

# Creating and Interpreting Abstract Visualizations of Emotion

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## ABSTRACT

People use non-verbal cues, such as facial expressions, body language, and tonal variations in speech, to help communicate emotion; however, these cues are not always available in computer-supported environments. Without emotional cues, we can have difficulty communicating and relating to others. In this paper, we develop and evaluate a system for creating abstract visualizations of emotion using arousal and valence. Through two user studies, we show that without prior training, people can naturally understand the represented emotion conveyed by the visualization.

**Keywords:** Emotion, affect, visualization.

**Index Terms:** H1.2 Human Factors, H5.2. User Interfaces: Evaluation/methodology, H.5.m Miscellaneous

## 1 INTRODUCTION

Expressing our emotion is critical for our interpersonal relationships to succeed [2]. We constantly communicate how we feel when we interact with other people. We do this by using non-verbal cues, such as facial expressions, body language and tonal variations in speech [4]. However, these cues do not always exist in computer-supported environments. Without emotional cues, we are less engaged and less interested when communicating with other people [22,30], negatively influencing interpersonal relationships. It is more difficult for us to work well with other people and our productivity on teams suffers [2]. Therefore, we need these emotion cues to successfully communicate.

Existing means of communicating emotion via technology do not work well as a substitute for these cues. Many are either too specific or are not suitable across different media or communication channels. For example, showing emotion on a scale or Russell's affect grid [23] is informative but requires people to have a familiarity and comfort with psychological concepts. Semantic labels of discrete emotions are limited to the vocabulary and common language of the users, and they do not always suit the medium or environment. Emoticons are limited to a subset of discrete emotions, sometimes require instruction to interpret, and can be specific to a language or culture (e.g., [20]). Abstract methods of representing emotion can solve the problems of discretization and semantic labels, but often require users to agree on a common representation prior to using the visualizations [3,27]. Existing systems are not usable for at-a-glance understanding of emotional state without prior instruction of the visualization mapping.

To allow people to represent and communicate emotion in computer-supported environments without prior instruction, we propose to use abstract emotion visualizations that are based on an understanding of the visual perception of colour, geometry, and motion. We focus on abstract visualizations because we believe

they are more likely to afford a natural understanding and be widely interpretable. While other work has attempted to create systems for generating visualizations to encode emotion (e.g., [13,27]), none have been successful in their level of comprehension among participants or applicability for multiple purposes. In this paper, we present a system for creating abstract visualizations of emotion using a combination of visual characteristics suitable for use across media types. We created and evaluated a system for generating visualizations that can encompass emotion represented by Russell's two-dimensional model of arousal and valence [24]. Our visualizations are designed to be usable in a variety of environments and be parametric in nature, such that they can transition smoothly as the represented emotion (i.e., an individual's emotion) changes organically over time. We used techniques from affective computing, art, psychology and dance to create our visualizations.

We evaluated our abstract visualizations of emotion in two studies, and show that users are able to: (1) interpret the intended emotion quadrant through ratings and categorization; and (2) distinguish subtle transitions within emotion quadrants. Our paper is the first system for abstract representation of emotion that has been shown through a comprehensive evaluation to be interpretable without prior instruction. Our visualizations of emotion can help improve interpersonal interaction in a variety of computer-supported communication environments.

## 2 RELATED WORK

We now provide an overview of affect, emotion and measurement techniques, provide examples of using them to capture the emotional response to visual stimuli, and discuss existing systems that generate graphics that encode emotion.

### 2.1 Affect and Emotion

The terms affect, emotion and mood are often used interchangeably. For the purposes of this paper, we will use affect to describe the low-level response to a stimulus (e.g., increased heart rate), emotion to describe the cognitive interpretation of the response (e.g., excitement, fear), and mood to describe the state as emotions are experienced over time.

There are two approaches used in psychology to describe emotions: categorical and dimensional. Ekman [10] proposed a categorical model where semantic labels (e.g., pride, fear) are applied to discrete states. Russell [24] proposed a dimensional model (circumplex model) where emotions are represented by two orthogonal axes called arousal and valence. Arousal describes the energy or activation of an emotion and is a continuum between high activation (positive arousal) and low activation or sleepiness (negative arousal). Valence describes the pleasure (positive valence) and displeasure (negative valence) of an emotion. The circumplex model can be used to describe categorical emotion labels [24]. For example, anger would be high arousal, low valence, whereas as a feeling of relaxed would be low arousal, high valence.

Together, these two dimensions have been used for emotional assessment. Although there are many methods for measuring emotion, we focus on methods for measuring emotion using visual representations of arousal and valence. Based on their circumplex model, Russell et al. developed the affect grid [23] as a tool for participants to quickly assess affect in terms of arousal and valence. To avoid using semantic labels, Bradley and Lang [6]

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developed the self-assessment manikin (SAM) as a 9-point pictorial scale for subjective self-report of arousal and valence. The SAM provides a fast and language-agnostic way of assessing emotional state (see figure 1 in [6]). One drawback to the arousal-valence approach of representing emotion is that the two orthogonal dimensions might not be completely independent [18]. For example, if a feeling is truly unpleasant, it is unlikely to also have very low arousal.

