Contents

1 XEngine (SDL2) — Engine Documentation

> **Project context:** XEngine is a lightweight 2D game engine built on top of **SDL2** (+ SDL_image, SDL_ttf, SDL_mixer).
> It follows a **Unity-like workflow** (Scene → GameObjects → Components/Behaviours) and organizes most subsystems as **manager singletons** (window, input, rendering, assets, audio, scenes, collisions, physics, UI, random, time).

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1. High-Level Overview

XEngine is designed to build small-to-medium 2D games with a codebase that stays **simple, explicit, and extendable**.

Core ideas: - **Scenes** contain and own all game objects. - **GameObjects** are lightweight entities that aggregate **Components**. - **Components** implement functionality; **Behaviours** are Components with enable/disable and gameplay callbacks (Unity-like). - A central **Engine loop** updates managers, runs fixed-step physics, updates gameplay, renders, and safely applies queued changes (destroyed objects / scene switches).

The design balances: - **Low-level control** (plain C++, SDL renderer, explicit managers) - **High-level ergonomics** (BaseTypes math, C#-style properties, safe lifecycle, caching asset pipeline)

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2. Project Structure

Conceptually, the engine is split into:

2.1 Core

- **Engine**: orchestrates startup/shutdown and the full game loop.

- **BaseTypes**: math + utility value types used everywhere (vectors, rects, colors, helpers).
- **Singleton**: template singleton used by managers.
- **ErrorHandler / Logging**: centralized error reporting.
- **Property system**: C#-style `.position`, `.zoom`, `.viewRect`, etc. in C++.

2.2 Scene & Entity System

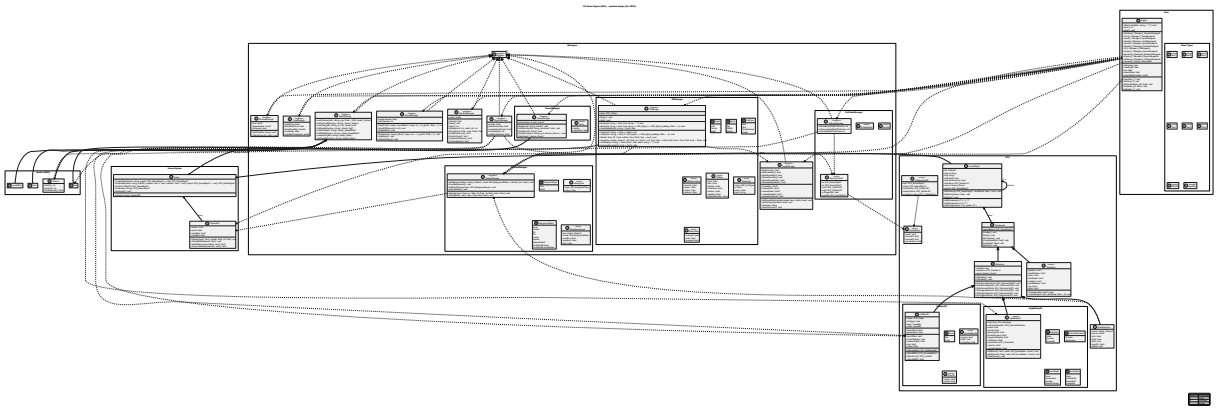
- **Scene**
  - Owns all objects (`std::vector<std::unique_ptr<GameObject>>`)
  - Runs global lifecycle (`AwakeAll`, `StartAll`, `FixedUpdate`, `Update`, `Render`)
  - Provides safe creation/destruction through queues
- **GameObject**
  - Has an ID, name, hierarchy (parent/children)
  - Holds a list of `Components`
  - Dispatches lifecycle and collision/trigger events to components/behaviours
- **Component**
  - Base class for everything attached to a GameObject
  - Unity-like lifecycle + loops (`Awake`/`Start`/`FixedUpdate`/`Update`/`Render`/`OnDestroy`)
- **Behaviour**
  - A component that can be enabled/disabled at runtime
  - Adds hooks like `OnEnable`, `OnDisable` and collision/trigger callbacks

