

Developer Guide: Solar System Simulator

1. Overview and Architecture

The Solar System Simulator is built as a *single-file application* using the Racket programming language, specifically the *Intermediate Student with Lambda (ISL+)* language level. It relies on the *big-bang* system from the *2htdp/universe* library to manage the simulation loop, state updates, and rendering.

The application state is centralized in a single structure (*SimState*), which is updated every clock tick to simulate physics and rendered every frame to display the simulation.

Source Files

- *solar.rkt*: The entire source code is contained within this single file. It includes data definitions, constant declarations, logic helpers, the physics engine, the rendering engine, and input handlers.

External Libraries

- *2htdp/image*: Used for all graphical operations. It handles loading external assets (e.g., *bitmap/file* for planet images), creating geometric primitives (e.g., *circle*, *rectangle* for UI), and compositing the scene using *place-image* and *overlay*.
- *2htdp/universe*: Provides the runtime engine. It manages the simulation loop via *big-bang*, linking the clock ticks (*on-tick*), rendering (*to-draw*), and input events (*on-key*, *on-mouse*).

2. Core Data Structures (The Model)

The simulation creates a virtual universe defined by the following key structures:

- *SimState*: The root structure representing the world at any specific moment. It holds the list of celestial bodies, the current camera settings (*zoom*, *Locked-body-name*), user interface state (*active-tab*, *gallery-index*), the *day-counter*, transient objects like the *asteroid-belt* and *active-comets*, and mission-specific fields: *active-missions* (list of current probes), *mission-mode* (UI state flag), *selected-departure*, and *sim-time* (absolute tick counter).
- *Probe*: A non-recursive structure tracking Cartesian physics (*x*, *y*, *vx*, *vy*), fuel, and launch status ("in-transit", "arrived").

- *Mission*: Wraps a *Probe* with its logical departure and target planets.
- *CelestialBody*: Represents a major planet. It contains physical properties (radius, orbit distance) and dynamic properties (current *angle*, *angular-speed*). Uniquely, it is a recursive structure that contains a list of *Satellite* structures (moons).
- *Location*: A helper structure used to map polar coordinates (orbit angle/distance) into Cartesian coordinates (x,y) for rendering.

3. Top-Level Functions

A. The Physics Engine: *next-world*

This function serves as the *State Updater*. Triggered every 1/100th of a second, it transforms the current *SimState* into the next valid state.

- *Time Scaling*: It retrieves the current simulation speed from the *SPEED-LEVELS* list using *speed-index*. This multiplier (*speed-mult*) allows the user to pause or accelerate time. Moreover, it updates the *day-counter* field to synchronize the calendar date with the movement of the planets.
- *Orbital Mechanics*: It calls the helper *update-bodies*, which recursively applies *next-body-state*. This increments the *angle* of every planet and moon based on their specific angular speeds.
- *Mission Physics*: Calls *update-missions-smart* to update position ($x+vx$) for all active probes, decrease fuel, and detect collisions with target planets (arrival logic).
- *Dynamic Entities*:
 - *update-asteroids*: Updates the orbital position of the asteroid belt.
 - *filter-comets & maybe-spawn-comet*: Updates the linear position of comets ($x+vx$), removes those that drift off-screen, and probabilistically spawns new ones.

B. The Rendering Engine: *draw-world*

This function is responsible for *Displaying the State*. It consumes the *SimState* and produces a single, composited *Image*.

- *Camera Logic*: The simulator does not use a static viewpoint.
 1. It searches for the currently locked planet using *find-body-by-name*.
 2. It converts that planet's angle and orbit radius into Cartesian coordinates (*target-Loc*) using *angle-to-Location*.
 3. All other objects are drawn relative to this *target-Loc*, ensuring the locked planet remains fixed at the screen center (*CENTER-X*, *CENTER-Y*).

- *Mission Layer*: If Mission Mode is active, it invokes *draw-intercept-trajectory* to render the predicted path using vector math. It also renders active probes with a trailing visual effect relative to the camera.
- *Layering*: The scene is built from back to front:
 1. *Space Scene*: Comets, asteroids, and planets are drawn using *draw-all-bodies*. This helper handles the scaling of bitmaps based on the *zoom* factor and draws orbital paths.
 2. *Interface*: The *draw-interface* function overlays the HUD, Legend, and Info Panel on top of the space scene. It handles the logic for displaying the correct text and gallery images based on *active-tab*, and includes logic to convert the *day-counter* into a readable *Year* and *Day* format (using floor and modulo arithmetic) for the Heads-Up Display.

C. Input Handling:

→ *handle-mouse*

This is the most complex control function, managing two distinct interaction layers simultaneously:

1. *UI Interaction*: Detects clicks within the Info Panel buttons to update the *active-tab* or *gallery-index*.
2. *Camera Control*: Clicking a planet updates *Locked-body-name*, triggering the camera to pan to that object. This functions in both normal and mission modes.
3. *Mission State Machine*: If *mission-mode* is active, the click simultaneously advances the mission logic: the first click sets the origin, and the second click sets the target and launches the probe.

→ *handle-key*

This function manages global simulation variables:

1. *Zooming*: Maps the Up/Down and +/- keys to increment or decrement the *zoom* field.
2. *Time Control*: Maps the 'i' and 'd' keys to modify the *speed-index*, altering the flow of time.
3. *Simulation Reset*: Maps the 'r' key to reload the INITIAL-STATE, effectively resetting the planets and the calendar to their starting positions.
4. *Controls*: Maps 'm' to toggle Mission Mode and 'r' to reset the simulation state and date.

4. Helper Utilities

Several utility functions support the main logic:

- *angle-to-location*: A math helper that converts the polar coordinates used for physics (r, β) into Cartesian coordinates used for drawing (x, y) using trigonometric functions (\cos, \sin).
- *get-planet-info*: A lookup function that returns static data (mass, diameter, description) for the UI panel based on the planet name.
- *find-body-by-name*: A recursive list search used by the camera system to locate the target planet's data.
- *calculate-intercept-trajectory*: Uses an iterative approximation algorithm to predict the future position of a target planet and computes the precise velocity vector (v_x, v_y) required for interception.