Deimos: Asteroid Simulator - NASA Space Apps Challenge

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Abstract

The study of Near-Earth Objects (NEOs) has become a topic of growing global interest. Various space agencies have dedicated significant time and resources to the investigation of these bodies, aiming to assess their potential risks and to develop mitigation strategies against possible impact events. In particular, Potentially Hazardous Asteroids (PHAs) are a major focus due to the potential consequences they may pose to both the environment and human life.

Within the framework of the NASA Space Apps Challenge, and under the "Meteor Madness" project, this initiative explores the development of technological solutions that contribute to public awareness and risk management regarding asteroid impacts. The project seeks to create a tool that facilitates both public and technical understanding of the phenomenon through the integration of scientific data and interactive visual resources.

1 Introduction

This report describes the development of an interactive, intuitive, and freely accessible tool designed for the general public, allowing users to explore real asteroid data, visualize their orbits, and simulate impact scenarios on Earth. Through a web interface, the system integrates maps, graphics, and simulations that visually convey the possible consequences of an impact event, promoting education, scientific outreach, and awareness of space risk management.

Information was collected from open sources, primarily from the Small-Body Database (SBDB) of NASA's Center for Near-Earth Object Studies (CNEOS), which currently records more than 2,500 potentially hazardous asteroids, along with their physical, orbital, and impact risk parameters. Additionally, data from OpenTopoData and the World Bank Data were incorporated, providing topographic and demographic information used to estimate damage and consequences derived from hypothetical impacts.

2 Development

A traditional development scheme was established for the creation of the tool. First, an analysis of the requirements defined by the "Challenge" was conducted, followed by the design of the basic engineering, considering both technical and functional aspects.

The project was structured into different stages: In the first phase, the back-end was developed entirely in Python, where data acquisition and processing were carried out. Then, the front-end was implemented in various languages to provide a user-friendly interface.

2.1 Back-End

The system's Back-End was developed entirely in Python, chosen for its versatility, extensive library support, and efficiency in managing and processing large volumes of data. Its main function is the acquisition, structuring, and processing of scientific information from open-access sources, ensuring the coherence, integrity, and usability of the data before being used by the visualization and simulation

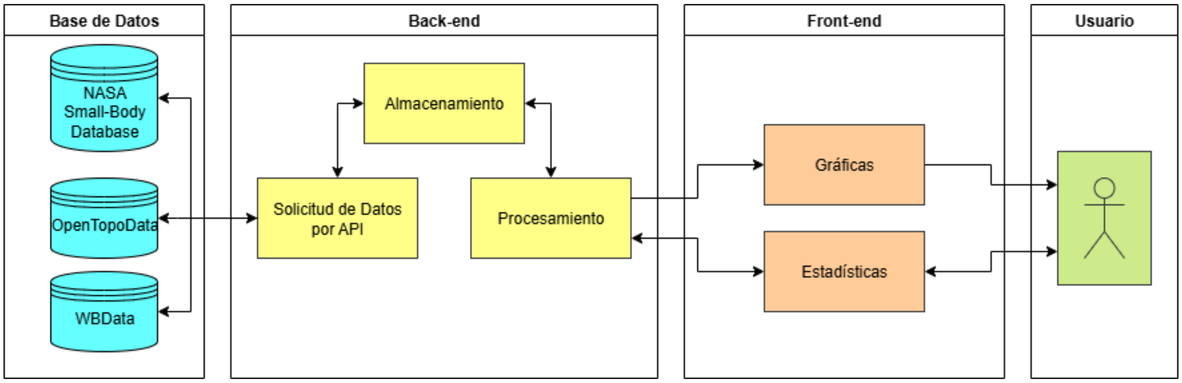

Figure 1: General operating scheme of the app.

