2. Design Tokens

2.1 Luminosity and Color

This design system prioritizes defining components based on their luminosity, ensuring a foundation rooted in perceived brightness and accessibility. By establishing luminosity as the primary metric, we create a consistent baseline that can be translated into various color spaces for flexibility and adaptability. This approach enables seamless transformations to accommodate accessibility requirements, such as color blindness, and to integrate locally associated rich media, enhancing the visual experience while maintaining functional integrity.

The definition of luminosity as used in this document is based on the guidelines provided by the Web Content Accessibility Guidelines (WCAG) 2.1, which in turn derives its concepts from the International Standards Organization (ISO). Access to the specific ISO standards requires purchase.

2.1.1 What Is Luminosity

Luminosity, in the context of design and accessibility, refers to the perceived brightness of a color as seen by the human eye. Unlike the raw intensity of light emitted by a display, luminosity accounts for human vision's sensitivity to different wavelengths, with green being the most prominent, followed by red, and then blue. This characteristic makes luminosity a fundamental aspect of visual design, influencing how easily users can distinguish elements on a screen. By starting with luminosity, we establish a foundation for understanding color contrast and accessibility, ensuring that design choices accommodate a wide range of visual abilities and device technologies.

2.1.2 Calculating Luminosity

Luminosity palettes differ based on user preferences such as theme and accessibility which are sometimes mutually exclusive. User Interface is inherently designed in sRGB color space and requires designers to calculate luminosity based on the following equations as defined by WCAG:

2.1.2.1 Normalize the RGB Values

Most color processing calculations require normalized values to ensure consistency, especially when working across different bit depths or color systems. By normalizing, the values are expressed as percentages of their maximum possible value. In this step, the RGB values from the typical 8-bit integer range [0, 255] are normalized to the range [0, 1].

$$X_{sRGB} = \frac{X_{8bit}}{255}$$

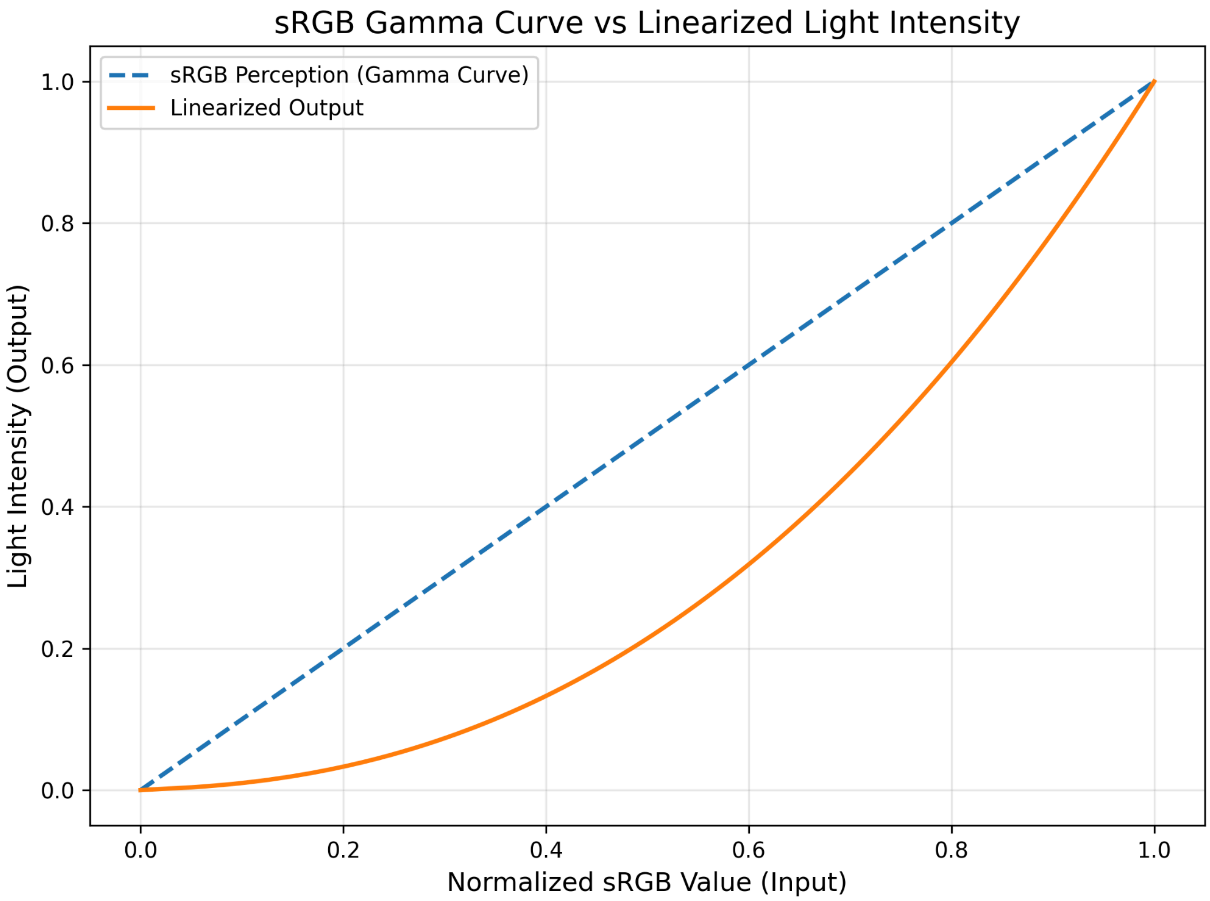
Where X_{sRGB} represents the normalized 8bit value of either the red, green, or blue value in standard RGB space (sRGB)

