“*Solar System Simulation*”

Team Pegasus

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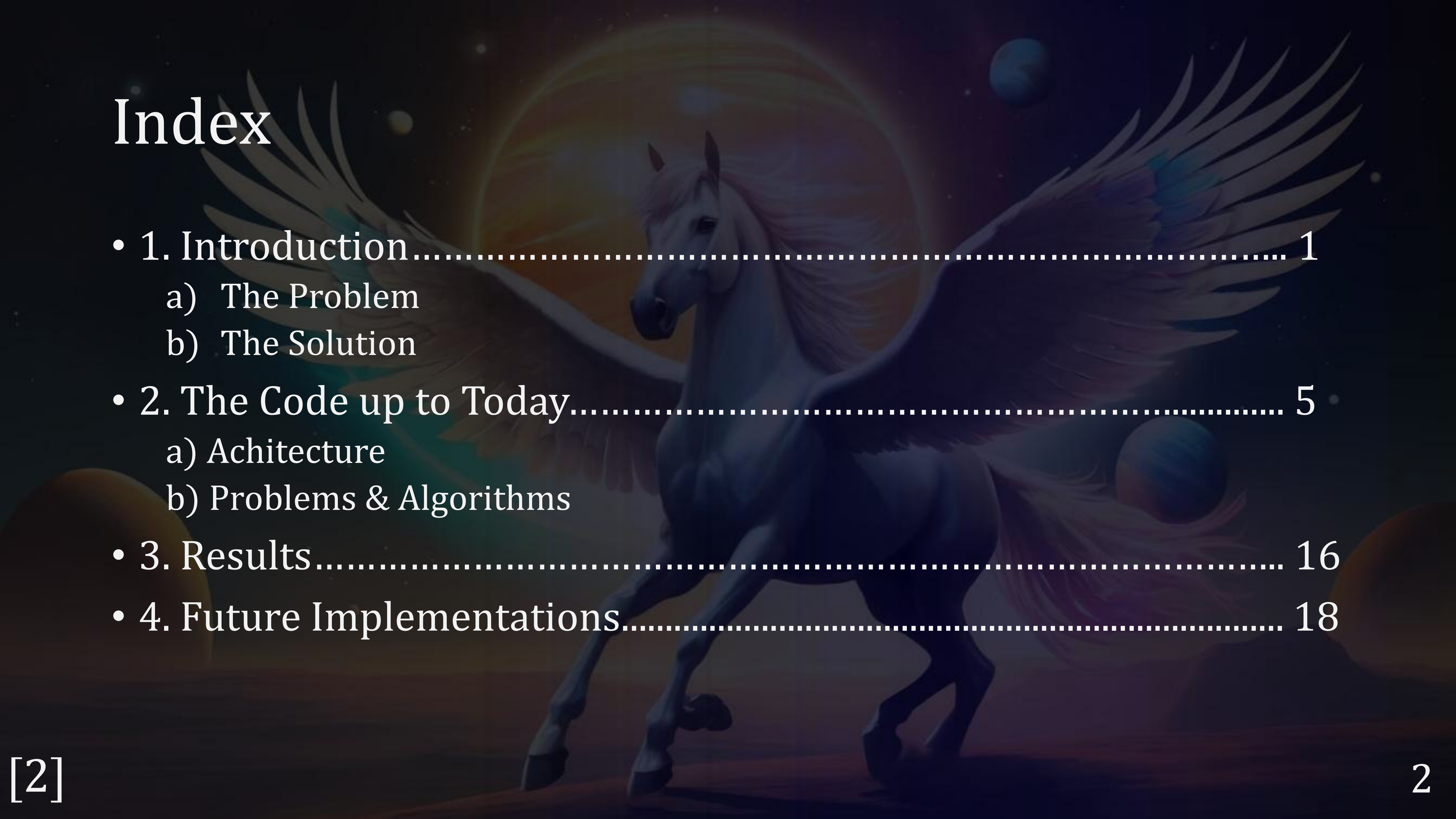

[2]

The Problem

Simulation Solar System.

No analytical solution for > 2 bodies.

The Solution

$$\sum \vec{F} = m \cdot \vec{a} = m \frac{d^2 \vec{r}}{dt^2} \qquad \vec{F} = -\frac{GMm}{r^2} \vec{u}_{\vec{r}}$$

Velocity Verlet

Architecture

2. The Code up to Today

Architecture

simulation_parameters.conf

initial_conditions.ini

output_data

data_tables_reader

pegasus

main.py

astros.py

verlet.py

file_io.py

save_state.py

animation.py

kepler.py

eclipse_search.py

moon_phase.py

2. The Code up to Today

Architecture

- astros.py
- file_io.py
- verlet.py
- save_state.py
- animation.py
- kepler.py
- eclipse_search.py
- moon_phase.py

main.py

A) output_data

astros_i.dat

initial_conditions.ini

B) Display: graphs
Terminal: additional data
Animation

Problems
&
Algorithms

2. The Code up to Today

Data Mining

data_tables_reader

NASA Horizon System

Horizons Web Application

Save/Load Settings...

