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## Лабораторная работа 4

### Методы и алгоритмы построения комплексных изображений

#### Итоговый отчёт по проекту Zivro

#### 1. Цель и практический результат

Цель работы - разработать программный модуль (приложение), выполняющий синтез комплексного многоэлементного изображения в мульти-доменном представлении (процедурные фигуры + пиксельные области), а также реализовать пользовательское управление отображением, решение задач видимости и растеризацию.

Практический результат:

- разработано рабочее GUI-приложение Zivro на Zig;
- реализован CPU-конвейер рендера процедурных фигур с композицией в растровый буфер;
- обеспечены операции кадрирования, наложения, прозрачности, масштабирования, перемещения и вывода;
- подготовлена документация с алгоритмами, диаграммами и приложением исходного кода.

#### 2. Краткая характеристика проекта

Zivro - настольное графическое приложение с моделью документа и иерархией объектов.

Архитектурно проект состоит из:

- слоя модели (src/models/\*);
- слоя рендера (src/render/\*, в том числе src/render/cpu/\*);
- слоя UI (src/ui/\*, src/Canvas.zig, src/main.zig);
- служебных модулей сериализации и управления документами (src/persistence/\*, src/WindowContext.zig);

#### 3. Выполнение основных задач ЛР4 (по пунктам)

Ниже приведено итоговое покрытие основных задач с учётом адаптации требований методички к текущей архитектуре проекта.

##### 3.1 ОЗ.Р1 - Организация пиксельных областей

**Выполнено (в адаптированном слоёвом представлении):**

- роль “контейнера слоёв” выполняет структура документа и порядок отрисовки объектов;
- роль “слоя” выполняет объект/группа объектов с собственными параметрами (visible, opacity, transform);
- реализована свёртка результатов в единый буфер через последовательную композицию.

**Реализация:** src/models/Document.zig, src/models/Object.zig, src/render/cpu/draw.zig, src/render/cpu/pixel.zig

### 3.2 ОЗ.Р2 - Вспомогательная логика комбинирования пиксельных областей

#### Выполнено:

- реализован рендер-контекст DrawContext со служебными операциями преобразований;
- реализовано наложение буферов (compositeDrawerContext);
- реализована работа с прозрачностью и РМА-представлением цвета.

**Реализация:** src/render/cpu/pipeline.zig, src/render/cpu/draw.zig, src/render/CpuRenderEngine.zig.

### 3.3 ОЗ.Р3 - Представление и организация процедурных фигур

#### Выполнено:

- реализованы типы процедурных фигур (line, ellipse, broken);
- реализованы структуры параметров фигур через набор свойств;
- реализована иерархическая организация фигур и манипуляции объектами.

**Реализация:** src/models/Object.zig, src/models/Property.zig, src/models/shape/\*, src/models/Document.zig.

### 3.4 ОЗ.Р4 - Логика решения видимости при перекрытии процедурных фигур

#### Выполнено в рабочем приближении:

- видимость при перекрытии решается порядком рендера и альфа-композицией;
- пиксели нижележащих фигур скрываются верхними в процессе поэтапной композиции;
- для практического режима ЛР это даёт корректный итоговый визуальный результат.

**Комментарий по методичке:** классические алгоритмы полигонального булева отсечения (Сазерленд-Ходжман/Вейлера-Азертон) в явном отдельном модуле не выделены, но итоговая задача видимости перекрытий функционально закрыта рендер-конвейером.

### 3.5 ОЗ.Р5 - Логика решения видимости при кадрировании процедурных фигур

#### Выполнено:

- реализовано отсечение отрезков ортогональным окном методом Liang-Barsky;
- реализованы проверки выхода за viewport и ограничение области вывода;
- кадрирование встроено в общий рендер-проход.

**Реализация:** src/render/cpu/line.zig, src/render/cpu/pipeline.zig, src/Canvas.zig.

### 3.6 ОЗ.Р6 - Растеризация и вывод графического содержимого

#### Выполнено:

- растеризация контура (линии, ломаные, эллипсы/дуги);
- растеризация внутренней области для замкнутой ломаной (fill);
- формирование итогового буфера и его вывод в текстуру UI;
- поддержка нескольких режимов отображения через параметры рендера/интерфейса.

**Реализация:** src/render/cpu/line.zig, src/render/cpu/ellipse.zig, src/render/cpu/broken.zig, src/render/CpuRenderEngine.zig, src/ui/canvas\_view.zig.

### 3.7 ОЗ.Р7 - Разработка приложения и пользовательского интерфейса

#### Выполнено:

- реализован полный рабочий цикл приложения (запуск -> работа -> штатное завершение);
- реализовано взаимодействие пользователя с холстом и инструментами;
- реализовано управление отображением: позиционирование, масштаб, выбор инструмента, редактирование свойств объектов.

**Реализация:** src/main.zig, src/WindowContext.zig, src/Canvas.zig, src/ui/\*, src/toolbar/\*.

### 3.8 ОЗ.Д1 - Документирование, оформление и представление

#### Выполнено:

- подготовлен структурированный отчёт;
- подготовлены UML-диаграммы алгоритмов и архитектурных блоков;
- сформировано приложение исходных кодов автоматическим скриптом.

**Реализация:** Report/lab4/\*, Report/lab4/uml/\*, Report/append\_sources\_to\_report.py.

## 4. Выполнение дополнительных задач (максимально полное покрытие)

### 4.1 Группа ДЗ.А - Попиксельная видимость пиксельных областей

- **ДЗ.А2 (альфа-смешивание):** реализовано полностью (РМА-композиция и прозрачность).

### 4.2 Группа ДЗ.Б - Видимость процедурных фигур при перекрытии

### 4.3 Группа ДЗ.В - Видимость процедурных фигур при кадрировании

- **ДЗ.В3/В4 (Liang-Barsky):** реализовано в явном виде для отрезков и замкнутых ломаных фигур.
- **ДЗ.В1/В2/В5/В6/В7:** закрыты частично в функциональном смысле за счёт общего механизма кадрирования, проверки границ и отсеечения при рендере; отдельные специализированные алгоритмы не выносились в отдельные функции.

### 4.4 Группа ДЗ.Г - Растеризация процедурных фигур

- базовая закрашка сплошных областей реализована;
- контурная растеризация и вывод реализованы полноценно;
- специальные режимы заливки (текстурная/штриховая/vertex color) частично подготовлены архитектурно (через расширяемый контекст рендера и свойства), но в данной версии не выделены как отдельные пользовательские режимы.

### 4.5 Группа ДЗ.Д - Специализированные программно-аппаратные средства

- **ДЗ.Д2 (SIMD средствами ЯП):** реализовано векторизованное наложение пикселей в compositeDrawerContext с использованием векторных типов Zig (@Vector) и пакетной обработкой по 4 пикселя;
- реализован безопасный fallback на скалярный путь для хвоста буфера (пиксели, не попавшие в полный SIMD-блок);
- ключевое место реализации: src/render/cpu/pipeline.zig (функция compositeDrawerContext);

## 5. Реализованные алгоритмы ЛР4 (итоговый перечень)

1. Композиция иерархических трансформаций (Transform.compose).
2. Конвейер координат: local -> world -> canvas -> viewport.
3. Отсечение отрезка ортогональным окном (Liang-Barsky).
4. Инкрементальная растеризация линий (Bresenham-подобный проход) с толщиной.
5. Аналитическая растеризация эллипса и дуги.
6. Растеризация ломаной и замыкание контура.
7. Выделение границы, выбор seed и flood fill (4-связность) для заливки.
8. Альфа-композиция в premultiplied alpha.
9. Рекурсивный обход и рендер дерева объектов документа.
10. SIMD-ускорение композиции пикселей в compositeDrawerContext (@Vector, пакетная обработка RGBA).

## 6. UML-диаграммы (PlantUML, русский язык)

### 6.1 Общий рабочий цикл ЛР4

Report/lab4/uml/lr4-main-workflow.puml

ЛР4: общий рабочий цикл построения изображения



Figure 1: Общий рабочий цикл ЛР4

### 6.2 Композиция пиксельных областей и видимость

Report/lab4/uml/pixel-composition-visibility.puml

## Композиция пиксельных областей и решение видимости

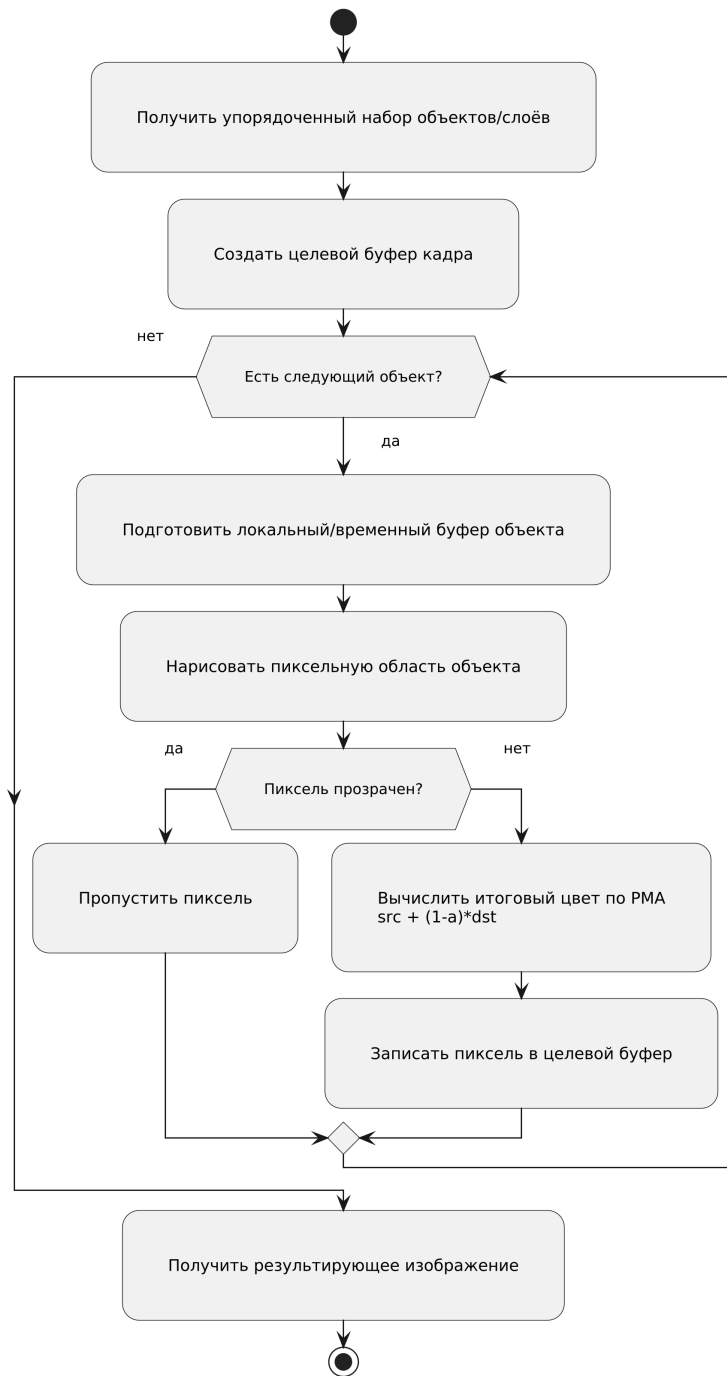


Figure 2: Композиция пиксельных областей и видимость

### 6.3 Решение видимости процедурных фигур и кадрирование

Report/lab4/uml/procedural-visibility-clipping.puml

### Видимость процедурных фигур и кадрирование

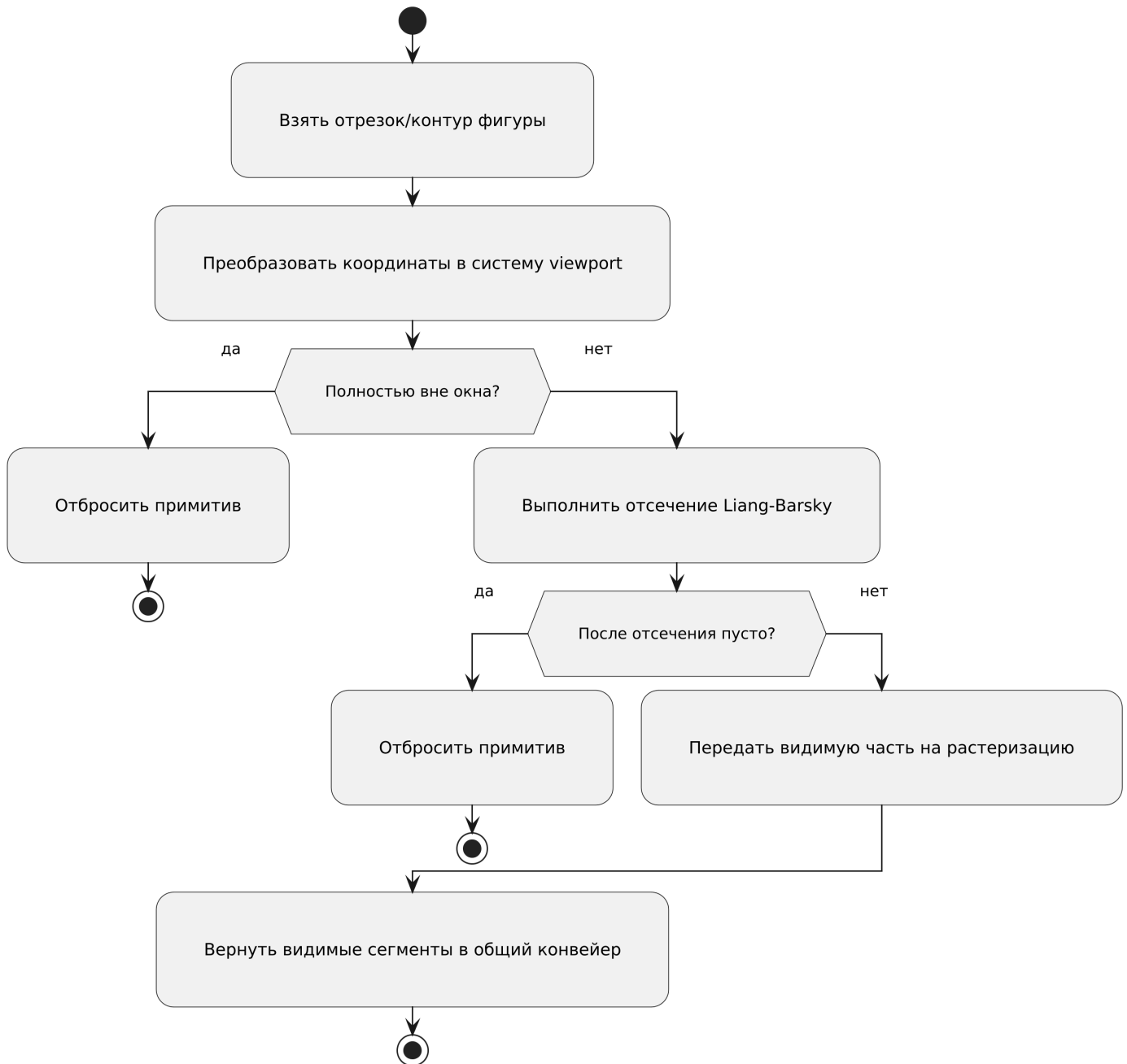


Figure 3: Видимость процедурных фигур и кадрирование

## 6.4 Растеризация и вывод графического содержимого

Report/lab4/uml/rasterization-and-output.puml

## Растеризация и вывод графического содержимого



Figure 4: Растеризация и вывод

### 6.5 Основной рабочий цикл приложения и UI

Report/lab4/uml/application-ui-cycle.puml



#### Рабочий цикл приложения и пользовательского интерфейса

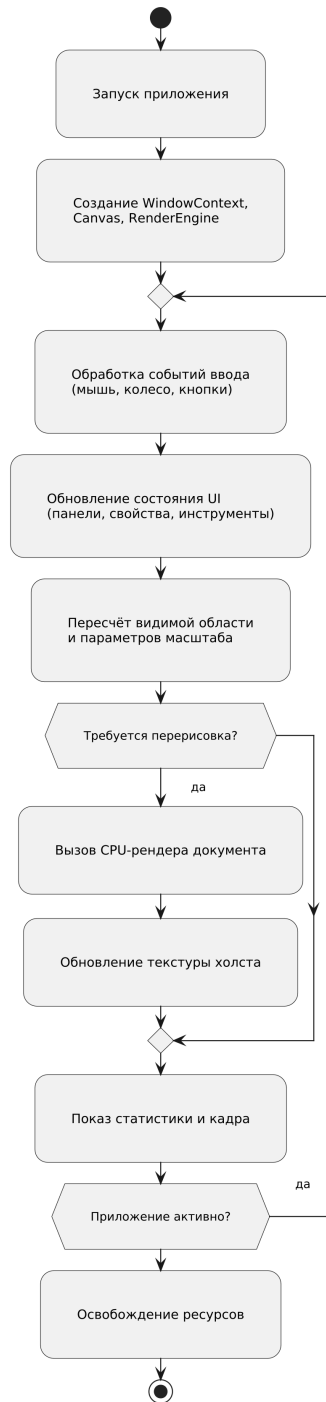


Figure 5: Рабочий цикл приложения и UI

## 7. Вывод

В рамках ЛР4 проект Zivro оформлен как целостное программное решение, которое покрывает основные требования по организации данных, рендеру, кадрированию, композиции и пользовательскому взаимодействию.

Дополнительные задачи представлены в отчёте по принципу максимального покрытия: полностью реализованные пункты выделены явно, а частично реализованные обоснованы через действующие механизмы конвейера рендера и архитектурные заделы проекта.

---

## Приложение А. Исходные тексты

Сформировано автоматически скриптом Report/append\_sources\_to\_report.py (файлов: 39).

