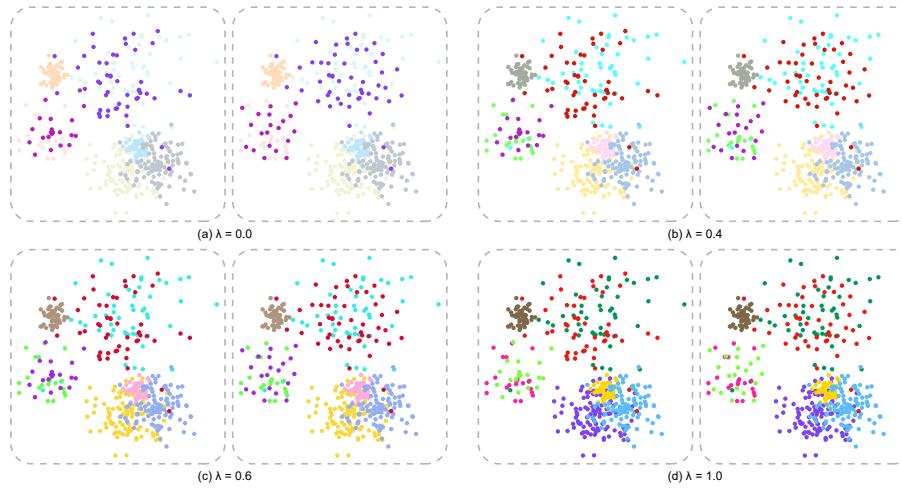


Fig. 4. Effect of λ : (a) result generated by only considering contrast to the background; (b) result generated by setting λ to 0.4; (c) result generated by setting λ to 0.6; (d) result generated by only considering contrast with nearest classes.

Balancing Weight λ . Although this parameter modulates the influence between the class contrast with neighbors and background, it offers a compromise between DR1 and DR2. As shown in Fig. 4(a), considering only the contrast to the background would have a good ‘pop out’ effect but other classes are hard to discriminate. While considering only the contrast with nearest neighbors, such as Fig. 4(d), all the classes are each to distinguish but the changed classes are hard to find out. This is reasonable, because pre-attentive vision lets a bright saturated color region within regions of de-saturated colors “pop-out” to the viewer [26]. In our experiments, we found that setting $\lambda = 0.4$ as the default allows to simultaneously emphasize changes and preserve the discriminability between classes, see an example in Fig. 4(b).

Importance Threshold κ . The threshold κ selects the classes with large importance to be highlighted. With a default value of zero, all classes with importance value larger than zero are ensured to be highlighted. Likewise, a large κ will de-emphasize classes with a small importance. We further allow users to specify κ by interaction through the control panel (see Sec. 3).

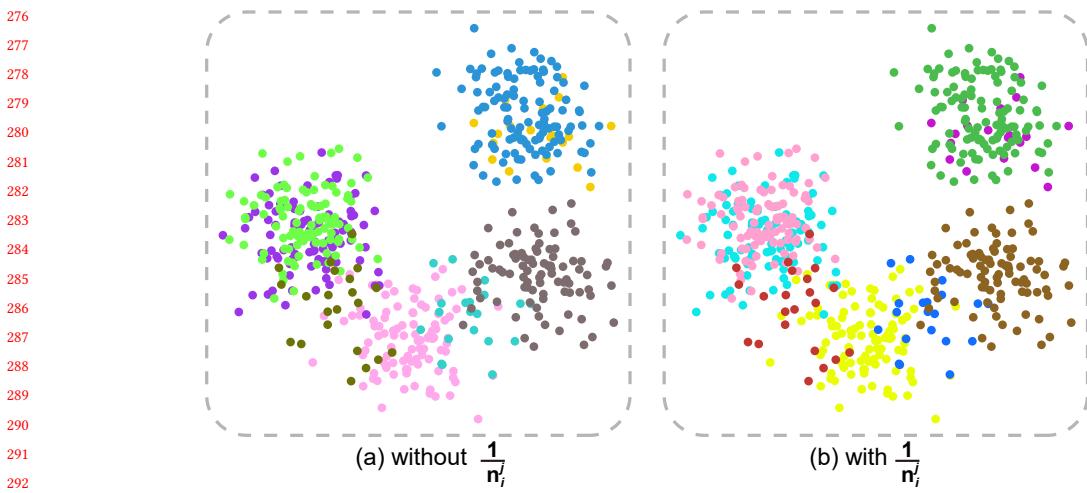


Fig. 5. Effect of $\frac{1}{n_i^j}$: (a) without this term the small classes are hard to catch user’s attention; (b) with this term, small classes are easy to find. Palettes are generated with same scatterplot.

We can observe that when there’s only one scatterplot and θ_i of each class is zero, then Equation. 1 is very similar to the objective function of [54]. Our method extends Wang et.al’s work to multiple scatterplots with a carefully designed co-saliency model. Besides, we add $\frac{1}{n_i^j}$ to emphasize the class with less points. As shown in Fig. 5(b), with this new term, the little classes, like red, blue and purple classes, become more discriminable.

3 INTERACTIVE SYSTEM

To help users interactively design colors for comparing multi-class scatterplots, we developed a web-based multi-view visualization tool¹ (see Fig. 6). It consists of four coordinated views: (a) a settings panel, (b) a control panel for adjusting importance threshold κ and even importance value of each class, (c) the juxtaposed visualizations, and (d) a history view. The control panel shows the decision which classes are highlighted, and the history view allows to quickly explore and access previous color mappings.