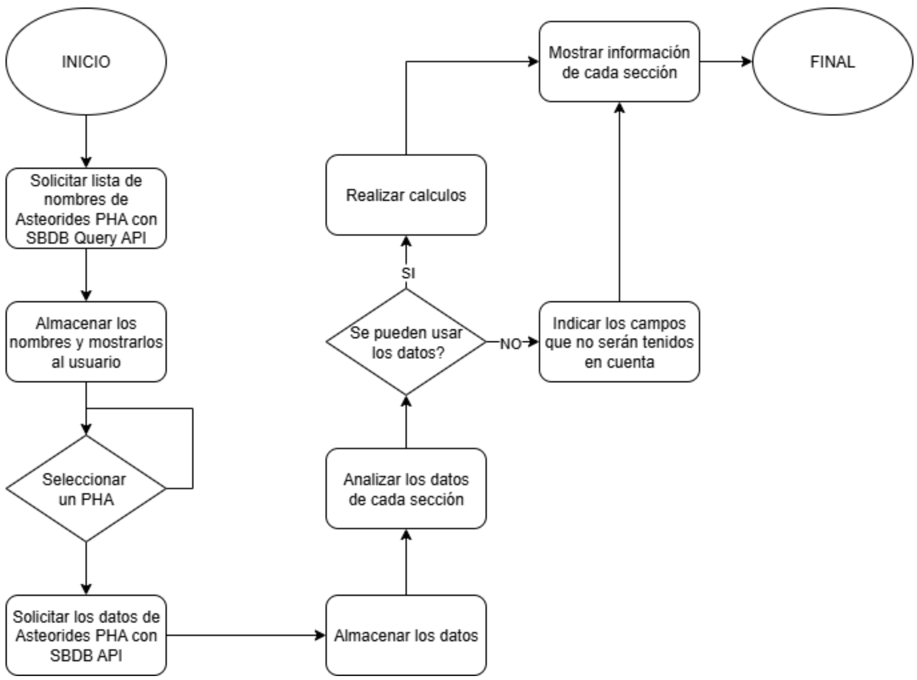

Figure 2: Back-End flow diagram.

modules.

The system connects directly to the open programming interfaces (APIs) provided by NASA, particularly the Small-Body Database Query API and the Small-Body Database API, both belonging to the Jet Propulsion Laboratory (JPL) and the Center for Near-Earth Object Studies (CNEOS). These interfaces allow access to real orbital and physical parameters of Near-Earth Objects (NEOs) and Potentially Hazardous Asteroids (PHAs), which are periodically updated by the agency.

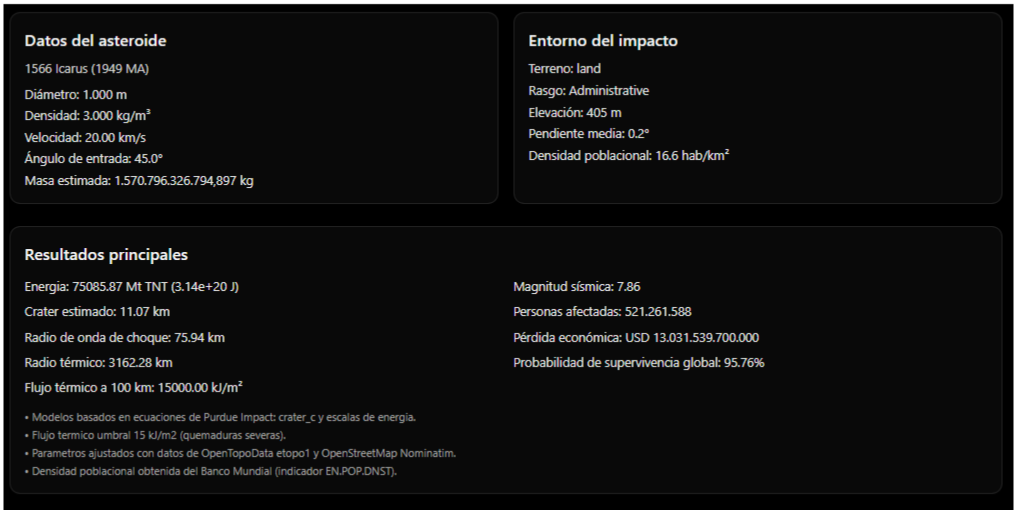

Figure 3: Data obtained through the SBDB.

The process of data acquisition and processing is organized into two main stages:

1. An initial query is made to the "SBDB Query" API, retrieving the names of the available PHAs and their unique identification numbers.
2. The "SBDB" API is then used to obtain complete information for each individual object. The results of both queries are integrated into a unified structure, generating a consolidated JSON file that is used by the processing modules.