### A.1. build.zig

```
const std = @import("std");

pub fn build(b: *std.Build) void {
    const target = b.standardTargetOptions(.{});
    const optimize = b.standardOptimizeOption(.{});

    const dvui_dep = b.dependency("dvui", .{ .target = target, .optimize = optimize, .backend = .sdl3
↵ });

    const exe = b.addExecutable(.{
        .name = "Zivro",
        // .use_llvm = true,
        // .use_lld = true,
        .root_module = b.createModule(.{
            .root_source_file = b.path("src/main.zig"),
            .target = target,
            .optimize = optimize,
            .imports = &.{
                .{ .name = "dvui", .module = dvui_dep.module("dvui_sdl3") },
                .{ .name = "sdl-backend", .module = dvui_dep.module("sdl3") },
            },
        }),
    });
    exe.bundle_compiler_rt = true;
    b.installArtifact(exe);

    const run_step = b.step("run", "Run the app");

    const run_cmd = b.addRunArtifact(exe);
    run_step.dependOn(&run_cmd.step);

    run_cmd.step.dependOn(b.getInstallStep());

    if (b.args) |args| {
        run_cmd.addArgs(args);
    }

    const exe_tests = b.addTest(.{
        .root_module = b.createModule(.{
            .root_source_file = b.path("src/tests.zig"),
            .target = target,
            .optimize = optimize,

            .imports = &.{
                .{ .name = "dvui", .module = dvui_dep.module("dvui_sdl3") },
                .{ .name = "sdl-backend", .module = dvui_dep.module("sdl3") },
            },
        }),
    });

    const run_exe_tests = b.addRunArtifact(exe_tests);

    const test_step = b.step("test", "Run tests");
    test_step.dependOn(&run_exe_tests.step);
}
```

## A.2. build.zig.zon

```
.{
```

```
// This is the default name used by packages depending on this one. For
// example, when a user runs `zig fetch --save <url>`, this field is used
// as the key in the `dependencies` table. Although the user can choose a
// different name, most users will stick with this provided value.
//
// It is redundant to include "zig" in this name because it is already
// within the Zig package namespace.
.name = .Zivro,
// This is a [Semantic Version](https://semver.org/).
// In a future version of Zig it will be used for package deduplication.
.version = "0.0.0",
// Together with name, this represents a globally unique package
// identifier. This field is generated by the Zig toolchain when the
// package is first created, and then *never changes*. This allows
// unambiguous detection of one package being an updated version of
// another.
//
// When forking a Zig project, this id should be regenerated (delete the
// field and run `zig build`) if the upstream project is still maintained.
// Otherwise, the fork is *hostile*, attempting to take control over the
// original project's identity. Thus it is recommended to leave the comment
// on the following line intact, so that it shows up in code reviews that
// modify the field.
.fingerprint = 0x62d7ebal4686811e, // Changing this has security and trust implications.
// Tracks the earliest Zig version that the package considers to be a
// supported use case.
.minimum_zig_version = "0.15.2",
// This field is optional.
// Each dependency must either provide a `url` and `hash`, or a `path`.
// `zig build --fetch` can be used to fetch all dependencies of a package, recursively.
// Once all dependencies are fetched, `zig build` no longer requires
// internet connectivity.
.dependencies = .{
    .dvui = .{
        .url = "git+https://github.com/david-vanderson/dvui#edb2d5a4cd2981fca74ee5f096277b91333c1316",
        .hash = "dvui-0.4.0-dev-AQFJmeGB3QAwun9qF76CDE5IopA4nUVRgD-IwwTs0o4H",
    },

    // See `zig fetch --save <url>` for a command-line interface for adding dependencies.
    .example = .{
        // // When updating this field to a new URL, be sure to delete the corresponding
        // // `hash`, otherwise you are communicating that you expect to find the old hash at
        // // the new URL. If the contents of a URL change this will result in a hash mismatch
        // // which will prevent zig from using it.
        // .url = "https://example.com/foo.tar.gz",
        //
        // // This is computed from the file contents of the directory of files that is
        // // obtained after fetching `url` and applying the inclusion rules given by
        // // `paths`.
        // //
        // // This field is the source of truth; packages do not come from a `url`; they
        // // come from a `hash`. `url` is just one of many possible mirrors for how to
        // // obtain a package matching this `hash`.
        // //
        // // Uses the [multihash](https://multiformats.io/multihash/) format.
        // .hash = "...",
    },
},
```

```

//
// // When this is provided, the package is found in a directory relative to the
// // build root. In this case the package's hash is irrelevant and therefore not
// // computed. This field and `url` are mutually exclusive.
// .path = "foo",
//
// // When this is set to `true`, a package is declared to be lazily
// // fetched. This makes the dependency only get fetched if it is
// // actually used.
// .lazy = false,
// },
},
// Specifies the set of files and directories that are included in this package.
// Only files and directories listed here are included in the `hash` that
// is computed for this package. Only files listed here will remain on disk
// when using the zig package manager. As a rule of thumb, one should list
// files required for compilation plus any license(s).
// Paths are relative to the build root. Use the empty string (``) to refer to
// the build root itself.
// A directory listed here means that all files within, recursively, are included.
.paths = .{
    "build.zig",
    "build.zig.zon",
    "src",
    // For example...
    //"LICENSE",
    //"README.md",
},
}

```

### A.3. src/Canvas.zig

```

const std = @import("std");
const builtin = @import("builtin");
const dvui = @import("dvui");
const Document = @import("models/Document.zig");
const RenderEngine = @import("render/RenderEngine.zig").RenderEngine;
const basic_models = @import("models/basic_models.zig");
const Rect_i = basic_models.Rect_i;
const Size_i = basic_models.Size_i;
const Point2_f = @import("models/basic_models.zig").Point2_f;
const Color = dvui.Color;
const tools = @import("toolbar/tools.zig");
const Toolbar = @import("toolbar/Toolbar.zig");
const random_document = @import("random_document.zig");
const Canvas = @This();

allocator: std.mem.Allocator,
document: *Document,
render_engine: RenderEngine,
toolbar: Toolbar,
texture: ?dvui.Texture = null,
pos: dvui.Point = dvui.Point{ .x = 400, .y = 400 },
scroll: dvui.ScrollInfo = .{
    .vertical = .auto,
    .horizontal = .auto,
},
native_scaling: bool = true,
cursor_document_point: ?Point2_f = null,
draw_document: bool = true,
show_render_stats: bool = true,
/// Rect тулбара (из предыдущего кадра) для исключения кликов по нему из handleCanvasMouse.

```

```

toolbar_rect_scale: ?dvui.RectScale = null,
/// Rect панели свойств (из предыдущего кадра) для исключения кликов по нему из handleCanvasMouse.
properties_rect_scale: ?dvui.RectScale = null,
redraw_throttle_ms: u32 = 50,
frame_index: u64 = 0,

_zoom: f32 = 1,
_rendering_quality: f32 = 100.0,
_last_redraw_time_ms: i64 = 0, /// Метка последней перерисовки чтобы ограничить частоту
_visible_rect: ?Rect_i = null,
_redraw_pending: bool = false,

pub fn init(allocator: std.mem.Allocator, document: *Document, engine: RenderEngine) Canvas {
    return .{
        .allocator = allocator,
        .document = document,
        .render_engine = engine,
        .toolbar = Toolbar.init(&tools.default_tools),
    };
}

pub fn deinit(self: *Canvas) void {
    self.toolbar.deinit();
    if (self.texture) |texture| {
        dvui.Texture.destroyLater(texture);
        self.texture = null;
    }
}

fn redraw(self: *Canvas) !void {
    const full = self.getZoomedImageSize();

    const vis_full: Rect_i = self._visible_rect orelse Rect_i{ .x = 0, .y = 0, .w = 0, .h = 0 };

    if (vis_full.w == 0 or vis_full.h == 0) {
        if (self.texture) |tex| {
            dvui.Texture.destroyLater(tex);
            self.texture = null;
        }
        return;
    }

    /// Качество рендеринга задаётся в процентах площади (1–100),
    /// при этом фактически уменьшаем ширину/высоту холста на корень из этой доли.
    const quality_percent: f32 = self.getRenderingQuality();
    const quality_area: f32 = quality_percent / 100.0;
    const quality_side: f32 = std.math.sqrt(quality_area);
    const scale: f32 = std.math.clamp(quality_side, 0.01, 1.0);

    const canvas_size: Size_i = .{
        .w = @max(@as(u32, 1), @as(u32, @intFromFloat(@as(f32, @floatFromInt(full.w)) * scale))),
        .h = @max(@as(u32, 1), @as(u32, @intFromFloat(@as(f32, @floatFromInt(full.h)) * scale))),
    };

    var vis_scaled = Rect_i{
        .x = @as(u32, @intFromFloat(@as(f32, @floatFromInt(vis_full.x)) * scale)),
        .y = @as(u32, @intFromFloat(@as(f32, @floatFromInt(vis_full.y)) * scale)),
        .w = @max(@as(u32, 1), @as(u32, @intFromFloat(@as(f32, @floatFromInt(vis_full.w)) * scale))),
        .h = @max(@as(u32, 1), @as(u32, @intFromFloat(@as(f32, @floatFromInt(vis_full.h)) * scale))),
    };

    if (vis_scaled.x >= canvas_size.w or vis_scaled.y >= canvas_size.h) {
        if (self.texture) |tex| {
            dvui.Texture.destroyLater(tex);
            self.texture = null;
        }
    }
}

```

```

        return;
    }

    const max_vis_w: u32 = canvas_size.w - vis_scaled.x;
    const max_vis_h: u32 = canvas_size.h - vis_scaled.y;
    if (vis_scaled.w > max_vis_w) vis_scaled.w = max_vis_w;
    if (vis_scaled.h > max_vis_h) vis_scaled.h = max_vis_h;

    const new_texture = if (self.draw_document)
        self.render_engine.render(self.document, canvas_size, vis_scaled) catch null
    else
        self.render_engine.example(canvas_size, vis_scaled) catch null;

    if (new_texture) |tex| {
        if (self.texture) |old_tex| {
            dvui.Texture.destroyLater(old_tex);
        }

        self.texture = tex;
    }
    self._last_redraw_time_ms = std.time.milliTimestamp();
    self.frame_index += 1;
    self.redraw_throttle_ms = @max(1, @as(u32, @intCast(self.render_engine.getStats().render_time_ns /
        ↪ std.time.ns_per_ms / 3)));
}

pub fn exampleReset(self: *Canvas) !void {
    self.render_engine.exampleReset();
    try self.redraw();
}

pub fn addRandomShapes(self: *Canvas) !void {
    try random_document.addRandomShapes(self.document, self allocator, std.crypto.random);
    self.requestRedraw();
}

pub fn setZoom(self: *Canvas, value: f32) void {
    self._zoom = @max(value, 0.01);
}

pub fn addZoom(self: *Canvas, value: f32) void {
    self._zoom += value;
    self._zoom = @max(self._zoom, 0.01);
}

pub fn multZoom(self: *Canvas, value: f32) void {
    self._zoom *= value;
    self._zoom = @max(self._zoom, 0.01);
}

pub fn getZoom(self: Canvas) f32 {
    return self._zoom;
}

pub fn setRenderingQuality(self: *Canvas, value: f32) void {
    self._rendering_quality = std.math.clamp(value, 1.0, 100.0);
    self.requestRedraw();
}

pub fn getRenderingQuality(self: Canvas) f32 {
    return self._rendering_quality;
}

pub fn requestRedraw(self: *Canvas) void {
    self._redraw_pending = true;
}

```

```

pub fn processPendingRedraw(self: *Canvas) !void {
    if (!self._redraw_pending) return;
    if (self.redraw_throttle_ms == 0) {
        self._redraw_pending = false;
        try self.redraw();
        return;
    }
    const now_ms = std.time.milliTimestamp();
    const elapsed: i64 = if (self._last_redraw_time_ms == 0) self.redraw_throttle_ms else now_ms -
        ↪ self._last_redraw_time_ms;
    if (elapsed < @as(i64, @intCast(self.redraw_throttle_ms))) return;
    self._redraw_pending = false;
    try self.redraw();
}

pub fn getZoomedImageSize(self: Canvas) Rect_i {
    const doc = self.document;
    return .{
        .x = @intFromFloat(self.pos.x),
        .y = @intFromFloat(self.pos.y),
        .w = @intFromFloat(doc.size.w * self._zoom),
        .h = @intFromFloat(doc.size.h * self._zoom),
    };
}

/// Точка контента -> координаты документа.
pub fn contentPointToDocument(self: Canvas, content_point: dvui.Point, natural_scale: f32) Point2_f {
    const img = self.getZoomedImageSize();
    const px_x = content_point.x * natural_scale - @as(f32, @floatFromInt(img.x));
    const px_y = content_point.y * natural_scale - @as(f32, @floatFromInt(img.y));
    return .{
        .x = px_x / self._zoom,
        .y = px_y / self._zoom,
    };
}

/// Точка контента внутри холста.
pub fn isContentPointOnDocument(self: Canvas, content_point: dvui.Point, natural_scale: f32) bool {
    const img = self.getZoomedImageSize();
    const left_n = @as(f32, @floatFromInt(img.x)) / natural_scale;
    const top_n = @as(f32, @floatFromInt(img.y)) / natural_scale;
    const right_n = @as(f32, @floatFromInt(img.x + img.w)) / natural_scale;
    const bottom_n = @as(f32, @floatFromInt(img.y + img.h)) / natural_scale;
    return content_point.x >= left_n and content_point.x < right_n and
        content_point.y >= top_n and content_point.y < bottom_n;
}

pub fn updateVisibleImageRect(self: *Canvas, viewport: dvui.Rect, scroll_offset: dvui.Point) bool {
    const next = computeVisibleImageRect(self.*, viewport, scroll_offset);
    var changed = false;
    if (self._visible_rect) |vis| {
        changed |= next.x != vis.x or next.y != vis.y or next.w != vis.w or next.h != vis.h;
    }
    self._visible_rect = next;
    if (changed or self.texture == null) {
        return true;
    }
    return false;
}

fn computeVisibleImageRect(self: Canvas, viewport: dvui.Rect, scroll_offset: dvui.Point) Rect_i {
    const image_rect = self.getZoomedImageSize();

    const img_w: u32 = image_rect.w;
    const img_h: u32 = image_rect.h;

```

```

const vis_w: u32 = @min(@as(u32, @intFromFloat(viewport.w)), img_w);
const vis_h: u32 = @min(@as(u32, @intFromFloat(viewport.h)), img_h);

const raw_x: i64 = @intFromFloat(scroll_offset.x - @as(f32, @floatFromInt(image_rect.x)));
const raw_y: i64 = @intFromFloat(scroll_offset.y - @as(f32, @floatFromInt(image_rect.y)));

const vis_x: u32 = @intCast(std.math.clamp(raw_x, 0, @as(i64, img_w) - @as(i64, vis_w)));
const vis_y: u32 = @intCast(std.math.clamp(raw_y, 0, @as(i64, img_h) - @as(i64, vis_h)));

return Rect_i{
    .x = vis_x,
    .y = vis_y,
    .w = vis_w,
    .h = vis_h,
};
}

```

#### A.4. src/WindowContext.zig

```

const std = @import("std");
const Canvas = @import("Canvas.zig");
const CpuRenderEngine = @import("render/CpuRenderEngine.zig");
const RenderEngine = @import("render/RenderEngine.zig").RenderEngine;
const Document = @import("models/Document.zig");
const random_document = @import("random_document.zig");
const basic_models = @import("models/basic_models.zig");

const WindowContext = @This();

pub const OpenDocument = struct {
    document: Document,
    cpu_render: CpuRenderEngine,
    canvas: Canvas,
    /// Выбранный объект в дереве (id объекта).
    selected_object_id: ?u64 = null,

    pub fn init(allocator: std.mem.Allocator, self: *OpenDocument) void {
        initWithDocument(allocator, self, .init({
            .w = 800,
            .h = 600,
        }));
    }

    pub fn initWithDocument(allocator: std.mem.Allocator, self: *OpenDocument, doc: Document) void {
        self.document = doc;
        self.cpu_render = CpuRenderEngine.init(allocator, .Squares);
        self.canvas = Canvas.init(
            allocator,
            &self.document,
            (&self.cpu_render).renderEngine(),
        );
        self.selected_object_id = null;
    }

    pub fn deinit(self: *OpenDocument, allocator: std.mem.Allocator) void {
        self.document.deinit(allocator);
        self.canvas.deinit();
    }
};

allocator: std.mem.Allocator,
documents: std.ArrayList(*OpenDocument),
active_document_index: ?usize,

```



```

pub fn init(allocator: std.mem.Allocator) !WindowContext {
    const documents = std.ArrayList(*OpenDocument).empty;
    const active_document_index: ?usize = null;
    return .{
        .allocator = allocator,
        .documents = documents,
        .active_document_index = active_document_index,
    };
}

pub fn deinit(self: *WindowContext) void {
    for (self.documents.items) |ptr| {
        ptr.deinit(self.allocator);
        self.allocator.destroy(ptr);
    }
    self.documents.deinit(self.allocator);
}

pub fn activeDocument(self: *WindowContext) ?*OpenDocument {
    const i = self.active_document_index orelse return null;
    if (i >= self.documents.items.len) return null;
    return self.documents.items[i];
}

pub fn addNewDocument(self: *WindowContext) !void {
    const ptr = try self.allocator.create(OpenDocument);
    errdefer self.allocator.destroy(ptr);
    OpenDocument.init(self.allocator, ptr);
    //try random_document.addRandomShapes(&ptr.document, std.crypto.random);
    try self.documents.append(self.allocator, ptr);
    self.active_document_index = self.documents.items.len - 1;
}

pub fn addDocument(self: *WindowContext, doc: Document) !void {
    const ptr = try self.allocator.create(OpenDocument);
    errdefer self.allocator.destroy(ptr);
    var doc_mut = doc;
    errdefer doc_mut.deinit(self.allocator);
    OpenDocument.initWithDocument(self.allocator, ptr, doc_mut);
    try self.documents.append(self.allocator, ptr);
    self.active_document_index = self.documents.items.len - 1;
}

pub fn setActiveDocument(self: *WindowContext, index: usize) void {
    if (index < self.documents.items.len) {
        self.active_document_index = index;
    }
}

pub fn closeDocument(self: *WindowContext, index: usize) void {
    if (index >= self.documents.items.len) return;
    const open_doc = self.documents.items[index];
    open_doc.deinit(self.allocator);
    self.allocator.destroy(open_doc);
    _ = self.documents.orderedRemove(index);

    if (self.active_document_index) |*active| {
        if (index < active.*) {
            active.* -= 1;
        } else if (index == active.*) {
            if (self.documents.items.len > 0) {
                active.* = @min(index, self.documents.items.len - 1);
            } else {
                self.active_document_index = null;
            }
        }
    }
}

```

```

    }
}

```

## A.5. src/icons.zig

```

const dvui = @import("dvui");

pub const line = dvui.entypo.flow_line;
pub const ellipse = dvui.entypo.circle;
pub const broken = dvui.entypo.line_graph;
pub const trash = dvui.entypo.trash;
pub const cross = dvui.entypo.cross;
pub const plus = dvui.entypo.plus;

```

## A.6. src/main.zig

```

const std = @import("std");
const dvui = @import("dvui");
const SDLBackend = @import("sdl-backend");
const WindowContext = @import("WindowContext.zig");
const ui = @import("ui/frame.zig");

pub fn main() !void {
    // std.heap.GeneralPurposeAllocator was renamed to DebugAllocator recently.
    var gpa: std.heap.DebugAllocator(.{}) = .init;
    defer _ = gpa.deinit();

    const allocator = gpa.allocator();

    var backend = try SDLBackend.initWindow(.{
        .allocator = allocator,
        .size = .{ .w = 800.0, .h = 600.0 },
        .title = "My DVUI App",
        .vsync = true,
    });
    defer backend.deinit();

    var win = try dvui.Window.init(@src(), allocator, backend.backend(), .{
        .theme = switch (backend.preferredColorScheme() orelse .light) {
            .light => dvui.Theme.builtin.adwaita_light,
            .dark => dvui.Theme.builtin.adwaita_dark,
        },
    });
    defer win.deinit();

    var ctx = try WindowContext.init(allocator);
    defer ctx.deinit();

    var interrupted = false;
    main_loop: while (true) {
        const nstime = win.beginWait(interrupted);
        try win.begin(nstime);
        try backend.addAllEvents(&win);

        _ = SDLBackend.c.SDL_SetRenderDrawColor(backend.renderer, 0, 0, 0, 255);
        _ = SDLBackend.c.SDL_RenderClear(backend.renderer);

        if (!ui.guiFrame(&ctx)) break :main_loop;

        const end_micros = try win.end(.{});
        try backend.setCursor(win.cursorRequested());
        try backend.textInputRect(win.textInputRequested());
        try backend.renderPresent();

        const wait_event_micros = win.waitTime(end_micros);
    }
}

```

```

        interrupted = try backend.waitEventTimeout(wait_event_micros);
    }
}

```

## A.7. src/models/Document.zig

```

const std = @import("std");
const basic_models = @import("basic_models.zig");
const Size_f = basic_models.Size_f;
const Document = @This();

pub const Object = @import("Object.zig");
const shape = @import("shape/shape.zig");

size: Size_f,
objects: std.ArrayList(Object),
next_object_id: u64,

pub fn init(size: Size_f) Document {
    return .{
        .size = size,
        .objects = std.ArrayList(Object).empty,
        .next_object_id = 1,
    };
}

pub fn deinit(self: *Document, allocator: std.mem.Allocator) void {
    for (self.objects.items) |*obj| obj.deinit(allocator);
    self.objects.deinit(allocator);
}

pub fn clone(self: *const Document, allocator: std.mem.Allocator) !Document {
    var objects_list = std.ArrayList(Object).empty;
    errdefer {
        for (objects_list.items) |*obj| obj.deinit(allocator);
        objects_list.deinit(allocator);
    }
    var next_id = self.next_object_id;
    for (self.objects.items) |obj| {
        try objects_list.append(allocator, try obj.clone(allocator, &next_id));
    }
    return .{
        .size = self.size,
        .objects = objects_list,
        .next_object_id = next_id,
    };
}

pub fn addObject(self: *Document, allocator: std.mem.Allocator, template: Object) !void {
    const obj = try template.clone(allocator, &self.next_object_id);
    try self.objects.append(allocator, obj);
}

/// Добавляет объект в документ: как ребёнка родителя (если id найден), иначе в корень.
pub fn addObjectUnderParentId(self: *Document, allocator: std.mem.Allocator, parent_id: ?u64, template:
↵ Object) !void {
    if (parent_id) |id| {
        if (self.findObjectById(id)) |parent| {
            try parent.addChild(allocator, template, &self.next_object_id);
            return;
        }
    }
    try self.addObject(allocator, template);
}