2.3 Managers (Singletons)

- **WindowManager**: SDL_Window creation, resolution/fullscreen, close events
- **RenderManager**: SDL_Renderer, camera world→screen conversion, debug draw, backgrounds/parallax
- **InputManager**: keyboard/mouse states (pressed/down/released), mouse world position, text input buffer
- **TimeManager**: deltaTime, fixedDeltaTime, timeScale, timestamps
- **AssetManager**: cached loading of textures/fonts/sfx/music, base asset folder
- **SoundManager**: music + SFX playback, channels, optional ducking
- **SceneManager**: scene registry and safe switching
- **CollisionManager**: broadphase + narrowphase, trigger/collision dispatch
- **PhysicsManager**: rigidbody integration + impulse solve + positional correction (substeps for fast bodies)
- **UIManager**: immediate-mode UI widgets

- **RandomManager**: seeded RNG utilities

2.4 UML Class Diagram



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3. BaseTypes (Math & Common Value Types)

BaseTypes is the shared foundation used across rendering, physics, UI, and gameplay.

Key goals: - Avoid scattering raw SDL structs across the engine. - Provide small **value types** that are easy to copy, pass, serialize, and debug. - Keep math consistent across all subsystems.

Typical contents: - **Vectors**: `TVec2<T>`, `TVec3<T>` and aliases such as `Vec2f`, `Vec2i`, `Vec3f` - **Rectangles**: `TRect<T>` and aliases such as `Rectf`, `Recti` - **Color**: RGBA value type used by renderer and UI - **Math utilities**: clamp, lerp, dot, length, normalize, angle helpers, epsilon comparisons

Why this matters: - Physics contacts, camera conversions, sprite placement, and UI layouts all share the same types. - Less friction when moving data between systems (world-space <-> screen-space, float <-> int).

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4. Property System (C#-Style API in C++)

XEngine includes a `Property` / `PropertyR0` system to expose clean gameplay APIs without exposing internal state.

4.1 Motivation

In Unity, you naturally write: - `transform.position = ...` - `camera.zoom = ...` - `rect = camera.viewRect` (read-only)

In raw C++, that often becomes: - verbose getters/setters - or public fields (harder to validate / maintain invariants)

Properties provide: - **Readable syntax** - **Controlled access** (read-only vs read/write) - **Encapsulation** (setters can mark dirty flags, clamp values, trigger callbacks)

4.2 Property types

- **PropertyRO**: read-only property (returns from a getter)
- **Property**: read/write property (getter + setter)

Example: Camera exposes a read-only `viewRect` and editable `center`/`zoom` via properties (pattern shown in Camera code). This gives a clean API while keeping the implementation private.

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5. Startup & Configuration

5.1 Startup sequence

`Engine::Start()` typically: 1. Loads configuration (JSON) or defaults 2. Initializes SDL subsystems (video + audio + image/ttf/mixer) 3. Creates/initializes managers in dependency order: - Window → Renderer → Time → Random → Input → Assets → Sound → Collision → Physics → UI → Scenes 4. Loads a default font for UI/debug 5. Marks engine ready to run

5.2 Configuration

A JSON config file usually defines: - Window: size, fullscreen, title - Rendering: vsync, acceleration - Time: fixed timestep - Assets: base folder - Audio: channels, master volume, ducking - Physics: gravity and solver parameters - UI: default style values

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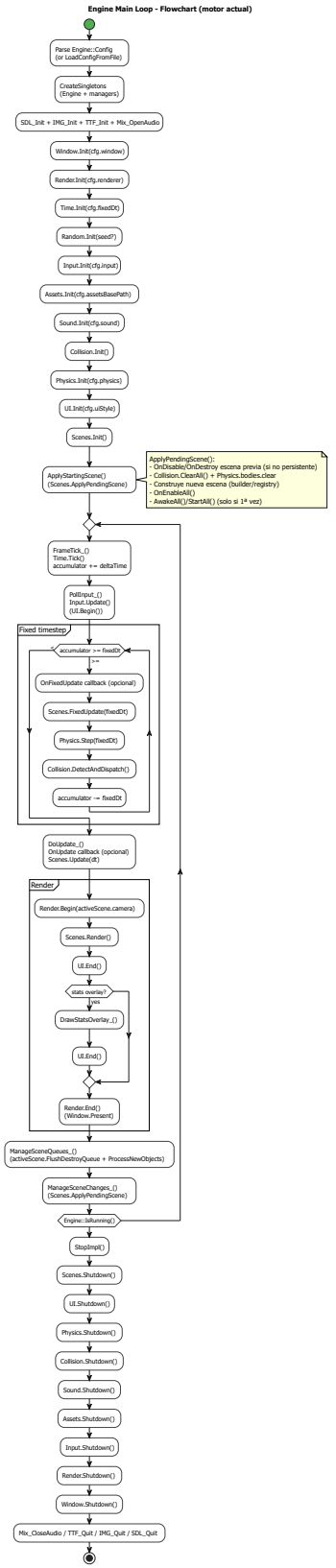
6. Main Game Loop (How It Works Internally)