2.1.1.2 Linearize the Normalized Values

The normalized RGB values represent color intensities, but they aren't proportional to the actual light emitted because of gamma correction in the sRGB color space. The process of linearization adjusts the normalized sRGB values to reflect actual light intensity as perceived by display devices. This step reverses the gamma correction applied during sRGB encoding, which distorts physical luminance to better align with human visual perception. By linearizing the values, we return to a linear light intensity model, allowing for accurate calculations of relative luminance and contrast ratios.

Figure X (see below) illustrates the relationship between normalized sRGB values, the gamma-corrected encoding, and the linearized light intensity:

2.1.1.2.1 Figure X: sRGB Gamma Curve vs Linearized Light Intensity



2.1.1.2.2 Formula for Linearization:

The formula for linearizing sRGB values applies a conditional function to each color channel based on its normalized value (X_{sRGB}):

- If $X_{sRGB} \leq 0.04045$:

$$X_{linear} = \frac{X_{sRGB}}{12.92}$$

- If $X_{sRGB} > 0.04045$:

$$X_{linear} = (\frac{X_{sRGB}+0.055}{1.055})$$

2.1.1.2.3 Explanation of Constants

This section explains the math behind the Formula for Linearization by going through each constant step-by-step. These formulas come from IEC 61966-2-1:1999, the international standard defining the sRGB color space, though this source is paywalled.

2.1.1.2.3.1 Linear Scaling Factor (12.92):

This constant is used to scale small normalized sRGB values XsRGB ≤ 0.04045 linearly. Below this threshold, the human eye perceives brightness linearly, so no power-law adjustment is needed.

2.1.1.2.3.2 Threshold Between Linear and Non-Linear Regions (0.04045):

This threshold separates the linear and non-linear regions of the sRGB gamma curve. Values below this threshold are treated linearly, while those above require a power-law correction.

2.1.1.2.3.3 Offset for Non-Linear Adjustment (0.055):

This offset ensures a smooth transition between the linear and non-linear regions of the gamma curve, avoiding discontinuities.

Source: Derived from the same standard as above.

2.1.1.2.3.4 Scaling Factor for Non-Linear Region (1.055):

The divisor is used in the non-linear formula to normalize higher sRGB values within the range [0, 1]. This factor complements the offset (0.055) in the power-law function.