```

```

pub fn addShape(self: *Document, allocator: std.mem.Allocator, parent: ?*Object, shape_kind:
↪ Object.ShapeKind) !void {
    const obj = try shape.createObject(allocator, shape_kind);
    if (parent) |p| {
        try p.addChild(allocator, obj, &self.next_object_id);
    } else {
        try self.addObject(allocator, obj);
    }
}

/// Удаляет объект из документа (из корня или из детей родителя). Возвращает true, если объект был
↪ найден и удалён.
pub fn removeObject(self: *Document, allocator: std.mem.Allocator, obj: *Object) bool {
    for (self.objects.items, 0..) |*item, i| {
        if (item == obj) {
            var removed = self.objects.orderedRemove(i);
            removed.deinit(allocator);
            return true;
        }
        if (removeFromChildren(allocator, &item.children, obj)) return true;
    }
    return false;
}

/// Удаляет объект по id. Возвращает true, если объект был найден и удалён.
pub fn removeObjectById(self: *Document, allocator: std.mem.Allocator, obj_id: u64) bool {
    for (self.objects.items, 0..) |*item, i| {
        if (item.id == obj_id) {
            var removed = self.objects.orderedRemove(i);
            removed.deinit(allocator);
            return true;
        }
        if (removeFromChildrenById(allocator, &item.children, obj_id)) return true;
    }
    return false;
}

pub fn findObjectById(self: *Document, obj_id: u64) ?*Object {
    for (self.objects.items) |*item| {
        if (item.id == obj_id) return item;
        if (findInChildrenById(&item.children, obj_id)) |found| return found;
    }
    return null;
}

fn removeFromChildren(allocator: std.mem.Allocator, children: *std.ArrayList(Object), obj: *Object)
↪ bool {
    for (children.items, 0..) |*item, i| {
        if (item == obj) {
            var removed = children.orderedRemove(i);
            removed.deinit(allocator);
            return true;
        }
        if (removeFromChildren(allocator, &item.children, obj)) return true;
    }
    return false;
}

fn removeFromChildrenById(allocator: std.mem.Allocator, children: *std.ArrayList(Object), obj_id: u64)
↪ bool {
    for (children.items, 0..) |*item, i| {
        if (item.id == obj_id) {
            var removed = children.orderedRemove(i);
            removed.deinit(allocator);
            return true;
        }
    }
}

```

```

    }
    if (removeFromChildrenById(allocator, &item.children, obj_id)) return true;
}
return false;
}

fn findInChildrenById(children: *std.ArrayList(Object), obj_id: u64) ?*Object {
    for (children.items) |*item| {
        if (item.id == obj_id) return item;
        if (findInChildrenById(&item.children, obj_id)) |found| return found;
    }
    return null;
}

```

## A.8. src/models/Object.zig

```

const std = @import("std");
const Property = @import("Property.zig").Property;
const PropertyData = @import("Property.zig").Data;
const Object = @This();

pub const ShapeKind = enum {
    line,
    ellipse,
    broken,
};

const default_common_data = [_]PropertyData{
    .{ .position = .{ .x = 0, .y = 0 } },
    .{ .angle = 0 },
    .{ .scale = .{ .scale_x = 1, .scale_y = 1 } },
    .{ .visible = true },
    .{ .opacity = 1.0 },
    .{ .locked = false },
    .{ .stroke_rgba = 0x000000FF }, // чёрный, полная непрозрачность
    .{ .thickness = 2.0 },
};

pub const defaultCommonProperties: [default_common_data.len]Property = blk: {
    var result: [default_common_data.len]Property = undefined;
    for (default_common_data, &result) |d, *p| {
        p.* = .{ .data = d };
    }
    break :blk result;
};

id: u64,
shape: ShapeKind,
properties: std.ArrayList(Property),
children: std.ArrayList(Object),

pub fn getProperty(self: Object, comptime tag: std.meta.Tag(PropertyData)) ?@FieldType(PropertyData,
↪ @tagName(tag)) {
    for (self.properties.items) |*prop| {
        if (std.meta.activeTag(prop.data) == tag) return @field(prop.data, @tagName(tag));
    }
    return null;
}

/// Забирает владение Property
pub fn setProperty(self: *Object, allocator: std.mem.Allocator, prop: Property) !void {
    for (self.properties.items, 0..) |*p, i| {
        if (std.meta.activeTag(p.data) == std.meta.activeTag(prop.data)) {
            if (p.data == .points) allocator.free(p.data.points);
            self.properties.items[i] = prop;
        }
    }
}

```

```

        return;
    }
}
return error.PropertyNotFound;
}

pub fn addChild(self: *Object, allocator: std.mem.Allocator, template: Object, next_id: *u64) !void {
    const obj = try template.clone(allocator, next_id);
    try self.children.append(allocator, obj);
}

pub fn clone(self: Object, allocator: std.mem.Allocator, next_id: *u64) !Object {
    var properties_list = std.ArrayList(Property).empty;
    errdefer properties_list.deinit(allocator);
    for (self.properties.items) |prop| {
        try properties_list.append(allocator, try prop.clone(allocator));
    }

    var children_list = std.ArrayList(Object).empty;
    errdefer children_list.deinit(allocator);
    for (self.children.items) |child| {
        try children_list.append(allocator, try child.clone(allocator, next_id));
    }

    return .{
        .id = allocId(next_id),
        .shape = self.shape,
        .properties = properties_list,
        .children = children_list,
    };
}

fn allocId(next_id: *u64) u64 {
    const id = next_id.*;
    next_id.* += 1;
    return id;
}

pub fn deinit(self: *Object, allocator: std.mem.Allocator) void {
    for (self.children.items) |*child| child.deinit(allocator);
    self.children.deinit(allocator);
    for (self.properties.items) |*prop| prop.deinit(allocator);
    self.properties.deinit(allocator);
    self.* = undefined;
}

```

## A.9. src/models/Property.zig

```

const std = @import("std");
const basic_models = @import("basic_models.zig");
const Point2_f = basic_models.Point2_f;
const Scale2_f = basic_models.Scale2_f;
const Size_f = basic_models.Size_f;
const Radii_f = basic_models.Radii_f;

pub const Data = union(enum) {
    position: Point2_f,
    angle: f32,
    scale: Scale2_f,
    visible: bool,
    opacity: f32,
    locked: bool,

    size: Size_f,
    radii: Radii_f,
}

```

```

    /// Процент дуги эллипса: 100 – полный эллипс, 50 – полуэллипс (0..100).
    arc_percent: f32,
    end_point: Point2_f,

    /// Владеет памятью; при deinit/clone – free/duplicate.
    points: []const Point2_f,
    /// Замкнутый контур (для ломаной: отрезок последняя–первая точка + заливка).
    closed: bool,

    /// Включена ли заливка.
    filled: bool,

    /// Цвет заливки, 0xRRGGBBAA.
    fill_rgba: u32,
    /// Цвет обводки, 0xRRGGBBAA.
    stroke_rgba: u32,

    thickness: f32,
};

pub const Property = struct {
    data: Data,

    pub fn deinit(self: *Property, allocator: std.mem.Allocator) void {
        switch (self.data) {
            .points => |slice| allocator.free(slice),
            else => {},
        }
        self.* = undefined;
    }

    pub fn clone(self: Property, allocator: std.mem.Allocator) !Property {
        return switch (self.data) {
            .points => |slice| .{
                .data = .{
                    .points = blk: {
                        const copy = try allocator.dupe(Point2_f, slice);
                        break :blk copy;
                    },
                },
            },
            else => .{ .data = self.data },
        };
    }
};

```

#### A.10. src/models/basic\_models.zig

```

pub const Rect_i = struct {
    x: u32,
    y: u32,
    w: u32,
    h: u32,
};

pub const Size_i = struct {
    w: u32,
    h: u32,
};

pub const Size_f = struct {
    w: f32,
    h: f32,
};

```

```

pub const Point2_f = struct {
    x: f32 = 0,
    y: f32 = 0,
};

pub const Point2_i = struct {
    x: i32 = 0,
    y: i32 = 0,
};

pub const Radii_f = struct {
    x: f32,
    y: f32,
};

pub const Scale2_f = struct {
    scale_x: f32 = 1,
    scale_y: f32 = 1,
};

pub const Rect_f = struct {
    x: f32 = 0,
    y: f32 = 0,
    w: f32 = 0,
    h: f32 = 0,
};

```

#### A.11. src/models/shape/broken.zig

```

const std = @import("std");
const Object = @import("../Object.zig");
const Property = @import("../Property.zig").Property;
const PropertyData = @import("../Property.zig").Data;
const Point2_f = @import("../basic_models.zig").Point2_f;
const Rect_f = @import("../basic_models.zig").Rect_f;
const shape_mod = @import("shape.zig");

/// Свойства фигуры по умолчанию (добавляются к общим). points – слайс на статический массив.
pub const default_shape_properties_points = [_]Point2_f{
    .{ .x = 0, .y = 0 },
    .{ .x = 80, .y = 0 },
    .{ .x = 80, .y = 60 },
};

pub const default_shape_properties = [_]Property{
    .{ .data = .{ .points = &default_shape_properties_points } },
    .{ .data = .{ .closed = false } },
    .{ .data = .{ .filled = true } },
    .{ .data = .{ .fill_rgba = 0x000000FF } },
};

```

#### A.12. src/models/shape/ellipse.zig

```

const std = @import("std");
const Object = @import("../Object.zig");
const Property = @import("../Property.zig").Property;
const Rect_f = @import("../basic_models.zig").Rect_f;
const shape_mod = @import("shape.zig");

/// Свойства фигуры по умолчанию (добавляются к общим).
pub const default_shape_properties = [_]Property{
    .{ .data = .{ .radii = .{ .x = 50, .y = 50 } } },
    .{ .data = .{ .arc_percent = 100.0 } },
    .{ .data = .{ .closed = true } },
    .{ .data = .{ .filled = false } },
    .{ .data = .{ .fill_rgba = 0x000000FF } },
};

```



```
};
```

### A.13. src/models/shape/line.zig

```
const std = @import("std");
const Object = @import("../Object.zig");
const Property = @import("../Property.zig").Property;
const Rect_f = @import("../basic_models.zig").Rect_f;
const shape_mod = @import("shape.zig");

/// Свойства фигуры по умолчанию (добавляются к общим).
pub const default_shape_properties = [_]Property{
    .{ .data = .{ .end_point = .{ .x = 100, .y = 200 } } },
};
```

### A.14. src/models/shape/shape.zig

```
const std = @import("std");
const Object = @import("../Object.zig");
const Property = @import("../Property.zig").Property;
const PropertyData = @import("../Property.zig").Data;
const defaultCommonProperties = Object.defaultCommonProperties;
const basic_models = @import("../basic_models.zig");
const Point2_f = basic_models.Point2_f;
const line = @import("line.zig");
const ellipse = @import("ellipse.zig");
const broken = @import("broken.zig");
pub const Rect = basic_models.Rect_f;

/// Добавляет к объекту список свойств фигуры. Для .points дублирует слайс (объект владеет).
fn appendShapeProperties(allocator: std.mem.Allocator, obj: *Object, props: []const Property) !void {
    for (props) |prop| {
        if (prop.data == .points) {
            const pts = prop.data.points;
            const copy = try allocator.dupe(Point2_f, pts);
            try obj.properties.append(allocator, .{ .data = .{ .points = copy } });
        } else {
            try obj.properties.append(allocator, prop);
        }
    }
}

/// Создаёт объект с дефолтными общими и фигурными свойствами.
pub fn createObject(allocator: std.mem.Allocator, shape_kind: Object.ShapeKind) !Object {
    var obj = try createWithCommonProperties(allocator, shape_kind);
    errdefer obj.deinit(allocator);
    switch (shape_kind) {
        .line => try appendShapeProperties(allocator, &obj, &line.default_shape_properties),
        .ellipse => try appendShapeProperties(allocator, &obj, &ellipse.default_shape_properties),
        .broken => {
            try appendShapeProperties(allocator, &obj, &broken.default_shape_properties);
            try obj.setProperty(allocator, .{ .data = .{ .fill_rgba = obj.getProperty(.stroke_rgba)?.? } }
                ↪ );
        },
    }
    return obj;
}

fn createWithCommonProperties(allocator: std.mem.Allocator, shape_kind: Object.ShapeKind) !Object {
    var properties_list = std.ArrayList(Property).empty;
    errdefer properties_list.deinit(allocator);
    for (defaultCommonProperties) |prop| try properties_list.append(allocator, prop);
    return .{
        .id = 0,
        .shape = shape_kind,
    }
}
```

```

        .properties = properties_list,
        .children = std.ArrayList(Object).empty,
    };
}

```

### A.15. src/persistence/json\_io.zig

```

const std = @import("std");
const Document = @import("../models/Document.zig");

/// Сохраняет значение произвольного типа T в JSON-файл.
pub fn saveToFile(comptime T: type, value: *const T, path: []const u8) !void {
    var file = try std.fs.cwd().createFile(path, .{ .truncate = true });
    defer file.close();

    var buffer: [4096]u8 = undefined;
    var writer = file.writer(&buffer);

    try std.json.Stringify.value(value, .{ .whitespace = .indent_2 }, &writer.interface);

    try writer.interface.flush();
}

/// Загружает значение типа T из JSON-файла.
/// Для Document после разбора делается клон через allocator, т.к. парсер выделяет память
/// из арены — при закрытии документа её нельзя освобождать нашим аллокатором.
pub fn loadFromFile(comptime T: type, allocator: std.mem.Allocator, path: []const u8) !T {
    var file = try std.fs.cwd().openFile(path, .{});
    defer file.close();

    const data = try file.readToEndAlloc(allocator, std.math.maxInt(usize));
    defer allocator.free(data);

    var parsed = try std.json.parseFromSlice(T, allocator, data, .{ .ignore_unknown_fields = true });
    if (T == Document) {
        defer parsed.deinit();
        return try parsed.value.clone(allocator);
    }
    return parsed.value;
}

```

### A.16. src/random\_document.zig

```

const std = @import("std");
const Document = @import("models/Document.zig");
const Object = Document.Object;
const shape = @import("models/shape/shape.zig");
const basic_models = @import("models/basic_models.zig");
const Size_f = basic_models.Size_f;
const Point2_f = basic_models.Point2_f;
const Scale2_f = basic_models.Scale2_f;
const Radii_f = basic_models.Radii_f;

fn randFloat(rng: std.Random, min: f32, max: f32) f32 {
    return min + (max - min) * rng.float(f32);
}

fn randRgba(rng: std.Random) u32 {
    const r = rng.int(u8);
    const g = rng.int(u8);
    const b = rng.int(u8);
    const a: u8 = @intCast(rng.intRangeLessThan(usize, 128, 256));
    return (@as(u32, r) << 24) | (@as(u32, g) << 16) | (@as(u32, b) << 8) | a;
}

```

```

fn randomShapeKind(rng: std.Random) Object.ShapeKind {
    const shapes_implemented = [_]Object.ShapeKind{ .line, .ellipse, .broken };
    return shapes_implemented[rng.intRangeLessThan(usize, 0, shapes_implemented.len)];
}

fn randomizeObjectProperties(allocator: std.mem.Allocator, doc_size: *const Size_f, obj: *Object, rng:
↳ std.Random) !void {
    const margin: f32 = 8;
    const max_x = @max(0, doc_size.w - margin);
    const max_y = @max(0, doc_size.h - margin);

    try obj.setProperty(allocator, .{ .data = .{
        .position = .{
            .x = randFloat(rng, margin, if (max_x > margin) max_x else margin),
            .y = randFloat(rng, margin, if (max_y > margin) max_y else margin),
        },
    } });
    try obj.setProperty(allocator, .{ .data = .{ .angle = randFloat(rng, 0, 2 * std.math.pi) } });
    try obj.setProperty(allocator, .{ .data = .{
        .scale = .{
            .scale_x = randFloat(rng, 0.25, 2.0),
            .scale_y = randFloat(rng, 0.25, 2.0),
        },
    } });
    try obj.setProperty(allocator, .{ .data = .{ .visible = true } });
    try obj.setProperty(allocator, .{ .data = .{ .opacity = randFloat(rng, 0.3, 1.0) } });
    try obj.setProperty(allocator, .{ .data = .{ .locked = rng.boolean() } });

    const stroke = randRgba(rng);
    try obj.setProperty(allocator, .{ .data = .{ .stroke_rgba = stroke } });
    obj.setProperty(allocator, .{ .data = .{ .fill_rgba = randRgba(rng) } }) catch {};
    const thickness = randFloat(rng, max_x * 0.001, max_x * 0.01);
    try obj.setProperty(allocator, .{ .data = .{ .thickness = thickness } });

    switch (obj.shape) {
        .line => {
            const len = randFloat(rng, 20, @min(doc_size.w, doc_size.h) * 0.5);
            const angle = randFloat(rng, 0, 2 * std.math.pi);
            try obj.setProperty(allocator, .{ .data = .{
                .end_point = .{
                    .x = std.math.cos(angle) * len,
                    .y = std.math.sin(angle) * len,
                },
            } });
        },
        .ellipse => {
            const max_r = @min(120, @min(doc_size.w / 4, doc_size.h / 4));
            try obj.setProperty(allocator, .{ .data = .{
                .radii = .{
                    .x = randFloat(rng, 8, @max(8, max_r)),
                    .y = randFloat(rng, 8, @max(8, max_r)),
                },
            } });
        },
        .broken => {
            var list = std.ArrayList(Point2_f).empty;
            defer list.deinit(allocator);
            const n = rng.intRangeLessThan(usize, 2, 9);
            var x: f32 = 0;
            var y: f32 = 0;
            for (0..n) |_| {
                try list.append(allocator, .{ .x = x, .y = y });
                x += randFloat(rng, -40, 80);
                y += randFloat(rng, -30, 60);
            }
            const slice = try allocator.dupe(Point2_f, list.items);

```

```

        errdefer allocator.free(slice);
        try obj.setProperty(allocator, .{ .data = .{ .points = slice } });
    },
}
}

/// Создаёт в документе случайные фигуры (line, ellipse, broken).
pub fn addRandomShapes(doc: *Document, allocator: std.mem.Allocator, rng: std.Random) !void {
    const max_total: usize = 80;
    var total_count: usize = 0;

    const n_root = rng.intRangeLessThan(usize, 6, 15);
    for (0..n_root) |_| {
        if (total_count >= max_total) break;
        var obj = try shape.createObject(allocator, randomShapeKind(rng));
        defer obj.deinit(allocator);
        try randomizeObjectProperties(allocator, &doc.size, &obj, rng);
        try doc.addObject(allocator, obj);
        total_count += 1;
    }

    var stack = std.ArrayList(*Object).empty;
    defer stack.deinit(allocator);
    for (doc.objects.items) |*obj| {
        try stack.append(allocator, obj);
    }
    while (stack.pop()) |obj| {
        if (total_count >= max_total) continue;
        const n_children = rng.intRangeLessThan(usize, 0, 2);
        const base_len = obj.children.items.len;
        for (0..n_children) |_| {
            if (total_count >= max_total) break;
            var child = try shape.createObject(allocator, randomShapeKind(rng));
            defer child.deinit(allocator);
            try randomizeObjectProperties(allocator, &doc.size, &child, rng);
            try obj.addChild(allocator, child, &doc.next_object_id);
            total_count += 1;
        }
        for (obj.children.items[base_len..]) |*child| {
            try stack.append(allocator, child);
        }
    }
}
}