¹<https://c3-palette.github.io/>

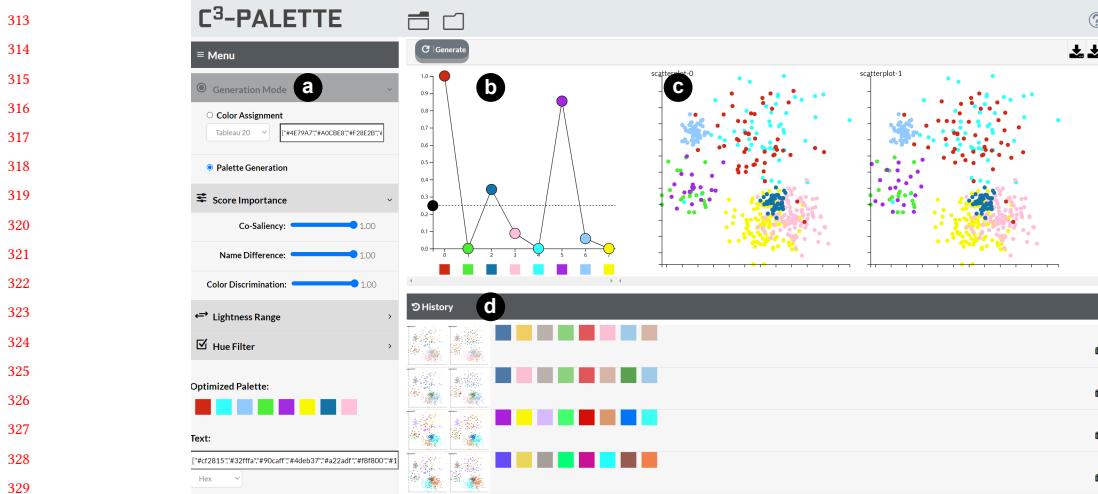


Fig. 6. Screenshot of the interactive system. (a) Settings Panel; (b) Control Panel; (c) Visualization Panel; (d) History Panel.

After uploading multiple labeled scatterplots, the user can either choose a default color palette or use our system to automatically generate color palettes. In this case, the system automatically finds an optimal color mapping scheme to colorize the input data, while each class is encoded as a circle where the x-axis represents class label and the y-axis indicates the importance of each class. By default, the importance is represented by the change degree and κ is set to zero. User can drag the circle to modify the corresponding importance value. The κ is controlled by a black circle on the y-axis which can also be dragged to modify. Our system finds a color mapping scheme to highlight the classes with large importance and renders the classes in ascending order of the corresponding importance. If users like the color mapping scheme, they can save it to the history view.

Using θ_i defined in Eq. 1, the classes whose importance values are larger than the threshold κ will be highlighted. Figs. 6(b,c) show an example, where the three classes with the adjusted importance values larger than κ are emphasized with salient red, blue and purple colors, respectively. This control panel allows users to select arbitrary classes of interest to highlight by simply adjust circle position and κ value.

4 EVALUATION

We evaluated the effectiveness of our method on supporting juxtaposed visual comparisons and the discriminability for reading scatterplots. We conducted two online controlled experiments through Amazon Mechanical Turk (AMT) with 160 participants in total, to evaluate how well our method can support people in *observing changes* and *visual separability* for juxtaposed categorical scatterplots:

- (i) *Spotting the Difference task*. To evaluate how well our method can support people in *observing changes* for juxtaposed categorical scatterplots;
- (ii) *Counting class number task*. To evaluate whether our method can support the *visual separability* of classes in each individual scatterplot, which is considered fundamental to juxtaposed comparison.

Independent Variables. In each of our studies, we investigated three independent variables: colorization method, change magnitude and change type.

Colorization method: We used six different ways to colorize scatterplots: four benchmark methods (*Random Assignment*, *Optimized Assignment*, *Alpha Blending* and *Palettailor*) and two experimental methods based on our approach (*C3-Palette Assignment*, *C3-Palette Generation*):

- C1: *Random Assignment* is randomly selecting and assigning colors from Tableau-20 palette to the classes.
- C2: *Optimized Assignment* uses the optimized assignment approach [54] for one of the two scatterplots with an input of Tableau-20 color palette.
- C3: *Alpha Blending* is changing the alpha of each unchanged class to 0.5 while the changed classes are stay to 1.0 based on *Optimized Assignment* result. We choose 0.5 since we also have the discrimination task.
- C4: *Palettailor* uses the method proposed by Lu et.al [37] for single scatterplot palette generation. The palette is generated for one of the two scatterplots with the default settings.
- C5: *C3-Palette Assignment* uses the color assignment optimization solution of Eq. 1 based on Tableau-20.
- C6: *C3-Palette Generation* uses the unified color generation and assignment optimization method, and produced the results with the parameters $\omega_0 = 1.0$, $\omega_1 = 1.0$ and $\omega_2 = 1.0$.

