Module Guide for SFWRENG 4G06 - Capstone Design Project

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1 Revision History

Date	Version	Notes
Nov 13	1.0	Initial doc
Jan 13	1.1	Added Slime Mold Algorithm modules (M16-M18) per Issue #75
Jan 19	1.2	Various formatting fixes

2 Abbreviations and Acronyms

Abbreviation	Definition
AC	Anticipated Change
DAG	Directed Acyclic Graph
GPU	Graphics Processing Unit
M	Module
MG	Module Guide
OS	Operating System
R	Requirement
SC	Scientific Computing
SMA	Slime Mold Algorithm
SRS	Software Requirements Specification
UC	Unlikely Change

Table 1: Abbreviations and Acronyms

3 Notation

The structure of the Module Guide (MG) for modules follows [1], with adaptations for Unity game engine components and 2D geometric operations. The mathematical notation comes from Chapter 3 of [1] and standard computational geometry references. For instance, the symbol := is used for assignment statements and conditional rules follow the form $(c_1 \Rightarrow r_1 | c_2 \Rightarrow r_2 | ... | c_n \Rightarrow r_n)$.

3.1 Primitive Data Types

The following table summarizes the primitive data types used by the Destructible Environment System.

Data Type	Notation	Description
character	char	A single symbol or digit
integer	$\mathbb{Z}$	A number without a fractional component in $(-\infty, \infty)$
natural number	$\mathbb{N}$	A number without a fractional component in $[1, \infty)$
real	$\mathbb{R}$	Any number in $(-\infty, \infty)$
boolean	$\mathbb{B}$	A truth value: true or false

3.2 Derived Data Types

The Destructible Environment System uses several derived data types: sequences, vectors, polygons, and tuples.

Sequences are lists filled with elements of the same data type, denoted as seq of T where T is the element type (ex. seq of Vector2 represents a sequence of 2D points).

Vectors represent 2D points or directions in space:

- Vector2 := $(x : \mathbb{R}, y : \mathbb{R})$

Polygons are sequences of vertices that form closed shapes:

- Polygon := seq of Vector2

Tuples contain a list of values and can be of different types. For example (Vector2, Vector2, $\mathbb{R}$) represents a tuple containing two 2D vectors and a real number.

Functions are defined by the data types of their inputs and outputs. Local functions are described by giving their type signature followed by their specification. For example:

- distance: Vector2 $\times$ Vector2 $\to \mathbb{R}$

3.3 Geometric Notation

The following geometric primitives and operations are used throughout the system:

Symbol	Type	Description
P_{entry}	Vector2	Entry point where cutting ray intersects object surface
P_{exit}	Vector2	Exit point where cutting ray leaves object surface
V	seq of Vector2	Ordered sequence of vertices defining a polygon
C	Vector2	Centroid (geometric center) of a polygon
$\hat{d}$	Vector2	Normalized direction vector where $\|\hat{d}\| = 1$
$\hat{n}$	Vector2	Unit normal (perpendicular) vector to $\hat{d}$
$\theta(P, C)$	$\mathbb{R}$	Angle from centroid C to point P

3.4 Cut Profile Parameters

Material cutting behaviour is defined by the following parameters:

Parameter	Type	Range	Description
σ	$\mathbb{R}$	$[0, 1]$	Softness coefficient: 0 = jagged, 1 = smooth
ψ	$\mathbb{R}$	$[0, 1]$	Strength coefficient: 0 = clean cut, 1 = max irregularity
n_{seg}	$\mathbb{N}$	$[3, 15]$	Number of segments along cut edge
δ_{max}	$\mathbb{R}$	$\mathbb{R}^+$	Maximum perpendicular offset from cut line

3.5 Physics Parameters

The following parameters govern the physical behaviour of objects and debris:

Parameter	Type	Description
m	$\mathbb{R}^+$	Mass of an object in kilograms
A	$\mathbb{R}^+$	Area of a polygon in square units
v	Vector2	Linear velocity vector
ω	$\mathbb{R}$	Angular velocity in degrees per second
F_{exp}	$\mathbb{R}^+$	Explosion force magnitude
κ	$\mathbb{R}^+$	Mass multiplier constant for debris fragments

3.6 Operators and Functions

3.6.1 Logical Operators

- $\wedge$: logical AND
- $\vee$: logical OR
- $\neg$: logical NOT
- $\Rightarrow$: implies

3.6.2 Set Operators

- $\in$: element of
- $\cup$: union
- $\cap$: intersection
- $\subseteq$: subset of
- $|$: such that (set builder notation)

3.6.3 Geometric Functions

Side(L, P): Determines which side of line L a point P lies on

- Type: (Vector2 $\times$ Vector2) $\times$ Vector2 $\to \mathbb{R}$
- Returns: positive (right), negative (left), or zero (on line)
- Definition: $(L_{end}.x - L_{start}.x) \times (P.y - L_{start}.y) - (L_{end}.y - L_{start}.y) \times (P.x - L_{start}.x)$

Area(V): Calculates the area of a polygon using the shoelace formula

- Type: seq of Vector2 $\to \mathbb{R}^+$
- Definition: $\frac{1}{2}|\sum_{i=0}^{n-1}(v_i.x \times v_{i+1}.y - v_{i+1}.x \times v_i.y)|$

Distance(P_1, P_2)**:** Euclidean distance between two points

- Type: Vector2 $\times$ Vector2 $\to \mathbb{R}^+$
- Definition: $\sqrt{(P_2.x - P_1.x)^2 + (P_2.y - P_1.y)^2}$

Normalize(v): Converts vector to unit length

- Type: Vector2 $\to$ Vector2
- Definition: $v/\|v\|$ where $\|v\| = \sqrt{v.x^2 + v.y^2}$

Lerp(a, b, t): Linear interpolation between values a and b

- Type: $\mathbb{R} \times \mathbb{R} \times \mathbb{R} \to \mathbb{R}$ where $t \in [0, 1]$
- Definition: $a + (b - a) \times t$

Sort_CW(V): Sorts vertices in clockwise order around their centroid

- Type: seq of Vector2 $\to$ seq of Vector2
- Ordering based on increasing $\theta(v_i, C)$

Snap(P, p_{size})**:** Snaps point to nearest grid position

- Type: Vector2 $\times \mathbb{R}^+ \to$ Vector2
- Definition: $(\lfloor P.x/p_{size} + 0.5 \rfloor \times p_{size}, \lfloor P.y/p_{size} + 0.5 \rfloor \times p_{size})$

3.7 Conditional Notation

Conditional rules in specifications follow the format:

$(c_1 \Rightarrow r_1 | c_2 \Rightarrow r_2 | ... | c_n \Rightarrow r_n)$

where c_i represents a condition and r_i represents the corresponding result. The conditions are evaluated in order and the first true condition determines the result.

