# Tincture Color Library Roadmap

This document outlines potential improvements, new features, and cleanup tasks for the Tincture color library.

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## Feature Proposals

### [Priority: High] CSS Color Level 4 Parsing Support

**Description:** Extend the color parsing to support modern CSS Color Level 4 syntax including `hsl()`, `hwb()`, `lab()`, `lch()`, `oklab()`, `oklch()`, and the `color()` function.

**Rationale:** CSS Color Level 4 is increasingly adopted in browsers. Supporting these formats would make Tincture more useful for web development workflows and CSS tool integration.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Parse.lean`

**Estimated Effort:** Medium

**Dependencies:** None

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### [Priority: High] Named Color Lookup by Closest Match

**Description:** Add a function to find the closest named color to an arbitrary color, using perceptual color distance (deltaE2000).

**Rationale:** Useful for color identification, accessibility tools, and generating human-readable color descriptions.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Named.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Distance.lean`

**Estimated Effort:** Small

**Dependencies:** Color distance functionality already exists

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### [Priority: Medium] Gamut Mapping for OkLab/OkLCH

**Description:** Implement gamut mapping to clamp out-of-gamut colors back into the sRGB gamut while preserving perceptual appearance as much as possible. Currently, conversions from wide-gamut color spaces can produce RGB values outside [0,1].

**Rationale:** OkLCH in particular can easily produce colors outside the sRGB gamut. Proper gamut mapping (e.g., via chroma reduction) provides better results than simple clamping.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/OkLab.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/OkLCH.lean`

**Estimated Effort:** Medium

**Dependencies:** None

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**[Priority: Medium] Display-P3 and Adobe RGB Color Spaces**

**Description:** Add support for wide-gamut color spaces like Display-P3 (used on modern Apple devices) and Adobe RGB (used in photography).

**Rationale:** Wide-gamut displays are increasingly common. Supporting these spaces would enable accurate color representation for professional graphics workflows.

**Affected Files:** - New file: `Tincture/Space/DisplayP3.lean` - New file: `Tincture/Space/AdobeRGB.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Convert.lean`

**Estimated Effort:** Medium

**Dependencies:** None

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**[Priority: Medium] ICC Profile Support (Basic)**

**Description:** Add basic ICC profile parsing for CMYK conversions. The current CMYK implementation uses a simple formula that does not account for real-world printing profiles.

**Rationale:** Professional print workflows require ICC profile-based color management for accurate results.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/CMYK.lean` - New file: `Tincture/ICC.lean`

**Estimated Effort:** Large

**Dependencies:** May require FFI for profile parsing or implementing a subset of ICC in pure Lean

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**[Priority: Medium] Color Quantization / Palette Extraction**

**Description:** Implement algorithms to extract dominant colors from a set of colors (e.g., median cut, k-means clustering). This is useful for extracting color palettes from images.

**Rationale:** Common use case for design tools and image processing.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Palette.lean` or new file `Tincture/Quantize.lean`

**Estimated Effort:** Medium

**Dependencies:** None

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**[Priority: Medium] Color Interpolation Easing Functions**

**Description:** Add support for non-linear interpolation in gradients (ease-in, ease-out, ease-in-out, custom bezier curves).

**Rationale:** Non-linear interpolation produces more visually appealing gradients and animations.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Gradient.lean`

**Estimated Effort:** Small

**Dependencies:** None

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**[Priority: Low] Spectral Color Representation**

**Description:** Add support for spectral colors (wavelength-based representation) and conversion to/from XYZ/sRGB.

**Rationale:** Useful for scientific applications, accurate color mixing, and educational purposes.

**Affected Files:** - New file: `Tincture/Space/Spectral.lean`

**Estimated Effort:** Medium

**Dependencies:** None

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**[Priority: Low] Temperature to Color (Kelvin)**

**Description:** Add function to generate blackbody radiation colors from temperature in Kelvin. Useful for lighting and photography applications.

**Rationale:** Common feature in color libraries for simulating light sources.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Adjust.lean` or new file `Tincture/Temperature.lean`

**Estimated Effort:** Small

**Dependencies:** None

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**[Priority: Low] Compile-Time Color Literals**

**Description:** Add a macro or elaborator for compile-time validated color literals (e.g., `color!"#ff0000"` or `color!"rgb(255, 0, 0)"`).

**Rationale:** Catches color parsing errors at compile time rather than runtime, improves developer experience.

**Affected Files:** - New file: `Tincture/Syntax.lean`

**Estimated Effort:** Small

**Dependencies:** None

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## Code Improvements

**[Priority: High] Consolidate Gamma Conversion Functions**

**Current State:** The gamma conversion functions (`gammaToLinear`, `linearToGamma`) are duplicated across multiple files: - `Tincture/Space/RGB.lean` (lines 20-31) - `Tincture/Space/XYZ.lean` (lines 25-37, marked `private`) - `Tincture/Space/OkLab.lean` (lines 56-68, marked `private`) - `Tincture/Blindness.lean` (lines 48-55, marked `private`)

**Proposed Change:** Move these functions to a shared utility module (e.g., `Tincture/Util.lean` or export from `Tincture/Space/RGB.lean`) and have all files use the shared implementation.