## 2.2 Emotional Response to Visual Stimuli

Many researchers have focused on user response to real photographs. Lang et al. created the International Affective Picture System (IAPS)—a set of photographs for use as experimental stimuli [17]. They used the SAM to measure the emotional response to the images, and this image set has become a standard visual stimuli for measuring emotional response.

We are instead interested in abstract representations of emotion, and base our approach on literature on the emotional response to visual stimuli.

### 2.2.1 Colour and Geometry in Visual Art and Design

Researchers have evaluated the emotional content of visual stimuli from the perspective of visual art and design. Valdez and Mehrabian [28] evaluated colours using arousal and valence. They found blue to be the most pleasant colour and yellow to be the least pleasant. They also found that more saturated and less bright colours are more arousing. Simmons [26] supported their findings; however, Hevner [12] found that red is happy and exciting but blue is serene, sad and dignified. Clarke and Costall [7] performed interviews to determine that warm colours were associated with feelings of anger and rage while green and blue were associated with low anxiety. Kaya and Epps [16] coded open-ended responses into positive and negative emotions to find that green is the most positive colour and yellow-green is the most negative. From colour theory in visual art, Itten [15] describes the compositional effects of colour contrast. While he does not use terms used in Russell's model of emotion, we can infer that the use of high contrast colours is more activating.

Mono [21] wrote that circles, spirals, and shapes with smooth curves were more pleasant than shapes with hard angles. Hevner [12] found a relationship between line style and emotion. Curves were found to be serene while hard angles were found to be agitating. Halper et al. [11] found a relationship between line style and perceptions of safety—objects rendered using jagged lines were perceived as more dangerous than objects rendered using smooth lines.

### 2.2.2 Movement

Detenber et al. [9] used the SAM and physiological measures to assess the effects of motion on arousal. They found a positive relationship between increased motion and arousal. Arnheim [1] observed that animations featuring mechanical movements demonstrated less emotion than more natural movements. Boone and Cunningham [5] asked children to label dance moves as angry, fearful, happy or sad and found that children were able to correctly decode the intended emotion of the dancers. They extracted body movements to determine that angry movements involved directional and tempo changes, fearful movements involved rigidity in the body, happy movements included many upward movements of the arms, and sad movements included extended periods of downward gaze.

## 2.3 Generating Graphics with Emotional Content

Work in the previous section focused on evaluating emotional content; we now describe work that has focused on generating graphics with emotional content.

Ibanez [13] created a system to represent emotion using abstract imagery by varying movement and symmetry. The results from his user study suggest that movement and symmetry worked for expressing arousal and valence, respectively. Ibanez did not find that participants could identify small degrees of granularity in arousal or valence, only that they were able to identify discrete emotions representing the quadrant of Russell's circumplex to which they belonged.

Sundström et al. [27] created eMoto to express emotion in mobile messaging using colour, shape and animation. They did not find that the visualizations were interpreted consistently between users. They observed that participants tended to vary the representation of emotion based on the recipient of the message. This implies that their solution is not a generalizable means of creating visualizations of emotion.

Shugrina et al. [25] and Colton et al. [8] created systems to generate images using non-photorealistic rendering (NPR) techniques based on viewer emotion as detected by facial expression recognition. However, both of these systems focused on choosing appropriate NPR styles and rendering appropriate imagery. Neither system was evaluated to determine whether the choice of NPR algorithm conveyed the intended emotion.

Balaam et al. [3] created physical objects (Subtle Stones) used by students in classroom environments to communicate their emotion to the teacher. Emotion was represented by the colour the Subtle Stone displayed and students and teachers had to agree in advance on a mapping between colour to discrete emotional state.

## 3 GENERATING VISUALIZATIONS OF EMOTION

We created EmotiViz to generate visualizations to represent emotion with the goal of making them easily interpretable without prior instruction. We created our visualizations using the LaVizKit toolkit—developed for creating visualizations in a layer over the Windows desktop [31]. The toolkit generates visualizations using graphical effects; we used the following: fractal noise, waves, and static sprites. EmotiViz uses Russell's dimensional model of emotion [24] to generate visualizations based on the emotion quadrant. Within each quadrant, visualizations are generated based on the specific arousal and valence value provided to EmotiViz. Figure 1 shows sample visualizations for each quadrant.

For the *low valence/high arousal quadrant (angry)*, we created a lava visualization. This visualization glows red and appears to shake violently. The effect is an abstract allusion to a hardening lava flow. We varied the colour intensity by valence (based on [28]) and the speed of the effect by arousal (based on [9]).

For the *high valence/high arousal quadrant (happy)*, we created a fireworks visualization, which appears as a black screen with explosions of particles of bright colours meant to suggest fireworks in a night sky. The rate of explosions is determined by arousal (based on [9]) and the direction of the particles after the explosion is determined by valence: the higher the valence, the more directly upward the particles move (based on [5]).