```

#### A.17. src/render/CpuRenderEngine.zig

```

const std = @import("std");
const builtin = @import("builtin");
const dvui = @import("dvui");
const RenderEngine = @import("RenderEngine.zig").RenderEngine;
const Document = @import("../models/Document.zig");
const basic_models = @import("../models/basic_models.zig");
const cpu_draw = @import("cpu/draw.zig");
const RenderStats = @import("RenderStats.zig");
const Size_i = basic_models.Size_i;
const Rect_i = basic_models.Rect_i;
const Allocator = std.mem.Allocator;
const Color = dvui.Color;

const CpuRenderEngine = @This();
const Type = enum {
    Gradient,
    Squares,
};

```

```

type: Type,
gradient_start: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 255 },
gradient_end: Color.PMA = .{ .r = 255, .g = 255, .b = 255, .a = 255 },
_allocator: Allocator,
_renderStats: RenderStats,

pub fn init(allocator: Allocator, render_type: Type) CpuRenderEngine {
    return .{
        _allocator = allocator,
        .type = render_type,
        _renderStats = .{
            .render_time_ns = 0,
        },
    };
}

pub fn exampleReset(self: *CpuRenderEngine) void {
    var prng = std.Random.DefaultPrng.init(@intCast(std.time.microTimestamp()));
    const random = prng.random();
    self.gradient_start = Color.PMA{ .r = random.int(u8), .g = random.int(u8), .b = random.int(u8), .a
        ↪ = 255 };
    self.gradient_end = Color.PMA{ .r = random.int(u8), .g = random.int(u8), .b = random.int(u8), .a =
        ↪ 255 };
}

fn renderGradient(self: CpuRenderEngine, pixels: []Color.PMA, width: u32, height: u32, full_w: u32,
    ↪ full_h: u32, visible_rect: Rect_i) void {
    var y: u32 = 0;
    while (y < height) : (y += 1) {
        var x: u32 = 0;
        while (x < width) : (x += 1) {
            const gx: u32 = visible_rect.x + x;
            const gy: u32 = visible_rect.y + y;

            const denom_x: f32 = if (full_w > 1) @as(f32, @floatFromInt(full_w - 1)) else 1;
            const denom_y: f32 = if (full_h > 1) @as(f32, @floatFromInt(full_h - 1)) else 1;
            const fx: f32 = @as(f32, @floatFromInt(gx)) / denom_x;
            const fy: f32 = @as(f32, @floatFromInt(gy)) / denom_y;
            const factor: f32 = std.math.clamp((fx + fy) / 2, 0, 1);

            const r_f: f32 = @as(f32, @floatFromInt(self.gradient_start.r)) + factor * (@as(f32,
                ↪ @floatFromInt(self.gradient_end.r)) - @as(f32, @floatFromInt(self.gradient_start.r)));
            const g_f: f32 = @as(f32, @floatFromInt(self.gradient_start.g)) + factor * (@as(f32,
                ↪ @floatFromInt(self.gradient_end.g)) - @as(f32, @floatFromInt(self.gradient_start.g)));
            const b_f: f32 = @as(f32, @floatFromInt(self.gradient_start.b)) + factor * (@as(f32,
                ↪ @floatFromInt(self.gradient_end.b)) - @as(f32, @floatFromInt(self.gradient_start.b)));

            const r: u8 = @intFromFloat(std.math.clamp(r_f, 0, 255));
            const g: u8 = @intFromFloat(std.math.clamp(g_f, 0, 255));
            const b: u8 = @intFromFloat(std.math.clamp(b_f, 0, 255));
            pixels[y * width + x] = .{ .r = r, .g = g, .b = b, .a = 255 };
        }
    }
}

fn renderSquares(pixels: []Color.PMA, canvas_size: Size_i, visible_rect: Rect_i) void {
    const colors = [_]Color.PMA{
        .{ .r = 255, .g = 0, .b = 0, .a = 255 },
        .{ .r = 255, .g = 165, .b = 0, .a = 255 },
        .{ .r = 255, .g = 255, .b = 0, .a = 255 },
        .{ .r = 0, .g = 255, .b = 0, .a = 255 },
        .{ .r = 0, .g = 255, .b = 255, .a = 255 },
        .{ .r = 0, .g = 0, .b = 255, .a = 255 },
    };
};

```

```

const squares_num = 5;
var thickness: u32 = @intFromFloat(@as(f32, @floatFromInt(canvas_size.w + canvas_size.h)) / 2 *
↪ 0.03);
if (thickness == 0) thickness = 1;

const squares_sum_w = canvas_size.w - thickness * (squares_num + 1);
const base_w = squares_sum_w / squares_num;
const extra_w = squares_sum_w % squares_num;
const squares_sum_h = canvas_size.h - thickness * (squares_num + 1);
const base_h = squares_sum_h / squares_num;
const extra_h = squares_sum_h % squares_num;

var x_pos: [6]u32 = undefined;
x_pos[0] = 0;
for (1..squares_num + 1) |i| {
    const w = base_w + if (i - 1 < extra_w) @as(u32, 1) else 0;
    x_pos[i] = x_pos[i - 1] + thickness + w;
}

var y_pos: [6]u32 = undefined;
y_pos[0] = 0;
for (1..squares_num + 1) |i| {
    const h = base_h + if (i - 1 < extra_h) @as(u32, 1) else 0;
    y_pos[i] = y_pos[i - 1] + thickness + h;
}

var y: u32 = 0;
while (y < visible_rect.h) : (y += 1) {
    const canvas_y = y + visible_rect.y;
    if (canvas_y >= canvas_size.h) continue;
    var x: u32 = 0;
    while (x < visible_rect.w) : (x += 1) {
        const canvas_x = x + visible_rect.x;
        if (canvas_x >= canvas_size.w) continue;

        var vertical_index: ?u32 = null;
        for (0..x_pos.len) |i| {
            if (canvas_x >= x_pos[i] and canvas_x < x_pos[i] + thickness) {
                vertical_index = @intCast(i);
                break;
            }
        }

        var horizontal_index: ?u32 = null;
        for (0..y_pos.len) |i| {
            if (canvas_y >= y_pos[i] and canvas_y < y_pos[i] + thickness) {
                horizontal_index = @intCast(i);
                break;
            }
        }

        if (vertical_index) |idx| {
            pixels[y * visible_rect.w + x] = colors[idx];
        } else if (horizontal_index) |idx| {
            pixels[y * visible_rect.w + x] = colors[idx];
        } else {
            var square_x: u32 = 0;
            for (0..squares_num) |i| {
                if (canvas_x >= x_pos[i] + thickness and canvas_x < x_pos[i + 1]) {
                    square_x = @intCast(i);
                    break;
                }
            }

            var square_y: u32 = 0;
            for (0..squares_num) |i| {
                if (canvas_y >= y_pos[i] + thickness and canvas_y < y_pos[i + 1]) {

```

```

        square_y = @intCast(i);
        break;
    }
}
if (square_x % 2 == square_y % 2) {
    pixels[y * visible_rect.w + x] = .{ .r = 255, .g = 255, .b = 255, .a = 255 };
} else {
    pixels[y * visible_rect.w + x] = .{ .r = 0, .g = 0, .b = 0, .a = 255 };
}
}
}
}

pub fn example(self: CpuRenderEngine, canvas_size: Size_i, visible_rect: Rect_i) !?dvui.Texture {
    const full_w = canvas_size.w;
    const full_h = canvas_size.h;

    const width = visible_rect.w;
    const height = visible_rect.h;

    const pixels = try self._allocator.alloc(Color.PMA, @as(usize, width) * height);
    defer self._allocator.free(pixels);

    switch (self.type) {
        .Gradient => self.renderGradient(pixels, width, height, full_w, full_h, visible_rect),
        .Squares => renderSquares(pixels, canvas_size, visible_rect),
    }

    return try dvui.textureCreate(pixels, width, height, .nearest, .abgr_8_8_8_8);
}

pub fn renderEngine(self: *CpuRenderEngine) RenderEngine {
    return .{ .cpu = self };
}

/// Растеризует документ в текстуру (фон + фигуры через конвейер).
pub fn renderDocument(self: *CpuRenderEngine, document: *const Document, canvas_size: Size_i,
    ↪ visible_rect: Rect_i) !?dvui.Texture {
    const width = visible_rect.w;
    const height = visible_rect.h;
    const pixels = try self._allocator.alloc(Color.PMA, @as(usize, width) * height);
    defer self._allocator.free(pixels);

    for (pixels) |*p| p.* = .{ .r = 255, .g = 255, .b = 255, .a = 255 };
    var t = try std.time.Timer.start();
    try cpu_draw.drawDocument(pixels, width, height, visible_rect, document, canvas_size,
    ↪ self._allocator);
    self._renderStats.render_time_ns = t.read();

    return try dvui.textureCreate(pixels, width, height, .nearest, .abgr_8_8_8_8);
}

pub fn getStats(self: CpuRenderEngine) RenderStats {
    return self._renderStats;
}

```

#### A.18. src/render/RenderEngine.zig

```

const dvui = @import("dvui");
const CpuRenderEngine = @import("CpuRenderEngine.zig");
const Document = @import("../models/Document.zig");
const basic_models = @import("../models/basic_models.zig");
const RenderStats = @import("RenderStats.zig");

```

```

pub const RenderEngine = union(enum) {
    cpu: *CpuRenderEngine,

    pub fn exampleReset(self: RenderEngine) void {
        switch (self) {
            .cpu => |cpu_r| cpu_r.exampleReset(),
        }
    }

    pub fn example(self: RenderEngine, canvas_size: basic_models.Size_i, visible_rect:
        ↪ basic_models.Rect_i) !?dvui.Texture {
        return switch (self) {
            .cpu => |cpu_r| cpu_r.example(canvas_size, visible_rect),
        };
    }

    pub fn getStats(self: RenderEngine) RenderStats {
        return switch (self) {
            .cpu => |cpu_r| cpu_r.getStats(),
        };
    }
}

/// Растеризует документ в текстуру.
pub fn render(self: RenderEngine, document: *const Document, canvas_size: basic_models.Size_i,
    ↪ visible_rect: basic_models.Rect_i) !?dvui.Texture {
    return switch (self) {
        .cpu => |cpu_r| cpu_r.renderDocument(document, canvas_size, visible_rect),
    };
}
};

```

#### A.19. src/render/RenderStats.zig

```

const RenderStats = @This();

render_time_ns: u64, // Время рендера кадра в наносекундах

```

#### A.20. src/render/cpu/broken.zig

```

const std = @import("std");
const Document = @import("../models/Document.zig");
const pipeline = @import("pipeline.zig");
const line = @import("line.zig");
const DrawContext = pipeline.DrawContext;
const Color = @import("dvui").Color;

const Object = Document.Object;
const default_stroke: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 255 };
const default_fill: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 0 };
const default_thickness: f32 = 2.0;

/// Ломаная по точкам, обводка stroke_rgba. При closed – отрезок последняя–первая точка и заливка
↪ fill_rgba.
pub fn draw(
    ctx: *DrawContext,
    obj: *const Object,
    allocator: std.mem.Allocator,
) !void {
    const pts = obj.getProperty(.points) orelse return;
    if (pts.len < 2) return;
    const stroke = if (obj.getProperty(.stroke_rgba)) |stroke_rgba| pipeline.rgbToPma(stroke_rgba)
        ↪ else default_stroke;
    const thickness = obj.getProperty(.thickness) orelse default_thickness;
    const closed = obj.getProperty(.closed) orelse false;
    const filled = obj.getProperty(.filled) orelse true;
}

```



```

const fill_color = if (obj.getProperty(.fill_rgba)) |fill_rgba| pipeline.rgbToPma(fill_rgba) else
↳ default_fill;

const buffer = try allocator.alloc(Color.PMA, ctx.buf_width * ctx.buf_height);
@memset(buffer, .{ .r = 0, .g = 0, .b = 0, .a = 0 });
defer allocator.free(buffer);

var copy_ctx = ctx.*;
copy_ctx.pixels = buffer;
copy_ctx.replace_mode = true;

const do_fill = closed and filled;

if (do_fill) {
    copy_ctx.startFill(allocator) catch return;
}

var i: usize = 0;
while (i + 1 < pts.len) : (i += 1) {
    line.drawLine(&copy_ctx, pts[i].x, pts[i].y, pts[i + 1].x, pts[i + 1].y, stroke, thickness,
↳ true);
}
if (closed and pts.len >= 2) {
    const last = pts.len - 1;
    line.drawLine(&copy_ctx, pts[last].x, pts[last].y, pts[0].x, pts[0].y, stroke, thickness, true);
}

if (do_fill) {
    copy_ctx.stopFill(allocator, fill_color);
}

ctx.compositeDrawerContext(&copy_ctx, copy_ctx.transform.opacity);
}

```

### A.21. src/render/cpu/draw.zig

```

const std = @import("std");
const Document = @import("../models/Document.zig");
const pipeline = @import("pipeline.zig");
const line = @import("line.zig");
const ellipse = @import("ellipse.zig");
const broken = @import("broken.zig");
const basic_models = @import("../models/basic_models.zig");
const Rect_i = basic_models.Rect_i;
const Size_i = basic_models.Size_i;

const Object = Document.Object;
const DrawContext = pipeline.DrawContext;
const Transform = pipeline.Transform;

fn isVisible(obj: *const Object) bool {
    return obj.getProperty(.visible) orelse true;
}

fn drawObject(
    ctx: *DrawContext,
    obj: *const Object,
    parent_transform: Transform,
    allocator: std.mem.Allocator,
) !void {
    if (!isVisible(obj)) return;
    const local = Transform.init(obj);
    const world = Transform.compose(parent_transform, local);
    ctx.setTransform(world);
}

```

```

switch (obj.shape) {
    .line => line.draw(ctx, obj),
    .ellipse => try ellipse.draw(ctx, obj, allocator),
    .broken => try broken.draw(ctx, obj, allocator),
}

for (obj.children.items) |*child| {
    try drawObject(ctx, child, world, allocator);
}
}

/// Рекурсивно рисует документ в буфер (объекты и потомки по порядку).
/// allocator опционален; если передан, ломанные рисуются через слой (без двойного наложения при alpha <
    ↪ 1).
pub fn drawDocument(
    pixels: []@import("dvui").Color.PMA,
    buf_width: u32,
    buf_height: u32,
    visible_rect: Rect_i,
    document: *const Document,
    canvas_size: Size_i,
    allocator: std.mem.Allocator,
) !void {
    const scale_x: f32 = if (document.size.w > 0) @as(f32, @floatFromInt(canvas_size.w)) /
        ↪ document.size.w else 0;
    const scale_y: f32 = if (document.size.h > 0) @as(f32, @floatFromInt(canvas_size.h)) /
        ↪ document.size.h else 0;

    var ctx = DrawContext{
        .pixels = pixels,
        .buf_width = buf_width,
        .buf_height = buf_height,
        .visible_rect = visible_rect,
        .scale_x = scale_x,
        .scale_y = scale_y,
    };
    const identity = Transform{};
    for (document.objects.items) |*obj| {
        try drawObject(&ctx, obj, identity, allocator);
    }
}

```

## A.22. src/render/cpu/ellipse.zig

```

const std = @import("std");
const std_math = std.math;
const Document = @import("../models/Document.zig");
const pipeline = @import("pipeline.zig");
const line = @import("line.zig");
const DrawContext = pipeline.DrawContext;
const Color = @import("dvui").Color;
const basic_models = @import("../models/basic_models.zig");
const Point2_f = basic_models.Point2_f;

const Object = Document.Object;
const default_stroke: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 255 };
const default_fill: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 0 };
const default_thickness: f32 = 2.0;

/// Эллипс с центром (0,0) и полуосями radii. Обводка – полоса расстояния до контура (чёткая линия, не
    ↪ круги).
/// arc_percent: 100 – полный эллипс, иначе одна дуга; обход в коде от (0,gy) по квадрантам (визуально
    ↪ может казаться от низа против часовой из-за экранной Y).
/// Отрисовка в отдельный буфер и один composite, чтобы при alpha<255 пиксели не накладывались
    ↪ несколько раз.

```

```

pub fn draw(ctx: *DrawContext, obj: *const Object, allocator: std.mem.Allocator) !void {
    const radii = obj.getProperty(.radii) orelse return;
    const rx = radii.x;
    const ry = radii.y;
    if (rx <= 0 or ry <= 0) return;

    const stroke = if (obj.getProperty(.stroke_rgba)) |stroke_rgba| pipeline.rgbToPma(stroke_rgba)
        ↪ else default_stroke;
    const thickness = if (obj.getProperty(.thickness)) |thickness| thickness else default_thickness;
    const arc_percent = std.math.clamp(if (obj.getProperty(.arc_percent)) |arc_percent| arc_percent
        ↪ else 100.0, 0.0, 100.0);
    const closed = obj.getProperty(.closed) orelse true;
    const filled = obj.getProperty(.filled) orelse false;
    const fill_color = if (obj.getProperty(.fill_rgba)) |fill_rgba| pipeline.rgbToPma(fill_rgba) else
        ↪ default_fill;
    const do_fill = filled and (closed or arc_percent >= 100.0);

    const t = &ctx.transform;
    const min_r = @min(rx, ry);
    const half_norm = thickness / (2.0 * min_r);
    const inner = @max(0.0, 1.0 - half_norm);
    const outer = 1.0 + half_norm;
    const d_inner_sq = inner * inner;
    const d_outer_sq = outer * outer;

    const margin = 1.0 + half_norm;
    const corners = [_]Point2_f{
        .{ .x = -rx * margin, .y = -ry * margin },
        .{ .x = rx * margin, .y = -ry * margin },
        .{ .x = rx * margin, .y = ry * margin },
        .{ .x = -rx * margin, .y = ry * margin },
    };
    var min_bx: f32 = std.math.inf(f32);
    var min_by: f32 = std.math.inf(f32);
    var max_bx: f32 = -std.math.inf(f32);
    var max_by: f32 = -std.math.inf(f32);
    for (corners) |c| {
        const w = ctx.localToWorld(c.x, c.y);
        const b = ctx.worldToBufferF(w.x, w.y);
        min_bx = @min(min_bx, b.x);
        min_by = @min(min_by, b.y);
        max_bx = @max(max_bx, b.x);
        max_by = @max(max_by, b.y);
    }
    const buf_w: i32 = @intCast(ctx.buf_width);
    const buf_h: i32 = @intCast(ctx.buf_height);
    const x0: i32 = @max(0, @as(i32, @intFromFloat(std.math.floor(min_bx))));
    const y0: i32 = @max(0, @as(i32, @intFromFloat(std.math.floor(min_by))));
    const x1: i32 = @min(buf_w, @as(i32, @intFromFloat(std.math.ceil(max_bx))) + 1);
    const y1: i32 = @min(buf_h, @as(i32, @intFromFloat(std.math.ceil(max_by))) + 1);

    const buffer = try allocator.alloc(Color.PMA, ctx.buf_width * ctx.buf_height);
    @memset(buffer, .{ .r = 0, .g = 0, .b = 0, .a = 0 });
    defer allocator.free(buffer);

    var stroke_ctx = ctx.*;
    stroke_ctx.pixels = buffer;
    stroke_ctx.replace_mode = true;

    if (do_fill) {
        stroke_ctx.startFill(allocator) catch return;
    }

    const inv_rx = 1.0 / rx;
    const inv_ry = 1.0 / ry;
    const arc_len = 2.0 * std.math.pi * arc_percent / 100.0;

```

```

var by: i32 = y0;
while (by < y1) : (by += 1) {
    const buf_y = @as(f32, @floatFromInt(by)) + 0.5;
    var bx: i32 = x0;
    while (bx < x1) : (bx += 1) {
        const buf_x = @as(f32, @floatFromInt(bx)) + 0.5;
        const w = stroke_ctx.bufferToWorld(buf_x, buf_y);
        const loc = stroke_ctx.worldToLocal(w.x, w.y);
        const nx = loc.x * inv_rx;
        const ny = loc.y * inv_ry;
        const d = nx * nx + ny * ny;
        if (d < d_inner_sq or d > d_outer_sq) continue;
        if (arc_percent < 100.0) {
            var diff = std_math.pi / 2.0 - std_math.atan2(ny, nx);
            if (diff < 0) diff += 2.0 * std_math.pi;
            if (diff > arc_len) continue;
        }
        stroke_ctx.blendPixelAtBuffer(bx, by, stroke);
    }
}

if (closed and arc_percent < 100.0) {
    const end_x = rx * std_math.sin(arc_len);
    const end_y = ry * std_math.cos(arc_len);
    line.drawLine(&stroke_ctx, 0, 0, 0, ry, stroke, thickness, false);
    line.drawLine(&stroke_ctx, 0, 0, end_x, end_y, stroke, thickness, false);
}

if (do_fill) {
    stroke_ctx.stopFill(allocator, fill_color);
}

ctx.compositeDrawerContext(&stroke_ctx, t.opacity);
}

```

### A.23. src/render/cpu/line.zig

```

const std = @import("std");
const Document = @import("../models/Document.zig");
const pipeline = @import("pipeline.zig");
const DrawContext = pipeline.DrawContext;
const Color = @import("dvui").Color;
const base_models = @import("../models/basic_models.zig");
const Point2_i = base_models.Point2_i;

const Object = Document.Object;
const default_stroke: Color.PMA = .{ .r = 0, .g = 0, .b = 0, .a = 255 };
const default_thickness: f32 = 2.0;

/// Линия от (0,0) до end_point.
pub fn draw(ctx: *DrawContext, obj: *const Object) void {
    const end_point = obj.getProperty(.end_point) orelse return;
    const end_x = end_point.x;
    const end_y = end_point.y;
    const stroke = if (obj.getProperty(.stroke_rgba)) |stroke_rgba| pipeline.rgbToPma(stroke_rgba)
        ↪ else default_stroke;
    const thickness = obj.getProperty(.thickness) orelse default_thickness;
    drawLine(ctx, 0, 0, end_x, end_y, stroke, thickness, false);
}

/// Рисует отрезок по локальным концам (перевод в буфер внутри).
/// draw_when_outside: если true, участки линии за экраном тоже рисуются (толщиной 1 px); в буфере —
    ↪ обычная толщина.