**Benefits:** DRY principle, easier maintenance, single source of truth for sRGB gamma curve.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/RGB.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/XYZ.lean` - `/Users/Shared/Projects/lean-work` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Blindness.lean`

**Estimated Effort:** Small

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**[Priority: High] Add Alpha Channel Preservation to Color Space Conversions**

**Current State:** Alpha channel handling is inconsistent across color space types. For example, `HSL`, `HSV`, `HWB`, `Lab`, `LCH`, `OkLab`, `OkLCH`, `XYZ`, and `CMYK` structures do not store alpha. The alpha is passed separately to `toColor` but lost during `fromColor`.

**Proposed Change:** Either: 1. Add an `alpha` field to each color space structure, or 2. Create wrapper types that consistently carry alpha alongside the color space data, or 3. Document the pattern clearly and ensure all `toColor` methods accept alpha

**Benefits:** Consistent alpha handling, prevents subtle bugs when converting between color spaces.

**Affected Files:** - All files in `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/`

**Estimated Effort:** Medium

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**[Priority: Medium] Add Typeclass for Color Space Conversion**

**Current State:** Each color space has its own `fromColor` and `toColor` functions, but there is no common interface (typeclass).

**Proposed Change:** Create a `ColorSpace` typeclass with `fromColor` and `toColor` methods. This would enable generic programming over color spaces.

```
class ColorSpace (S : Type) where
  fromColor : Color -> S
  toColor : S -> Float -> Color  -- Float is alpha
```

**Benefits:** Enables generic algorithms, cleaner API, better composability.

**Affected Files:** - All files in `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Convert.lean`

**Estimated Effort:** Medium

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**[Priority: Medium] Optimize Named Color Lookup**

**Current State:** `namedColors` is a `List (String x Color)` and lookup is O(n) via `List.find?`.

**Proposed Change:** Use a `HashMap` or `RBMap` for O(log n) or O(1) lookup. The list has 147+ entries.

**Benefits:** Faster color name lookups.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Named.lean`

**Estimated Effort:** Small

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**[Priority: Medium] Add Infix Operators for Common Operations**

**Current State:** Common operations like color mixing and blending use function calls.

**Proposed Change:** Add optional infix operators: - `c1 +c c2` for additive mixing (linear RGB) - `c1 *c c2` for multiply blend - `c1 |> blend` for blending operations

**Benefits:** More ergonomic API for color manipulation DSLs.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Blend.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Adjust.lean`

**Estimated Effort:** Small

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[**Priority: Medium**] **Improve Float Parsing Robustness**

**Current State:** The `parseFloat` function in `Parse.lean` (lines 82-103) is a basic implementation that: - Does not handle negative numbers - Does not handle scientific notation - Does not handle leading zeros well

**Proposed Change:** Improve the parser to handle more edge cases or use Lean's built-in parsing utilities if available.

**Benefits:** More robust color parsing, fewer parsing failures.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Parse.lean`

**Estimated Effort:** Small

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[**Priority: Low**] **Add Benchmarking Suite**

**Current State:** No performance benchmarks exist.

**Proposed Change:** Add benchmarks for: - Color space conversions (especially Lab and OkLab which are more compute-intensive) - Delta E calculations - Gradient sampling - Parsing/formatting

**Benefits:** Identify performance regressions, guide optimization efforts.

**Affected Files:** - New file: `TinctureTests/Benchmarks.lean` or similar

**Estimated Effort:** Medium

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[**Priority: Low**] **Lazy Gradient Sampling**

**Current State:** `Gradient.sample` eagerly computes all colors into an Array.

**Proposed Change:** Add a lazy/iterator-based API for sampling gradients, useful when only a few samples are needed from a potentially large gradient.

**Benefits:** Better memory efficiency for large sample counts.

**Affected Files:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Gradient.lean`

**Estimated Effort:** Small

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## Code Cleanup

[**Priority: High**] **Remove Duplicate Helper Functions in Tests**

**Issue:** The test files each define their own `approxEq` and `colorApproxEq` helper functions: - `TinctureTests/ColorTests.lean` (lines 14-22) - `TinctureTests/SpaceTests.lean` (lines 14-21) - `TinctureTests/BlendTests.lean` (lines 14-21) - `TinctureTests/ContrastTests.lean` (lines 14-15) - `TinctureTests/HarmonyTests.lean` (lines 14-15) - `TinctureTests/ParseFormatTests.lean` (lines 14-21) - `TinctureTests/PropertyTests.lean` (lines 63-69)

**Location:** All test files in `/Users/Shared/Projects/lean-workspace/tincture/TinctureTests/`

**Action Required:** Extract shared test utilities into a common file (e.g., `TinctureTests/TestUtils.lean`) and import from all test files.