1 Ephemeris Type: Vector Table

2 Edit Target Body: **Moon [Luna]**

3 Edit Coordinate Center: **Sun (body center)** [500@10]

4 Edit Time Specification: Start=**2024-03-25** TDB , Stop=**2024-03-27**, Step=**1** (days)

5 Edit Table Settings: *defaults*

After specifying settings above (items 1 to 5), generate an ephemeris by pressing the "Generate Ephemeris" button b
settings above can be viewed by using this link.

Generate Ephemeris

```
*******************************************************************************
Revised: April 12, 2021                  Earth                              399

GEOPHYSICAL PROPERTIES (revised May 9, 2022):
 Vol. Mean Radius (km)    = 6371.01+-0.02   Mass x10^24 (kg)= 5.97219+-0.0006
 Equ. radius, km          = 6378.137        Mass layers:
 Polar axis, km           = 6356.752          Atmos         = 5.1   x 10^18 kg
 Flattening               = 1/298.257223563   oceans        = 1.4   x 10^21 kg
 Density, g/cm^3          = 5.51              crust         = 2.6   x 10^22 kg
 J2 (IERS 2010)           = 0.00108262545     mantle        = 4.043 x 10^24 kg
 g_p, m/s^2  (polar)      = 9.8321863685      outer core    = 1.835 x 10^24 kg
 g_e, m/s^2  (equatorial) = 9.7803267715      inner core    = 9.675 x 10^22 kg
 g_o, m/s^2               = 9.82022         Fluid core rad  = 3480 km
 GM, km^3/s^2             = 398600.435436   Inner core rad  = 1215 km
 GM 1-sigma, km^3/s^2     =      0.0014     Escape velocity = 11.186 km/s
 Rot. Rate (rad/s)        = 0.00007292115   Surface area:
 Mean sidereal day, hr    = 23.9344695944     land          = 1.48 x 10^8 km
 Mean solar day 2000.0, s = 86400.002         sea           = 3.62 x 10^8 km
 Mean solar day 1820.0, s = 86400.0         Love no., k2    = 0.299
 Moment of inertia        = 0.3308          Atm. pressure   = 1.0 bar
 Mean surface temp (Ts), K= 287.6           Volume, km^3    = 1.08321 x 10^12
 Mean effect. temp (Te), K= 255             Magnetic moment = 0.61 gauss Rp^3
 Geometric albedo         = 0.367           Vis. mag. V(1,0)= -3.86
 Solar Constant (W/m^2)   = 1367.6 (mean), 1414 (perihelion), 1322 (aphelion)
HELIOCENTRIC ORBIT CHARACTERISTICS:
 Obliquity to orbit, deg  = 23.4392911  Sidereal orb period  = 1.0000174 y
 Orbital speed, km/s      = 29.79       Sidereal orb period  = 365.25636 d
 Mean daily motion, deg/d = 0.9856474   Hill's sphere radius = 234.9
*******************************************************************************
```

2. The Code up to Today

Data Mining

data_tables_reader

```
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  Mean daily motion, deg/d = 0.9856474   Hill's sphere radius = 234.9
*******************************************************************************
```

```
# Name, x, y, z, vx, vy, vz (DATE------ on last line)
sun,      0.0,   0.0,   0.0,   0.0,   0.0,   0.0,
mercury, -41084118770.39495,   29973759541.5448,   6217890408.222714,  -38657.430103836516,   -37338.8907
venus,   -106998742239.8024,   -11455725151.139051,   6016588327.139665,  3513.460276994624,  -34977.5562
earth,   -24810993259.6539, 144994861273.6719, -8215203.670851886, -29841.463655186788,   -5126.2622868596
moon,    -25178945790.79584,   145161393068.9555,  16962113.94185573,  -30251.231504808882,   -6001.889331
mars,    -43885774573.789825,  -217084926474.7524, -3473007284.583151, 24661.91455128526,  -2722.16016197737
jupiter, 522570857624.45465,   531826882772.1269,  -13900732858.81653,  -9481.190567392032, 9781.94240035008
saturn,  1345793242617.2231,   -555929417811.5253, -43892626095.79784, 3146.297313479314,  8917.916155362638,
uranus,  1835714294722.568,    -555929417811.5253
neptune, 4464446647141.849, -267915833507.38452,   -97365836775.08334, 281.8440617089212,  5469.942022851474,
#   2460310.500000000 = A.D. 2024-Jan-01 00:00:00.0000 TDB
```

Units: Km/s

Mass :(

```
# name, mass
# sun,      1.98847E30,
# mercury,  3.302E23,
# venus,    48.685E23,
# earth,    5.97219E24,
# moon,     7.349E22,
# mars,     6.4171E23,
# jupiter,  189818.722E22,
# saturn,   5.6834E26,
# uranus,   86.813E24,
# neptune,  102.409E24,
```