```

```

pub fn drawLine(ctx: *DrawContext, x0: f32, y0: f32, x1: f32, y1: f32, color: Color.PMA, thickness:
↪ f32, draw_when_outside: bool) void {
    const w0 = ctx.localToWorld(x0, y0);
    const w1 = ctx.localToWorld(x1, y1);
    const b0 = ctx.worldToBuffer(w0.x, w0.y);
    const b1 = ctx.worldToBuffer(w1.x, w1.y);
    const t = &ctx.transform;
    const scale = @sqrt(t.scale.scale_x * ctx.scale_x * t.scale.scale_y * ctx.scale_y);
    const thickness_px: u32 = @as(u32, @intFromFloat(std.math.round(thickness * scale)));
    if (thickness_px > 0)
        drawLineInBuffer(ctx, b0.x, b0.y, b1.x, b1.y, color, thickness_px, draw_when_outside);
}

```

```

inline fn clip(p: f32, q: f32, t0: *f32, t1: *f32) bool {
    if (p == 0) {
        return q >= 0;
    }
    const r = q / p;
    if (p < 0) {
        if (r > t1.*) return false;
        if (r > t0.*) t0.* = r;
    } else {
        if (r < t0.*) return false;
        if (r < t1.*) t1.* = r;
    }
    return true;
}

```

*/// Liang-Barsky отсечение отрезка (x0,y0)-(x1,y1) прямоугольником [left,right]x[top,bottom].  
 /// Координаты концов модифицируются по месту. Возвращает false, если отрезок целиком вне  
 ↪ прямоугольника.*

```

fn liangBarskyClip(
    x0: *i32,
    y0: *i32,
    x1: *i32,
    y1: *i32,
    left: i32,
    top: i32,
    right: i32,
    bottom: i32,
) bool {
    const fx0: f32 = @floatFromInt(x0.*);
    const fy0: f32 = @floatFromInt(y0.*);
    const fx1: f32 = @floatFromInt(x1.*);
    const fy1: f32 = @floatFromInt(y1.*);

    const dx = fx1 - fx0;
    const dy = fy1 - fy0;

    var t0: f32 = 0.0;
    var t1: f32 = 1.0;

    const fl: f32 = @floatFromInt(left);
    const ft: f32 = @floatFromInt(top);
    const fr: f32 = @floatFromInt(right);
    const fb: f32 = @floatFromInt(bottom);

    if (!clip(-dx, fx0 - fl, &t0, &t1)) return false; // x >= left
    if (!clip(dx, fr - fx0, &t0, &t1)) return false; // x <= right
    if (!clip(-dy, fy0 - ft, &t0, &t1)) return false; // y >= top
    if (!clip(dy, fb - fy0, &t0, &t1)) return false; // y <= bottom

    const nx0 = fx0 + dx * t0;
    const ny0 = fy0 + dy * t0;
    const nx1 = fx0 + dx * t1;
    const ny1 = fy0 + dy * t1;
}

```

```

x0.* = @intFromFloat(std.math.round(nx0));
y0.* = @intFromFloat(std.math.round(ny0));
x1.* = @intFromFloat(std.math.round(nx1));
y1.* = @intFromFloat(std.math.round(ny1));

return true;
}

/// Отсекает отрезок буфером ctx (0..buf_width-1, 0..buf_height-1).
fn clipLineToBuffer(ctx: *DrawContext, a: *Point2_i, b: *Point2_i, thickness: i32) bool {
    var x0 = a.x;
    var y0 = a.y;
    var x1 = b.x;
    var y1 = b.y;

    const left: i32 = -thickness;
    const top: i32 = -thickness;
    const right: i32 = @as(i32, @intCast(ctx.buf_width - 1)) + thickness;
    const bottom: i32 = @as(i32, @intCast(ctx.buf_height - 1)) + thickness;

    if (!liangBarskyClip(&x0, &y0, &x1, &y1, left, top, right, bottom)) {
        return false;
    }

    a.* = .{ .x = x0, .y = y0 };
    b.* = .{ .x = x1, .y = y1 };
    return true;
}

fn drawLineInBuffer(ctx: *DrawContext, bx0: i32, by0: i32, bx1: i32, by1: i32, color: Color.PMA,
    ↪ thickness_px: u32, draw_when_outside: bool) void {
    // Коррекция толщины в зависимости от угла линии.
    var thickness_corrected: u32 = thickness_px;
    var use_vertical: bool = undefined;
    const dx_f: f32 = @floatFromInt(bx1 - bx0);
    const dy_f: f32 = @floatFromInt(by1 - by0);
    const len: f32 = @sqrt(dx_f * dx_f + dy_f * dy_f);
    if (len > 0) {
        const cos_theta = @abs(dx_f) / len;
        const sin_theta = @abs(dy_f) / len;
        const desired: f32 = @floatFromInt(thickness_px);
        const eps: f32 = 1e-3;

        const vertical_based = desired / @max(sin_theta, eps);
        const horizontal_based = desired / @max(cos_theta, eps);

        use_vertical = sin_theta >= cos_theta;
        const corrected_f = if (use_vertical) vertical_based else horizontal_based;

        thickness_corrected = @max(@as(u32, 1), @as(u32, @intFromFloat(std.math.round(corrected_f))));
    }
    const half_thickness: i32 = @intCast(thickness_corrected / 2);
    const thickness_corrected_i: i32 = @as(i32, @intCast(thickness_corrected));

    var p0 = Point2_i{ .x = bx0, .y = by0 };
    var p1 = Point2_i{ .x = bx1, .y = by1 };

    // Отсечение только когда не рисуем вне viewport: иначе линия идёт целиком, толщина 1 px снаружи.
    if (!draw_when_outside) {
        if (!clipLineToBuffer(ctx, &p0, &p1, @as(i32, @intCast(thickness_corrected)))) return;
    }

    var x0 = p0.x;
    var y0 = p0.y;
    const ex = p1.x;

```

```

const ey = pl.y;

const dx: i32 = @intCast(@abs(ex - x0));
const sx: i32 = if (x0 < ex) 1 else -1;
const dy_abs: i32 = @intCast(@abs(ey - y0));
const dy: i32 = -dy_abs;
const sy: i32 = if (y0 < ey) 1 else -1;

var err: i32 = dx + dy;
const buf_w_i: i32 = @intCast(ctx.buf_width);
const buf_h_i: i32 = @intCast(ctx.buf_height);

while (true) {
    // Внутри viewport — полная толщина; снаружи при draw_when_outside — только 1 пиксель.
    const in_viewport = x0 >= -thickness_corrected_i and x0 < buf_w_i + thickness_corrected_i and y0
        ↪ >= -thickness_corrected_i and y0 < buf_h_i + thickness_corrected_i;
    const effective_half: i32 = if (draw_when_outside and !in_viewport) 0 else half_thickness;

    var thick: i32 = -effective_half;
    while (thick <= effective_half) {
        const x = if (use_vertical) x0 + thick else x0;
        const y = if (use_vertical) y0 else y0 + thick;
        ctx.blendPixelAtBuffer(x, y, color);

        thick += 1;
    }

    if (x0 == ex and y0 == ey) break;

    const e2: i32 = 2 * err;
    if (e2 >= dy) {
        err += dy;
        x0 += sx;
    }
    if (e2 <= dx) {
        err += dx;
        y0 += sy;
    }
}
}

```

#### A.24. src/render/cpu/pipeline.zig

```

const std = @import("std");
const dvui = @import("dvui");
const basic_models = @import("../models/basic_models.zig");
const Document = @import("../models/Document.zig");
const Point2_f = basic_models.Point2_f;
const Point2_i = basic_models.Point2_i;
const Scale2_f = basic_models.Scale2_f;
const Rect_i = basic_models.Rect_i;
const Color = dvui.Color;

/// Трансформ объекта: позиция, угол, масштаб, непрозрачность.
pub const Transform = struct {
    position: Point2_f = .{},
    angle: f32 = 0,
    scale: Scale2_f = .{},
    opacity: f32 = 1.0,

    pub fn init(obj: *const Document.Object) Transform {
        const pos = obj.getProperty(.position) orelse Point2_f{ .x = 0, .y = 0 };
        const angle = obj.getProperty(.angle) orelse 0;
        const scale = obj.getProperty(.scale) orelse Scale2_f{ .scale_x = 1, .scale_y = 1 };
        const opacity = obj.getProperty(.opacity) orelse 1.0;
    }
}

```

```

    return .{
        .position = pos,
        .angle = angle,
        .scale = scale,
        .opacity = opacity,
    };
}

/// Композиция: world = parent * local.
pub fn compose(parent: Transform, local: Transform) Transform {
    const cos_a = std.math.cos(parent.angle);
    const sin_a = std.math.sin(parent.angle);
    const sx = parent.scale.scale_x * local.scale.scale_x;
    const sy = parent.scale.scale_y * local.scale.scale_y;
    const local_px = local.position.x * parent.scale.scale_x;
    const local_py = local.position.y * parent.scale.scale_y;
    const rx = cos_a * local_px - sin_a * local_py;
    const ry = sin_a * local_px + cos_a * local_py;
    return .{
        .position = .{
            .x = parent.position.x + rx,
            .y = parent.position.y + ry,
        },
        .angle = parent.angle + local.angle,
        .scale = .{ .scale_x = sx, .scale_y = sy },
        .opacity = parent.opacity * local.opacity,
    };
}

};

/// Мировые -> локальные для заданного трансформ.
pub fn worldToLocalTransform(t: Transform, wx: f32, wy: f32) Point2_f {
    const dx = wx - t.position.x;
    const dy = wy - t.position.y;
    const cos_a = std.math.cos(-t.angle);
    const sin_a = std.math.sin(-t.angle);
    const sx = if (t.scale.scale_x != 0) t.scale.scale_x else 1.0;
    const sy = if (t.scale.scale_y != 0) t.scale.scale_y else 1.0;
    return .{
        .x = (dx * cos_a - dy * sin_a) / sx,
        .y = (dx * sin_a + dy * cos_a) / sy,
    };
}

/// Конвейер отрисовки: локальные координаты -> трансформ -> буфер.
pub const DrawContext = struct {
    pixels: []Color.PMA,
    buf_width: u32,
    buf_height: u32,
    visible_rect: Rect_i,
    scale_x: f32,
    scale_y: f32,
    transform: Transform = .{},
    /// Если true, blendPixelAtBuffer перезаписывает пиксель без бленда
    replace_mode: bool = false,
    _fill_canvas: ?*FillCanvas = null,

    pub fn setTransform(self: *DrawContext, t: Transform) void {
        self.transform = t;
    }
}

/// Локальные -> мировые.
pub fn localToWorld(self: *const DrawContext, local_x: f32, local_y: f32) Point2_f {
    const t = &self.transform;
    const cos_a = std.math.cos(t.angle);
    const sin_a = std.math.sin(t.angle);

```



```

    return .{
        .x = t.position.x + (local_x * t.scale.scale_x) * cos_a - (local_y * t.scale.scale_y) *
        ↪ sin_a,
        .y = t.position.y + (local_x * t.scale.scale_x) * sin_a + (local_y * t.scale.scale_y) *
        ↪ cos_a,
    };
}

/// Мировые -> буфер (float).
pub fn worldToBufferF(self: *const DrawContext, wx: f32, wy: f32) Point2_f {
    const canvas_x = wx * self.scale_x;
    const canvas_y = wy * self.scale_y;
    const vx = @as(f32, @floatFromInt(self.visible_rect.x));
    const vy = @as(f32, @floatFromInt(self.visible_rect.y));
    return .{
        .x = canvas_x - vx,
        .y = canvas_y - vy,
    };
}

/// Мировые -> буфер (целые).
pub fn worldToBuffer(self: *const DrawContext, wx: f32, wy: f32) Point2_i {
    const b = self.worldToBufferF(wx, wy);
    return .{
        .x = @intFromFloat(std.math.round(b.x)),
        .y = @intFromFloat(std.math.round(b.y)),
    };
}

/// Буфер -> мировые.
pub fn bufferToWorld(self: *const DrawContext, buf_x: f32, buf_y: f32) Point2_f {
    const vx = @as(f32, @floatFromInt(self.visible_rect.x));
    const vy = @as(f32, @floatFromInt(self.visible_rect.y));
    const canvas_x = buf_x + vx;
    const canvas_y = buf_y + vy;
    const sx = if (self.scale_x != 0) self.scale_x else 1.0;
    const sy = if (self.scale_y != 0) self.scale_y else 1.0;
    return .{
        .x = canvas_x / sx,
        .y = canvas_y / sy,
    };
}

/// Мировые -> локальные.
pub fn worldToLocal(self: *const DrawContext, wx: f32, wy: f32) Point2_f {
    return worldToLocalTransform(self.transform, wx, wy);
}

/// Смешивает цвет в пикселе буфера с учётом opacity трансформы. В replace_mode просто
    ↪ перезаписывает пиксель.
/// Если активен fill canvas, каждый записанный пиксель помечается как граница для заливки.
pub fn blendPixelAtBuffer(self: *DrawContext, bx_i32: i32, by_i32: i32, color: Color.PMA) void {
    if (self._fill_canvas) |fc| fc.setBorder(bx_i32, by_i32);

    if (bx_i32 < 0 or by_i32 < 0 or bx_i32 >= self.buf_width or by_i32 >= self.buf_height) return;
    const bx: u32 = @intCast(bx_i32);
    const by: u32 = @intCast(by_i32);
    const idx = by * self.buf_width + bx;
    const dst = &self.pixels[idx];
    if (self.replace_mode) {
        dst.* = color;
        return;
    }
    const t = &self.transform;
    const a = @as(f32, @floatFromInt(color.a)) / 255.0 * t.opacity;
    const src_r = @as(f32, @floatFromInt(color.r)) * t.opacity;

```

```

const src_g = @as(f32, @floatFromInt(color.g)) * t.opacity;
const src_b = @as(f32, @floatFromInt(color.b)) * t.opacity;
const inv_a = 1.0 - a;
dst.r = @intFromFloat(std.math.clamp(src_r + inv_a * @as(f32, @floatFromInt(dst.r)), 0, 255));
dst.g = @intFromFloat(std.math.clamp(src_g + inv_a * @as(f32, @floatFromInt(dst.g)), 0, 255));
dst.b = @intFromFloat(std.math.clamp(src_b + inv_a * @as(f32, @floatFromInt(dst.b)), 0, 255));
dst.a = @intFromFloat(std.math.clamp(a * 255 + inv_a * @as(f32, @floatFromInt(dst.a)), 0, 255));
}

/// Накладывает буфер другого контекста на этот с заданной прозрачностью (один бленд на пиксель).
↳ Размеры буферов должны совпадать.
pub fn compositeDrawerContext(self: *DrawContext, other: *const DrawContext, opacity: f32) void {
if (self.buf_width != other.buf_width or self.buf_height != other.buf_height) return;
const n = self.buf_width * self.buf_height;
const lanes = 4;
const VF = @Vector(lanes, f32);
const VU8 = @Vector(lanes, u8);
const zero_f: VF = @splat(0.0);
const max_f: VF = @splat(255.0);
const opacity_v: VF = @splat(opacity);
const inv_255_v: VF = @splat(1.0 / 255.0);

var i: usize = 0;
while (i + lanes <= n) : (i += lanes) {
const src0 = other.pixels[i + 0];
const src1 = other.pixels[i + 1];
const src2 = other.pixels[i + 2];
const src3 = other.pixels[i + 3];

const src_a_u8: VU8 =.{ src0.a, src1.a, src2.a, src3.a };
const nonzero_mask = src_a_u8 != @as(VU8, @splat(0));
if (!@reduce(.Or, nonzero_mask)) continue;

const src_r_f: VF = @as(VF, @floatFromInt(@as(VU8, .{ src0.r, src1.r, src2.r, src3.r }))) *
↳ opacity_v;
const src_g_f: VF = @as(VF, @floatFromInt(@as(VU8, .{ src0.g, src1.g, src2.g, src3.g }))) *
↳ opacity_v;
const src_b_f: VF = @as(VF, @floatFromInt(@as(VU8, .{ src0.b, src1.b, src2.b, src3.b }))) *
↳ opacity_v;
const src_a_f: VF = @as(VF, @floatFromInt(src_a_u8)) * inv_255_v * opacity_v;
const inv_a_f: VF = @as(VF, @splat(1.0)) - src_a_f;

const dst_r_u8: VU8 =.{ self.pixels[i + 0].r, self.pixels[i + 1].r, self.pixels[i + 2].r,
↳ self.pixels[i + 3].r };
const dst_g_u8: VU8 =.{ self.pixels[i + 0].g, self.pixels[i + 1].g, self.pixels[i + 2].g,
↳ self.pixels[i + 3].g };
const dst_b_u8: VU8 =.{ self.pixels[i + 0].b, self.pixels[i + 1].b, self.pixels[i + 2].b,
↳ self.pixels[i + 3].b };
const dst_a_u8: VU8 =.{ self.pixels[i + 0].a, self.pixels[i + 1].a, self.pixels[i + 2].a,
↳ self.pixels[i + 3].a };

const dst_r_f: VF = @as(VF, @floatFromInt(dst_r_u8));
const dst_g_f: VF = @as(VF, @floatFromInt(dst_g_u8));
const dst_b_f: VF = @as(VF, @floatFromInt(dst_b_u8));
const dst_a_f: VF = @as(VF, @floatFromInt(dst_a_u8));

const out_r_f = @min(@max(src_r_f + inv_a_f * dst_r_f, zero_f), max_f);
const out_g_f = @min(@max(src_g_f + inv_a_f * dst_g_f, zero_f), max_f);
const out_b_f = @min(@max(src_b_f + inv_a_f * dst_b_f, zero_f), max_f);
const out_a_f = @min(@max(src_a_f * @as(VF, @splat(255.0)) + inv_a_f * dst_a_f, zero_f),
↳ max_f);

const out_r_u8: VU8 = @intFromFloat(out_r_f);
const out_g_u8: VU8 = @intFromFloat(out_g_f);
const out_b_u8: VU8 = @intFromFloat(out_b_f);