2.1.1.2.3.5 Exponent for Gamma Correction (2.4):

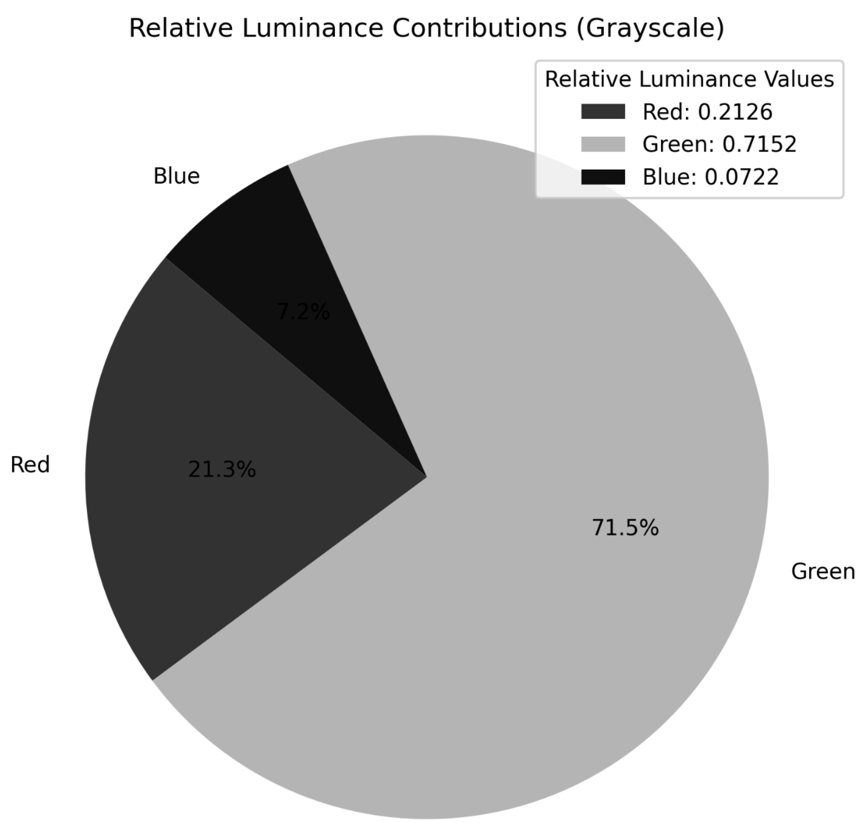
The exponent used in the power-law function reflects the human eye's non-linear perception of brightness. This value is slightly adjusted compared to traditional gamma curves (e.g., gamma 2.2 for CRTs) to optimize for digital display rendering.

2.1.1.3 Find Relative Luminance

Once we have the linearized values (R_{linear}, G_{linear}, B_{linear}), we use the linear components to compute the relative luminance (L). The formula assigns different weights to each linearized component because the human eye is most sensitive to green light, less sensitive to red, and least sensitive to blue.

$$L = 0.2126 \bullet R_{linear} + 0.7152 \bullet G_{linear} + 0.0722 \bullet B_{linear}$$

The weights for relative luminance (0.2126 for red, 0.7152 for green, 0.0722 for blue) reflect the human eye's varying sensitivity to light across the visible spectrum. Green dominates because the photopic luminosity function—modeling brightness perception under normal lighting—peaks at 555 nm, aligning with green wavelengths. These constants, derived from the ITU-R BT.709 standard and CIE 1931 color space, integrate the chromaticity coordinates of RGB primaries with the human eye's spectral sensitivity. This ensures that brightness calculations match human perception, accurately representing how red, green, and blue contribute to luminance.



2.1.1.4 Achromatic Design Feature

Simplifying calculations is critical for scalability in a system handling diverse color transformations. In achromatic colors, all sRGB components share the same value, meaning the linearized components are also equal to one another. Consequently, the relative luminance of an achromatic color is identical to the value of any individual linearized component. This simplifies calculations, as normalization and linearization must be performed on only a single channel, significantly reducing computational overhead. For this reason, all elements in this design system will be prototyped using achromatic styling, ensuring consistency and efficiency in the initial design phase before applying broader color transformations.

2.1.2 Contrast Ratios

Contrast is a cornerstone of effective design, shaping how users perceive and interact with visual elements. It defines shapes and boundaries, enabling users to distinguish between components and understand their function. By leveraging differences in brightness and color, contrast allows designs to communicate relationships, priorities, and actions effectively. This principle aligns with the guidelines established by WCAG, which provide minimum and maximum contrast ratios to ensure that designs remain legible and accessible for all users, including those with visual impairments. By prioritizing contrast, we ensure that our designs are visually clear, intuitive, and inclusive.

2.1.2.1 Calculating Luminosity Contrast Ratios

Luminosity Contrast Ratios measure the difference in brightness between two relative luminosities. It's a key metric for ensuring visual accessibility, as defined by the WCAG. This ratio determines how easily a foreground element (e.g., a button or text) can be distinguished from its background.

The contrast ratio (CR) between two colors with relative luminance values of L_1, the lighter color, and L_2, the darker color, is calculated as:

$$CR = \frac{L_1 + 0.05}{L_2 + 0.05}$$

The constant 0.05 is added to both luminance values to account for perceived brightness differences in very dark colors.

2.1.2.2 Deriving Target Luminance From Target Contrast Ratio

Understanding contrast ratios allows us to calculate target luminosities, ensuring all components meet accessibility standards across themes. To create accessible designs, determining a luminosity that meets a specific contrast ratio to an existing background or foreground luminosity is often necessary. By manipulating the contrast ratio formula, the precise luminance (L) required to achieve the desired contrast can be calculated, ensuring compliance with accessibility standards.

To solve for the unknown luminance (L_{target}) the contrast ratio formula can be rewritten using a known luminosity value.