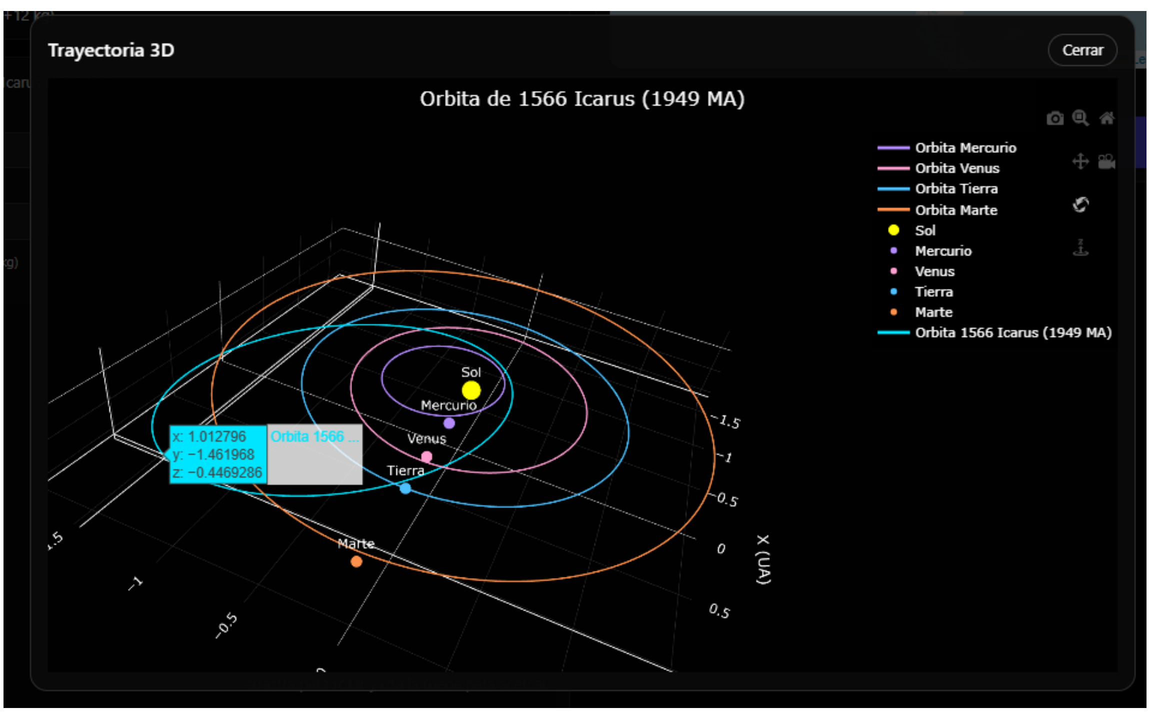

Figure 4: Orbit visualizer.

With the obtained orbital information, the asteroid's trajectory is reconstructed (Figure 4).

2.2 Front-End

The project's Front-End was developed using React and Tailwind, allowing the integration of HTML, CSS, and TypeScript. Meanwhile, the Back-End was built with Python, leveraging its wide range of libraries (such as Pandas and NumPy) and FastAPI as the web framework. VSCode was used as the development environment, and Vite and NodeJS for compilation.