3.8 State Variables

State variables represent the mutable state of system components:

- V_{visual} : seq of Vector2 - Current visual mesh vertices
- $V_{collider}$: seq of Vector2 - Current physics collider vertices
- highlighted : $\mathbb{B}$ - Whether object is currently highlighted
- cultivated : $\mathbb{B}$ - Whether a valid cut is currently targeted

3.9 Module Access Constants

The following constants define access restrictions for module operations:

- **exported:** Operation is accessible to external modules
- **local:** Operation is only accessible within the module
- **read-only:** State can be read but not modified externally

4 Introduction

Decomposing a system into modules is a commonly accepted approach to developing software. A module is a work assignment for a programmer or programming team [4]. We advocate a decomposition based on the principle of information hiding [2]. This principle supports design for change, because the "secrets" that each module hides represent likely future changes. Design for change is valuable in SC, where modifications are frequent, especially during initial development as the solution space is explored.

Our design follows the rules layed out by [4], as follows:

- System details that are likely to change independently should be the secrets of separate modules.
- Each data structure is implemented in only one module.
- Any other program that requires information stored in a module's data structures must obtain it by calling access programs belonging to that module.

After completing the first stage of the design, the Software Requirements Specification (SRS), the Module Guide (MG) is developed [4]. The MG specifies the modular structure of the system and is intended to allow both designers and maintainers to easily identify the parts of the software. The potential readers of this document are as follows:

- New project members: This document can be a guide for a new project member to easily understand the overall structure and quickly find the relevant modules they are searching for.
- Maintainers: The hierarchical structure of the module guide improves the maintainers' understanding when they need to make changes to the system. It is important for a maintainer to update the relevant sections of the document after changes have been made.
- Designers: Once the module guide has been written, it can be used to check for consistency, feasibility, and flexibility. Designers can verify the system in various ways, such as consistency among modules, feasibility of the decomposition, and flexibility of the design.

The rest of the document is organized as follows. Section 5 lists the anticipated and unlikely changes of the software requirements. Section 6 summarizes the module decomposition that was constructed according to the likely changes. Section 7 specifies the connections between the software requirements and the modules. Section 8 gives a detailed description of the modules. Section 9 includes two traceability matrices. One checks the completeness of the design against the requirements provided in the SRS. The other shows the relation between anticipated changes and the modules. Section 10 describes the use relation between modules. Section 11 covers the key user interfaces the system uses. Section 12 describes the design of communication protocols. Section 13 details the development timeline and team responsibilities for the project.

5 Anticipated and Unlikely Changes

This section lists possible changes to the system. According to the likeliness of the change, the possible changes are classified into two categories. Anticipated changes are listed in Section 5.1, and unlikely changes are listed in Section 5.2.

5.1 Anticipated Changes

Anticipated changes are the source of the information that is to be hidden inside the modules. Ideally, changing one of the anticipated changes will only require changing the one module that hides the associated decision. The approach adapted here is called design for change.

AC1: Hardware that the game is made available in (Windows, Mac, Linux, Android, iOS, etc.).

AC2: Input device being used (mouse and keyboard, touchscreen, etc.).

AC3: Rendering resolution and pixel density for different display types.

AC4: Material properties for different destructible objects (softness, strength, friction, texture patterns, etc.).

AC5: Number, size, shape and behaviour of debris objects generated from cuts in destructible objects.

AC6: Pixel size used for pixelated cut edge rendering.

AC7: Algorithm used for irregular edge generation when destroying objects.

AC8: Debug and production visualization style of the cutting line and intersection points (colors, sizes, styles).

AC9: The physics properties of the environment (i.e. intensity of gravity).

AC10: Methodology for cut object selection (top, bottom, closest to player).

AC11: Mesh triangulation algorithm (Bresenhan algorithm versus alternatives).

AC12: Format and storage location of cut profile configuration data (JSON, databases, etc.).

AC13: Force range and patterns for destructible environment.

AC14: The lifetime and cleanup behaviour of debris fragments after spawning from destroyed objects.

AC15: The collision detection layers and filtering rules/parameters for raycasting.

AC16: Number of slime mold agents and simulation resolution.

AC17: Slime mold agent movement parameters (speed, turn rate, sensor angles).

AC18: Trail diffusion and evaporation rates for pheromone simulation.

AC19: Attraction source types and strength parameters (water, light, etc.).

AC20: The availability of accessibility modes, such as contrast adjustments for colorblindness.

5.2 Unlikely Changes

The module design should be as general as possible. However, a general system is more complex. Sometimes this complexity is not necessary. Fixing some design decisions at the system architecture stage can simplify the software design. If these decision should later need to be changed, then many parts of the design will potentially need to be modified. Hence, it is not intended that these decisions will be changed.

UC1: Game engine (Unity).

UC2: Dimensionality (2D).

UC3: Focus and use of physics simulation for object behaviour and world simulation.

UC4: Requirement for real-time object destruction physics.

UC5: The fundamental geometric representation of objects as pixel-based polygons.

UC6: Use of entry and exit points as a basis of destructive tools.

UC7: The partitioning of objects into two entities (original object, cut off object) per tool use.

UC8: The coordinate system (right-handed 2D cartesian coordinates).

UC9: Use of mesh rendering techniques for displaying cut objects.

UC10: Use of GPU compute shaders for slime mold simulation.

6 Module Hierarchy

This section provides an overview of the module design. Modules are summarized in a hierarchy decomposed by secrets in Table 2. The modules listed below, which are leaves in the hierarchy tree, are the modules that will actually be implemented.