If the unknown luminosity is lighter (L_1):

$$L_1 = (CR \bullet (L_2 + 0.05)) - 0.05$$

If the unknown luminosity is darker (L_2):

$$L_2 = \frac{L_1 + 0.05}{CR} - 0.05$$

2.1.3 Luminosity as a System of Visual Communication

Luminosity is a fundamental tool for creating clear, effective visual communication in user interfaces. By understanding how the human eye perceives contrast, depth, and hierarchy, designers can leverage luminosity to guide attention, differentiate layers, and optimize interaction feedback. This section builds upon the principles and calculations of relative luminance and contrast ratios to establish practical guidelines for designing accessible and intuitive interfaces. Each subsection explores specific applications, such as defining depth with contrast, maintaining focus states, and addressing potential issues like halation and eye strain.

2.1.3.1 Layers, Depth, and Attention

Luminosity encodes depth and hierarchy in visual attention processing. Brighter objects appear closer to the user, demanding more attention than darker objects within the same frame.

Differentiate layers with a minimum contrast ratio of 3:1 to establish clear visual hierarchy and depth. This ratio ensures that UI layers, such as backgrounds, cards, and buttons, remain distinct and easily interpretable. The 3:1 contrast ratio aligns with WCAG 2.1 Success Criterion 1.4.11, which sets the standard for distinguishing essential visual elements.

Within each layer, use subtle micro-layer contrasts to guide user attention effectively. The human eye can detect contrast differences as subtle as 1.01:1 under optimal conditions, which represents roughly a 1% variation in contrast. This insight comes from research into the Contrast Sensitivity Function (CSF) (ScienceDirect Overview of Spatial Contrast), though the primary research is behind a paywall.

Since sensitivity to such subtle differences varies among individuals and viewing environments, this design system sets a default micro-layer contrast ratio of 1.2:1. This subtle difference effectively guides attention within layers without overwhelming the visual hierarchy. These values are not strict rules but represent best practices based on practical experience and principles of visual perception.

2.1.3.2 Icons and Non-Text UI Elements

Ensure essential icons and non-text UI elements have a minimum contrast ratio of 3:1 against their background. Elements include:

- Buttons
- Controls
- Indicators (e.g., toggles, checkboxes, sliders)

These elements must remain distinguishable to support usability and accessibility. The 3:1 contrast ratio ensures they are visible, even for users with visual impairments.

2.1.3.3 Focus States and Interaction Feedback

Focus states play a crucial role in signaling interactivity and guiding users through an interface. To ensure clarity, maintain a 3:1 contrast ratio between the default state and the focused state. This contrast level aligns with accessibility guidelines and is considered a best practice for distinguishing focused elements.

For interactive elements, a 1.5:1 contrast ratio is recommended as the inactive state within a 3:1 active contrast range. This subtle visual cue for hover states helps establish a clear, intuitive interaction hierarchy without overwhelming the design. These recommendations are grounded in practical experience and the need for consistent interaction feedback though available research on this topic is lacking.

2.1.3.4 Typography and Tokenized Language

Ensure text meets these minimum contrast ratios for readability:

- 4.5:1 for standard text.
- 3:1 for large text (18pt or 14pt bold).
- 7:1 for optimal legibility in critical content.

Text in a design system is a fundamental form of luminosity encoding. It transmits language through patterns of light and dark, making clear contrast essential for readability and comprehension. These ratios are grounded in WCAG 2.1 Success Criteria 1.4.3 and 1.4.6.

The 7:1 ratio is particularly important for text that users rely on for critical information, ensuring maximum legibility even in challenging viewing conditions.

2.1.3.5 Halation and Eye Strain

Research into contrast ratios primarily focuses on minimum requirements for readability, with no definitive guidelines for maximum contrast. While halation — the visual effect where bright areas bleed into adjacent dark regions — can cause eye strain, its severity depends on factors such as device settings and ambient lighting.

Based on practical experience, starting with a contrast ratio of 14-15:1 for critical information helps balance clarity with visual comfort. This range provides sufficient distinction without introducing excessive halation. Although this design system does not impose a maximum contrast ratio, designers should be mindful of potential eye strain and offer users options to adjust themes or brightness levels for a more comfortable experience.

2.1.3.6 Rich Media and Graphics

Rich content (images, videos, ads) can use the full contrast range without adhering to strict thresholds. Unlike core UI elements, rich media serves a different purpose — to convey visual richness and detail. While rich content does not need to meet accessibility ratios, designers should ensure it does not interfere with essential UI elements.

2.1.4 Practical Considerations of Luminosity and Contrast Ratios

This section applies the guidelines and principles from the previous sections to real-world scenarios. By considering hardware limitations, user vision capabilities, and accessibility standards, we can establish practical luminosity palettes that maintain consistency, durability, and inclusivity. These palettes will help designers achieve optimal visual hierarchy, minimize eye strain, and ensure accessibility compliance across a variety of user needs and devices.