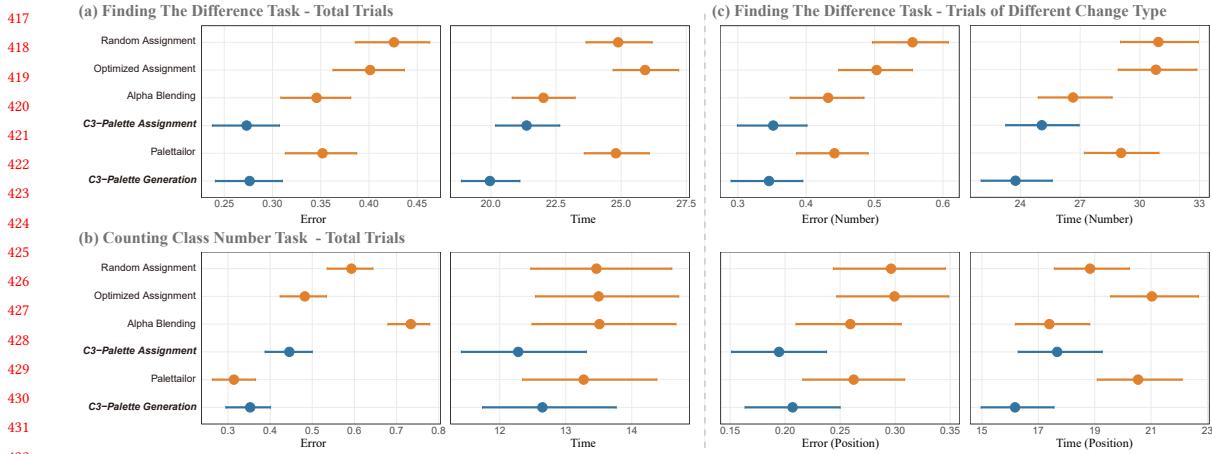
Our approach are all using the default parameters $\lambda = 0.4$ and $\kappa = 0$.

Change magnitude and *Change type*: While the colorization method is the primary independent variable to be investigated, we are also interested in how the effect of our methods would vary based on the level of change and the different change type between the two scatterplots. Thus we first define two types of changes that a class would have across multiple scatterplots: *point number* and *point position*. Then for each change type, we define three levels of change magnitude calculated using Eq. 8: *small*, *medium*, and *large*. (See the next paragraph for the detailed calculation.)

Scatterplot Dataset Generation. The paired scatterplot datasets used in our studies were generated as follows. First, we designed a set of multi-class scatterplots, each containing 8 classes. Each class was generated using Gaussian random sampling and placed randomly in a 600×600 area. Similar to [37], these classes belong to one of the four settings of varying size and density: small & dense ($n = 50, \sigma = 20$), small & sparse ($n = 20, \sigma = 50$), large & dense ($n = 100, \sigma = 50$), and large & sparse ($(n = 50, \sigma = 100)$).

Then, for each scatterplot generated above, we produced its paired scatterplot by randomly choosing one or more classes and changing the positions or number of their data points. To systematically compute the changes, we defined two variables: *change ratio* and *number of changed classes*. *Change ratio* defines how large the change of a type is, ranging from 0 to 1; and number of changed classes defines the number of classes that are changed, ranging from 1 to 3. We summarize our basic idea of data generation for each change type as below.

- *Point number:* For each class in the original scatterplot, we calculated the new point number by multiplying the original number by $(1 \pm \text{change ratio})$. An addition means to increase the point number, which was implemented by generating the new points with the same distribution as the original class. Subtraction was achieved by randomly deleting data points from the original class.
- *Point position:* Point position contains many types, such as class center position change and shape change. In our experiment, we use the two different position changes mentioned above. For center position change, the center of a class can be moved in a certain *direction* with a specific *distance*. We moved the center towards a random direction by a distance calculated by multiplying a maximal change distance (400 by default) by the *change ratio*. For shape change, we define the shape of a class as the bounding box of its data points. We simulated a shape change of a class by modifying the density parameter of its Gaussian distribution to the opposite direction. For example, a small & dense class ($n = 50, \sigma = 20$) would be changed into a small & sparse ($n = 50, \sigma = 50$) class. In



	C1	C2	C3	C4	C5	C6
Dataset 1: Position Small 1	G1	G2	G3	G4	G5	G6
Dataset 2: Position Small 1	G6	G1	G2	G3	G4	G5
Dataset 3: Position Small 2	G5	G6	G1	G2	G3	G4
Dataset 4: Position Small 2	G4	G5	G6	G1	G2	G3
Dataset 5: Position Small 3	G3	G4	G5	G6	G1	G2
Dataset 6: Position Small 3	G2	G3	G4	G5	G6	G1
Dataset 7: Position Medium 1	G1	G2	G3	G4	G5	G6
Dataset 8: Position Medium 1	G6	G1	G2	G3	G4	G5
...						
Dataset 35: Number Large 3	G3	G4	G5	G6	G1	G2
Dataset 36: Number Large 3	G2	G3	G4	G5	G6	G1

469 4.1 Experiment 1: Spotting the Difference

470 To evaluate how well our approach can assist observing changes between juxtaposed categorical scatterplots, we
 471 conduct an online “spot-the-difference” experiment through Amazon Mechanical Turk (AMT) with 136 participants.