Level 1	Level 2	Ref
Hardware-Hiding	Unity Input System	M1
	Unity Physics 2D	M2
	Unity Rendering	M3
	Unity Collider System	M4
Behaviour-Hiding	Player Control	M5
	Raycast Visualization	M6
	Cut Execution	M7
	Debris Generation	M8
	Cut Profile Manager	M9
Software Decision	Geometric Operations	M10
	Polygon Partitioning	M11
	Mesh Generation	M12
	Pixelation	M13
	Physics Update	M14
	Material Properties	M15
	Slime Mold Simulation	M16
	Slime Mold Manager	M17
	Attraction Source	M18

Table 2: Module Hierarchy

7 Connection Between Requirements and Design

The design of the system is intended to satisfy the requirements developed in the SRS. In this stage, the system is decomposed into modules. The connection between requirements and modules is listed in Table 3.

7.1 Design Decisions

The following design decisions are made to bridge the gap between requirements and implementation:

DD1: Dual Representation
All cut objects have a pixelated mesh texture using Bresenham algorithm applied to them in contrast with the smooth collision mesh even if the cut was irregular and/or diagonal in order to ensure adherence to the visual style (R6).
Related modules: M12, M13

DD2: Material Profile System In order to meet the requirement for different cutting behaviour on different materials (R5) a JSON-based configuration system maps material names/tags to extendable cutting parameters (softness and strength).
Related modules: M9, M15

DD3: Modular Cutting Pipeline
Cutting object flow can be broken into the following key phases of visualization, partitioning, mesh generation, and debris spawning thereby allowing each phase to be optimized independently and meeting the requirement for real-time interactive cutting (R3) in an extendable and maintainable way.
Related modules: M6, M7, M11, M12, M8

DD4: Entry-Exit Point Model
In order for players to have a clear understanding of what the tool destroys (R2), cuts are defined by exactly two intersection points for each object (entry and exit) which simplifies the logic and provides clear visualization and working feedback to the player.
Related modules: M6, M7

DD5: Area-Proportional Mass
For realistic physics behaviour after cutting (R4), object mass is updated proportionally to the change in area, maintaining consistent density.
Related modules: M10, M14

8 Module Decomposition

Modules are decomposed according to the principle of "information hiding" proposed by Parnas et al. [4]. The Secrets field in a module decomposition is a brief statement of the design decision hidden by the module. The Services field specifies what the module will do without documenting how to do it. For each module, a suggestion for the implementing software is given under the Implemented By title. If the entry is OS, this means that the module is provided by the operating system or by standard programming language libraries. ProgName means the module will be implemented by the ProgName software.

Only the leaf modules in the hierarchy have to be implemented. If a dash (-) is shown, this means that the module is not a leaf and will not have to be implemented.

8.1 Hardware Hiding Modules

8.1.1 Unity Input System (M1)

Secrets: The data structure and algorithm used to detect and process user input events (mouse position, button presses, keyboard input).

State Variables:

- $mousePosition : \mathbb{R}^2$ — Current mouse position in screen coordinates
- $mouseButtonDown : \mathbb{B}$ — Whether left mouse button is pressed
- $keyboardInput$: seq of char — Currently pressed keyboard keys

Environment Variables:

- Physical mouse device
- Physical keyboard device
- Screen resolution and DPI

Access Programs:

Name	In	Out	Exceptions
GetMousePosition	-	Vector2	-
GetMouseButton	int	$\mathbb{B}$	-
GetKey	KeyCode	$\mathbb{B}$	-
ScreenToWorldPoint	Vector2	Vector2	-

Services: Detects mouse movement and clicks for aiming and tool use, detects keyboard input for player movement and jumping and translates screen coordinates to world coordinates.

Implemented By: Unity (UnityEngine.InputSystem)

Type of Module: Library

8.1.2 Unity Physics2D (M2)

Secrets: Library used for rigid bodies, physics, and collisions.

State Variables:

- $gravity : \mathbb{R}^2$ — Global gravity vector
- $physicsTimeStep : \mathbb{R}^+$ — Fixed time step for physics updates

Environment Variables:

- System time
- CPU processing capabilities

Access Programs:

Name	In	Out	Exceptions
Raycast	Vector2, Vector2, $\mathbb{R}$, LayerMask	RaycastHit2D	-
AddForce	Rigidbody2D, Vector2	-	-
OverlapPoint	Vector2	Collider2D	-

Services: Performs 2D raycasting with filtering, manages Rigidbody2D components, detects collisions between 2D colliders, applies forces and velocities to objects, simulates gravity and momentum.

Implemented By: Unity (UnityEngine.Physics2D)

Type of Module: Library

8.1.3 Unity Rendering (M3)

Secrets: The algorithm for rendering 2D sprites, meshes, and line renderers to the screen with proper depth sorting.

State Variables:

- *renderQueue* : seq of RenderObject — Queue of objects to render
- *sortingLayers* : seq of Layer — Defined sorting layers

Environment Variables:

- Graphics card capabilities
- Display output device
- Screen resolution

Access Programs:

Name	In	Out	Exceptions
DrawMesh	Mesh, Material	-	-
DrawSprite	Sprite, Vector2	-	-
DrawLine	Vector2, Vector2, Color	-	-

Services: Renders sprites, renders dynamically generated meshes with textures, renders LineRenderer components for visualization, manages render order and sorting layers, applies materials and shaders.

Implemented By: Unity (UnityEngine.Rendering, UnityEngine.SpriteRenderer, UnityEngine.LineRenderer)

Type of Module: Library

8.1.4 Unity Collider System (M4)

Secrets: The data structure and algorithm for storing and querying 2D collider shapes, including dynamic collider modification.

State Variables:

- *colliders* : seq of Collider2D — All active colliders in scene
- *collisionMatrix* : LayerMask × LayerMask → $\mathbb{B}$ — Layer collision matrix

Environment Variables: None

Access Programs:

Name	In	Out	Exceptions
CreatePolygonCollider	seq of Vector2	PolygonCollider2D	-
UpdateColliderPoints	PolygonCollider2D, seq of Vector2	-	-
GetColliderBounds	Collider2D	Bounds	-

Services: Provides BoxCollider2D and PolygonCollider2D components also used to update collider shapes dynamically at runtime for objects and manages collider events.

Implemented By: Unity (UnityEngine.Collider2D, UnityEngine.PolygonCollider2D, UnityEngine.BoxCollider2D)

Type of Module: Library

8.2 Behaviour-Hiding Modules

Secrets:

The contents of the required behaviours.