2.1.4.1 Hardware Considerations of Minimum Luminosity

To mitigate the risk of uneven LED aging caused by using absolute black (0,0,0) in one or more channels, it is recommended to set a low but non-zero minimum value. Based on practical experience, a minimum of sRGB 18,18,18 ensures that all LED channels remain engaged, promoting more uniform wear and extending the display's longevity. Due to the long lifespan of LEDs, this recommendation is made within the context of this system; validating it fully would require extensive, long-term research beyond the scope of this project and the available research in the field.

2.1.4.2 Vision Impairments and Accessibility Considerations

To understand how different types of color blindness impact visual perception, we will calculate the relative luminance of the minimum and maximum sRGB values listed in the table for each impairment type. These sRGB values were determined based on the functionality and limitations of the affected cone cells:

- 255 represents a fully perceived channel, ensuring maximum luminosity for that color.
- 0 indicates a channel that is effectively non-functional due to the impairment, meaning the affected color is not perceived.
- 18 is the minimum practical luminosity, chosen to avoid hardware issues like uneven LED wear while maintaining a low but non-zero baseline for partially effective channels.

For example, in the case of Red-Green Color Blindness (Protanopia or Deuteranopia), the red or green channels are non-functional, so the minimum sRGB value is set to (0, 18, 0) and the maximum to (0, 255, 0). This means the red channel is set to 0 (non-functional), the green channel varies between 18 (minimum) and 255 (maximum), and the blue channel is unaffected. By converting these sRGB values to their corresponding relative luminance values, we can determine the achievable contrast ratios for each impairment type.

The following table is an analysis that assesses compliance with accessibility guidelines, such as the minimum 3:1 contrast ratio defined by WCAG, and provides insights into optimizing luminosity and contrast for users with various color vision deficiencies.

Table X: WCAG Minimum Contrast Ratio Compliance for Vision Impairment

Impairment	Minimum L	Maximum L	Ratio	Compliance
None	0.0056	1.0000	18.89	Pass
Protanopia	0.0044	0.7874	15.39	Pass
Deuteranopia	0.0016	0.2848	6.49	Pass
Tritanopia	0.0049	0.9278	17.81	Pass
Blue-Green Blindness	0.0012	0.2126	5.13	Pass
Red-Blue Blindness	0.0040	0.0722	14.17	Pass
Red-Green Blindness	0.0004	0,255,0	2.43	Fail

Table X shows that all types of color blindness, except Red-Green Blindness, meet the WCAG minimum contrast ratio requirement of 3:1 for large text and non-text elements. The maximum achievable contrast ratio for Red-Green Blindness is only 2.43:1 due to the inability to perceive both red and green channels, leaving only the blue channel for visual differentiation. Because of this limitation, relying on vision-based interfaces may cause eye strain and confusion. To protect their remaining vision and ensure accessibility, users with Red-Green Blindness should be encouraged to use non-visual interfaces.

2.1.5 Themes

Themes define how luminosity and color are applied across various contexts to create accessible and visually coherent interfaces. Themes adapt to different user needs, visual capabilities, and content types, ensuring flexibility and consistency in design. This is done by conceptualizing layers of luminosity and defining them as zones for specific purposes.

2.1.5.1 Defining Luminosity Zones

To ensure accessibility across themes and visual impairments, a structured process is applied to determine the luminosity zones for each theme. The process adheres to the WCAG 2.1 guidelines for contrast ratios and integrates specific calculations tailored to each theme’s minimum and maximum working luminosity values.

2.1.5.1.1 Determine Minimum and Maximum Working Luminosity

To ensure accessibility across themes and visual impairments, a structured process is applied to determine the luminosity zones for each theme. The process adheres to the WCAG 2.1 guidelines for contrast ratios and integrates specific calculations tailored to each theme's minimum and maximum working luminosity values.

2.1.5.1.2 Calculate the Lower Boundaries for Each Layer

Using the WCAG 3:1 contrast ratio, the lower boundary for each successive layer is calculated. The contrast ratio formula is applied iteratively to move up through the luminosity spectrum:

$$L1 = (CR \bullet (L2 + 0.05) - 0.05$$

Where:

- CR is the contrast ratio (in this case, 3 for the 3:1 for layers).
- L_2 is the lower boundary (darker) of the current layer.
- L_1 becomes the lower boundary for the next brighter layer.