For the *low valence/low arousal quadrant (sad)*, we created a fog visualization. This effect appears like thick black or dark grey fog. The fog moves in a downward motion, based on [5], which suggests that downward movements convey sadness. We varied the arousal by velocity [9] and the valence by colour [28].



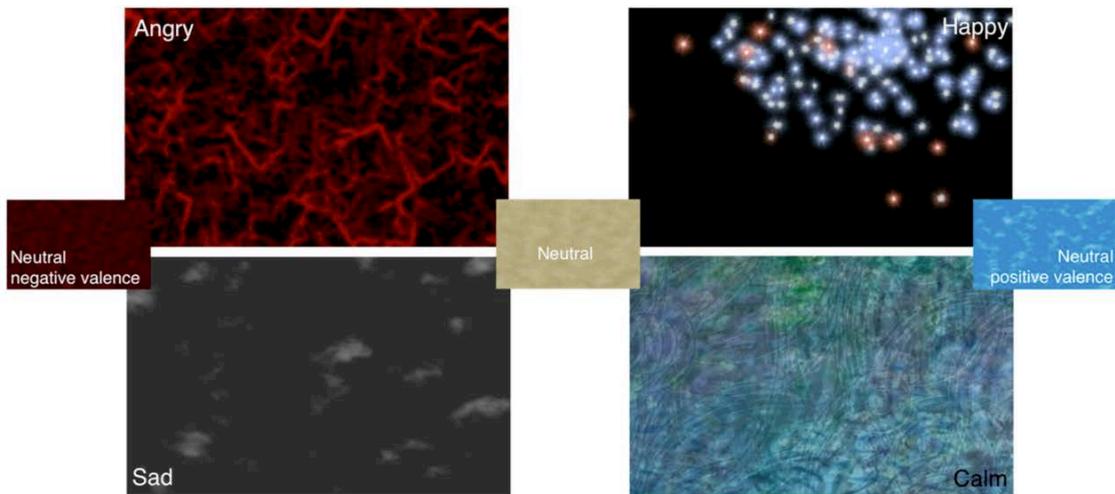


Figure 1: Abstract visualizations generated by EmotiViz.

For the *high valence/low arousal quadrant (calm)*, we created a water ripple visualization atop a background reminiscent of Monet’s palette. The background colours convey a calm feeling according to [28]. Water ripples appear like droplets on the surface and fade away. The quantity of droplets is determined by arousal (loosely based on [15]). For Study 1, the size of droplets was determined by valence but we changed this prior to Study 2 such that the size of the droplets are also determined by arousal and the darkness of the droplets and background mask are determined by valence—darker ripples and background convey lower valence [28].

For *neutral valence* locations, we created a mist visualization with neutral colour tones. This is also used for the intersection of both axes (neutral arousal and neutral valence). The speed at which the neutral-coloured mist moves is determined by arousal (based on [9]).

For *neutral arousal* locations, we also used the mist visualization but with varying colours. For negative valence, the mist is black on a red background while the mist is blue on a white background for positive valence [28]. For negative valence, the mist moves from right to left, while for positive valence, it moves from left to right.

Finally, it is important to note how the visualizations transition. Because the visualizations are created using a parametric toolkit, they transition smoothly along either axis within a quadrant. The visualizations are quite different for each quadrant, so we transition through neutral states (i.e., we fade in and out of the transitioning visualizations to avoid abrupt changes) when we shift between quadrants.

#### 4 EVALUATION

We evaluated EmotiViz in two stages. In Study 1, we wanted to determine whether people could identify *differences* between the emotion representations using our visualizations. In Study 2, we wanted to determine whether people could identify *transitions* in the represented emotion in the visualizations. The animated visualizations used in Study 1 represent a single point in arousal-valence space, whereas in Study 2, they represent movement between 2 points in AV space.

##### 4.1 Study 1

In Study 1, 39 participants (aged 18-44, mean 25, 9 female) responded to a series of questions to identify what emotions they thought were conveyed by the visualizations. Participants began by completing an informed consent followed by a brief Ishihara

Colour Plate Test [14] to screen out participants who showed colour vision deficiencies (CVD). Participants then completed training using 4 images from a set of emotionally-labeled images from the International Affective Picture System (IAPS) [17]. We presented IAPS images 6230, 8030, 2722 and 5000 on a black background for 5 seconds each. We used the IAPS images as training because there are normative arousal and valence ratings provided for these images, which we used to screen for outlier participants who did not fall within three standard deviations of the means provided by IAPS. No participants were removed from our analysis as a result of the IAPS screening process.

After training, participants viewed video clips of the visualizations generated by EmotiViz. We selected representative clips for 13 locations in AV space shown in Figure 2 labeled according to their quadrant (A=angry, H=happy, S=sad, C=calm, N=neutral). These locations included the extreme and mid-points of each quadrant, plus neutral locations on both axes. Participants were asked to determine what emotion the visualization was trying to convey. They responded by rating the arousal and valence values using the SAM [6].