Services:

Includes programs that provide externally visible behaviour of the system as specified in the software requirements specification (SRS) documents. This module serves as a communication layer between the hardware-hiding module and the software decision module. The programs in this module will need to change if there are changes in the SRS.

Implemented By:

–

8.2.1 Player Controller (M5)

Secrets: Controls behaviour of the player character such as movement speed, jump height, ground detection, etc.

State Variables:

- $playerPosition : \mathbb{R}^2$ — Current position of player
- $playerVelocity : \mathbb{R}^2$ — Current velocity vector
- $isGrounded : \mathbb{B}$ — Whether player is touching ground
- $moveSpeed : \mathbb{R}^+$ — Movement speed in units/second
- $jumpForce : \mathbb{R}^+$ — Upward force applied when jumping

Environment Variables:

- User input from M1
- Physics simulation from M2

Exported Constants

- $DEFAULT\_MOVE\_SPEED = 5.0$
- $DEFAULT\_JUMP\_FORCE = 10.0$
- $GROUND\_CHECK\_RADIUS = 0.2$

Access Programs:

Name	In	Out	Exceptions
Move	$\mathbb{R}$	-	-
Jump	-	-	exc := $\neg isGrounded$
UpdateGroundCheck	-	$\mathbb{B}$	-
InitializeRaycast	-	-	-

Services: Based on input from Unity's Input system, moves player character based on input, handles jumping when grounded, initializes and manages the raycast cutting system, visualizes ground check radius in editor.

Assumptions:

- The player GameObject has a Rigidbody2D component attached
- A ground layer exists and is properly configured in Unity's physics settings
- The Raycast module (M6) is initialized before player input is processed

Implemented By: PlayerController.cs

Type of Module: Abstract Object

8.2.2 Raycast Visualization Module (M6)

Secrets: How the cutting line and intersection points are visualized to the user, including colors, sizes, and rendering properties.

State Variables:

- $lineStartPoint : \mathbb{R}^2$ — Start position of cutting line
- $lineEndPoint : \mathbb{R}^2$ — End position of cutting line
- $entryPoint : \mathbb{R}^2$ — Entry intersection point
- $exitPoint : \mathbb{R}^2$ — Exit intersection point
- $targetObject$: GameObject — Currently targeted object
- $lineColor$: Color — Color of visualization line

Environment Variables:

- Mouse position from M1
- Raycast results from M2
- Rendering system from M3

Exported Constants

- $ENTRY\_POINT\_COLOR$ = Green
- $EXIT\_POINT\_COLOR$ = Orange
- $LINE\_WIDTH = 0.05$
- $POINT\_RADIUS = 0.1$

Access Programs:

Name	In	Out	Exceptions
DrawCuttingLine	Vector2, Vector2	-	-
DrawIntersectionPoints	Vector2, Vector2	-	-
HighlightCutRegion	seq of Vector2	-	-
DetectMouseClick	-	$\mathbb{B}$	-

Services: Draws a line from player to mouse cursor, displays entry point (green dot) and exit point (orange dot) on target object, highlights the portion of object that will be cut off, filters out invalid raycast targets (player, debris), detects mouse clicks to execute cuts.

Assumptions:

- Target objects have PolygonCollider2D components for accurate intersection detection
- LineRenderer components are available for visualization
- The camera is orthographic for consistent screen-to-world coordinate conversion

Implemented By: Raycast.cs

Type of Module: Abstract Object

8.2.3 Tool Raycast (M7)

Secrets: Coordinates between controller, reshape and debris systems as the executor and manager of the tool use.

State Variables:

- $currentCutTarget$: GameObject — Object being cut
- $entryPoint$: $\mathbb{R}^2$ — Cut entry point
- $exitPoint$: $\mathbb{R}^2$ — Cut exit point
- $cutLineDirection$: $\mathbb{R}^2$ — Direction of cut

Environment Variables:

- Visualization state from M6
- Material profiles from M9

Access Programs:

Name	In	Out	Exceptions
ExecuteCut	GameObject, Vector2, Vector2	-	exc := $target = null$
ApplyCutBehavior	GameObject, CutProfile	-	-
HighlightEdge	seq of Vector2	-	-
SelectCutPortion	GameObject	seq of Vector2	-

Services: Responsible for applying the appropriate cut behaviour and edge highlighting and cut selection coordinating between ObjectReshape and DebrisSpawner.

Assumptions:

- The target object implements the RaycastReceiver interface
- Cut profiles are loaded and available from M9 before cuts are executed
- Entry and exit points form a valid cutting line that intersects the object

Implemented By: RaycastReceiver.cs

Type of Module: Abstract Object

8.2.4 Debris Generation (M8)

Secrets: Generating and distributing debris fragments within the cut-off area, including fragment sizing and positioning.

State Variables:

- $activeDebris$: seq of GameObject — Currently active debris objects
- $debrisLifetime$: $\mathbb{R}^+$ — Time before debris cleanup
- $explosionForce$: $\mathbb{R}^+$ — Force applied to debris

Environment Variables:

- Physics system from M2
- Rendering system from M3
- Collider system from M4

Exported Constants

- $DEFAULT\_DEBRIS\_COUNT = 5$
- $DEFAULT\_LIFETIME = 10.0$
- $MASS\_MULTIPLIER = 0.1$

Access Programs:

Name	In	Out	Exceptions
SpawnDebris	seq of Vector2, int, Material	seq of GameObject	exc := $\|V\| < 3 \vee area \leq 0$
PositionFragment	Vector2, seq of Vector2	Vector2	-
ApplyExplosionForce	GameObject, Vector2, $\mathbb{R}$	-	-
CleanupDebris	GameObject	-	-

Services: Creates specified number of debris fragments based on object configuration and cut size, positions fragments within cut-off polygon using point-in-polygon testing, applies physics properties (mass, velocity, angular velocity) and applies explosion force radiating from cut centroid as well as managing debris lifetime and cleanup.

Assumptions:

- The cut-off polygon has sufficient area to contain debris fragments
- A debris prefab or template is available in the Unity project
- Physics simulation is active and configured correctly

Implemented By: DebrisSpawner.cs

Type of Module: Abstract Object

8.2.5 Cut Profile Manager (M9)

Secrets: Manager cut profiles and retrieval for material specific cutting profiles.