472 **Hypotheses.** We hypothesized that our approach would generally be more effective than the benchmark methods on
 473 the juxtaposed comparison tasks, and that this effect would vary based on *change magnitude*.
 474

- 475 **H1.** Our color generation method (*C3-Palette Generation*) outperforms the benchmark conditions (*Random Assignment*,
 476 *Optimized Assignment*, *Alpha Blending* and *Palettailor*) on the task performance.
 477
- 478 **H2.** Our color assignment method (*C3-Palette Assignment*) using a color palette with a larger range of brightness
 479 and saturation (*Tableau-20*) outperforms the benchmark conditions (*Random Assignment*, *Optimized Assignment*,
 480 *Alpha Blending* and *Palettailor*) on the task performance.
 481
- 482 **H3.** There would be an interaction effect between colorization methods and change magnitude. Specifically, the
 483 difference between the effect of our methods (*C3-Palette Generation* and *C3-Palette Assignment*) and that of the
 484 benchmark methods (*Random Assignment*, *Optimized Assignment*, *Alpha Blending* and *Palettailor*) would change
 485 based on the *change magnitude* between the two scatterplots.
 486
- 487 **H4.** There would be an interaction effect between colorization methods and change type. Specifically, the difference
 488 between the effect of our methods (*C3-Palette Generation* and *C3-Palette Assignment*) and that of the benchmark
 489 methods (*Random Assignment*, *Optimized Assignment*, *Alpha Blending* and *Palettailor*) would change based on
 490 the *change type* between the two scatterplots.
 491
- 492
- 493
- 494

495 4.1.1 Experimental Design.

496 **Task & Measures.** In this experiment, each participant was asked to perform a *spot-the-difference* task. Inspired by
 497 the Spot the Difference game where one needs to compare a pair of similar pictures to detect their differences [18], we
 498 asked participants to identify all the classes that have been changed in two scatterplots. At the beginning of each trial,
 499 the number of changed classes was provided. Each participant was asked to select all the changed classes by clicking
 500 the points belonging to these class in either of the scatterplots.
 501

502 For each participant, we measured the *time* taken for each trial, and counted the errors (0/1) indicating whether
 503 the actual changed classes are aligned with the participant’s response. Note that if any of the changed classes was
 504 mistakenly identified, the trial would be considered as “wrong” (1).
 505

506 While the participant was instructed to do the task “*as accurately as possible*”, we set a 60-second time limit for each
 507 trial. If the participant could not find all the changed classes during the time limit, they were directed to the next trial.
 508 There also will appear a “*Can’t Find it*” button after 30 seconds. This was done since we observed from the pilot study
 509 that when participants spent too much time on a single trial, they may decide to quit (which will lead to an incorrect
 510 answer) or to spend more time till they get the correct answer (which will lead to increasing time spent on the trial).
 511 This subject decision would add noise to our measurements. Thus we added a 30-second time limit, which was informed
 512 by our pilot study, where over 85% correct trials were completed within 30 seconds. More details can be found in the
 513 supplementary material.
 514

515 **Experiment Organization.** We tested the effects of the 6 method conditions across 36 paired multi-class scatterplot
 516 datasets using a *between-subject* experiment design. To avoid ordering effects, where the participant would get familiar
 517

521 with a dataset after seeing it several times, each participant was assigned to a group and saw a specific subset of datasets
 522 under different conditions. We used a Latin Square grouping (see Table. 1) to organize the trials for each participant.
 523

524 In addition, some participants might apply a “shortcut” strategy when seeing a class that is obviously more salient
 525 than the others, especially under the *C3-Palette Assignment* and *C3-Palette Generation* conditions. Thus, for quality
 526 control, we added 4 sentinels which were very simple trials with only one changed class and a large change magnitude,
 527 and we assigned a de-saturated color to the changed class that made it less salient. We add these 4 distractor trials to
 528 each group to identify whether the participants is doing the task seriously and reject the results with more than two
 529 wrong trials.
 530

531 Finally, there were 6 participant groups and each of them had 40 trials in total. To further avoid learning effects
 532 between trials, we randomly shuffled the display orders of all scatterplot pairs, and randomly placed the two scatterplots
 533 in each pair on the left or right side.
 534

535 Table 2. Participants details for each task.
 536

Task & Group	Spotting the Difference		Counting class number	
	Pilot(28)	Formal(108)	Pilot(29)	formal(52)
Group 1	5	18	5	9
Group 2	5	17	5	8
Group 3	5	19	4	8
Group 4	3	17	5	9
Group 5	5	19	5	9
Group 6	5	18	5	9

547 **Pilot Study & Power Analysis.** We conducted a pilot study involving 28 participants to check the experimental setup
 548 and determine the parameters, such as the time limit for a trial. Harnessing by the pilot study, we also obtained our
 549 expected effect sizes, which were in further fed into a power analysis. With an effect size Cohen’s d of 0.4, alpha level of
 550 0.05 and beta level of 0.8, the power analysis suggested a minimum number of 100 participants for the spot-the-difference
 551 task. See the supplementary material for more details.
 552

553 **Participants.** We recruited 108 participants(as shown in Table. 2) for the experiment on Amazon Mechanical Turk.
 554 According to the completion time in the pilot study, we paid each participant \$1.5 for the task based on the US minimum
 555 hourly wage. No participant claimed color vision deficiency on their informed consent.
 556

557 **Procedure.** Each participant went through the following steps in our experiment: (i) viewing a user guide of the task
 558 and completing three training trials; (ii) completing each trial as accurately as possible; (iii) providing demographic
 559 information.
 560

561 4.1.2 Results.