Following the SAM ratings, participants categorized the same set of 4 IAPS images and 13 EmotiViz visualizations with 5 categories (angry/enraged, excited/joyful, calm/satisfied, sad/depressed and neutral) based on the 4 quadrants of AV space,

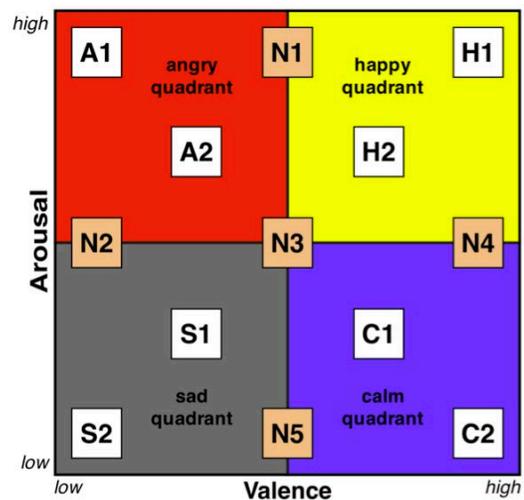


Figure 2: Locations of Study 1 stimuli in AV space.



similar to [13]. In both the ratings and categorization tasks, each of the 13 visualizations was presented for 15 seconds. Participants could re-watch the same clip by clicking a button.

For both the SAM ratings and quadrant categorization, we used a systematic ordering starting from the top left of AV space moving methodically toward the bottom right by moving left to right and top to bottom. We counterbalanced the starting position using a Latin Square to avoid any order of presentation effects.

The study took between 15 and 30 minutes. Participants were given \$5 to thank them for their participation. The behavioural ethics board at the University of Saskatchewan approved the experiment protocol.

The experiment was conducted on a Windows 7 computer with a 22" LCD display running at a resolution of 1680x1050. All visualizations were presented in full screen. The system logged all ratings data for subsequent analysis.

## 4.2 Study 2

In Study 1, we evaluated single points in AV space independently. In Study 2, we evaluated transitions between two points in AV space. 24 participants (aged 18-40, mean 25, 9 female, 10 from study 1) watched 25-second videos of visualizations transitioning in both directions between two emotional states within a quadrant and along the neutral axes for both arousal and valence, resulting in 12 representative videos generated from EmotiViz (see Figure 3). Within each quadrant, we selected transitions moving diagonally in AV space between the furthest point from neutral and a point close to neutral. For example, Q1 transitioned from A1 to A2. For neutral locations, we selected transitions moving between low valence and high valence with neutral arousal and transitions moving between high arousal and low arousal with neutral valence. After completing an informed consent and a colour vision test, participants viewed the transition videos and were asked to identify whether the change in emotion over time for each of arousal and valence was (a) increasing, (b) decreasing or (c) not changing.

We presented the transitions videos in a single ordering (as described for Study 1), and counterbalanced the starting position using a Latin Square to avoid any effects of order of presentation. The entire study took between 15 and 30 minutes. Participants were given \$5 to thank them for their participation.

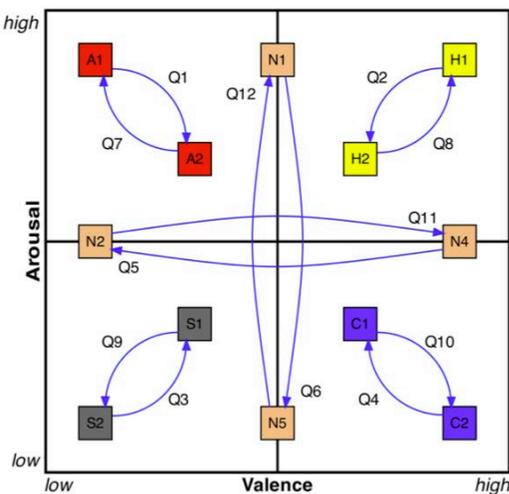


Figure 3: Study 2 stimuli (Q1-Q12).

## 5 RESULTS

We organize our analyses according to our research questions:

- Can users identify the intended emotion quadrant? (Study 1)
- Do participants differentiate between the visualizations in terms of arousal and valence ratings? (Study 1)
- Are participants able to identify transitions in visualized arousal and valence within an emotion quadrant? (Study 2)

### 5.1 Identifying the Intended Emotion Quadrant

In a forced-choice test in Study 1, participants were asked to choose a single category for the visualization from five options: angry/enraged, excited/joyful, calm/satisfied, sad/depressed and neutral. For each visualization, we conducted a chi-square test ( $df=4$ ) to determine whether one choice of category was made significantly more often than others. The chi-squared test was significant with  $p \approx .000$  for every stimulus ( $\chi^2$  values: A1-127.8, N1-37.3, H1-127.8, A2-79.8, H2-70.4, N2-26.0, N3-49.3, N4-119.0, S1-23.9, C1-87.5, S2-44.7, N5-61.6, C2-103.9).

	A1	N1	H1	A2	H2	N2	N3	N4	S1	C1	S2	N5	C2
Angry	36	1	0	30	0	7	0	0	1	0	4	0	0
Happy	2	2	36	3	28	0	0	2	0	4	0	0	0
Sad	0	5	0	1	1	19	7	0	11	1	24	3	1
Calm	0	9	1	1	8	4	8	35	15	31	6	10	33
Neutral	1	22	2	4	2	9	24	2	12	3	5	26	5

Table 1. Frequency of choice of emotion quadrant by stimulus. Italicized text indicates expected.