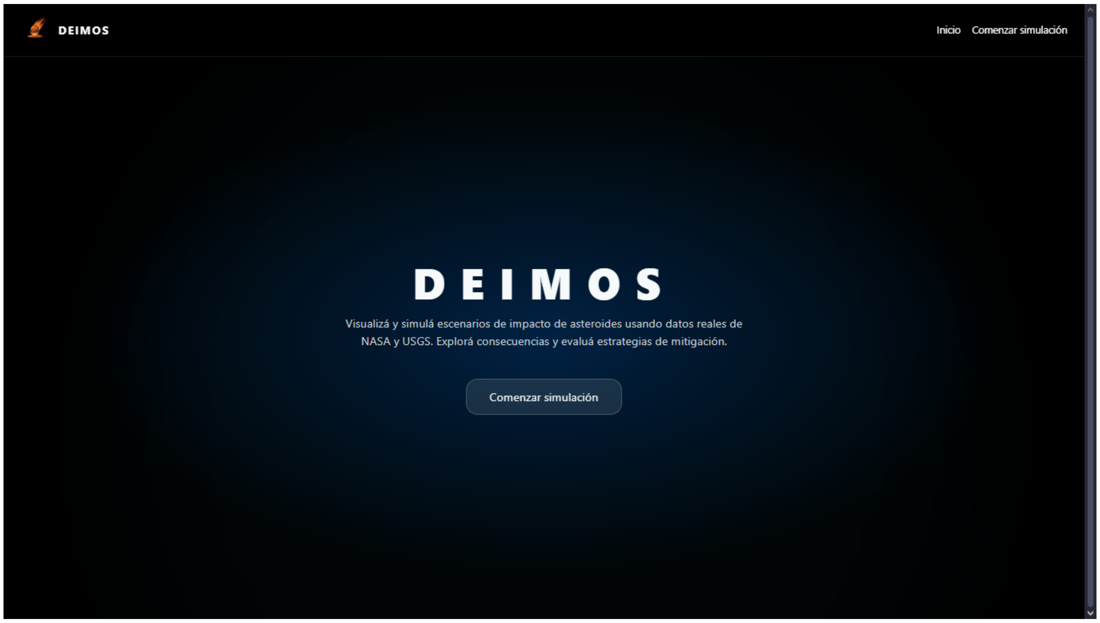

Figure 5: Deimos home page.

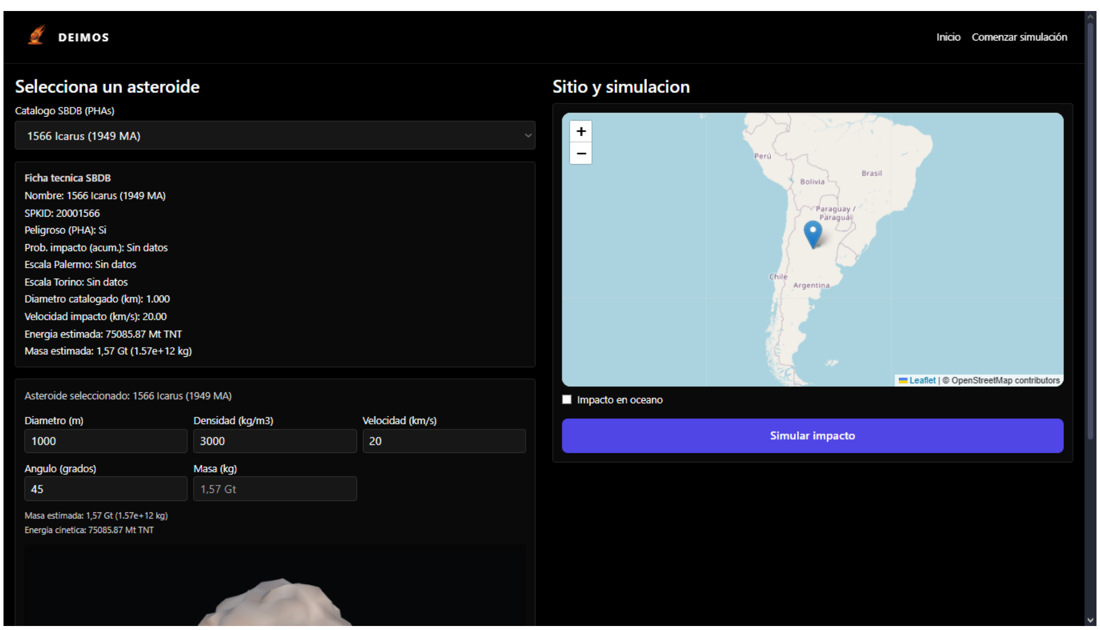

Figure 6: Deimos simulation page.

Figure 7: Impact point selection.

On the main page, a list of Potentially Hazardous Asteroids and their available data is displayed. A pop-up window provides a 3D graphical representation of the asteroid's orbit alongside the orbits of the inner planets of the Solar System. Additionally, another page includes a results module showing the impact zones and their estimated effects, such as radius, released energy, human and economic consequences, etc.
This can be seen in Figure 4.