2.1.5.1.3 Calculate the Upper Boundaries for Each Layer

The upper boundary of each layer is calculated based on the lower boundary of the layer above it, specifically using the deactivated state of the layer above as the limiting factor. This ensures a seamless transition between active and deactivated layers while maintaining the hierarchical integrity of the luminosity zones.

The formula for calculating the upper boundary is:

$$L2 = \frac{(L1+0.05)}{CR} - 0.05$$

Where:

- L1 is the lower boundary (brighter) of the next layer.
- The contrast ratio (1.5:1) ensures deactivated states remain distinguishable.
- L2 becomes the upper boundary for the current layer.

2.1.5.1.4 Deactivated Layer States

Deactivated layers are defined as 1.5:1 below the lower boundary of their active layer. They serve as both visual markers for inactive elements and structural guides for layer boundaries.

Deactivated layers are devoid of gradients and hue to indicate their inactive status. Gradients and hue are introduced upon activation, serving as an additional visual cue for functionality. This methodology enhances both functional clarity and visual consistency.

2.1.5.1.4 Defining Micro Layers

Micro layers are finer subdivisions within each luminosity layer, enabling nuanced depth and enhancing the visual hierarchy of designs. These subdivisions provide flexibility in distinguishing elements while maintaining a cohesive structure across the interface.

By default, micro layers are calculated using the same equation as the lower boundary for layers, with a contrast ratio of 1.2. This conservative ratio balances usability and flexibility, ensuring sufficient distinction between micro layers without overwhelming the design. Starting at the lower boundary of a parent layer, boundaries for micro layers are iteratively calculated until the upper boundary of the parent layer is reached.

However, micro layers are intentionally left less rigidly defined to allow for adaptation. The specific configuration of micro layers may vary depending on design needs, such as the presence of associated media or specific interface contexts. Designers have the discretion to adjust micro layers to incorporate rich media elements or emphasize hues from associated imagery.

A more adaptive approach to micro layers will be discussed in the "Incorporating Rich Media" section. This approach integrates LAB and HSV data to inform micro-layer divisions based on hues and color groupings derived from associated media. For now, the default 1.2 ratio provides a reliable framework to guide design decisions.

2.1.5.2 Adapting Luminosity Layers Across Themes

In the standard luminosity range (0.006 to 1), the design supports three distinct layers:

- Background Layer: The darkest layer, forming the visual foundation.
- Middle Layer: A transitional layer used for elements like cards or secondary content, bridging the gap between the background and the foreground.

- Foreground Layer: The brightest layer, reserved for actionable elements and primary content.

Gestalt theory supports this structure by suggesting that content with higher luminosity appears closer to the user, enhancing depth and visual hierarchy. This three-layer approach ensures clarity and distinction across all layers in the standard range.

However, in reduced ranges such as 0.0012 to 0.2126, only two layers are feasible due to the limited contrast ratio. In these cases:

- The middle layer is omitted, merging its purpose with either the background or foreground layers.
- The resulting structure consists of a background layer and a foreground layer, where the foreground is reserved for actionable content to maintain visual clarity and functionality.

This adjustment preserves the core hierarchy and usability principles, ensuring that even in constrained ranges, users can interact with and interpret the interface effectively. By dynamically adapting the number of layers, the design system remains flexible and accessible across varying visual requirements.

2.1.5.2.1 Changing Themes

Content elements are assigned a metadata priority rank that corresponds to their position within the luminosity layer scale. This metadata allows the system to adapt content dynamically when switching between themes. For example, a card assigned to the middle layer in one theme may adjust its luminosity and color when transitioning to a different theme, ensuring consistency in hierarchy and visual meaning.

When themes change, this metadata-driven approach automates the process of adjusting layers and micro-layers, reducing the need for manual intervention. The flexibility of this system ensures that the design remains adaptable to different visual needs and contexts.

2.1.5.3 Standard Luminosity Themes

To create accessible and visually coherent interfaces, themes are built on a unified theory of luminosity layers and micro-layers. Using the WCAG 2.1 contrast ratio guidelines and the structured calculation processes outlined earlier, we define a three-layer structure:

- Background Layer: Provides the foundation for the interface.
- Middle Layer: Bridges the background and foreground, typically used for secondary content.
- Foreground Layer: Reserved for actionable elements and primary content.

Each layer can be subdivided into micro-layers for finer control over depth and hierarchy. The number of micro-layers is determined by iteratively applying a 1.2 contrast ratio to the luminosity range of each parent layer.

2.1.5.3.1 Dark Mode

Dark Mode employs the unified theory while tailoring its application to a dark-background design. The luminosity hierarchy ensures that brighter foreground elements pop against the darker background, reducing glare and aiding visual hierarchy in low-light conditions.