```

```

    const out_a_u8: VU8 = @intFromFloat(out_a_f);

    for (0..lanes) |lane| {
        if (!nonzero_mask[lane]) continue;
        const dst = &self.pixels[i + lane];
        dst.r = out_r_u8[lane];
        dst.g = out_g_u8[lane];
        dst.b = out_b_u8[lane];
        dst.a = out_a_u8[lane];
    }
}

while (i < n) : (i += 1) {
    const src = other.pixels[i];
    if (src.a == 0) continue;
    const dst = &self.pixels[i];
    const a = @as(f32, @floatFromInt(src.a)) / 255.0 * opacity;
    const src_r = @as(f32, @floatFromInt(src.r)) * opacity;
    const src_g = @as(f32, @floatFromInt(src.g)) * opacity;
    const src_b = @as(f32, @floatFromInt(src.b)) * opacity;
    const inv_a = 1.0 - a;
    dst.r = @intFromFloat(std.math.clamp(src_r + inv_a * @as(f32, @floatFromInt(dst.r)), 0,
↪ 255));
    dst.g = @intFromFloat(std.math.clamp(src_g + inv_a * @as(f32, @floatFromInt(dst.g)), 0,
↪ 255));
    dst.b = @intFromFloat(std.math.clamp(src_b + inv_a * @as(f32, @floatFromInt(dst.b)), 0,
↪ 255));
    dst.a = @intFromFloat(std.math.clamp(a * 255 + inv_a * @as(f32, @floatFromInt(dst.a)), 0,
↪ 255));
}
}

/// Пиксель в локальных координатах (трансформ + PMA).
pub fn blendPixelLocal(self: *DrawContext, local_x: f32, local_y: f32, color: Color.PMA) void {
    const w = self.localToWorld(local_x, local_y);
    const b = self.worldToBufferF(w.x, w.y);
    const bx: i32 = @intFromFloat(b.x);
    const by: i32 = @intFromFloat(b.y);
    const vw = @as(i32, @intCast(self.visible_rect.w));
    const vh = @as(i32, @intCast(self.visible_rect.h));
    if (bx < 0 or bx >= vw or by < 0 or by >= vh) return;
    self.blendPixelAtBuffer(bx, by, color);
}

/// Начинает сбор границ для заливки: создаёт FillCanvas и при последующих вызовах
↪ blendPixelAtBuffer помечает пиксели как границу.
pub fn startFill(self: *DrawContext, allocator: std.mem.Allocator) !void {
    const fc = try FillCanvas.init(allocator, self.buf_width, self.buf_height);
    const ptr = try allocator.create(FillCanvas);
    ptr.* = fc;
    self._fill_canvas = ptr;
}

/// Рисует заливку по собранным границам цветом color, освобождает FillCanvas и сбрасывает режим.
pub fn stopFill(self: *DrawContext, allocator: std.mem.Allocator, color: Color.PMA) void {
    const fc = self._fill_canvas or else return;
    self._fill_canvas = null;
    fc.fillColor(self, allocator, color);
    fc.deinit();
    allocator.destroy(fc);
}

};

/// Конвертирует u32 0xRRGGBBAA в Color.PMA.
pub fn rgbaToPma(rgba: u32) Color.PMA {

```

```

const r: u8 = @intCast((rgba >> 24) & 0xFF);
const g: u8 = @intCast((rgba >> 16) & 0xFF);
const b: u8 = @intCast((rgba >> 8) & 0xFF);
const a: u8 = @intCast((rgba >> 0) & 0xFF);
if (a == 0) return .{ .r = 0, .g = 0, .b = 0, .a = 0 };
const af: f32 = @as(f32, @floatFromInt(a)) / 255.0;
return .{
    .r = @intFromFloat(@as(f32, @floatFromInt(r)) * af),
    .g = @intFromFloat(@as(f32, @floatFromInt(g)) * af),
    .b = @intFromFloat(@as(f32, @floatFromInt(b)) * af),
    .a = a,
};
}

/// Контекст для заполнения фигур цветом. Границы хранятся в set – по x и y можно добавлять
/// произвольные точки.
const FillCanvas = struct {
    /// Множество пикселей границы (x, y) – без ограничения по размеру буфера.
    border_set: std.AutoHashMap(Point2_i, void),
    buf_width: u32,
    buf_height: u32,

    pub fn init(allocator: std.mem.Allocator, width: u32, height: u32) !FillCanvas {
        const border_set = std.AutoHashMap(Point2_i, void).init(allocator);
        return .{
            .border_set = border_set,
            .buf_width = width,
            .buf_height = height,
        };
    }

    pub fn deinit(self: *FillCanvas) void {
        self.border_set.deinit();
    }

    /// Добавляет точку границы; координаты x, y могут быть любыми (условно бесконечное поле).
    pub fn setBorder(self: *FillCanvas, x: i32, y: i32) void {
        self.border_set.put(.{ .x = x, .y = y }, {}) catch {};
    }

    /// Заливка четырёхсвязным стековым алгоритмом от первой найденной внутренней точки.
    pub fn fillColor(self: *FillCanvas, draw_ctx: *DrawContext, allocator: std.mem.Allocator, color:
    ↪ Color.PMA) void {
        const n = self.border_set.count();
        if (n == 0) return;

        const buf_w_i: i32 = @intCast(self.buf_width);
        const buf_h_i: i32 = @intCast(self.buf_height);

        // Ключи один раз по (y, x) – по строкам x уже будут отсортированы.
        var keys_buf = std.ArrayList(Point2_i).empty;
        defer keys_buf.deinit(allocator);
        keys_buf.ensureTotalCapacity(allocator, n) catch return;
        var iter = self.border_set.keyIterator();
        while (iter.next()) |k| {
            keys_buf.appendAssumeCapacity(k.*);
        }
        std.mem.sort(Point2_i, keys_buf.items, {}, struct {
            fn lessThan(_: void, a: Point2_i, b: Point2_i) bool {
                if (a.y != b.y) return a.y < b.y;
                return a.x < b.x;
            }
        }.lessThan);

        // Семена: по строкам находим сегменты (пары x), пересекаем с окном буфера, берём середину
        ↪ сегмента.

```

```

var seeds = findFillSeeds(keys_buf.items, buf_w_i, buf_h_i, allocator) catch return;
defer seeds.deinit(allocator);

var stack = std.ArrayList(Point2_i).empty;
defer stack.deinit(allocator);
var filled = std.AutoHashMap(Point2_i, void).init(allocator);
defer filled.deinit();

for (seeds.items) |s| {
    if (self.border_set.contains(s)) continue;
    if (filled.contains(s)) continue;
    stack.clearRetainingCapacity();
    stack.append(allocator, s) catch return;
    while (stack.pop()) |cell| {
        if (self.border_set.contains(cell)) continue;
        const gop = filled.getOrPut(cell) catch return;
        if (gop.found_existing) continue;

        if (cell.x >= 0 and cell.x < buf_w_i and cell.y >= 0 and cell.y < buf_h_i) {
            draw_ctx.blendPixelAtBuffer(cell.x, cell.y, color);
        }
        if (cell.x > 0) stack.append(allocator, .{ .x = cell.x - 1, .y = cell.y }) catch return;
        if (cell.x < buf_w_i - 1) stack.append(allocator, .{ .x = cell.x + 1, .y = cell.y })
            catch return;
        if (cell.y > 0) stack.append(allocator, .{ .x = cell.x, .y = cell.y - 1 }) catch return;
        if (cell.y < buf_h_i - 1) stack.append(allocator, .{ .x = cell.x, .y = cell.y + 1 })
            catch return;
    }
}

}

/// По строкам: рёбра (подряд идущие x) → сегменты между ними. Семена — середины чётных сегментов
/// (при чётном числе границ).
fn findFillSeeds(
    keys: []const Point2_i,
    buf_w_i: i32,
    buf_h_i: i32,
    allocator: std.mem.Allocator,
) !std.ArrayList(Point2_i) {
    var list = std.ArrayList(Point2_i).empty;
    errdefer list.deinit(allocator);
    var segments = std.ArrayList(struct { left: i32, right: i32 }).empty;
    defer segments.deinit(allocator);

    var i: usize = 0;
    while (i < keys.len) {
        const y = keys[i].y;
        const row_start = i;
        while (i < keys.len and keys[i].y == y) : (i += 1) {}
        const row = keys[row_start..i];
        if (row.len < 2 or y < 0 or y >= buf_h_i) continue;

        segments.clearRetainingCapacity();
        var run_end_x: i32 = row[0].x;
        for (row[1..]) |p| {
            if (p.x != run_end_x + 1) {
                try segments.append(allocator, .{ .left = run_end_x + 1, .right = p.x - 1 });
                run_end_x = p.x;
            } else {
                run_end_x = p.x;
            }
        }
    }
    // Семена только при чётном числе границ
    if ((segments.items.len + 1) % 2 != 0) continue;

    for (segments.items, 0..) |seg, gi| {

```

```

        if (gi % 2 != 0 or seg.left > seg.right) continue;
        const left = @max(seg.left, 0);
        const right = @min(seg.right, buf_w_i - 1);
        if (left <= right) {
            try list.append(allocator, .{ .x = left + @divTrunc(right - left, 2), .y = y });
        }
    }
}
return list;
};

```

## A.25. src/tests.zig

```

// Корень для `zig build test`. Тесты из импортированных здесь модулей выполняются (в Zig не
↳ подтягиваются из транзитивных импортов).
// Добавляй сюда _ = @import("path/to/module.zig"); для каждого модуля с test-блоками.
// Чтобы увидеть список всех тестов: после `zig build test` выполни `./zig-out/bin/test`.
test "discover tests" {
    _ = @import("main.zig");
    _ = @import("models/Property.zig");
    _ = @import("models/shape/shape.zig");
}

// Убедиться, что выполнены все ожидаемые тесты: этот тест пройдёт только если до него дошли (т.е.
↳ все предыдущие прошли).
test "all module tests completed" {
    const std = @import("std");
    std.debug.print("\n (все тесты модулей выполнены)\n", .{});
}

```

## A.26. src/toolbar/Tool.zig

```

const basic_models = @import("../models/basic_models.zig");
const Point2_f = basic_models.Point2_f;
const Canvas = @import("../Canvas.zig");
const Document = @import("../models/Document.zig");
const pipeline = @import("../render/cpu/pipeline.zig");
const Transform = pipeline.Transform;

pub const ToolContext = struct {
    canvas: *Canvas,
    document_point: Point2_f,
    selected_object_id: ?u64,

    pub fn addObject(self: *const ToolContext, template: Document.Object) !void {
        var obj = template;
        const local_pos = self.computeLocalPosition();
        try obj.setProperty(self.canvas.allocator, .{ .data = .{ .position = local_pos } });
        try self.canvas.document.addObjectUnderParentId(self.canvas.allocator, self.selected_object_id,
↳ obj);
        self.canvas.requestRedraw();
    }

    fn computeLocalPosition(self: *const ToolContext) Point2_f {
        if (self.selected_object_id | parent_id | {
            if (findWorldTransformById(self.canvas.document, parent_id)) |parent_world| {
                return pipeline.worldToLocalTransform(parent_world, self.document_point.x,
↳ self.document_point.y);
            }
        }
        return self.document_point;
    }
};

```

```

fn findWorldTransformById(doc: *Document, target_id: u64) ?Transform {
    const identity = Transform{};
    for (doc.objects.items) |*obj| {
        if (findWorldTransformInTree(obj, identity, target_id)) |t| return t;
    }
    return null;
}

fn findWorldTransformInTree(obj: *const Document.Object, parent: Transform, target_id: u64) ?Transform
↪ {
    const local = Transform.init(obj);
    const world = Transform.compose(parent, local);
    if (obj.id == target_id) return world;
    for (obj.children.items) |*child| {
        if (findWorldTransformInTree(child, world, target_id)) |t| return t;
    }
    return null;
}

pub const Tool = struct {
    onCanvasClick: *const fn (*const ToolContext) anyerror!void,
};

```

## A.27. src/toolbar/Toolbar.zig

```

const Tool = @import("Tool.zig");

const Toolbar = @This();

pub const ToolDescriptor = struct {
    name: []const u8,
    icon_tvg: []const u8,
    implementation: *const Tool.Tool,
};

tools: []const ToolDescriptor,
selected_index: ?usize,

pub fn init(tools_list: []const ToolDescriptor) Toolbar {
    return .{
        .tools = tools_list,
        .selected_index = null,
    };
}

pub fn deinit(_: *Toolbar) void {}

pub fn currentDescriptor(self: *const Toolbar) ?*const ToolDescriptor {
    if (self.tools.len == 0) return null;
    if (self.selected_index) |index| {
        return &self.tools[index];
    }
    return null;
}

pub fn select(self: *Toolbar, index: ?usize) void {
    if (index == self.selected_index) {
        self.selected_index = null;
        return;
    }
    if (index) |i| {
        if (i < self.tools.len) {
            self.selected_index = i;
        }
    } else {

```

```

        self.selected_index = null;
    }
}

```

## A.28. src/toolbar/tools.zig

```

const Toolbar = @import("Toolbar.zig");
const line = @import("tools/line.zig");
const ellipse = @import("tools/ellipse.zig");
const broken = @import("tools/broken.zig");
const icons = @import("../icons.zig");

pub const default_tools = [_]Toolbar.ToolDescriptor{
    .{
        .name = "Line",
        .icon_tvg = icons.line,
        .implementation = &line.tool,
    },
    .{
        .name = "Ellipse",
        .icon_tvg = icons.ellipse,
        .implementation = &ellipse.tool,
    },
    .{
        .name = "Broken line",
        .icon_tvg = icons.broken,
        .implementation = &broken.tool,
    },
};

```

## A.29. src/toolbar/tools/broken.zig

```

const Tool = @import("../Tool.zig");
const shape = @import("../models/shape/shape.zig");

fn onCanvasClick(ctx: *const Tool.ToolContext) !void {
    const canvas = ctx.canvas;
    var obj = shape.createObject(canvas.allocator, .broken) catch return;
    defer obj.deinit(canvas.allocator);
    try ctx.addObject(obj);
}

pub const tool = Tool.Tool{ .onCanvasClick = onCanvasClick };

```

## A.30. src/toolbar/tools/ellipse.zig

```

const Tool = @import("../Tool.zig");
const shape = @import("../models/shape/shape.zig");

fn onCanvasClick(ctx: *const Tool.ToolContext) !void {
    const canvas = ctx.canvas;
    var obj = shape.createObject(canvas.allocator, .ellipse) catch return;
    defer obj.deinit(canvas.allocator);
    try ctx.addObject(obj);
}

pub const tool = Tool.Tool{ .onCanvasClick = onCanvasClick };

```

## A.31. src/toolbar/tools/line.zig

```

const std = @import("std");
const Canvas = @import("../Canvas.zig");
const Tool = @import("../Tool.zig");
const shape = @import("../models/shape/shape.zig");

fn onCanvasClick(ctx: *const Tool.ToolContext) !void {

```



```

const canvas = ctx.canvas;
var obj = shape.createObject(canvas.allocator, .line) catch return;
defer obj.deinit(canvas.allocator);
try ctx.addObject(obj);
}
pub const tool = Tool.Tool{ .onCanvasClick = onCanvasClick };

```

### A.32. src/ui/canvas\_view.zig

```

const std = @import("std");
const dvui = @import("dvui");
const dvui_ext = @import("dvui_ext.zig");
const Canvas = @import("../Canvas.zig");
const Document = @import("../models/Document.zig");
const Property = @import("../models/Property.zig").Property;
const PropertyData = @import("../models/Property.zig").Data;
const Rect_i = @import("../models/basic_models.zig").Rect_i;
const Point2_f = @import("../models/basic_models.zig").Point2_f;
const Tool = @import("../toolbar/Tool.zig");
const RenderStats = @import("../render/RenderStats.zig");
const icons = @import("../icons.zig");

pub fn canvasView(canvas: *Canvas, selected_object_id: ?u64, content_rect_scale: dvui.RectScale) void {
    var textured = dvui_ext.texturedBox(content_rect_scale, dvui.Rect.all(20));
    {
        var overlay = dvui.overlay(@src(), .{ .expand = .both });
        {
            const overlay_parent = dvui.parentGet();
            const init_options: dvui.ScrollAreaWidget.InitOpts = .{
                .scroll_info = &canvas.scroll,
                .vertical_bar = .auto,
                .horizontal_bar = .auto,
                .process_events_after = false,
            };
            var scroll = dvui.scrollArea(
                @src(),
                init_options,
                .{
                    .expand = .both,
                    .background = false,
                },
            );
            {
                drawCanvasContent(canvas, scroll);
                handleCanvasZoom(canvas, scroll);
                handleCanvasMouse(canvas, scroll, selected_object_id);
            }

            const scroll_parent = dvui.parentGet();
            dvui.parentSet(overlay_parent);

            const vbar = scroll.vbar;
            const hbar = scroll.hbar;
            if (vbar != null) {
                // std.debug.print("{any}", .{vbar?.data()});
            }
            if (hbar != null) {
                // std.debug.print("{any}", .{hbar?.data()});
            }

            // Тулбар поверх scroll
            var toolbar_box = dvui.box(
                @src(),
                .{ .dir = .horizontal },
            );

```

```

        .{}},
    );
    {
        drawToolbar(canvas);
        // Сохраняем rect тулбара для следующего кадра – в handleCanvasMouse исключаем из него
        ↪ клики
        canvas.toolbar_rect_scale = toolbar_box.data().contentRectScale();
    }
    toolbar_box.deinit();

    // Панель свойств поверх scroll (правый верхний угол)
    if (selected_object_id) |obj_id| {
        if (canvas.document.findObjectById(obj_id)) |obj| {
            var properties_box = dvui.box(
                @src(),
                .{ .dir = .horizontal },
                .{
                    .gravity_x = 1.0,
                    .gravity_y = 0.0,
                },
            );
            {
                drawPropertiesPanel(canvas, obj);
                // Сохраняем rect панели свойств для следующего кадра – в handleCanvasMouse
                ↪ исключаем из него клики
                canvas.properties_rect_scale = properties_box.data().contentRectScale();
            }
            properties_box.deinit();
        }
    }

    drawCanvasLabelPanel();
    if (canvas.show_render_stats)
        drawStatsPanel(canvas.render_engine.getStats(), canvas.frame_index);

    if (canvas.properties_rect_scale) |prs| {
        for (dvui.events()) |*e| {
            if (e.handled) continue;
            if (e.evt != .mouse) continue;
            const mouse = &e.evt.mouse;
            if (mouse.action != .wheel_x and mouse.action != .wheel_y) continue;
            const pt = prs.pointFromPhysical(mouse.p);
            const r = prs.r;
            if (pt.x >= 0 and pt.x * prs.s < r.w and pt.y >= 0 and pt.y * prs.s < r.h) {
                e.handled = true;
            }
        }
    }

    if (!init_options.process_events_after) {
        if (scroll.scroll) |*sc| {
            dvui.clipSet(sc.prevClip);
            sc.processEventsAfter();
        }
    }

    dvui.parentSet(scroll_parent);
    scroll.deinit();
}
overlay.deinit();
}
textured.deinit();
}

fn drawCanvasContent(canvas: *Canvas, scroll: anytype) void {
    const natural_scale = if (canvas.native_scaling) 1 else dvui.windowNaturalScale();