562 Following previous studies, we analyzed the results using 95% confidence intervals, and also conducted Mann-Whitney
 563 tests to compare the differences between conditions. The non-parametric test was used due to observations of non-
 564 normally distributed data from our pilot study. In addition, we computed the effect size using Cohen’s d , i.e., the
 565 difference in means of the conditions divided by the pooled standard deviation. We used ANOVA to examine the
 566 interaction effect between variables.
 567

568 Results of the online experiment are shown in Figure 7 (a). First, we found that our approach(*C3-Palette Assignment*
 569 and *C3-Palette Generation*) leads to a significantly lower error rate in task performance than all benchmark conditions,
 570

including the random methods *Random Assignment* ($p < 0.001$), the optimized assignment method *Optimized Assignment* ($p < 0.001$) and the alpha blending method based on optimized assignment *Alpha Blending* ($p < 0.001$). *C3-Palette Generation* also leads to significantly less time compared to *Random Assignment* ($p = 0.001$), *Optimized Assignment* ($p < 0.001$), *Alpha Blending* ($p < 0.001$) and *Palettailor*(**H1** confirmed).

Finally, we did not find significant interaction effect between *colorization methods* and *change magnitude*, meaning that the effect of our method is not necessarily influenced by the magnitude of change between the two scatterplots (**H3** not confirmed).

4.2 Experiment 2: Counting Class Number

To evaluate whether our approach can fundamentally support the visual separability of the classes in each scatterplot, we conduct an online “counting class number” experiment through Amazon Mechanical Turk (AMT) with 81 participants. The experimental design was similar to the first study, but we set up with different task during the experiment. We expected to see different patterns of the discriminability across different conditions. Specifically, our methods would lead to a shorter error and time than *Random Assignment* and *Alpha Blending* conditions.

Hypotheses. We hypothesized that our approach would generally be more effective than the benchmark methods on the discrimination tasks, and that this effect would not vary based on *change magnitude* or *change type*.

H1. Our color generation method (*C3-Palette Generation*) outperforms the benchmark conditions (*Random Assignment*, *Optimized Assignment*, *Alpha Blending*), while is comparable to *Palettailor* on the task performance.

H2. Our color assignment method (*C3-Palette Assignment*) based on *Tableau-20* outperforms the benchmark conditions (*Random Assignment*, *Alpha Blending*), while is comparable to *Optimized Assignment* condition on the task performance.

H3. *Change magnitude* or *change type* would have no effect on discrimination task between different conditions.

4.2.1 Experimental Design. Task & Measures. Following previous methodologies [37, 54], each participant was asked to perform a *counting class number* task. We asked participants to identify how many classes(colors) are there in the given two scatterplots and then choose an answer among several options below the two scatterplots. We recorded the participant’s answer and response time for each trial, while *error* is 0 if the participant’s response not equal to the actual class number, else 1.

Pilot Study & Power Analysis. We conducted a pilot study involving 29 participants to check the experimental setup and determine the parameters, such as the time limit for a trial. Harnessing by the pilot study, we also obtained our expected effect sizes, which were in further fed into a power analysis. With an effect size Cohen’s d of 0.6, alpha level of 0.05 and beta level of 0.8, the power analysis suggested a minimum number of 50 participants for the spot-the-difference task. See the supplementary material for more details.

Participants. We recruited 52 participants(as shown in Table. 2) for the experiment on Amazon Mechanical Turk. According to the completion time in the pilot study, we paid each participant \$1.5 for the task based on the US minimum hourly wage. No participant claimed color vision deficiency on their informed consent.

4.2.2 Results. Through this study we found that first the task performance results (time and error) are aligned with those in our online experiment (see supplemental materials for more details). Second, as shown in Figure ?? (a), we found a slight trend that our methods (*Ours Generation*, *Ours Tableau 20* and *Ours Tableau 10*) leads to a shorter scanpath

625 on average than the benchmark conditions (*Random Tableau-10* and *Random Tableau-20*) and *Optimized Tableau*. From
626 Figure ?? (b,c), where we plot the participant's scanpaths of two example trials, we can see that the participant had
627 longer gazes and more eye movements across the two scatterplots under *Random Tableau-20*, compared to *Ours Tableau*
628 20. This indicates that our approach might reduce people's cognitive load needed when performing the task.
629

630 4.3 Discussion

631 In summary, we evaluated the effectiveness of our approach against the benchmark conditions through a series of
632 studies. We found that first, our experimental methods (*Ours Generation*, *Ours Tableau-20* and *Ours Tableau-10*) generally
633 support the fundamental visual separability of the classes. Second, our methods outperform the benchmark methods
634 on juxtaposed comparison tasks, and their effects are influenced by the color variety of the input palettes, yet not
635 necessarily influenced by the change magnitude of the two scatterplots. Third, we observed some evidences indicating
636 that our methods might help alleviate eye movement distance when doing the comparison tasks.
637

638 Some limitations exist in our evaluation. First, our experiment focuses on scatterplots, a single visualization type.
639 While scatterplots are commonly used in juxtaposed comparison (e.g., correlation matrix), the effectiveness of our
640 approach might be different for other types of visualizations such as line charts or bar charts. Second, our experiment
641 focuses on identifying the differences between two scatterplots, which is a simplified situation, since in real-world
642 cases often more than two visualizations are compared. Third, we cannot further analyze the effect of *change type*,
643 given the current study design, though we did observe some trends that for certain types of change, our methods are
644 more effective. That brings us to a series of more fundamental questions: how can we properly define the types of
645 changes? What is the just noticeable change magnitude for each change type? Further research is needed to answer
646 these questions so that our approach can be thoroughly evaluated.
647