Background Layer

Micro-Layer	Luminosity Range
1	0.0060 - 0.0172
2	0.0173 - 0.0307
3	0.0308 - 0.0653

Middle Layer

Micro-Layer	Luminosity Range
1	0.1181 - 0.1518
2	0.1519 - 0.1921
3	0.1922 - 0.2406
4	0.2407 - 0.3000

Foreground Layer

Micro-Layer	Luminosity Range
1	0.4586 - 0.5603
2	0.5604 - 0.6824
3	0.6825 - 1.000

2.1.5.3.2 Light Mode

Light Mode mirrors the unified theory while adapting it to a light-background design. The visual hierarchy is inverted, with darker elements serving as actionable components and lighter ones forming the foundation.

Background Layer

Micro-Layer	Luminosity Range
1	0.6825 - 1.000
2	0.5604 - 0.6824
3	0.4586 - 0.5603

Middle Layer

Micro-Layer	Luminosity Range
1	0.2407 - 0.3000
2	0.1922 - 0.2406
3	0.1519 - 0.1921
4	0.1181 - 0.1518

Foreground Layer

Micro-Layer	Luminosity Range
1	0.0308 - 0.0653
2	0.0173 - 0.0307
3	0.0060 - 0.0172

2.1.5.3.3 Colorblind Themes

Colorblind themes have been carefully considered during the research phase to ensure accessibility for users with different types of color vision deficiencies, such as Protanopia, Deuteranopia, and Tritanopia. However, implementing these themes falls outside the scope of the Minimum Viable Product (MVP).

In future phases, these themes will be designed to adapt the luminosity and color layers appropriately for each type of color blindness. The goal will be to ensure that interfaces maintain sufficient contrast, clear differentiation of elements, and visual hierarchy regardless of color perception differences. This approach will provide a customizable experience that meets accessibility guidelines and user needs.

2.1.6 Adapting Themes to Rich Media

Rich media, such as images, videos, and graphics, provides a dynamic source of color information for themes. By analyzing the color data from rich media, the system transforms the achromatic palette into a chromatic one. This approach ensures visual harmony between the interface and its content, enhancing the user experience while maintaining accessibility principles.

The process involves extracting dominant color groupings from the image using the LAB color space and then interpreting these groupings within the HSV color space to determine the overall color scheme. These outputs inform how color can be mapped to the defined luminosity layers and micro-layers, allowing themes to adapt dynamically to the media they contain.

2.1.6.1 Analyzing LAB Space Groupings

The LAB color space represents color in a way that closely aligns with human perception, using three dimensions:

- L (Lightness): Represents luminosity.
- A (Green-Red): Represents the color spectrum from green to red.
- B (Blue-Yellow): Represents the color spectrum from blue to yellow.

This model is particularly useful because it separates luminosity from color information, allowing us to analyze contrast and color independently. LAB's perceptual uniformity makes it ideal for clustering processes that require meaningful groupings of color based on human vision.

2.1.6.1.1 Density-Based Spatial Clustering of Applications with Noise (DBSCAN)

To cluster colors in the LAB space, we employ DBSCAN (Density-Based Spatial Clustering of Applications with Noise) because it is particularly well-suited to the characteristics of our data. LAB space introduces three dimensions (L, A, B), where density and relative distance play critical roles in identifying meaningful groupings. DBSCAN excels in handling such density-based data while accommodating the complexity of multidimensional color spaces. It does not require a predetermined number of clusters, making it adaptable to the unique variations of each image.

Two key parameters define the clustering process with DBSCAN:

- eps: This parameter sets the maximum distance between two points in the LAB space to be considered part of the same cluster. It defines the neighborhood size and directly influences the granularity of clusters.
- min_samples: This defines the minimum number of points required to form a cluster. It acts as a threshold to ensure that clusters are meaningful rather than representing noise or isolated data points.

DBSCAN's strength lies in its ability to identify clusters of varying shapes and sizes while treating outliers as noise. This is particularly important when processing LAB data because the density of colors often varies across different images. The flexibility of DBSCAN makes it an ideal choice for clustering in this context, as it dynamically adapts to the distribution of color points.

2.1.6.1.1 Defining EPS

While DBSCAN is highly effective for clustering in LAB space due to its adaptability to varying densities, its performance and accuracy depend heavily on the eps parameter. The eps parameter defines the maximum distance between two points for them to be considered part of the same cluster. Selecting an appropriate eps value ensures that clusters represent meaningful groupings rather than arbitrary associations or excessive merging.