State Variables:

- $cutProfiles$: Tag $\rightarrow$ CutProfile — Mapping of tags to profiles
- $defaultProfile$: CutProfile — Default cutting parameters

Environment Variables:

- JSON configuration file

Exported Constants

- $DEFAULT\_SOFTNESS = 0.5$
- $DEFAULT\_STRENGTH = 0.5$
- $DEFAULT\_DEBRIS\_COUNT = 5$

Access Programs:

Name	In	Out	Exceptions
LoadProfiles	string	-	exc := invalid JSON
GetProfileForObject	GameObject	CutProfile	-
ApplyIrregularCut	seq of Vector2, CutProfile	seq of Vector2	-

Services: Loads cut profiles from JSON configuration and applies them based on object tag (otherwise supplies default profile when specific profile not found) and applies irregular cutting based on material properties (softness and strength parameters).

Assumptions:

- The JSON configuration file exists and follows the expected schema
- Objects have tags assigned that match profile keys in the configuration
- The configuration is loaded before any cutting operations are performed

Implemented By: CutProfileManager.cs

Type of Module: Abstract Object

8.3 Software Decision Modules

Secrets:

The design decision based on mathematical theorems, physical facts, or programming considerations. The secrets of this module are not described in the SRS.

Services:

Includes data structure and algorithms used in the system that do not provide direct interaction with the user.

Implemented By:

–

8.3.1 Geometric Operations (M10)

Secrets: Algorithms for fundamental geometric calculations on 2D shapes including the shoelace formula, cross products, and distance calculations.

State Variables: None (stateless module)

Environment Variables: None

Exported Constants

- $EPSILON = 10^{-6}$ — Floating point comparison tolerance

Access Programs:

Name	In	Out	Exceptions
CalculateArea	seq of Vector2	$\mathbb{R}^+$	-
CalculateCentroid	seq of Vector2	Vector2	-
CrossProduct	Vector2, Vector2	$\mathbb{R}$	-
Distance	Vector2, Vector2	$\mathbb{R}^+$	-
Normalize	Vector2	Vector2	exc := $\|v\| = 0$

Services: Calculates polygon areas for object reshaping after a cut is applied from the raycast for both colliders and mesh renders.

Assumptions:

- Input polygons are simple (non-self-intersecting) and closed
- Vertices are ordered consistently (clockwise or counter-clockwise)
- Floating point precision is sufficient for the scale of game objects

Implemented By: ObjectReshape.cs (geometric utility functions), PixelatedCutRenderer.cs (grid operations)

Type of Module: Library

8.3.2 Polygon Partitioning (M11)

Secrets: The algorithm for splitting a polygon into two parts, the original piece and the cutoff piece along a cut line using cross product side determination.

State Variables: None (stateless module)

Environment Variables: None

Access Programs:

Name	In	Out	Exceptions
PartitionPolygon	seq of Vector2, Vector2, Vector2	(seq of Vector2) × (seq of Vector2)	exc := intersections ≠ 2
DetermineKeepSide	seq of Vector2, seq of Vector2, Vector2	seq of Vector2	-
AddIntersectionPoints	seq of Vector2, Vector2, Vector2	seq of Vector2	-

Services: Partitions polygon vertices based on which side of cut line they fall on, adds entry and exit points to both resulting polygons and determines which partition matches highlighted shape using centroid comparison while preserving vertex ordering.

Assumptions:

- The cut line intersects the polygon at exactly two points (entry and exit)
- The polygon has at least 3 vertices
- Both resulting partitions are valid simple polygons

Implemented By: ObjectReshape.cs (CutOffPortion method)

Type of Module: Library

8.3.3 Mesh Generation Module (M12)

Secrets: Converting polygon vertices into renderable mesh data using ear clipping triangulation.

State Variables: None (stateless module)

Environment Variables:

- Rendering system from M3

Access Programs:

Name	In	Out	Exceptions
TriangulatePolygon	seq of Vector2	seq of int	exc := $\|V\| < 3$
GenerateUVs	seq of Vector2	seq of Vector2	-
CreateMesh	seq of Vector2, seq of int	Mesh	-
IsEar	Vector2, Vector2, Vector2, seq of Vector2	$\mathbb{B}$	-

Services: Implements ear-clipping algorithm to triangulate arbitrary polygons, automatically generates UV coordinates based on the polygon's bounding box, constructs Unity Mesh objects given the vertex data, supports both convex and concave shapes.

Assumptions:

- Input polygon is simple (non-self-intersecting)
- Polygon has at least 3 vertices to form a valid mesh
- Unity's rendering system is available and initialized

Implemented By: ObjectReshape.cs (UpdateVisualMesh, TriangulatePolygon methods)

Type of Module: Library

8.3.4 Pixelation Module (M13)

Secrets: For visual uniformity, converting smooth diagonal cut lines into pixel-aligned staircase patterns using a modified Bresenham approach.

State Variables: None (stateless module)

Environment Variables: None

Exported Constants

- $DEFAULT\_PIXEL\_SIZE = 0.0625$

Access Programs:

Name	In	Out	Exceptions
PixelateCutEdges	seq of Vector2, $\mathbb{R}^+$	seq of Vector2	exc := $pixelSize \leq 0$
SnapToGrid	Vector2, $\mathbb{R}^+$	Vector2	-
IdentifyCutEdges	seq of Vector2, Vector2, Vector2	seq of (int $\times$ int)	-

Services: Pixelates only cut edges while keeping original edges intact, snaps points to a pixel grid with floor-based rounding, creates staircase patterns with horizontal and vertical segments only.

Assumptions:

- Pixel size is positive and consistent across the game world
- Cut edges can be identified by their adjacency to entry/exit points
- The pixel grid aligns with the game's visual style

Implemented By: PixelatedCutRenderer.cs

Type of Module: Library

8.3.5 Physics Update Module (M14)

Secrets: The algorithm for updating physics properties after shape modification including the area-based mass calculation method.

State Variables: None (stateless module)

Environment Variables:

- Physics system from M2
- Collider system from M4

Access Programs:

Name	In	Out	Exceptions
UpdateCollider	GameObject, seq of Vector2	-	exc := $obj = null$
UpdateRigidbodyMass	Rigidbody2D, $\mathbb{R}^+$, $\mathbb{R}^+$	-	-
ConvertToPolygonCollider	GameObject	PolygonCollider2D	-

Services: Converts from BoxCollider2D to PolygonCollider2D to match new object shape and adjusts proportionally the RigidBody 2D mass to match the new area change using the shoelace area calculation, creates smooth collider for physics and pixelated visual mesh for visual consistency.