648 5 CONCLUSION

649 We presented an interactive color design approach for the effective juxtaposed comparison of multiple labeled datasets.
650 It is built upon a novel co-saliency model, which characterizes the most co-salient features between juxtaposed labeled
651 data visualizations while maintaining class discrimination in the individual visualizations. We evaluated this approach
652 in three ways: a numeric study for the class separability in each view, an online study for its usability of detecting
653 changes between multiple views, and a lab study with eye tracking to learn if our approach can alleviate eye movements.
654 The results demonstrate that our produced color mapping schemes are well suited for efficient visual comparison. We
655 further demonstrated the effectiveness of our approach for visually comparing juxtaposed line charts with a case study.
656

657 Our work concentrated on juxtaposed comparisons to detect changes between multiple datasets. Although detecting
658 changes is a fundamental visual comparison task, its optimal color palette might not be appropriate for understanding
659 other analytical comparison tasks (such as max delta and correlation tasks [40]). Future work needs to investigate the
660 effectiveness and extensions of our approach for such comparison tasks. Furthermore, our approach produces colors
661 with salient hue to highlight classes with large changes, but those colors do not visually indicate the ranking of class
662 changes. It would be helpful to associate the color ordering constraint [10] with the degree of changes, so that the
663 ranking of class changes can be shown clearly. Last, while we only studied the interaction effect between change
664 magnitude and different colorization methods, we plan to investigate how this effect is influenced by different types of
665 changes, such as point number, center position and shape.
666

6 TEMPLATE OVERVIEW

As noted in the introduction, the “`acmart`” document class can be used to prepare many different kinds of documentation — a double-blind initial submission of a full-length technical paper, a two-page SIGGRAPH Emerging Technologies abstract, a “camera-ready” journal article, a SIGCHI Extended Abstract, and more — all by selecting the appropriate *template style* and *template parameters*.

This document will explain the major features of the document class. For further information, the *L^AT_EX User’s Guide* is available from <https://www.acm.org/publications/proceedings-template>.

6.1 Template Styles

The primary parameter given to the “`acmart`” document class is the *template style* which corresponds to the kind of publication or SIG publishing the work. This parameter is enclosed in square brackets and is a part of the `documentclass` command:

```
\documentclass[STYLE]{acmart}
```

Journals use one of three template styles. All but three ACM journals use the `acmsmall` template style:

- `acmsmall`: The default journal template style.
- `acmlarge`: Used by JOCCH and TAP.
- `acmtog`: Used by TOG.

The majority of conference proceedings documentation will use the `acmconf` template style.

- `acmconf`: The default proceedings template style.
- `sigchi`: Used for SIGCHI conference articles.
- `sigchi-a`: Used for SIGCHI “Extended Abstract” articles.
- `sigplan`: Used for SIGPLAN conference articles.

6.2 Template Parameters

In addition to specifying the *template style* to be used in formatting your work, there are a number of *template parameters* which modify some part of the applied template style. A complete list of these parameters can be found in the *L^AT_EX User’s Guide*.

Frequently-used parameters, or combinations of parameters, include:

- `anonymous, review`: Suitable for a “double-blind” conference submission. Anonymizes the work and includes line numbers. Use with the `\acmSubmissionID` command to print the submission’s unique ID on each page of the work.
- `authorversion`: Produces a version of the work suitable for posting by the author.
- `screen`: Produces colored hyperlinks.

This document uses the following string as the first command in the source file:

```
\documentclass[sigconf, authordraft]{acmart}
```

729 7 MODIFICATIONS

730 Modifying the template – including but not limited to: adjusting margins, typeface sizes, line spacing, paragraph and
731 list definitions, and the use of the \vspace command to manually adjust the vertical spacing between elements of your
732 work – is not allowed.

733 **Your document will be returned to you for revision if modifications are discovered.**

736 8 TYPEFACES

738 The “acmart” document class requires the use of the “Libertine” typeface family. Your TeX installation should include
739 this set of packages. Please do not substitute other typefaces. The “lmodern” and “ltimes” packages should not be used,
740 as they will override the built-in typeface families.
741

743 9 TITLE INFORMATION

745 The title of your work should use capital letters appropriately - <https://capitalizemytitle.com/> has useful rules for
746 capitalization. Use the title command to define the title of your work. If your work has a subtitle, define it with the
747 subtitle command. Do not insert line breaks in your title.
748

749 If your title is lengthy, you must define a short version to be used in the page headers, to prevent overlapping text.

750 The title command has a “short title” parameter:

```
751 \title[short title]{full title}
```

754 10 AUTHORS AND AFFILIATIONS

756 Each author must be defined separately for accurate metadata identification. Multiple authors may share one affiliation.
757 Authors’ names should not be abbreviated; use full first names wherever possible. Include authors’ e-mail addresses
758 whenever possible.
759

760 Grouping authors’ names or e-mail addresses, or providing an “e-mail alias,” as shown below, is not acceptable:

```
761 \author{Brooke Aster, David Mehldau}  
762 \email{dave,judy,steve@university.edu}  
763 \email{firstname.lastname@phillips.org}
```

766 The authornote and authornotemark commands allow a note to apply to multiple authors – for example, if the
767 first two authors of an article contributed equally to the work.
768

769 If your author list is lengthy, you must define a shortened version of the list of authors to be used in the page headers,
770 to prevent overlapping text. The following command should be placed just after the last \author{} definition:
771

```
772 \renewcommand{\shortauthors}{McCartney, et al.}
```

774 Omitting this command will force the use of a concatenated list of all of the authors’ names, which may result in
775 overlapping text in the page headers.
776

777 The article template’s documentation, available at <https://www.acm.org/publications/proceedings-template>, has a
778 complete explanation of these commands and tips for their effective use.
779

780 Note that authors’ addresses are mandatory for journal articles.

781 11 RIGHTS INFORMATION

782 Authors of any work published by ACM will need to complete a rights form. Depending on the kind of work, and the
783 rights management choice made by the author, this may be copyright transfer, permission, license, or an OA (open
784 access) agreement.