The Euclidean distance measures the straight-line distance between points in LAB space, encompassing both the color's hue and chroma (via the A and B channels) and its lightness (via the L channel). Calculating the average Euclidean distance between all points in a dataset provides a robust way to estimate the density of points. This value serves as a baseline for determining eps, ensuring that clusters are neither too tight (leading to over-segmentation) nor too loose (resulting in merged, indistinct clusters)

2.1.6.1.2 Downsampling for EPS Caluclations

Calculating pairwise Euclidean distances for all points in an image scales quadratically with the number of pixels, resulting in computational inefficiency for large datasets. For instance, an 8K image with over 33 million pixels would require distance calculations on the order of $O(n^2)$, a prohibitively large computation even with modern GPUs.

Downsampling mitigates this issue by reducing the number of pixels used for parameter calculation while preserving the overall color composition of the image. A baseline resolution of 512x512 pixels has been chosen for this process. This value provides a manageable number of points for efficient computation while retaining the image's dominant color relationships. The baseline resolution is arbitrary and may be refined in future iterations based on experimental results.

Downsampling Process:

- Rescaling: The image is scaled down to 512x512 pixels while maintaining its original aspect ratio. This ensures that the resized image is a proportionate representation of the original, regardless of irregular dimensions.
- Extracting LAB Values: The color values from the downsampled image are converted into LAB space.
- Calculating EPS: The average Euclidean distance is computed across all points in the downsampled LAB dataset. This value defines eps, serving as a measure of the typical density of points.
- Optimization with KD-Tree: A KD-tree algorithm is used to optimize distance calculations, reducing the computational complexity from $O(n2)$ to $O(n \log n)$. This optimization ensures efficiency without compromising accuracy.

By downsampling to 512x512 and calculating eps using the average Euclidean distance in LAB space, we achieve a scalable and effective way to parameterize DBSCAN. This approach ensures that clusters reflect meaningful relationships in the image while keeping computational demands manageable.

2.1.6.1.2 Defining min_samples

The min_samples parameter in DBSCAN determines the minimum number of points required to form a cluster. This parameter ensures that clusters represent meaningful groupings rather than noise, balancing inclusivity with relevance. Clusters must have at least the specified number of points within the eps radius to be recognized. Points that do not meet this density requirement are classified as noise or remain unclustered.

To adapt min_samples to varying image resolutions, we calculate it dynamically based on the total pixel count N in the original image. The formula is:

$$ms = max(10, \frac{N}{5000})$$

Where:

- N is the total number of LAB data points (pixels) in the original image.
- 5000 is a scaling factor to ensure the parameter adapts to image size.
- A lower limit of 10 guarantees sufficient density for small images.

While the formula provides a robust starting point, adjustments may be necessary to achieve meaningful clusters in specific contexts.

- Sparse Clusters (Too Few Clusters): If the algorithm fails to identify sufficient clusters, increase the inclusivity of clusters by reducing min_samples by multiplying it by 0.8
- Overpopulated Clusters (Too Many Clusters): If too many clusters are formed, increase the exclusivity by multiplying min_samples by 1.2.

Iterative tuning allows the system to refine cluster groupings based on the image's unique characteristics, ensuring a balance between noise filtering and cluster relevance.

2.1.6.1.3 Post-Processing Analysis

After clustering, post-processing analysis ensures that the resulting clusters align with design objectives and the inherent characteristics of the image. Two key considerations during this phase are:

- Noise Levels: Evaluate the percentage of points classified as noise. Excessive noise may indicate that the eps parameter is too restrictive, resulting in overly stringent density thresholds. Adjusting eps may help reduce noise and incorporate valid points into clusters.
- Cluster Validation: Visualize and analyze the resulting clusters to confirm they represent dominant and meaningful groupings within the LAB space. Dominant clusters should correspond to perceptually significant colors or hues in the image, ensuring they align with the visual hierarchy and design intent.

By conducting this analysis, the system refines the clustering results to ensure they provide a strong foundation for theme adaptation and design implementation.

2.1.6.2 Analyzing Color Scheme Through HSV

After identifying LAB groupings, the color data is converted to HSV (Hue, Saturation, Value) for further analysis. The hue component, represented as degrees on the color wheel, helps classify the color scheme (e.g., complementary, analogous, triadic). By reducing LAB groups to hue values, the system can determine the relationships between these hues.

The system calculates the percentage of pixels that fall within each hue grouping. This percentage informs how much of the interface should adopt each color. Based on this analysis, the system recommends a color mapping that aligns with the theme’s micro-layers and overall visual hierarchy.

[Figure showing HSV analysis and resulting color scheme classification.]

This adaptive approach ensures that the theme integrates rich media seamlessly, maintaining both aesthetic coherence and accessibility.