2.3 Parameter Calculations

The SBDB API provides identification and naming information for objects, as well as orbital and physical data for all known asteroids and comets within the Solar System. It also offers complementary data such as close approaches and potential virtual impact events.

The following parameters are requested:

Section	Parameter	Description
object	—	Object details: designation, name, orbital class, etc.
orbit	no-orbit	Orbital details: elements, model parameters, etc.
orbit_defs	orbit-defs	Definitions of orbital parameters: title, units, description, etc.
phys_par	phys-par	Physical parameters: absolute magnitude (H), rotation period, etc.
vi_data	vi-data	Virtual impactor (VI) data, if available.
discovery	discovery	Discovery data, including IAU name citation (if known).

Table 1: Structure of data presented in each section.

The equations used for asteroid impact calculations are listed below:

Energy formula (if not provided in the dataset):

$$E = \frac{1}{2} m_i v_0^2 = \frac{\pi}{12} \rho_i L_0^3 v_0^2 \tag{1}$$

Where:
m_i: asteroid mass

Field	**Label**	**Description**
orbit_id	—	Orbital solution identifier, usually the JPL solution number. For short-period comets, includes a perihelion prefix.
elements	—	Array of data objects with osculating orbital elements.
Orbital Subsection: elements		
Short name	Label	Description
e	e	eccentricity
q	q	perihelion distance (au)
w	peri	argument of perihelion (°)
i	i	inclination (°)
a	a	semi-major axis (au)
per	period	orbital period (days)
n	n	mean motion (°/day)

Table 2: Fields of the orbital section.

Name	Label	Description
date	—	Potential impact date (UTC: YYYY-MM-DD.DD)
ps	—	Palermo Scale risk
ts	—	Torino Scale risk
ip	—	Impact probability
energy	—	Impact kinetic energy (megatons TNT)
dist	—	Minimum geocentric distance in the b-plane (Earth radii)
v_inf	—	Relative entry velocity (km/s)
v_imp	—	Atmospheric impact velocity (km/s)
h	—	Absolute magnitude H
diam	—	Estimated diameter (km)
mass	—	Estimated mass (kg)

Table 3: Fields of the Virtual Impact (vi_data) section.

Name	Label	Description
date	—	Discovery date (YYYY-MMM-DD)
location	—	Discovery site (e.g., "Kitt Peak")
site	—	MPC observatory code

Table 4: Fields of the Discovery section.

v_0: asteroid velocity
ρ_i: asteroid density
L_0: asteroid diameter

Crater diameter:

$$D_{tc} = c \left(\frac{\rho_i}{\rho_t} \right)^{\frac{1}{3}} L^{0.78} V_i^{0.44} g_E^{-0.22} \sin \theta^{1/3} \tag{2}$$

Where:
c: constant depending on the impact site (1.161 for land, 1.365 for water)
ρ_i: impactor density (asteroid)
ρ_t: target density (Earth)
L: impactor diameter after atmospheric entry
V_i: surface impact velocity
g_E: Earth gravity
θ: impact angle

—

Thermal energy per unit area:

$$\Phi = \frac{\eta E}{2\phi r^2} \tag{3}$$

Where:
η: 3×10^{-3}
E: impact energy calculated previously
r: distance from the impact center to the observer
—
Seismic magnitude [Gutenberg-Richter scale]:

$$M = 0.67 \log_{10} E - 5.87 \tag{4}$$

Where:
E: previously calculated kinetic energy

Figure 8: Displayed impact data.

2.4 Conclusions

The development experience of the application led to the following conclusions:

1. The use of databases allowed exploration of NEOs and PHAs in an educational way, through the study of asteroid parameters and how these affect their entry into Earth's atmosphere.

2. The tool also improved the understanding of asteroids that pose a threat to Earth, by simulating their trajectories and potential effects on the planet.

3. The application successfully achieves its goal of being an integral tool with potential for educational and scientific outreach use, by implementing interactive maps, graphics, and asteroid creation options that allow intuitive understanding of the phenomenon. The added value and learning gained by the team throughout the experience are also noteworthy.

4. Finally, it is important to acknowledge the significant support in the prototype's development and implementation through the use of Artificial Intelligence tools, which served as a source of ideas, learning, and solutions compensating for the team's limited prior experience in web development.

References

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