```

```

const img_size = canvas.getZoomedImageSize();
const viewport_rect = scroll.data().contentRect();
const scroll_current = dvui.Point{ .x = canvas.scroll.viewport.x, .y = canvas.scroll.viewport.y };

const viewport_px = dvui.Rect{
    .x = viewport_rect.x * natural_scale,
    .y = viewport_rect.y * natural_scale,
    .w = viewport_rect.w * natural_scale,
    .h = viewport_rect.h * natural_scale,
};
const scroll_px = dvui.Point{
    .x = scroll_current.x * natural_scale,
    .y = scroll_current.y * natural_scale,
};

const changed = canvas.updateVisibleImageRect(viewport_px, scroll_px);
if (changed)
    canvas.requestRedraw();
canvas.processPendingRedraw() catch |err| {
    std.debug.print("processPendingRedraw error: {}\n", .{err});
};

const content_w_px: u32 = img_size.x + img_size.w;
const content_h_px: u32 = img_size.y + img_size.h;
const content_w = @as(f32, @floatFromInt(content_w_px)) / natural_scale;
const content_h = @as(f32, @floatFromInt(content_h_px)) / natural_scale;

var canvas_layer = dvui.overlay(
    @src(),
    .{ .min_size_content = .{ .w = content_w, .h = content_h }, .background = false },
);
{
    if (canvas.texture) |tex| {
        const vis = canvas._visible_rect orelse Rect_i{ .x = 0, .y = 0, .w = 0, .h = 0 };
        const left = @as(f32, @floatFromInt(img_size.x + vis.x)) / natural_scale;
        const top = @as(f32, @floatFromInt(img_size.y + vis.y)) / natural_scale;

        _ = dvui.image(
            @src(),
            .{ .source = .{ .texture = tex } },
            .{
                .background = false,
                .expand = .none,
                .gravity_x = 0.0,
                .gravity_y = 0.0,
                .margin = .{ .x = left, .y = top, .w = canvas.pos.x, .h = canvas.pos.y },
                .min_size_content = .{
                    .w = @as(f32, @floatFromInt(vis.w)) / natural_scale,
                    .h = @as(f32, @floatFromInt(vis.h)) / natural_scale,
                },
                .max_size_content = .{
                    .w = @as(f32, @floatFromInt(vis.w)) / natural_scale,
                    .h = @as(f32, @floatFromInt(vis.h)) / natural_scale,
                },
            },
        );
    }
}
canvas_layer.deinit();
}

fn handleCanvasZoom(canvas: *Canvas, scroll: anytype) void {
    const ctrl = dvui.currentWindow().modifiers.control();
    if (!ctrl) return;

    const natural_scale = if (canvas.native_scaling) 1 else dvui.windowNaturalScale();

```

```

for (dvui.events()) |*e| {
    switch (e.evt) {
        .mouse => |*mouse| {
            const action = mouse.action;
            if (dvui.eventMatchSimple(e, scroll.data()) and (action == .wheel_x or action ==
                ↪ .wheel_y)) {
                switch (action) {
                    .wheel_y => |y| {
                        const viewport_pt =
                            ↪ scroll.data().contentRectScale().pointFromPhysical(mouse.p);
                        const content_pt = dvui.Point{
                            .x = viewport_pt.x + canvas.scroll.viewport.x,
                            .y = viewport_pt.y + canvas.scroll.viewport.y,
                        };
                        const doc_pt = canvas.contentPointToDocument(content_pt, natural_scale);

                        // canvas.addZoom(y / 1000);
                        canvas.multZoom(1 + y / 2000);
                        canvas.requestRedraw();

                        const doc_pt_after = canvas.contentPointToDocument(content_pt, natural_scale);

                        const zoom = canvas.getZoom();
                        const dx = (doc_pt_after.x - doc_pt.x) * zoom / natural_scale;
                        const dy = (doc_pt_after.y - doc_pt.y) * zoom / natural_scale;

                        canvas.scroll.viewport.x -= dx;
                        canvas.scroll.viewport.y -= dy;
                    },
                    else => {},
                }
                e.handled = true;
            }
        },
        else => {},
    }
}

}

fn handleCanvasMouse(canvas: *Canvas, scroll: *dvui.ScrollAreaWidget, selected_object_id: ?u64) void {
    const natural_scale = if (canvas.native_scaling) 1 else dvui.windowNaturalScale();
    const scroll_data = scroll.data();

    for (dvui.events()) |*e| {
        switch (e.evt) {
            .mouse => |*mouse| {
                if (mouse.action != .press or mouse.button != .left) continue;
                if (e.handled) continue;
                if (!dvui.eventMatchSimple(e, scroll_data)) continue;

                // Не обрабатывать клик, если он попал в область тулбара (rect с предыдущего кадра).
                if (canvas.toolbar_rect_scale) |trs| {
                    const pt = trs.pointFromPhysical(mouse.p);
                    const r = trs.r;
                    if (pt.x >= 0 and pt.x * trs.s < r.w and pt.y >= 0 and pt.y * trs.s < r.h) continue;
                }
                // Не обрабатывать клик, если он попал в область панели свойств (rect с предыдущего
                ↪ кадра).
                if (canvas.properties_rect_scale) |prs| {
                    const pt = prs.pointFromPhysical(mouse.p);
                    const r = prs.r;
                    if (pt.x >= 0 and pt.x * prs.s < r.w and pt.y >= 0 and pt.y * prs.s < r.h) continue;
                }

                const viewport_pt = scroll_data.contentRectScale().pointFromPhysical(mouse.p);

```

```

        const content_pt = dvui.Point{
            .x = viewport_pt.x + canvas.scroll.viewport.x,
            .y = viewport_pt.y + canvas.scroll.viewport.y,
        };
        const doc_pt = canvas.contentPointToDocument(content_pt, natural_scale);
        canvas.cursor_document_point = if (canvas.isContentPointOnDocument(content_pt,
↪ natural_scale)) doc_pt else null;
        if (canvas.cursor_document_point) |point| {
            if (canvas.toolbar.currentDescriptor()) |desc| {
                var ctx = Tool.ToolContext{
                    .canvas = canvas,
                    .document_point = point,
                    .selected_object_id = selected_object_id,
                };
                desc.implementation.onCanvasClick(&ctx) catch |err| {
                    std.debug.print("onCanvasClick error: {}\n", .{err});
                };
            }
        },
        else => {},
    }
}

fn drawToolbar(canvas: *Canvas) void {
    const tools_list = canvas.toolbar.tools;
    if (tools_list.len == 0) return;

    var bar = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{
            .gravity_x = 0.0,
            .gravity_y = 0.0,
            .padding = dvui.Rect.all(6),
            .corner_radius = dvui.Rect.all(8),
            .background = true,
            .color_fill = dvui.Color.black.opacity(0.2),
            .margin = dvui.Rect{ .x = 16, .y = 16 },
        },
    );
    {
        var to_select: ?usize = null;
        for (tools_list, 0..) |*tool_desc, i| {
            const is_selected = canvas.toolbar.selected_index == i;
            const selected_fill = dvui.themeGet().focus;
            const opts: dvui.Options = .{
                .id_extra = i,
                .color_fill = if (is_selected) selected_fill else null,
            };
            if (dvui.buttonIcon(@src(), tool_desc.name, tool_desc.icon_tvg, .{}, .{}, opts)) {
                to_select = i;
            }
        }
        if (to_select) |index| {
            canvas.toolbar.select(index);
        }
    }
    bar.deinit();
}

fn drawPropertiesPanel(canvas: *Canvas, selected_object: *Document.Object) void {
    var panel = dvui.box(
        @src(),
        .{ .dir = .vertical },
    );
}

```

```

        .{
            .padding = dvui.Rect.all(8),
            .corner_radius = dvui.Rect.all(8),
            .background = true,
            .color_fill = dvui.Color.black.opacity(0.2),
            .min_size_content = .width(300),
            .max_size_content = .width(300),
            .margin = dvui.Rect{ .w = 32, .y = 16, .h = 100 },
        },
    );
    {
        dvui.label(@src(), "Properties", .{}, .{});
        var scroll = dvui.scrollArea(@src(), .{
            .horizontal = .none,
            .vertical = .auto,
        }, .{
            .expand = .both,
        });
        {
            for (selected_object.properties.items, 0..) |*prop, i| {
                drawPropertyEditor(canvas, selected_object, prop, i);
            }
        }
        scroll.deinit();
    }
    panel.deinit();
}

fn drawCanvasLabelPanel() void {
    var panel = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{
            .gravity_x = 0.5,
            .gravity_y = 0.0,
            .padding = dvui.Rect.all(8),
            .corner_radius = dvui.Rect.all(8),
            .background = true,
            .color_fill = dvui.Color.black.opacity(0.2),
            .margin = dvui.Rect{ .x = 16, .y = 16 },
        },
    );
    {
        dvui.label(@src(), "Canvas", .{}, .{});
    }
    panel.deinit();
}

fn drawStatsPanel(stats: RenderStats, frame_index: u64) void {
    var panel = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{
            .gravity_x = 0.0,
            .gravity_y = 1.0,
            .padding = dvui.Rect.all(8),
            .corner_radius = dvui.Rect.all(8),
            .background = true,
            .color_fill = dvui.Color.black.opacity(0.2),
            .margin = dvui.Rect{ .x = 16, .h = 16 },
        },
    );
    {
        dvui.label(@src(), "Frame time: {d:.2}ms", .{@as(f32, @floatFromInt(stats.render_time_ns)) /
        ↪ std.time.ns_per_ms}, .{});
        dvui.label(@src(), "Frame index: {}", .{frame_index}, .{});
    }
}

```

```

    }
    panel.deinit();
}

fn applyPropertyPatch(canvas: *Canvas, obj: *Document.Object, patch: Property) void {
    obj.setProperty(canvas.allocator, patch) catch {};
    canvas.requestRedraw();
}

fn drawPropertyEditor(canvas: *Canvas, obj: *Document.Object, prop: *const Property, row_index: usize)
↪ void {
    const row_id: usize = row_index * 16;
    const is_even = row_index % 2 == 0;
    var row = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{
            .id_extra = row_id,
            .expand = .horizontal,
            .padding = dvui.Rect{ .y = 2, .x = 4 },
            .corner_radius = dvui.Rect.all(4),
            .background = is_even,
            .color_fill = if (is_even) dvui.Color.black.opacity(0.4) else .{},
        },
    );
    {
        const tag = std.meta.activeTag(prop.data);

        dvui.labelNoFmt(@src(), propertyLabel(tag), .{}, .{});

        switch (prop.data) {
            .position => |pos| {
                var next = pos;
                var changed = false;
                {
                    var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
                    dvui.labelNoFmt(@src(), "x:", .{}, .{});
                    const T = @TypeOf(next.x);
                    const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.x }, .{ .expand =
↪ .horizontal });
                    subrow.deinit();
                    changed = res.changed or changed;
                }
            }
            {
                var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
                dvui.labelNoFmt(@src(), "y:", .{}, .{});
                const T = @TypeOf(next.y);
                const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.y }, .{ .expand =
↪ .horizontal });
                subrow.deinit();
                changed = res.changed or changed;
            }
            if (changed) {
                applyPropertyPatch(canvas, obj, .{ .data = .{ .position = next } });
            }
        },
        .angle => |angle| {
            var next = angle;
            {
                var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
                dvui.labelNoFmt(@src(), "deg:", .{}, .{});
                var degrees: f32 = next * 180.0 / std.math.pi;
                const res = dvui.textEntryNumber(@src(), f32, .{ .value = &degrees }, .{ .expand =
↪ .horizontal });
                subrow.deinit();
            }
        }
    }
}

```

```

        if (res.changed) {
            next = degrees * std.math.pi / 180.0;
            applyPropertyPatch(canvas, obj, .{ .data = .{ .angle = next } });
        }
    },
    .scale => |scale| {
        var next = scale;
        var changed = false;
        {
            var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
            dvui.labelNoFmt(@src(), "x:", .{ }, .{ });
            const T = @TypeOf(next.scale_x);
            const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.scale_x, .min = @as(T,
                ↪ 0.0), .max = @as(T, 10.0) }, .{ .expand = .horizontal });
            subrow.deinit();
            changed = res.changed or changed;
        }
        {
            var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
            dvui.labelNoFmt(@src(), "y:", .{ }, .{ });
            const T = @TypeOf(next.scale_y);
            const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.scale_y, .min = @as(T,
                ↪ 0.0), .max = @as(T, 10.0) }, .{ .expand = .horizontal });
            subrow.deinit();
            changed = res.changed or changed;
        }
        if (changed) {
            applyPropertyPatch(canvas, obj, .{ .data = .{ .scale = next } });
        }
    },
    .visible => |v| {
        var next = v;
        if (dvui.checkbox(@src(), &next, "Visible", .{ })) {
            applyPropertyPatch(canvas, obj, .{ .data = .{ .visible = next } });
        }
    },
    .opacity => |opacity| {
        var next = opacity;
        if (dvui.sliderEntry(@src(), "{d:0.2}", .{ .value = &next, .min = 0.0, .max = 1.0,
            ↪ .interval = 0.01 }, .{ .expand = .horizontal })) {
            applyPropertyPatch(canvas, obj, .{ .data = .{ .opacity = next } });
        }
    },
    .locked => |v| {
        var next = v;
        if (dvui.checkbox(@src(), &next, "Locked", .{ })) {
            applyPropertyPatch(canvas, obj, .{ .data = .{ .locked = next } });
        }
    },
    .size => |size| {
        var next = size;
        var changed = false;
        {
            var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
            dvui.labelNoFmt(@src(), "w:", .{ }, .{ });
            const T = @TypeOf(next.w);
            const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.w, .min = @as(T, 0.0)
                ↪ }, .{ .expand = .horizontal });
            subrow.deinit();
            changed = res.changed or changed;
        }
        {
            var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
            dvui.labelNoFmt(@src(), "h:", .{ }, .{ });

```



```

        const T = @TypeOf(next.h);
        const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.h, .min = @as(T, 0.0)
        ↪ }, .{ .expand = .horizontal });
        subrow.deinit();
        changed = res.changed or changed;
    }
    if (changed) {
        applyPropertyPatch(canvas, obj, .{ .data = .{ .size = next } });
    }
},
.radii => |radii| {
    var next = radii;
    var changed = false;
    {
        var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
        dvui.labelNoFmt(@src(), "x:", .{ }, .{ });
        const T = @TypeOf(next.x);
        const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.x, .min = @as(T, 0.0)
        ↪ }, .{ .expand = .horizontal });
        subrow.deinit();
        changed = res.changed or changed;
    }
    {
        var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
        dvui.labelNoFmt(@src(), "y:", .{ }, .{ });
        const T = @TypeOf(next.y);
        const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.y, .min = @as(T, 0.0)
        ↪ }, .{ .expand = .horizontal });
        subrow.deinit();
        changed = res.changed or changed;
    }
    if (changed) {
        applyPropertyPatch(canvas, obj, .{ .data = .{ .radii = next } });
    }
},
.arc_percent => |pct| {
    var next = pct;
    if (dvui.sliderEntry(@src(), "{d:0.0}%", .{ .value = &next, .min = 0.0, .max = 100.0,
    ↪ .interval = 1.0 }, .{ .expand = .horizontal })) {
        applyPropertyPatch(canvas, obj, .{ .data = .{ .arc_percent = next } });
    }
},
.end_point => |pt| {
    var next = pt;
    var changed = false;
    {
        var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
        dvui.labelNoFmt(@src(), "x:", .{ }, .{ });
        const T = @TypeOf(next.x);
        const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.x }, .{ .expand =
        ↪ .horizontal });
        subrow.deinit();
        changed = res.changed or changed;
    }
    {
        var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
        dvui.labelNoFmt(@src(), "y:", .{ }, .{ });
        const T = @TypeOf(next.y);
        const res = dvui.textEntryNumber(@src(), T, .{ .value = &next.y }, .{ .expand =
        ↪ .horizontal });
        subrow.deinit();
        changed = res.changed or changed;
    }
    if (changed) {
        applyPropertyPatch(canvas, obj, .{ .data = .{ .end_point = next } });
    }
}

```

```

    }
},
.points => |points| {
    var list = std.ArrayList(Point2_f).empty;
    list.appendSlice(canvas allocator, points) catch {
        dvui.label(@src(), "Points: {d}", .{points.len}, .{});
        return;
    };
    defer list.deinit(canvas allocator);
    dvui.label(@src(), "Points: {d}", .{list.items.len}, .{});

    var changed = false;
    var to_delete: ?usize = null;

    for (list.items, 0..) |*pt, i| {
        // Одна строка: крестик удаления + paned с X/Y пополам
        var subrow = dvui.box(
            @src(),
            .{ .dir = .horizontal },
            .{
                .expand = .horizontal,
                .id_extra = i,
            },
        );
        {
            // Крестик удаления
            if (dvui.buttonIcon(@src(), "Delete", icons.cross, .{}, .{}, .{
                .id_extra = i,
                .gravity_y = 0.5,
                .margin = .{
                    .x = 8,
                },
            })) {
                to_delete = i;
            }

            // Панель с X и Y, разделёнными пополам
            var split_ratio: f32 = 0.5;
            var paned = dvui.paned(
                @src(),
                .{
                    .direction = .horizontal,
                    .collapsed_size = 0.0,
                    .split_ratio = &split_ratio,
                    .handle_size = 0,
                },
                .{
                    .expand = .horizontal,
                },
            );
            {
                if (paned.showFirst()) {
                    var x_box = dvui.box(
                        @src(),
                        .{ .dir = .horizontal },
                        .{ .expand = .both },
                    );
                    {
                        dvui.labelNoFmt(@src(), "x:", .{}, .{
                            .gravity_y = 0.5,
                        });
                        const Tx = @TypeOf(pt.x);
                        const res_x = dvui.textEntryNumber(
                            @src(),
                            Tx,
                            .{ .value = &pt.x },
                        );
                    }
                }
            }
        }
    }
}

```

```

        .{ .expand = .horizontal },
    );
    changed = res_x.changed or changed;
}
x_box.deinit();
}

if (paned.showSecond()) {
    var y_box = dvui.box(
        @src(),
        .{ .dir = .horizontal },
        .{ .expand = .both },
    );
    {
        dvui.labelNoFmt(@src(), "y:", .{ }, .{
            .gravity_y = 0.5,
        });
        const Ty = @TypeOf(pt.y);
        const res_y = dvui.textEntryNumber(
            @src(),
            Ty,
            .{ .value = &pt.y },
            .{ .expand = .horizontal },
        );
        changed = res_y.changed or changed;
    }
    y_box.deinit();
}
paned.deinit();
}
subrow.deinit();
}

// Удаление выбранной точки
if (to_delete) |idx| {
    _ = list.orderedRemove(idx);
    changed = true;
}

// Кнопка добавления новой точки (одна на весь список)
if (dvui.button(@src(), "Add point", .{ }, .{ })) {
    const T = @TypeOf(list.items[0]);
    const new_point: T = if (list.items.len > 0)
        list.items[list.items.len - 1]
    else
        .{ .x = 0, .y = 0 };
    list.append(canvas allocator, new_point) catch {};
    changed = true;
}

if (changed) {
    const slice = canvas.allocator.dupe(Point2_f, list.items) catch return;
    obj.setProperty(canvas.allocator, .{ .data = .{ .points = slice } }) catch {
        canvas.allocator.free(slice);
    };
    return;
};
canvas.requestRedraw();
}
},
.fill_rgba => |rgba| {
    drawColorEditor(canvas, obj, rgba, true);
},
.stroke_rgba => |rgba| {
    drawColorEditor(canvas, obj, rgba, false);
},
},