The engine is single-threaded by default and follows a stable classic loop:

1. **Time tick**
   - `TimeManager::Tick()` updates delta time (with timeScale)
2. **Input polling**
   - `InputManager::Update()` stores pressed/down/released for keyboard + mouse
3. **FixedUpdate**
   - Accumulator loop:
     - while `accumulator >= fixedDt`, run fixed step(s)
   - Used for physics and deterministic logic
4. **Update**
   - Variable time gameplay logic using `deltaTime`
5. **Render**
   - Render current scene using active camera through RenderManager
6. **Safe queues**
   - Flush destroy queue (remove objects safely after updates)
   - Apply pending scene switch

This avoids deleting objects during iteration and keeps lifecycle deterministic.

6.1 Engine Flowchart



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7. Scene System & Lifecycle

7.1 Ownership and safe destruction

- A `Scene` owns `GameObject` instances (`unique_ptr`).
- `DestroyObject()` enqueues IDs.
- `FlushDestroyQueue()` removes objects in a safe moment (after updates).

7.2 Unity-like lifecycle

For each GameObject and its Components: - **Awake**: once when scene loads - **Start**: once before first frame - **FixedUpdate / Update / Render**: per frame (if active) - **OnDestroy**: cleanup hook

Behaviours add: - **OnEnable / OnDisable** when activation changes

7.3 Instantiation workflows

XEngine supports both: - **Prefab-like cloning** (copy an existing GameObject tree) - **Builder-style instantiation** (recommended extension / workflow) - `Instantiate(name, lambda(go){ ...add components... })`

The builder approach avoids complex generic cloning and makes construction explicit.

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8. GameObject, Components, and Transform

8.1 Composition model

- A `GameObject` is a container of Components.
- Components implement behaviour (render, physics, scripts).
- Some components are *unique* (e.g., Transform-like pattern).

8.2 Hierarchy

- GameObjects can be parented.
- Transform works with local/world conversions and caching (dirty flags).
- Parent transforms affect children automatically.

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9. Rendering System

9.1 Renderer backend

- Uses `SDL_Renderer` for drawing.
- RenderManager provides world-space and screen-space draw calls.

9.2 Sprite rendering

`SpriteRenderer` typically supports: - Texture + source rectangle (spritesheets) - Tint (RGBA) - Rotation + pivot (0..1) - Flip X/Y - Local offsets

9.3 Camera2D

Camera provides: - Center position - Zoom - Base view size - World <-> screen conversion - Follow and clamp helpers

9.4 Debug tools

- Debug lines/rectangles (world space)
- Optional stats overlay (FPS, frame time, draw calls)

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10. Assets Layer (SDL Wrappers + Caching)

XEngine wraps SDL resources into **move-only C++ asset types** instead of passing raw pointers everywhere.

10.1 SDL wrapper types

The engine defines wrappers: - `Texture` wraps `SDL_Texture*`, stores width/height and supports pixels-per-unit metadata - `Font` wraps `TTF_Font*` - `SoundEffect` wraps `Mix_Chunk*` - `Music` wraps `Mix_Music*`

Important design points: - They are **move-only** (copy disabled) to avoid double-free and accidental shared ownership - Destructors release the underlying SDL resources (RAII) - Internal access uses `GetSDL()` for systems that must call SDL directly (e.g., RenderManager / SoundManager)

10.2 AssetManager caching

`AssetManager` is responsible for: - Loading assets once and caching them (by path and/or by logical key). - Storing them as `std::unique_ptr<...>` in internal maps (textures, fonts, sfx, music). - Providing `LoadX()` and `GetX()` methods (plus `ByKey` variants).

This keeps: - file I/O and SDL load calls centralized - consistent error handling/logging - stable asset lifetime across the whole game

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11. Audio System (SoundManager)

SoundManager handles playback using the asset wrappers above.