We then checked whether the most frequently selected category matched the expected category for each stimulus (Table 1). For non-neutral stimuli (those that are not on one of the axes of arousal-valence space), the selected quadrant matched the expected quadrant for 7 of the 8 stimuli. The only exception was S1, where the expected category was sad/depressed and the selected category was calm/satisfied.

For neutral valence stimuli, we expected that participants would select the neutral category rather than one of the four quadrants. For N1, N3 and N5 (neutral valence with varying arousal) the most frequently chosen category was neutral, as expected. However, participants selected the quadrant for N2 (neutral arousal, low valence) and N4 (neutral arousal, high valence) that matched the perceived valence but with low arousal (sad/depressed and calm/satisfied respectively).

These results show that participants were able to accurately identify the intended emotion quadrant for all but 3 of the stimuli, which were identified as a neighboring category in AV space.

### 5.2 Differentiating Visualizations

Means and standard deviations from the arousal and valence ratings from Study 1 are plotted in Figure 4. We conducted Friedman Analysis of Variance by Ranks on both the arousal and valence ratings. Results showed that there were significant differences in the ratings depending on the presented visualization (arousal:  $F_{12}=277.6, p \approx .000$ ; valence:  $F_{12}=272.1, p \approx .000$ ). Because there are 13 visualizations, we present the pairwise comparisons for major (between quadrants) and minor (within-quadrant) differences separately. Pairwise comparisons are made using Wilcoxon signed ranks tests.



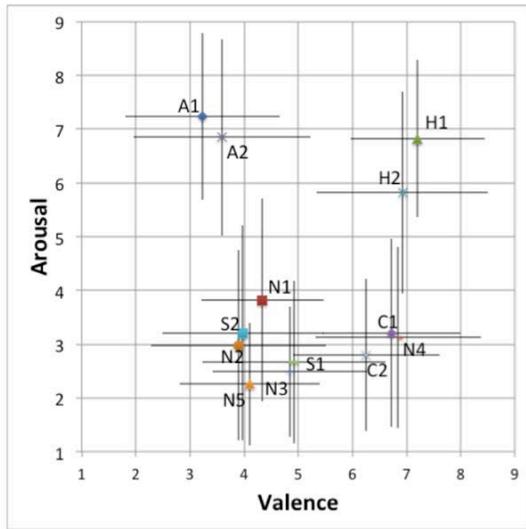


Figure 4: Arousal-valence plot of mean SAM ratings from Study 1. Error bars show standard deviation.

### 5.2.1 Arousal

	A1	A2	H1	H2	S1	S2	C1	C2
A1	-	.494	.458	.028	.000	.000	.000	.000
A2	-	-	.954	.131	.000	.000	.000	.000
H1	-	-	-	.146	.000	.000	.000	.000
H2	-	-	-	-	.000	.000	.000	.000
S1	-	-	-	-	-	.295	.233	.716
S2	-	-	-	-	-	-	.884	.494
C1	-	-	-	-	-	-	-	.407
C2	-	-	-	-	-	-	-	-

Table 2. p-values for pairwise comparisons between stimuli for arousal. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of expected minor difference; white cells indicate no expected difference.

Using these pairwise comparisons, we look at differences between stimuli with major variations in arousal (e.g., A1 to S2) in Table 2. Significant differences were found for all 16 between-quadrant differences. Next, we look at differences between stimuli with minor variations in arousal (e.g., A1 to A2, A1 to H2). Only A1-H2 was significant in this case.

### 5.2.2 Valence

	A1	A2	H1	H2	S1	S2	C1	C2
A1	-	.282	.000	.000	.000	.257	.000	.000
A2	-	-	.000	.000	.013	.954	.000	.000
H1	-	-	-	.684	.000	.000	.450	.069
H2	-	-	-	-	.000	.000	.727	.159
S1	-	-	-	-	-	.015	.000	.001
S2	-	-	-	-	-	-	.000	.000
C1	-	-	-	-	-	-	-	.289
C2	-	-	-	-	-	-	-	-

Table 3. p-values for pairwise comparisons between stimuli for valence. Light shaded cells indicate a comparison of major difference; dark shaded cells indicate a comparison of expected minor difference; white cells indicate no expected difference.

Using pairwise comparisons, we look at differences between stimuli with major variations in valence (e.g., A1 to H1) in Table 3. All of the 16 potential major between-quadrant differences showed significant differences in the pairwise comparison. Next, we look for differences between stimuli with minor variations in valence (e.g., A1 to A2). Two of these cases (A1-S1, S1-S2) were significant. In addition, the S1-A2 comparison was significantly different although it was not expected to be so as A2 and S1 represented the same valence, but with different arousal.