```

```

        .thickness => |t| {
            var next = t;
            {
                var subrow = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .horizontal });
                dvui.labelNoFmt(@src(), "thickness:", .{ }, .{ });
                const T = @TypeOf(next);
                const res = dvui.textEntryNumber(@src(), T, .{ .value = &next, .min = @as(T, 0.0),
                    ↪ .max = @as(T, 100.0) }, .{ .expand = .horizontal });
                subrow.deinit();
                if (res.changed) {
                    applyPropertyPatch(canvas, obj, .{ .data = .{ .thickness = next } });
                }
            }
        },
        .closed => |v| {
            var next = v;
            if (dvui.checkbox(@src(), &next, "Closed", .{ })) {
                applyPropertyPatch(canvas, obj, .{ .data = .{ .closed = next } });
            }
        },
        .filled => |v| {
            var next = v;
            if (dvui.checkbox(@src(), &next, "Filled", .{ })) {
                applyPropertyPatch(canvas, obj, .{ .data = .{ .filled = next } });
            }
        },
    },
}
row.deinit();
}

fn drawColorEditor(canvas: *Canvas, obj: *Document.Object, rgba: u32, is_fill: bool) void {
    var hsv = dvui.Color.HSV.fromColor(rgbaToColor(rgba));
    if (dvui.colorPicker(
        @src(),
        .{ .hsv = &hsv, .dir = .horizontal, .sliders = .rgb, .alpha = true, .hex_text_entry = true },
        .{ .expand = .horizontal },
    )) {
        const next = colorToRgba(hsv.toColor());
        const patch: Property = if (is_fill)
            .{ .data = .{ .fill_rgba = next } }
        else
            .{ .data = .{ .stroke_rgba = next } };
        applyPropertyPatch(canvas, obj, patch);
    }
}

fn propertyLabel(tag: std.meta.Tag(PropertyData)) []const u8 {
    return switch (tag) {
        .position => "Position",
        .angle => "Angle",
        .scale => "Scale",
        .visible => "Visible",
        .opacity => "Opacity",
        .locked => "Locked",
        .size => "Size",
        .radii => "Radii",
        .arc_percent => "Arc %",
        .end_point => "End point",
        .points => "Points",
        .fill_rgba => "Fill color",
        .stroke_rgba => "Stroke color",
        .thickness => "Thickness",
        .closed => "Closed",
        .filled => "Filled",
    };
}

```

```

}

fn rgbaToColor(rgba: u32) dvui.Color {
    return .{
        .r = @intCast((rgba >> 24) & 0xFF),
        .g = @intCast((rgba >> 16) & 0xFF),
        .b = @intCast((rgba >> 8) & 0xFF),
        .a = @intCast((rgba >> 0) & 0xFF),
    };
}

fn colorToRgba(color: dvui.Color) u32 {
    return (@as(u32, color.r) << 24) |
        (@as(u32, color.g) << 16) |
        (@as(u32, color.b) << 8) |
        (@as(u32, color.a) << 0);
}

```

### A.33. src/ui/dvui\_ext.zig

```

const std = @import("std");
const dvui = @import("dvui");
const TexturedBox = @import("../types/TexturedBox.zig");

pub fn texturedBox(rs: dvui.RectScale, corner_radius: dvui.Rect) TexturedBox {
    return TexturedBox.init(rs, corner_radius);
}

```

### A.34. src/ui/frame.zig

```

const dvui = @import("dvui");
const WindowContext = @import("../WindowContext.zig");
const menu_bar = @import("menu_bar.zig");
const tab_bar = @import("tab_bar.zig");
const left_panel = @import("left_panel.zig");
const right_panel = @import("right_panel.zig");

pub fn guiFrame(ctx: *WindowContext) bool {
    for (dvui.events()) |*e| {
        if (e.evt == .window and e.evt.window.action == .close) return false;
        if (e.evt == .app and e.evt.app.action == .quit) return false;
    }

    var root = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{ .expand = .both, .background = true, .style = .window },
    );
    {
        menu_bar.menuBar(ctx);
        tab_bar.tabBar(ctx);

        var content_row = dvui.box(@src(), .{ .dir = .horizontal }, .{ .expand = .both });
        {
            left_panel.leftPanel(ctx);

            right_panel.rightPanel(ctx);
        }
        content_row.deinit();
    }
    root.deinit();

    return true;
}

```

### A.35. src/ui/left\_panel.zig

```
const std = @import("std");
const dvui = @import("dvui");
const WindowContext = @import("../WindowContext.zig");
const Document = @import("../models/Document.zig");
const icons = @import("../icons.zig");
const Object = Document.Object;

const panel_gap: f32 = 12;
const panel_padding: f32 = 5;
const panel_radius: f32 = 24;
const fill_color = dvui.Color.black.opacity(0.2);

const ObjectTreeCallback = union(enum) {
    select: u64,
    delete: u64,
};

fn shapeLabel(shape: Object.ShapeKind) []const u8 {
    return switch (shape) {
        .line => "Line",
        .ellipse => "Ellipse",
        .broken => "Broken line",
    };
}

fn objectTreeRow(open_doc: *WindowContext.OpenDocument, obj: *Object, depth: u32, object_callback:
↪ *?ObjectTreeCallback) void {
    const indent_px = depth * 18;
    const is_selected: bool = open_doc.selected_object_id == obj.id;
    const row_id: usize = @intCast(obj.id);

    const focus_color = dvui.themeGet().focus;

    var row = dvui.box(
        @src(),
        .{ .dir = .horizontal },
        .{
            .id_extra = row_id,
            .expand = .horizontal,
        },
    );
    {
        var hovered: bool = false;
        const row_data = row.data();
        var select_row: bool = false;

        // Ручная обработка hover/click по строке без пометки события как handled,
        // чтобы кнопка удаления могла нормально получать свои события.
        for (dvui.events()) |*e| {
            switch (e.evt) {
                .mouse => |*mouse| {
                    if (!dvui.eventMatchSimple(e, row_data)) continue;
                    hovered = true;
                    if (mouse.action == .release and mouse.button == .left) {
                        select_row = true;
                    }
                },
                else => {},
            }
        }

        const background = is_selected or hovered;
        var content = dvui.box(@src(), .{ .dir = .horizontal }, .{
            .expand = .horizontal,
```

```

        .margin = dvui.Rect{ .x = @floatFromInt(indent_px) },
        .background = background,
        .color_fill = if (is_selected) focus_color.opacity(0.35) else if (hovered)
            ↪ focus_color.opacity(0.18) else null,
    });
    {
        dvui.LabelNoFmt(
            @src(),
            shapeLabel(obj.shape),
            .{ },
            .{ .id_extra = row_id, .expand = .horizontal },
        );

        if (hovered) {
            const delete_opts: dvui.Options = .{
                .id_extra = row_id + 1,
                .margin = dvui.Rect{ .x = 4, .w = 6 },
                .padding = dvui.Rect.all(2),
                .gravity_y = 0.5,
                .gravity_x = 1.0,
            };
            if (dvui.buttonIcon(@src(), "Delete object", icons.trash, .{ }, .{ }, delete_opts)) {
                object_callback.* = .{ .delete = obj.id };
                select_row = false;
            }
        }
    }
    content.deinit();

    if (select_row) {
        object_callback.* = .{ .select = obj.id };
    }
}
row.deinit();
for (obj.children.items) |*child| {
    objectTreeRow(open_doc, child, depth + 1, object_callback);
}
}

fn objectTree(ctx: *WindowContext) void {
    const active_doc = ctx.activeDocument();
    var object_callback: ?ObjectTreeCallback = null;
    if (active_doc) |open_doc| {
        const doc = &open_doc.document;
        if (doc.objects.items.len == 0) {
            dvui.Label(@src(), "No objects", .{ }, .{ });
        } else {
            for (doc.objects.items) |*obj| {
                objectTreeRow(open_doc, obj, 0, &object_callback);
            }
        }
    }
    if (object_callback) |callback| {
        switch (callback) {
            .select => |obj_id| {
                if (open_doc.selected_object_id == obj_id) {
                    open_doc.selected_object_id = null;
                } else {
                    open_doc.selected_object_id = obj_id;
                }
            },
            .delete => |obj_id| {
                _ = doc.removeObjectById(ctx allocator, obj_id);
                if (open_doc.selected_object_id == obj_id)
                    open_doc.selected_object_id = null;
                open_doc.canvas.requestRedraw();
            },
        }
    }
}

```

```

    }
} else {
    dvui.label(@src(), "No document", .{}, .{});
}
}

pub fn leftPanel(ctx: *WindowContext) void {
    var padding = dvui.Rect.all(panel_gap);
    padding.w = 0;
    var panel = dvui.box(
        @src(),
        .{ .dir = .vertical },
        .{
            .expand = .vertical,
            // Фиксированная ширина левой панели
            .min_size_content = .{ .w = 220 },
            .max_size_content = .{ .h = undefined, .w = 220 },
            .background = true,
            .padding = padding,
        },
    );
    {
        // Нижняя часть: настройки
        var settings_section = dvui.box(
            @src(),
            .{ .dir = .vertical },
            .{
                .expand = .horizontal,
                .gravity_y = 1.0,
                .margin = .{ .y = 5 },
                .padding = dvui.Rect.all(panel_padding),
                .corner_radius = dvui.Rect.all(panel_radius),
                .color_fill = fill_color,
                .background = true,
            },
        );
        {
            dvui.label(@src(), "Settings", .{}, .{});

            const active_doc = ctx.activeDocument();
            if (active_doc) |doc| {
                const canvas = &doc.canvas;
                if (dvui.checkbox(@src(), &canvas.native_scaling, "Scaling", .{})) {}
                if (dvui.checkbox(@src(), &canvas.draw_document, "Draw document", .{})) {
                    canvas.requestRedraw();
                }
                if (dvui.checkbox(@src(), &canvas.show_render_stats, "Show stats", .{})) {}
                {
                    dvui.label(@src(), "Rendering quality", .{}, .{});
                    var quality = canvas.getRenderingQuality();
                    if (dvui.sliderEntry(
                        @src(),
                        "{d:0.0}%",
                        .{ .value = &quality, .min = 1.0, .max = 100.0, .interval = 1.0 },
                        .{ .expand = .horizontal },
                    )) {
                        canvas.setRenderingQuality(quality);
                    }
                }
            }
            if (!canvas.draw_document) {
                if (dvui.button(@src(), if (doc.cpu_render.type == .Gradient) "Gradient" else
                    ↪ "Squares", .{}, .{})) {
                    if (doc.cpu_render.type == .Gradient) {
                        doc.cpu_render.type = .Squares;
                    }
                }
            }
        }
    }
}

```



```

        } else {
            doc.cpu_render.type = .Gradient;
        }
        canvas.requestRedraw();
    }
}
if (dvui.button(@src(), "Add random shapes", .{}, .{})) {
    canvas.addRandomShapes() catch {};
}
if (dvui.button(@src(), "Request redraw", .{}, .{})) {
    canvas.requestRedraw();
}
} else {
    dvui.label(@src(), "No document", .{}, .{});
}
}
settings_section.deinit();

// Верхняя часть: дерево объектов
var tree_section = dvui.box(
    @src(),
    .{ .dir = .vertical },
    .{
        .expand = .both,
        .padding = dvui.Rect.all(panel_padding),
        .corner_radius = dvui.Rect.all(panel_radius),
        .color_fill = fill_color,
        .background = true,
    },
);
{
    dvui.label(@src(), "Objects", .{}, .{
        .font = .{
            .line_height_factor = dvui.themeGet().font_heading.line_height_factor,
            .size = dvui.themeGet().font_heading.size + 8,
        },
        .gravity_x = 0.5,
    });
    var scroll = dvui.scrollArea(
        @src(),
        .{ .vertical = .auto, .horizontal = .auto },
        .{ .expand = .both, .background = false },
    );
    {
        objectTree(ctx);
    }
    scroll.deinit();
}
tree_section.deinit();
}
panel.deinit();
}

```

### A.36. src/ui/menu\_bar.zig

```

const std = @import("std");
const dvui = @import("dvui");
const WindowContext = @import("../WindowContext.zig");
const Document = @import("../models/Document.zig");
const json_io = @import("../persistence/json_io.zig");

pub fn menuBar(ctx: *WindowContext) void {
    var m = dvui.menu(@src(), .horizontal, .{ .background = true, .expand = .horizontal });
    defer m.deinit();
}

```

```

if (dvui.menuItemLabel(@src(), "File", .{ .submenu = true }, .{ .expand = .none })) |r| {
    var fm = dvui.floatingMenu(@src(), .{ .from = r }, .{});
    defer fm.deinit();

    if (dvui.menuItemLabel(@src(), "Open", .{}, .{ .expand = .horizontal }) != null) {
        m.close();
        openDocumentDialog(ctx);
    }

    if (dvui.menuItemLabel(@src(), "Save As", .{}, .{ .expand = .horizontal }) != null) {
        m.close();
        saveAsDialog(ctx);
    }
}

}

fn openDocumentDialog(ctx: *WindowContext) void {
    const path_z = dvui.dialogNativeFileOpen(ctx.allocator, .{
        .title = "Open",
        .filters = &.{ "*.json" },
        .filter_description = "JSON files",
    }) catch |err| {
        std.debug.print("Open dialog error: {}\n", .{err});
        return;
    } orelse return;
    defer ctx.allocator.free(path_z);

    const path = path_z[0..path_z.len];
    const doc = json_io.loadFromFile(Document, ctx.allocator, path) catch |err| {
        std.debug.print("Open file error: {}\n", .{err});
        return;
    };
    ctx.addDocument(doc) catch |err| {
        std.debug.print("Add document error: {}\n", .{err});
        return;
    };
}

fn saveAsDialog(ctx: *WindowContext) void {
    const open_doc = ctx.activeDocument() orelse return;
    const path_z = dvui.dialogNativeFileSave(ctx.allocator, .{
        .title = "Save As",
        .filters = &.{ "*.json" },
        .filter_description = "JSON files",
    }) catch |err| {
        std.debug.print("Save dialog error: {}\n", .{err});
        return;
    } orelse return;
    defer ctx.allocator.free(path_z);

    const path_raw = path_z[0..path_z.len];
    json_io.saveToFile(Document, &open_doc.document, path_raw) catch |err| {
        std.debug.print("Save file error: {}\n", .{err});
        return;
    };
}

```

### A.37. src/ui/right\_panel.zig

```

const std = @import("std");
const dvui = @import("dvui");
const WindowContext = @import("../WindowContext.zig");
const canvas_view = @import("canvas_view.zig");

pub fn rightPanel(ctx: *WindowContext) void {

```

```

const fill_color = dvui.Color.black.opacity(0.25);
var back = dvui.box(
  @src(),
  .{ .dir = .horizontal },
  .{ .expand = .both, .padding = dvui.Rect.all(12), .background = true },
);
{
  var panel = dvui.box(
    @src(),
    .{ .dir = .vertical },
    .{
      .expand = .both,
      .background = true,
      .padding = dvui.Rect.all(5),
      .corner_radius = dvui.Rect.all(24),
      .color_fill = fill_color,
    },
  );
  {
    const active_doc = ctx.activeDocument();
    if (active_doc) |doc| {
      const content_rect_scale = panel.data().contentRectScale();
      canvas_view.canvasView(&doc.canvas, doc.selected_object_id, content_rect_scale);
    } else {
      noDocView(ctx);
    }
  }
  panel.deinit();
}
back.deinit();
}

fn noDocView(ctx: *WindowContext) void {
  var center = dvui.box(
    @src(),
    .{ .dir = .vertical },
    .{
      .expand = .both,
      .padding = dvui.Rect.all(20),
    },
  );
  {
    var box = dvui.box(
      @src(),
      .{ .dir = .vertical },
      .{
        .gravity_x = 0.5,
        .gravity_y = 0.5,
      },
    );
    {
      dvui.label(@src(), "No document open", .{ }, .{ });
      if (dvui.button(@src(), "New document", .{ }, .{ })) {
        ctx.addNewDocument() catch |err| {
          std.debug.print("addNewDocument error: {}\n", .{err});
        };
      }
    }
    box.deinit();
  }
  center.deinit();
}
}

```

### A.38. src/ui/tab\_bar.zig

```
const std = @import("std");
const dvui = @import("dvui");
const icons = @import("../icons.zig");
const WindowContext = @import("../WindowContext.zig");

const DocCallback = union(enum) {
    select: usize,
    close: usize,
};

fn documentTab(ctx: *WindowContext, index: usize, callback: *?DocCallback) void {
    const row_id: usize = index;
    const is_selected = if (ctx.active_document_index) |active| active == index else false;
    const focus_color = dvui.themeGet().focus;

    var row = dvui.box(
        @src(),
        .{ .dir = .horizontal },
        .{
            .id_extra = row_id,
            .expand = .none,
            .gravity_y = 0.5,
        },
    );
    {
        var hovered: bool = false;
        var select_row: bool = false;
        const row_data = row.data();

        // Ручная обработка hover/click по строке без пометки события как handled,
        // чтобы кнопка закрытия могла нормально получать свои события.
        for (dvui.events()) |*e| {
            switch (e.evt) {
                .mouse => |*mouse| {
                    if (!dvui.eventMatchSimple(e, row_data)) continue;
                    hovered = true;
                    if (mouse.action == .release and mouse.button == .left) {
                        select_row = true;
                    }
                },
                else => {},
            }
        }

        var overlay = dvui.overlay(@src(), .{
            .margin = dvui.Rect{ .x = 4, .w = 4 },
            .padding = dvui.Rect{ .x = 12, .y = 0, .w = 0, .h = 0 },
            .background = is_selected or hovered,
            .color_fill = if (is_selected) focus_color.opacity(0.35) else if (hovered)
                ↪ focus_color.opacity(0.18) else null,
            .corner_radius = dvui.Rect.all(4),
        });
        {
            var buf: [32]u8 = undefined;
            const label = std.fmt.bufPrint(&buf, "Doc {d}", .{index + 1}) catch "Doc";
            dvui.labelNoFmt(@src(), label, .{
                .gravity_x = 0.5,
                .gravity_y = 0.5,
                .margin = .{ .w = 24 },
            });

            if (hovered) {
                if (dvui.buttonIcon(@src(), "Close", icons.cross, .{}, .{}, .{
                    .id_extra = row_id +% 1,
                }
            )
        }
    }
}
```

```

        .margin = dvui.Rect{ .x = 8, .w = 6 },
        .padding = dvui.Rect.all(2),
        .gravity_x = 1,
        .gravity_y = 0.5,
    ))) {
        callback.* = .{ .close = index };
        select_row = false;
    }
}
}
overlay.deinit();

if (select_row) {
    callback.* = .{ .select = index };
}
}
row.deinit();
}

pub fn tabBar(ctx: *WindowContext) void {
    var bar = dvui.box(
        @src(),
        .{ .dir = .horizontal },
        .{
            .expand = .horizontal,
            .background = true,
            .padding = .{
                .x = 12,
                .w = 12,
            },
        },
    );
    {
        var callback: ?DocCallback = null;
        for (ctx.documents.items, 0..) |_, i| {
            documentTab(ctx, i, &callback);
        }
        if (callback) |action| {
            switch (action) {
                .select => |index| ctx.setActiveDocument(index),
                .close => |index| ctx.closeDocument(index),
            }
        }

        if (dvui.buttonIcon(@src(), "Create", icons.plus, .{ }, .{ }, .{
            .gravity_y = 0,
        ))) {
            ctx.addNewDocument() catch |err| {
                std.debug.print("addNewDocument error: {}\n", .{err});
            };
        }
    }
    bar.deinit();
}
}

```

### A.39. src/ui/types/TexturedBox.zig

```

const std = @import("std");
const dvui = @import("dvui");
const TexturedBox = @This();

```

```

parent: dvui.Widget,
rs: dvui.RectScale,
pic: ?dvui.Picture,
corner_radius: dvui.Rect,

```

```

pub fn init(rs: dvui.RectScale, corner_radius: dvui.Rect) TexturedBox {
    const parent = dvui.parentGet();
    const pic = dvui.Picture.start(rs.r);
    return .{
        .parent = parent,
        .corner_radius = corner_radius,
        .rs = rs,
        .pic = pic,
    };
}

pub fn deinit(self: *TexturedBox) void {
    if (self.pic) |*picture| {
        picture.stop();

        const tex = dvui.textureFromTarget(picture.texture) catch null;
        if (tex) |t| {
            dvui.Texture.destroyLater(t);
            dvui.renderTexture(t, self.rs, .{
                .corner_radius = self.corner_radius,
            }) catch {};
        }
    }
}

```