**Estimated Effort:** Small

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**[Priority: Medium] Add Missing `Float.abs` Definition Location Documentation**

**Issue:** `Float.abs` is defined in `Tincture/Color.lean` (line 18), but it may shadow or conflict with any future standard library definition. Additionally, `Float.pi`, `Float.max`, `Float.min` are defined here too.

**Location:** `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Color.lean` (lines 8-18)

**Action Required:** Check if these are available in Lean's standard library now (Lean 4.26+) and remove duplicates if so. If not, document why they are needed.

**Estimated Effort:** Small

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**[Priority: Medium] Consistent Error Handling in Parsing**

**Issue:** Parsing functions return `Option Color` but do not provide error messages. Users cannot distinguish between different types of parse failures.

**Location:** `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Parse.lean`

**Action Required:** Consider adding an `Except String Color` variant that provides error messages, or at minimum document what types of inputs are rejected.

**Estimated Effort:** Small

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**[Priority: Medium] Update README to Match Current Features**

**Issue:** The README.md is minimal and does not reflect the full feature set of the library. It mentions only RGBA and HSV but the library supports 10+ color spaces, color blindness simulation, WCAG contrast, gradients, palettes, etc.

**Location:** `/Users/Shared/Projects/lean-workspace/tincture/README.md`

**Action Required:** Update README with: - Complete feature list - Examples for each major feature area - API documentation or links to generated docs

**Estimated Effort:** Medium

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**[Priority: Low] Add Module-Level Documentation Comments**

**Issue:** While individual functions have doc comments, module-level documentation explaining the purpose and usage of each file is minimal.

**Location:** All source files

**Action Required:** Add comprehensive doc comments at the top of each file explaining: - Purpose of the module - Key types and functions - Usage examples - Any important caveats

**Estimated Effort:** Medium

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**[Priority: Low] Inconsistent Hue Representation**

**Issue:** Hue is represented as `0.0 to 1.0` (normalized) in all color spaces, but some helper functions like `rotateHueDeg` accept degrees. The documentation could be clearer about this.

**Location:** - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/HSL.lean` - `/Users/Shared/Projects/lean-workspace/tincture/Tincture/Space/HSV.lean` - `/Users/Shared/Projects/lean-work` (line 41)

**Action Required:** Add clear documentation about the hue convention. Consider adding more degree-based convenience functions if commonly needed.

**Estimated Effort:** Small

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**[Priority: Low] Add Test Coverage for Color Blindness Simulation**

**Issue:** No unit tests exist for the color blindness simulation module.

**Location:** No `BlindnessTests.lean` file exists

**Action Required:** Create `TinctureTests/BlindnessTests.lean` with tests for: - Each type of color blindness simulation - Severity adjustment - `isDistinguishableFor` function

**Estimated Effort:** Small

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**[Priority: Low] Add Test Coverage for Distance Module**

**Issue:** No dedicated unit tests exist for the color distance module (deltaE76, deltaE94, deltaE2000). Only property tests in `PropertyTests.lean` cover some aspects.

**Location:** No `DistanceTests.lean` file exists

**Action Required:** Create `TinctureTests/DistanceTests.lean` with tests for: - Known deltaE values from the CIE publications - Edge cases (same color, black/white, complementary colors) - Symmetry and non-negativity

**Estimated Effort:** Small

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**[Priority: Low] Add Test Coverage for Gradient Module**

**Issue:** No dedicated unit tests exist for gradient functionality. Only property tests cover basic gradient behavior.

**Location:** No `GradientTests.lean` file exists

**Action Required:** Create `TinctureTests/GradientTests.lean` with tests for: - Different gradient spaces (sRGB, OkLab, etc.) - Hue interpolation methods - Multi-stop gradients - Reverse functionality - Sample function

**Estimated Effort:** Small

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**[Priority: Low] Add Test Coverage for Palette Module**

**Issue:** No dedicated unit tests exist for palette generation.

**Location:** No `PaletteTests.lean` file exists

**Action Required:** Create `TinctureTests/PaletteTests.lean` with tests for: - Sequential, diverging, and qualitative palettes - Warm, cool, earth, pastel, neon palettes - Accessible palette generation - Random palette with seed reproducibility

**Estimated Effort:** Small

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**[Priority: Low] Add Test Coverage for Adjust Module**

**Issue:** No dedicated unit tests exist for color adjustment operations (lighten, darken, saturate, etc.).

**Location:** No `AdjustTests.lean` file exists

**Action Required:** Create `TinctureTests/AdjustTests.lean` with tests for: - Lighten/darken - Saturate/desaturate - Hue rotation - Invert, grayscale, sepia - Brightness/contrast adjustments - OkLCH-based adjustments

**Estimated Effort:** Small