Assumptions:

- Original object has a valid Rigidbody2D component
- Original area is non-zero for mass ratio calculations
- The object remains valid for physics simulation after reshaping

Implemented By: ObjectReshape.cs (UpdateCollider, UpdateRigidbodyMass methods)

Type of Module: Library

8.3.6 Material Properties Module (M15)

Secrets: The data structure for storing material cutting characteristics and the algorithm for applying irregular edge offsets.

State Variables: None (stateless module)

Environment Variables: None

Exported Constants

- $MIN\_SEGMENTS = 3$
- $MAX\_SEGMENTS = 15$
- $SMOOTH\_THRESHOLD = 0.33$
- $JAGGED\_THRESHOLD = 0.67$

Access Programs:

Name	In	Out	Exceptions
GenerateIrregularEdge	Vector2, Vector2, $\mathbb{R}$, $\mathbb{R}$	seq of Vector2	-
CalculateSegmentCount	$\mathbb{R}$	$\mathbb{N}$	-
CalculateMaxOffset	$\mathbb{R}$, $\mathbb{R}$	$\mathbb{R}^+$	-
ApplySineWave	Vector2, Vector2, int, $\mathbb{R}$	seq of Vector2	-
ApplyRandomOffset	Vector2, Vector2, int, $\mathbb{R}$	seq of Vector2	-

Services: Defines softness parameter (0 = jagged and 1 = smooth) which affects segment count, defines strength parameter (0 = clean cut and 1 = maximum irregularity) affecting offset magnitude, generates irregular cut edges using different functions based on softness (sine waves for smooth, random for jagged and hybrid for medium).

Assumptions:

- Softness and strength parameters are normalized to the range $[0, 1]$
- The cut edge has sufficient length to accommodate the calculated segments
- Random number generation is seeded appropriately for consistent behaviour

Implemented By: CutProfileManager.cs (ApplyIrregularCut, GenerateIrregularEdge methods)

Type of Module: Library

8.4 Slime Mold Algorithm Modules

8.4.1 Slime Mold Simulation Module (M16)

Secrets: The GPU compute shader implementation for simulating slime mold agent behaviour, including movement, trail sensing, and pheromone deposition.

State Variables:

- $agents$: seq of Agent — Buffer containing all agent positions, angles, and types
- $trailMap$: Texture2D — 2D texture storing pheromone trail intensities
- $numAgents$: $\mathbb{N}$ — Number of active agents in simulation
- $moveSpeed$: $\mathbb{R}^+$ — Agent movement speed per frame
- $turnSpeed$: $\mathbb{R}^+$ — Maximum agent turn rate in degrees

Environment Variables:

- GPU compute capabilities
- System time for deltaTime calculations

Exported Constants

- $DEFAULT\_NUM\_AGENTS = 10000$
- $DEFAULT\_MOVE\_SPEED = 50.0$
- $DEFAULT\_TURN\_SPEED = 50.0$
- $DEFAULT\_SENSOR\_ANGLE = 30.0$

Access Programs:

Name	In	Out	Exceptions
InitializeAgents	int	-	exc := $numAgents \leq 0$
UpdateAgents	float	-	-
GetTrailMap	-	Texture2D	-
SetAttractionMaps	Texture2D, Texture2D	-	-

Services: Initializes agents in random positions, executes GPU compute shader to update agent positions based on trail sensing and attraction sources, applies trail diffusion and evaporation in post-processing pass, provides trail map texture for rendering.

Assumptions:

- GPU supports compute shaders (DirectX 11 / OpenGL 4.3 or higher)
- Sufficient GPU memory is available for agent buffers and trail textures
- Frame rate is stable enough for consistent deltaTime calculations

Implemented By: Slime.cs, Slime.compute

Type of Module: Abstract Object

8.4.2 Slime Mold Manager Module (M17)

Secrets: The coordination of multiple attraction sources and generation of attraction maps for the slime mold simulation.

State Variables:

- $waterSources$: seq of WaterSource — List of water attraction points
- $lightSources$: seq of LightSource — List of light attraction points
- $waterMap$: Texture2D — Generated water attraction intensity map
- $lightMap$: Texture2D — Generated light attraction intensity map
- $waterStrength$: $\mathbb{R}^+$ — Global water attraction multiplier
- $lightStrength$: $\mathbb{R}^+$ — Global light attraction multiplier

Environment Variables:

- Scene hierarchy for source discovery

Exported Constants

- $DEFAULT\_MAP\_RESOLUTION = 512$
- $DEFAULT\_UPDATE\_INTERVAL = 0.1$

Access Programs:

Name	In	Out	Exceptions
FindAllSources	-	-	-
UpdateAttractionMaps	-	-	-
GetWaterMap	-	Texture2D	-
GetLightMap	-	Texture2D	-

Services: Discovers attraction sources in scene hierarchy, generates 2D attraction maps with radial falloff from each source, coordinates with M16 to provide attraction data for agent steering, supports real-time source addition/removal.

Assumptions:

- Attraction sources are tagged or use specific component types for discovery
- Map resolution is sufficient to represent attraction gradients accurately
- The slime mold simulation module (M16) is initialized before maps are provided

Implemented By: SlimeMoldManager.cs

Type of Module: Abstract Object

8.4.3 Attraction Source Module (M18)

Secrets: The representation and configuration of individual attraction points that influence slime mold agent behaviour.

State Variables:

- $position : \mathbb{R}^2$ — World position of attraction source
- $radius : \mathbb{R}^+$ — Effective radius of attraction influence
- $strength : \mathbb{R}$ — Attraction strength multiplier (0-1)
- $isActive : \mathbb{B}$ — Whether source is currently affecting simulation

Environment Variables:

- Transform component for world position

Exported Constants

- $DEFAULT\_RADIUS = 5.0$
- $DEFAULT\_STRENGTH = 1.0$

Access Programs:

Name	In	Out	Exceptions
GetInfluence	Vector2	$\mathbb{R}$	-
SetActive	$\mathbb{B}$	-	-
GetWorldPosition	-	Vector2	-

Services: Calculates attraction influence at a given point using radial falloff function, provides visual debugging gizmos in editor, supports enable/disable for dynamic gameplay scenarios.