### 5.2.3 Neutral

	Arousal					Valence				
	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5
A1	*	*	*	*	*	#		#	*	
A2	*	*	*	*	*			#	*	
H1	*	*	*	*	*	*	*	*		*
H2	#	*	*	*	*		*	*		*
S1	#						#		*	
S2					#				*	
C1					#	*	*	*		*
C2	#					#	*	#		*
N1	-		#		#	-			*	
N2	-	-				-	-		*	
N3	-	-	-			-	-	-	*	
N4	-	-	-	-	#	-	-	-	-	*
N5	-	-	-	-	-	-	-	-	-	-

Table 4. Stimuli differences for neutral stimuli. \* indicates significant with  $p \approx .000$ , # indicates significant with  $p < .05$  and empty cells indicate  $p=1.00$ .

Table 4 shows a matrix of differences between stimuli for both arousal and valence. For arousal, there were differences between most neutral stimuli and non-neutral stimuli with positive arousal (e.g., A1 and N3, N5 etc.). For valence, there were differences between most neutral stimuli and non-neutral stimuli with positive valence (e.g., N2 and H2, C1, etc.).

### 5.3 Identifying Transitions in Visualizations

Results from Study 1 showed that participants could identify the intended quadrant for an emotional visualization and could differentiate between visualizations using ratings of arousal and valence for major variations (between quadrants), but have trouble differentiating between levels of the same visualization (within a quadrant). In Study 2, we looked to see whether participants could interpret changes in the levels of a visualization when these changes are presented dynamically in a video transitioning between two points within an emotion quadrant. Participants selected a category (increase, decrease, no change) for arousal and valence.

Participants rated the perceived change in emotion for 12 stimuli (see Figure 5). They identified whether the change during the clip was increasing, decreasing or not changing for each of arousal and valence. For each of the stimuli, we conducted a chi-square test ( $df=2$ ) for both arousal and valence, to determine the most frequently chosen option. Table 5 shows the frequency of responses by stimuli and Table 6 summarizes the results.



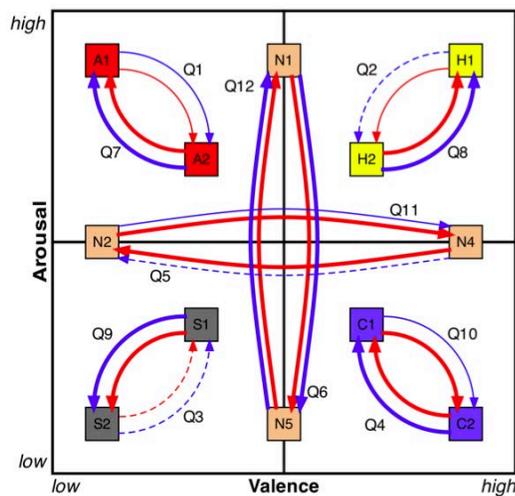


Figure 5: Study 2 stimuli. Each line represents the direction of transition in the stimulus clip (blue for arousal, red for valence). Dotted lines indicate no statistically significant difference; solid lines indicate significant differences; thick solid lines indicate significance matching the expected category.

Stimulus	1	2	3	4	5	6	7	8	9	10	11	12
<b>Arousal</b>												
Increase	15	11	9	16	9	0	22	21	0	8	6	15
Decrease	7	9	9	4	4	16	1	0	20	11	8	3
No change	2	4	6	4	11	8	1	3	4	5	10	6
<b>Valence</b>												
Increase	3	18	6	5	1	3	1	13	2	14	16	2
Decrease	16	1	12	15	22	5	21	3	16	3	2	1
No change	5	5	6	4	1	16	2	8	6	7	6	21

Table 5. Frequency of responses by stimuli.

Stimulus	Arousal			Valence		
	$\chi^2$ value	Sig.	Expected Category	$\chi^2$ value	Sig.	Expected Category
Q1	10.750	<b>0.005</b>	Decrease	12.25	<b>0.002</b>	Increase
Q2	3.250	0.197	Decrease	19.750	<b>0.000</b>	Decrease
Q3	0.750	0.687	Increase	3.000	0.223	Increase
Q4	12.000	<b>0.002</b>	<b>Increase</b>	9.250	<b>0.010</b>	<b>Decrease</b>
Q5	3.250	0.197	<b>No change</b>	36.750	<b>0.000</b>	<b>Decrease</b>
Q6	16.000	<b>0.000</b>	<b>Decrease</b>	12.250	<b>0.002</b>	<b>No change</b>
Q7	36.750	<b>0.000</b>	<b>Increase</b>	31.750	<b>0.000</b>	<b>Decrease</b>
Q8	32.250	<b>0.000</b>	<b>Increase</b>	6.250	<b>0.044</b>	<b>Increase</b>
Q9	28.00	<b>0.000</b>	<b>Decrease</b>	13.000	<b>0.000</b>	<b>Decrease</b>
Q10	2.250	0.325	<b>Decrease</b>	7.750	<b>0.021</b>	<b>Increase</b>
Q11	1.000	0.607	<b>No change</b>	13.000	<b>0.002</b>	<b>Increase</b>
Q12	9.750	<b>0.008</b>	<b>Increase</b>	31.750	<b>0.000</b>	<b>No change</b>

Table 6. Chi-squared test results for Study 2. Bold expected category text indicates the expected category matched the most frequently selected category.