785 Regardless of the rights management choice, the author will receive a copy of the completed rights form once it
786 has been submitted. This form contains L^AT_EX commands that must be copied into the source document. When the
787 document source is compiled, these commands and their parameters add formatted text to several areas of the final
788 document:

- 789
 - 790 • the “ACM Reference Format” text on the first page.
 - 791 • the “rights management” text on the first page.
 - 792 • the conference information in the page header(s).

793 Rights information is unique to the work; if you are preparing several works for an event, make sure to use the
794 correct set of commands with each of the works.

795 The ACM Reference Format text is required for all articles over one page in length, and is optional for one-page
796 articles (abstracts).

801 12 CCS CONCEPTS AND USER-DEFINED KEYWORDS

802 Two elements of the “acmart” document class provide powerful taxonomic tools for you to help readers find your work
803 in an online search.

804 The ACM Computing Classification System — <https://www.acm.org/publications/class-2012> — is a set of classifiers
805 and concepts that describe the computing discipline. Authors can select entries from this classification system, via
806 <https://dl.acm.org/ccs/ccs.cfm>, and generate the commands to be included in the L^AT_EX source.

807 User-defined keywords are a comma-separated list of words and phrases of the authors’ choosing, providing a more
808 flexible way of describing the research being presented.

809 CCS concepts and user-defined keywords are required for all articles over two pages in length, and are optional
810 for one- and two-page articles (or abstracts).

815 13 SECTIONING COMMANDS

816 Your work should use standard L^AT_EX sectioning commands: `section`, `subsection`, `subsubsection`, and `paragraph`.
817 They should be numbered; do not remove the numbering from the commands.

818 Simulating a sectioning command by setting the first word or words of a paragraph in boldface or italicized text is
819 **not allowed**.

823 14 TABLES

824 The “acmart” document class includes the “booktabs” package — <https://ctan.org/pkg/booktabs> — for preparing
825 high-quality tables.

826 Table captions are placed *above* the table.

827 Because tables cannot be split across pages, the best placement for them is typically the top of the page nearest
828 their initial cite. To ensure this proper “floating” placement of tables, use the environment `table` to enclose the table’s
829 contents and the table caption. The contents of the table itself must go in the `tabular` environment, to be aligned
830 with other elements on the page.

833 Table 3. Frequency of Special Characters
834

835 Non-English or Math	836 Frequency	837 Comments
836 Ø	837 1 in 1,000	838 For Swedish names
837 π	838 1 in 5	839 Common in math
838 \$	839 4 in 5	840 Used in business
839 Ψ ₁ ²	840 1 in 40,000	841 Unexplained usage

841 Table 4. Some Typical Commands
842

843 Command	844 A Number	845 Comments
844 \author	845 100	846 Author
845 \table	846 300	847 For tables
846 \table*	847 400	848 For wider tables

properly in rows and columns, with the desired horizontal and vertical rules. Again, detailed instructions on **tabular** material are found in the *LATEX User's Guide*.

Immediately following this sentence is the point at which Table 3 is included in the input file; compare the placement of the table here with the table in the printed output of this document.

To set a wider table, which takes up the whole width of the page's live area, use the environment **table*** to enclose the table's contents and the table caption. As with a single-column table, this wide table will "float" to a location deemed more desirable. Immediately following this sentence is the point at which Table 4 is included in the input file; again, it is instructive to compare the placement of the table here with the table in the printed output of this document.

Always use midrule to separate table header rows from data rows, and use it only for this purpose. This enables assistive technologies to recognise table headers and support their users in navigating tables more easily.

863 15 MATH EQUATIONS

864 You may want to display math equations in three distinct styles: inline, numbered or non-numbered display. Each of
865 the three are discussed in the next sections.
866

867 15.1 Inline (In-text) Equations

868 A formula that appears in the running text is called an inline or in-text formula. It is produced by the **math** environment,
869 which can be invoked with the usual `\begin{math} . . . \end{math}` construction or with the short form `$. . . $`. You can use any
870 of the symbols and structures, from α to ω , available in LATEX [35]; this section will simply show a few examples of
871 in-text equations in context. Notice how this equation: $\lim_{n \rightarrow \infty} x = 0$, set here in in-line math style, looks slightly
872 different when set in display style. (See next section).
873

874 15.2 Display Equations

875 A numbered display equation—one set off by vertical space from the text and centered horizontally—is produced by the
876 **equation** environment. An unnumbered display equation is produced by the **displaymath** environment.
877

878 Again, in either environment, you can use any of the symbols and structures available in LATEX; this section will just
879 give a couple of examples of display equations in context. First, consider the equation, shown as an inline equation
880

885 above:

$$\lim_{n \rightarrow \infty} x = 0 \quad (10)$$

888 Notice how it is formatted somewhat differently in the **displaymath** environment. Now, we'll enter an unnumbered
889 equation:

$$\sum_{i=0}^{\infty} x + 1$$

893 and follow it with another numbered equation:

$$\sum_{i=0}^{\infty} x_i = \int_0^{\pi+2} f \quad (11)$$

897 just to demonstrate L^AT_EX's able handling of numbering.