Assumptions:

- The attraction source has a valid Transform component for position
- Radius and strength values are positive
- The slime mold manager (M17) will periodically query all active sources

Implemented By: WaterSource.cs, LightSource.cs

Type of Module: Abstract Object

9 Traceability Matrix

This section shows two traceability matrices: Between the modules and the requirements, and between the modules and the anticipated changes.

Table 3: Trace Between Requirements and Modules

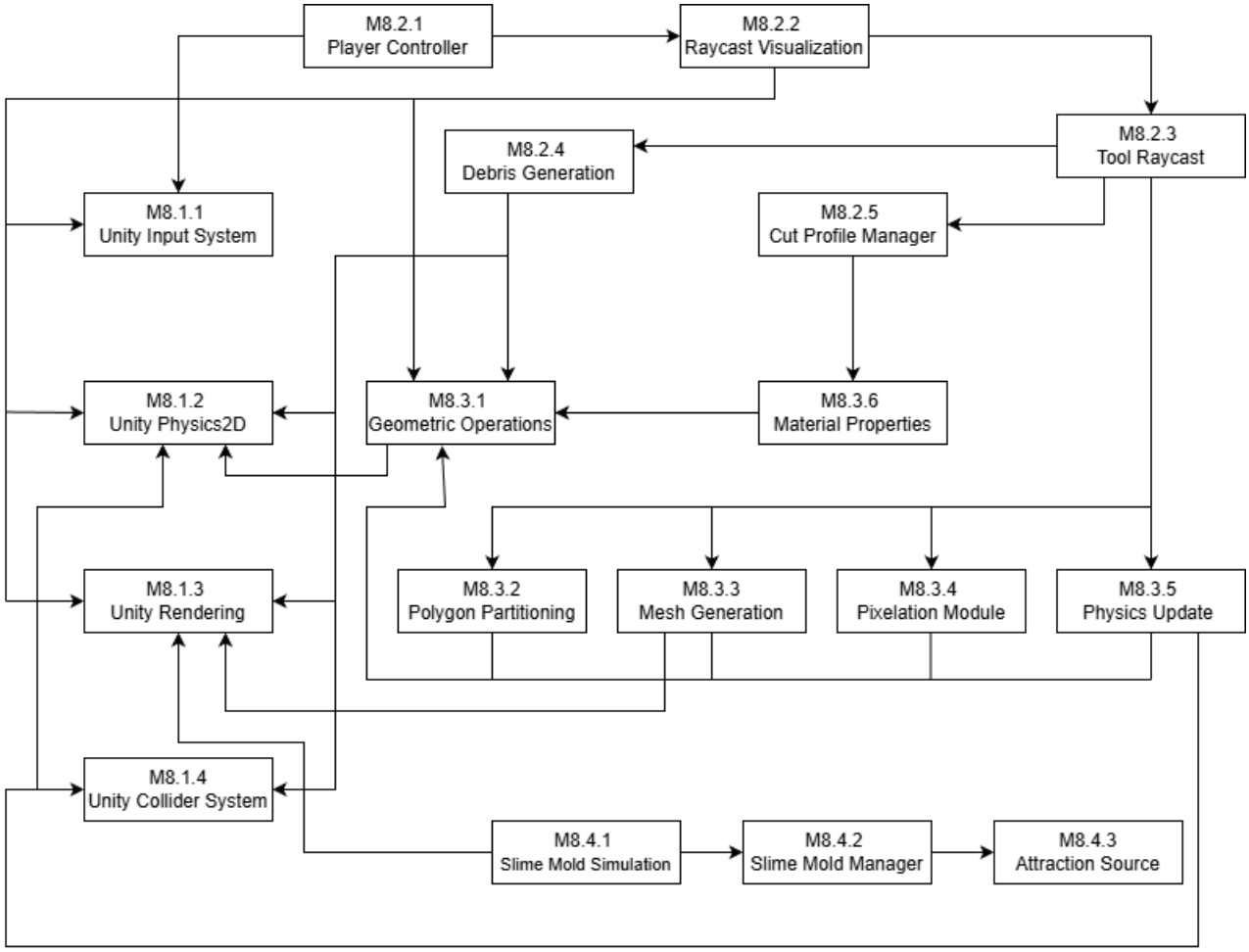
Requirement	**Modules**
R1: Player Movement and Control	M8.1.1, M8.1.2, M8.2.1
R2: Cutting Line Visualization	M8.1.1, M8.1.2, M8.1.3, M8.2.2
R3: Real-time Object Cutting	M8.1.2, M8.1.3, M8.1.4, M8.2.3, M8.3.1, M8.3.2, M8.3.3, M8.3.5
R4: Debris Generation	M8.1.2, M8.1.3, M8.1.4, M8.2.4, M8.3.1
R5: Material Specific Cutting	M8.2.3, M8.2.5, M8.3.6
R6: Pixelated Rendering	M8.1.3, M8.3.1, M8.3.3, M8.3.4
R7: Physics Simulation	M8.1.2, M8.1.4, M8.3.5
R8: Collision Detection	M8.1.2, M8.1.4, M8.2.2
R9: Visual Feedback	M8.1.3, M8.2.2, M8.2.3
R10: Multiple Cuts on Same Object	M8.2.3, M8.3.2, M8.3.3, M8.3.5
R11: Slime Mold Pathfinding	M8.4.1, M8.4.2, M8.4.3

Table 4: Trace between Anticipated Changes and Modules

AC	**Modules**
AC1	M8.1.1, M8.1.2, M8.1.3, M8.1.4
AC2	M8.1.1, M8.2.1
AC3	M8.1.3
AC4	M8.2.5, M8.3.6
AC5	M8.2.4
AC6	M8.3.4
AC7	M8.3.6
AC8	M8.2.2
AC9	M8.3.5
AC10	M8.2.3
AC11	M8.3.3
AC12	M8.2.5
AC13	M8.2.4
AC14	M8.2.4
AC15	M8.2.2
AC16	M8.4.1
AC17	M8.4.1
AC18	M8.4.1
AC19	M8.4.2, M8.4.3

10 Use Hierarchy Between Modules

The following graphic describes the direct dependencies between modules (A → B means A uses B):



10.1 Use Hierarchy Diagram

Table 5 shows the use hierarchy between modules organized by levels. Modules at higher levels use (depend on) modules at lower levels.