The chi-squared tests showed significant results for the most frequently chosen option for many of the stimuli, but we must also check whether the chosen category matches the expected category.

For stimuli Q1 through Q4 (where the direction of movement was toward the centre of AV space), only Q4 was both statistically significant and the most frequent category matched

the expected category. However, for Q7 through Q10 (where the direction of movement was away from the centre of AV space), the most frequently chosen option matched the expected category for both arousal and valence and were also statistically significant in all cases except for Q10 (see Table 6). Similarly, all neutral stimuli matched their expected categories and were statistically significant in 6 of 8 cases.

#### 5.4 Summary of the results

Our results can be summarized into the following points. Participants were able to:

1. Identify the intended emotion quadrant using forced-choice categorization.
2. Distinguish differences between stimuli from different quadrants for arousal and valence.
3. Distinguish differences in neutral stimuli for both arousal and valence.
4. Identify change in arousal and valence in transitioning visualizations within emotion quadrants (away from neutral) and along the neutral axes.

Participants had trouble distinguishing minor differences in arousal and valence for most stimuli within quadrants.

## 6 DISCUSSION

### 6.1 Interpreting Abstract Visualizations of Emotion

Results from Study 1 showed that participants could identify the intended quadrant for all stimuli except for S1. The evidence suggests that S1 expresses too much valence because it was rated as calm/satisfied rather than sad/depressed. The SAM ratings support this – the mean SAM valence rating was 4.92, which is slightly on the negative side of neutral valence (5.0). Our results also showed that participants are able to identify differences between major variations of stimuli. All of the major between-quadrant differences were significant for both arousal and valence.

The neutral stimuli were not found to be significantly different from one another based on the SAM ratings. Looking at arousal differences, there were no significant differences between steps along the arousal axes with neutral valence (i.e., N1, N3 and N5). The relative order of their mean arousal ratings matched the expected order; however, arousal ratings were all clustered below neutral arousal (5.0). The results also show similar problems with valence. We attribute these problems to the interaction of the arousal and valence axes. Although these axes are theoretically orthogonal, there is evidence that they are not entirely independent. Lang et al. [18] had difficulty finding images that represent the extreme regions of calm/satisfied quadrant. It seems that if an image is truly unpleasant, it cannot also be calm, suggesting some interplay between these two axes.

Results from Study 1 showed that participants had problems identifying differences between different levels of the visualizations (within quadrants) using the SAM scale. However, given the results of Study 2 (discussed shortly), we do not believe this is strictly a problem with the stimuli but rather a problem with the scale used. Our participants tended to avoid extreme values in the SAM scale, and likely did not interpret distances between different gradations of the scale equally. This suggests that for each of the two stimuli per quadrant, people tended to cluster their responses both away from neutral and away from the extreme value, whether it was high or low. This clustering of ratings makes it unlikely to find statistical differences between the means. We may have been better able to show a difference between minor variations of stimuli had we asked a forced-choice



categorical question to identify, for example, which of A1 and A2 expresses more anger.

This interplay between the axes may also explain why in some cases, relative arousal or valence values are reversed. For example, the relative arousal is the reverse of what was expected for S1 and S2 (S2 should be rated lower). In this case, increasing arousal was mapped to faster movement and increasing valence was mapped to lighter colours. So the cloud effect is darker in S2 than in S1, but S1 moves faster than S2. The reversal of ratings may be due in part to some interaction between movement and colour selection.

Study 2 showed that participants were able to identify differences when the visualizations transition from one point to another point within the same quadrant. Participants were able to detect increases, decreases and no change in both arousal and valence. Transitions starting from locations near the centre of arousal-valence space moving toward the outer edges worked better than the reverse direction. It is possible that change blindness [19] is a factor that contributes to participants' inability to detect certain types of change since the transitions were noticed in one direction but not the reverse. The ability to detect and interpret change might be harder when moving from weak to strong stimuli than from strong to weak stimuli.

Overall, our results showed that we successfully created abstract representations of emotion for all four emotion quadrants, in addition to neutral. Our evaluation showed that people are able to interpret the abstract representation. Participants were told how to use the SAM scale, but were not told how to interpret any of the visualizations or effects used within them. Unlike information art (e.g., where the size of the sun indicates the quantity of happiness in an individual or group), our visualizations do not require explanation or prior training. In addition, our visualizations were quickly interpretable; with only a 15-second clip of each visualization, participants were able to interpret the emotion we intended to convey. Most importantly, our visualizations work without training, prior instruction, or extended exposure to the visualizations. The visualizations generated by EmotiViz are the first abstract visualizations of emotion that have been experimentally shown to be naturally and widely interpretable without prior training.

## 6.2 Abstract Representations of Emotion

We chose to use abstract representations rather than concrete representations for several reasons. First, concrete representations are limited in their power to express emotion. Semantic labels are limited to what language can express, the use of language is limited to situations where users have a common language, and emoticons are limited to discrete emotions that don't facilitate gradations.