900 16 FIGURES

902 The “figure” environment should be used for figures. One or more images can be placed within a figure. If your figure
903 contains third-party material, you must clearly identify it as such, as shown in the example below.

904 Your figures should contain a caption which describes the figure to the reader.

905 Figure captions are placed *below* the figure.

907 Every figure should also have a figure description unless it is purely decorative. These descriptions convey whatâŽs
908 in the image to someone who cannot see it. They are also used by search engine crawlers for indexing images, and
909 when images cannot be loaded.

911 A figure description must be unformatted plain text less than 2000 characters long (including spaces). **Figure**
912 **descriptions should not repeat the figure caption** âŽ§ **their purpose is to capture important information**
913 **that is not already provided in the caption or the main text of the paper.** For figures that convey important and
914 complex new information, a short text description may not be adequate. More complex alternative descriptions can be
915 placed in an appendix and referenced in a short figure description. For example, provide a data table capturing the
916 information in a bar chart, or a structured list representing a graph. For additional information regarding how best to write
917 figure descriptions and why doing this is so important, please see <https://www.acm.org/publications/taps/describing-figures/>.

922 16.1 The “Teaser Figure”

924 A “teaser figure” is an image, or set of images in one figure, that are placed after all author and affiliation information,
925 and before the body of the article, spanning the page. If you wish to have such a figure in your article, place the
926 command immediately before the `\maketitle` command:

```
928
929 \begin{teaserfigure}
930   \includegraphics[width=\textwidth]{sampleteaser}
931   \caption{figure caption}
932   \Description{figure description}
933 \end{teaserfigure}
```

937 17 CITATIONS AND BIBLIOGRAPHIES

938 The use of \TeX for the preparation and formatting of one's references is strongly recommended. Authors' names should
 939 be complete – use full first names (“Donald E. Knuth”) not initials (“D. E. Knuth”) – and the salient identifying features
 940 of a reference should be included: title, year, volume, number, pages, article DOI, etc.

941 The bibliography is included in your source document with these two commands, placed just before the $\text{\end\{document\}}$
 942 command:
 943

```
945 \bibliographystyle{ACM-Reference-Format}
946 \bibliography{bibfile}
```

947 where “`bibfile`” is the name, without the “`.bib`” suffix, of the \TeX file.

948 Citations and references are numbered by default. A small number of ACM publications have citations and references
 949 formatted in the “author year” style; for these exceptions, please include this command in the **preamble** (before the
 950 command “ $\text{\begin\{document\}}$ ”) of your \LaTeX source:

```
951 \citetstyle{acmauthoryear}
```

952 Some examples. A paginated journal article [3], an enumerated journal article [13], a reference to an entire issue [12],
 953 a monograph (whole book) [33], a monograph/whole book in a series (see 2a in spec. document) [24], a divisible-book
 954 such as an anthology or compilation [15] followed by the same example, however we only output the series if the
 955 volume number is given [16] (so Editor00a's series should NOT be present since it has no vol. no.), a chapter in a divisible
 956 book [50], a chapter in a divisible book in a series [14], a multi-volume work as book [32], a couple of articles in a
 957 proceedings (of a conference, symposium, workshop for example) (paginated proceedings article) [4, 22], a proceedings
 958 article with all possible elements [49], an example of an enumerated proceedings article [21], an informally published
 959 work [23], a couple of preprints [7, 9], a doctoral dissertation [11], a master's thesis: [5], an online document / world
 960 wide web resource [2, 41, 51], a video game (Case 1) [39] and (Case 2) [38] and [36] and (Case 3) a patent [47], work
 961 accepted for publication [43], 'YYYYb'-test for prolific author [45] and [46]. Other cites might contain 'duplicate' DOI
 962 and URLs (some SIAM articles) [31]. Boris / Barbara Beeton: multi-volume works as books [28] and [27]. A couple of
 963 citations with DOIs: [29, 31]. Online citations: [51–53]. Artifacts: [42] and [6].

964 18 ACKNOWLEDGMENTS

965 Identification of funding sources and other support, and thanks to individuals and groups that assisted in the research
 966 and the preparation of the work should be included in an acknowledgment section, which is placed just before the
 967 reference section in your document.

968 This section has a special environment:

```
969 \begin{acks}
970 ...
971 \end{acks}
```

972 so that the information contained therein can be more easily collected during the article metadata extraction phase, and
 973 to ensure consistency in the spelling of the section heading.

974 Authors should not prepare this section as a numbered or unnumbered \section ; please use the “`acks`” environment.

989 19 APPENDICES

990 If your work needs an appendix, add it before the “`\end{document}`” command at the conclusion of your source
 991 document.

993 Start the appendix with the “`appendix`” command:

995 `\appendix`

997 and note that in the appendix, sections are lettered, not numbered. This document has two appendices, demonstrating
 998 the section and subsection identification method.

1000 20 SIGCHI EXTENDED ABSTRACTS

1002 The “sigchi-a” template style (available only in L^AT_EX and not in Word) produces a landscape-orientation formatted
 1003 article, with a wide left margin. Three environments are available for use with the “sigchi-a” template style, and
 1004 produce formatted output in the margin:

- 1006 • `sidebar`: Place formatted text in the margin.
- 1007 • `marginfigure`: Place a figure in the margin.
- 1008 • `margintable`: Place a table in the margin.

1011 ACKNOWLEDGMENTS

1013 To Robert, for the bagels and explaining CMYK and color spaces.

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A RESEARCH METHODS

A.1 Part One

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A.2 Part Two

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B ONLINE RESOURCES

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