Level	Category	Modules
5	Application (User Interface)	M8.2.1 (Player Controller)
4	Coordination (Behaviour)	M8.2.2 (Raycast Visualization), M8.2.3 (Tool Raycast)
3	Services (Coordination)	M8.2.4 (Debris), M8.2.5 (Cut Profile), M8.4.2 (SMA Manager), M8.4.3 (Attraction)
2	Algorithm (Core)	M8.3.2, M8.3.3, M8.3.4, M8.3.5, M8.3.6, M8.4.1
1	Utility (Basic Operations)	M8.3.1 (Geometric Operations)
0	Foundation (Hardware)	M8.1.1 (Input), M8.1.2 (Physics), M8.1.3 (Rendering), M8.1.4 (Collider)

Table 5: Use Hierarchy Levels - Higher levels depend on lower levels

10.2 Use Hierarchy Levels (Detailed)

Level 0 (Foundation - Hardware Hiding)

- M8.1.1 - Unity Input System
- M8.1.2 - Unity Physics2D
- M8.1.3 - Unity Rendering
- M8.1.4 - Unity Collider System

Level 1 (Utility - Basic Operations)

- M8.3.1 - Geometric Operations

Level 2 (Algorithm - Core Computations)

- M8.3.2 - Polygon Partitioning
- M8.3.3 - Mesh Generation
- M8.3.4 - Pixelation
- M8.3.5 - Physics Update

- M8.3.6 - Material Properties
- M8.4.1 - Slime Mold Simulation

Level 3 (Services - System Coordination)

- M8.2.4 - Debris Generation
- M8.2.5 - Cut Profile Manager
- M8.4.2 - Slime Mold Manager
- M8.4.3 - Attraction Source

Level 4 (Coordination - Behaviour Management)

- M8.2.2 - Raycast Visualization
- M8.2.3 - Tool Raycast

Level 5 (Application - User Interface)

- M8.2.1 - Player Controller

11 User Interfaces

11.1 Input Interface

- **Movement:** Keyboard input (A/D or Left/Right arrow keys) for horizontal movement
- **Jump:** Spacebar or W key for jumping when grounded
- **Cutting Tool Aim:** Mouse position determines the cutting line direction from the player
- **Cut Execution:** Left mouse button click executes the cut on the targeted object

11.2 Visual Feedback

- **Cutting Line:** A visible line from the player to the mouse cursor indicates the cutting direction
- **Entry/Exit Points:** Green dot marks the entry point; orange dot marks the exit point on targeted objects
- **Cut Preview:** The portion of the object that will be cut off is highlighted before execution
- **Debris Visualization:** Cut-off portions and debris fragments are rendered with pixelated edges to maintain visual style

11.3 Hardware Requirements

- **Display:** Standard monitor capable of rendering 2D graphics
- **Input Devices:** Keyboard and mouse (primary), with potential future support for touchscreen
- **Graphics:** GPU with support for Unity's 2D rendering pipeline

12 Design of Communication Protocols

12.1 Inter-Module Communication

The system uses Unity's component-based architecture for module communication:

Event-Based Communication:

- **Input Events:** Unity's Input System generates events for mouse clicks, movement, and jumps
- **Collision Events:** Physics2D triggers `OnCollisionEnter2D` events when debris or cut pieces collide
- **Frame Events:** Unity's `Update()` and `FixedUpdate()` provide timing for continuous operations

Direct Method Calls:

- M6 (Raycast Visualization) calls M7 (Cut Execution) via `ExecuteCut()`
- M7 calls M11 (Polygon Partitioning) via `PartitionPolygon()`
- M7 calls M8 (Debris Generation) via `SpawnDebris()`
- M9 (Cut Profile Manager) is accessed via static extension method `GetCutProfileForObject()`

Component References:

- Modules get references using `GetComponent<T>()` for same-GameObject communication
- Modules use `FindObjectOfType<T>()` for singleton manager access
- Parent-child relationships use `GetComponentInChildren<T>()`

12.2 Data Flow

1. **Input Phase:** M1 → M5 → M6
2. **Visualization Phase:** M6 → M2 → M10 → M7
3. **Execution Phase:** M7 → M11 → M15 → M12 → M13 → M14 → M8
4. **Physics Phase:** M8 → M2 → M4

12.3 State Management

- Most modules are stateless (M10, M11, M12, M13, M14, M15)
- State-holding modules use private fields with controlled access (M6, M7, M8, M9)
- No global variables—all state is encapsulated in components
- State persists via Unity's serialization (inspector-editable fields marked with `[SerializeField]`)

13 Timeline

The development schedule and task assignments for this project are managed through GitHub's project management features. For the most up-to-date information on implementation status, task assignments, and milestones, please refer to:

- **GitHub Repository:** https://github.com/felix-hurst/Ad-Natura
- **Issues:** Task tracking and bug reports are managed through GitHub Issues
- **Milestones:** Major deliverables aligned with course deadlines (Rev0, Rev1 demonstrations)

13.1 Team Responsibilities

Team Member	Primary Module Responsibilities
Felix Hurst	Team Coordinator, Player Control (M8.2.1)
Andy Liang	SMA modules (M8.4.1, M8.4.2, M8.4.3)
Bowen Liu	Cutting System (M8.2.2–M8.3.6)
Marcos Hernandez-Rivero	Documentation, Testing, Integration Support

Table 6: Team Member Module Responsibilities

13.2 Development Phases

Phase 1: Core Cutting System (Completed)

- M10: Geometric Operations Module
- M11: Polygon Partitioning Module
- M12: Mesh Generation Module
- M14: Physics Update Module

Phase 2: User Interaction (Completed)

- M5: Player Control Module
- M6: Raycast Visualization Module
- M7: Cut Execution Module

Phase 3: Enhanced Features (Completed)

- M8: Debris Generation Module
- M9: Cut Profile Manager Module
- M15: Material Properties Module

Phase 4: Visual Polish (Not Complete)

- M13: Pixelation Module
- Visual feedback refinements
- Debug visualization tools

References

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