Second, we cannot easily aggregate the emotion of multiple people with concrete representations. While tag clouds of semantic labels are a possibility, they are not quickly interpreted and often require thoughtful analysis to understand. In addition, concrete representations like semantic labels or emoticons cannot be averaged to create a succinct aggregate model for a group.

Third, our visualizations are naturally interpretable. Similar to research [5] that shows that emotions conveyed in dance were easily understood by children, our visualizations were based on characteristics of perception that we believe are naturally understood. While it has been suggested that emotion cannot be expressed or experienced without context, abstract visualizations based on discrete emotion labels from Russell's circumplex (e.g., anger) are easily understood and expressed without context in our experiment. We replace a semantic label (e.g., "excited") or position in arousal-valence space (e.g., high arousal-high valence)

with an abstract visualization, which our participants interpret consistently.

Fourth, we believe abstract representations to be more suitable for many types of applications and environments. Because colour, geometry, and motion are faster to process and less distracting than textual information [29], our visualizations are more suitable for use in applications where providing ambient or peripheral information is critical. Furthermore, the abstract visual nature is more likely to transcend culture than a more concrete representation.

## 6.3 Implications for Design

Our study has confirmed our approach to designing abstract visualizations of emotion. What we have learned is also useful for designers and artists building graphical representations of emotion. Fast motion was always rated as more arousing than slow motion. Blue and white clouds were rated as more positive than red and black clouds. Neutral colours are associated with neutral valence. Water ripples, perhaps due to cultural associations, were found to be calming. Downward movement connotes sadness or depression. In combination with the colours chosen for the sad/depressed quadrant, this visualization conveyed the intended sense.

## 6.4 Applications

With the success of our evaluation, we are confident that EmotiViz could be used successfully for a variety of applications. For situations, such as Subtle Stone [3], where abstract representations are required, EmotiViz prevents the need to use pre-determined mappings between participants. This is because of the naturally interpretable nature of the visualizations. EmotiViz could also be used to produce visualizations for status or mood messages in instant messaging or social media. The visualizations could accompany or entirely replace the mood message. Furthermore, it could be connected to sensors (e.g., physiological) to automatically produce visualizations that reflect the underlying emotional state of the user. For people who have difficulty interpreting other people's emotions through traditional means of facial expressions and body language (e.g., people with autism spectrum disorder), visualizations could be used to help them learn to recognize the traditional cues by adding an additional channel of information. The visualizations could be used to create an aggregate visualization to represent the emotion of a group of people, such as those who comprise an audience. Finally, because the visualizations are interpretable without prior exposure or training, they would be suitable for use on public ambient displays.

## 6.5 Future Work

Participants in our studies were from a variety of cultural backgrounds: 34 of our 63 participants were Canadian with English as their first language, whereas the remaining participants self-identified as Asian (India, China, Korea and Taiwan), Middle-Eastern (Afghanistan, Iran), African (Rwanda, South Africa) or Eastern European (Poland, Uzbekistan). Although our participants were from various cultures, over half were Canadian and there may be cultural associations that affect the interpretations of the visualizations used (e.g., fireworks, mist). Additional study is needed to determine whether our results will hold across a broader range of cultures and age groups.

We would like to know how quickly people are able to interpret the visualizations. Our participants viewed each visualization for 15 seconds, but would they have come to the same conclusion if they had only viewed a one-second sample? Using an understanding of the visual perception of colour, geometry, and motion to create our visualizations likely makes them fast to



interpret. We intend to explore the at-a-glance interpretability of our visualizations. We would also like to know how small the visualizations can be while still remaining interpretable.

We would like to perform detailed analyses on the effect of the separate visual characteristics used by EmotiViz to understand how each contributes to the conveyed emotion.

Additionally, we would like to use sensors to measure the physiological reaction to our visualizations to see if they match self-reported measurements of arousal and valence.

Finally, we would like to further investigate how we can design visualizations so there is a stronger differentiation between points within a quadrant. This may involve investigating a different evaluation strategy other than the SAM. Additionally, we would like to determine how we could design transitions between quadrants that are less abrupt. Because we used different effects for each quadrant, it would be useful to have effects that can transition smoothly between quadrants. Finally, we would like to gain further insight into the effect of direction of transition within quadrants. It is interesting that there was an effect in one direction and not the other, and we would like to explore this result further.

## 7 CONCLUSION

People constantly communicate their emotions when they interact with others. To express how they feel, they use non-verbal cues, such as facial expressions, body language, and tonal variations in speech. These cues are not always available in computer-supported environments. Without them, people can have difficulty communicating and relating to others, which negatively influences their relationships.

This paper makes 3 contributions. First, we have created abstract visualizations of emotion that are parametric in nature and can be used in digital environments to communicate emotion. Second, we demonstrate that it is possible to create naturally interpretable visualizations. Finally, we show that it is possible to create visualizations that can be interpreted without prior instruction.

We have created the first abstract visualizations of emotion that have been experimentally shown to be naturally and widely interpreted. These visualizations can be used in a variety of applications to communicate emotions in digital media environments.

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