Key features: - Configurable SFX channel pool (default example: 32 channels) - Global master volume applied to music and SFX - Optional **ducking** (reduce music volume while SFX are playing) with tunable duck volume and attack/release timings

Public API overview: - Music: `PlayMusic(...)`, `StopMusic()`, `IsMusicPlaying()` - SFX: `PlaySFX(...)`, `StopAllSFX()`, `StopSFXChannel()`, `IsAnySFXPlaying()` - Runtime tuning: `SetMasterVolume()`, `SetSFXChannelCount()`

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12. Input System

InputManager supports: - Keyboard: down / pressed / released - Mouse buttons: down / pressed / released - Mouse position + delta + wheel - Text input buffer (useful for UI and debug tools) - World-space mouse position via camera conversions

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13. Collision & Physics

13.1 CollisionManager

Responsible for: - Broadphase pair generation - Narrowphase collision tests (OBB/Circle combinations) - Trigger vs solid handling - Event dispatch: - `OnCollisionEnter/Stay/Exit` - `OnTriggerEnter/Stay/Exit`

Collision info can include contact points (point/normal/penetration) for physics response.

13.2 PhysicsManager

Provides: - Rigidbody integration (gravity, damping, constraints) - Impulse-based solver (restitution) - Positional correction to reduce overlap/sinking - Substepping for fast bodies (lightweight CCD approach)

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14. UI System (Immediate Mode)

UIManager provides a compact immediate-mode UI: - Panels, labels, images - Buttons (with hover/active states) - Invisible buttons - Checkbox / progress bar (if included in your build)

The UI renders in screen-space and uses fonts/textures from AssetManager.

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15. Two Games Built With XEngine

Two small games were developed to validate XEngine in real projects and showcase different engine features in practice.

Game 1 — Blob's Quest

- **Genre:** Top-down / twin-stick shooter
- **Core mechanics:** Move, shoot, avoid enemies, collect coins to increase score.
- **Engine features showcased:**
  Input handling, Scene management (restart/reload), Physics + Collisions (enemies/projectiles/pickups), UI (score + health bar + restart button), SFX + Music through the Asset pipeline.
- **Notable implementation detail:**
  The floor/background uses a **tiled physical background mode** instead of spawning many GameObjects, keeping the scene lightweight and efficient.
- **Gameplay:**

Game 2 — My Princess Run

- **Genre:** Endless runner
- **Core mechanics:** Jump and avoid obstacles while the run speed and score increase.
- **Engine features showcased:**
  SpriteRenderer + animation via custom Behaviour, runtime instantiation/spawning, Physics + Collisions for obstacle hits, UI image buttons, multi-layer parallax backgrounds.
- **Notable implementation detail:**
  The game uses a **"treadmill" scrolling approach** (environment moves and wraps) plus **parallax layers** at different speeds to add depth.
- **Gameplay:**

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16. Extending XEngine (Planned / Possible Improvements)

XEngine is designed to be extended. Possible next steps:

16.1 Multithreading (Recommended extension)

A natural evolution is adding **multithreading** to reduce frame time and improve scalability.

Good candidates for parallel work: - **Asset loading** on a background thread
(async texture/audio loading + main-thread upload to SDL renderer when ready) - **Physics** running in its own step thread - **Rendering** on its own thread to improve FPS (careful sync point before rendering; double-buffer transforms/contact data) - **Collision broadphase** / spatial partitioning updates in parallel - **Audio mixing / streaming** improvements (depending on backend constraints) - **Job system** (thread pool) with small tasks: AI updates, animation updates, particle updates

16.2 Tooling & workflow

- Scene serialization (save/load scenes to JSON)
- Editor/debug tooling (in-engine debug UI, gizmos, inspectors)
- Hot-reload for textures/audio/fonts

16.3 Rendering upgrades

- Sprite batching / sorting by texture to reduce draw calls
- Animation system (spritesheets + state machines)
- Particle system
- 2D lighting

16.4 Physics upgrades

- Friction (static + dynamic)
- Better contact manifolds (multiple contacts)
- Joints (distance/hinge/spring)
- True swept-shape CCD

16.5 UI upgrades

- Layout system (vertical/horizontal layout groups)
- Input widgets (sliders, text fields)
- UI scaling for different resolutions/aspect ratios

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17. Conclusion

XEngine provides a complete foundation for building 2D games in C++/SDL: - Clean Scene/GameObject/Component architecture with predictable lifecycle - Stable engine loop with fixed-step physics - Camera-based rendering with sprites, debug tools, and UI - Strong developer ergonomics via **BaseTypes** and the **Property system** - Robust resource management through an **asset-wrapper layer** and caching manager - A clear path for future extensions such as **multithreading**, tooling, and advanced rendering/physics