Moon Phases

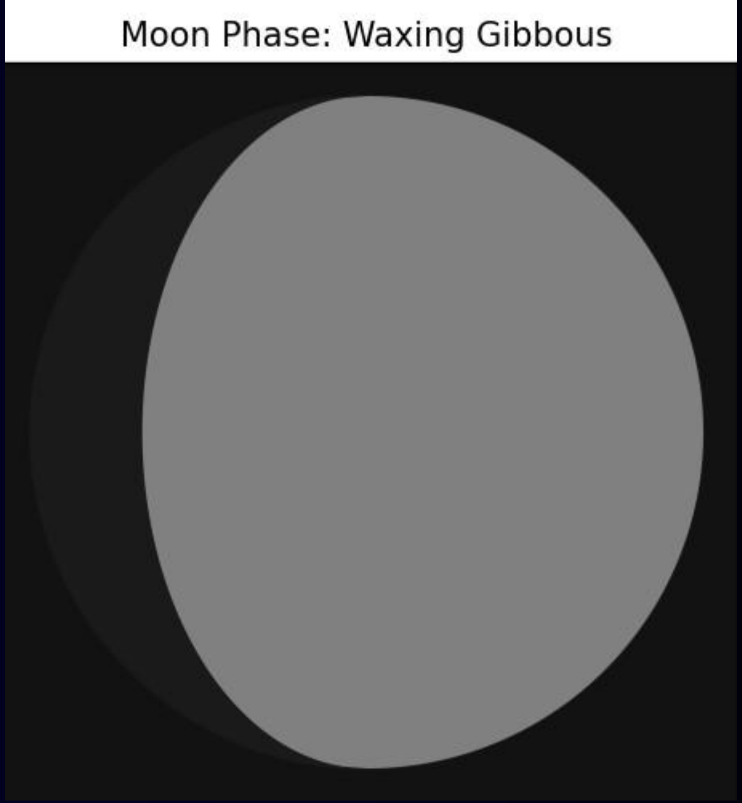
Extra Feature

moon_phase.py

Get how the moon is gonna exactly look…

unless it's cloudy

```
get_moon_phase(astrolist_states[-1])
```



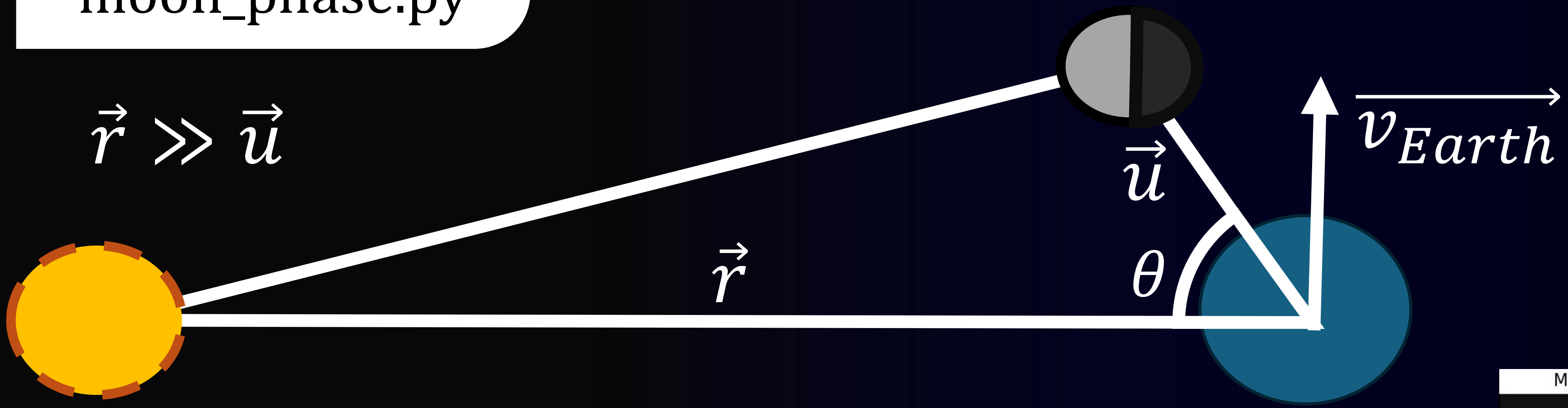
2. The Code up to Today

Moon Phases

Extra Feature

moon_phase.py

$\vec{r} \gg \vec{u}$



$$\left.\begin{array}{r}\theta = \arccos\left(\dfrac{\vec{r}\cdot\vec{u}}{|\vec{r}|\cdot|\vec{u}|}\right) \\ \vec{u}\cdot\overrightarrow{v_E} > 0\end{array}\right\} np.arccos(x) \rightarrow [0, \pi]$$

2. The Code up to Today

Moon Phases

Extra Feature

moon_phase.py

```
# Calculate the angle fromed by the Moon-Earth and Sun-Earth lines. Using scalar product.
u, v = r_e_m, r_earth
theta = np.arccos(np.dot(u, v) / (np.linalg.norm(u) * np.linalg.norm(v)))

# Since np.arccos() is only defined from [0,pi] the sign helps distinguish in [0,2pi]
sign = np.sign(np.dot(r_e_m, earth.velocity))
```

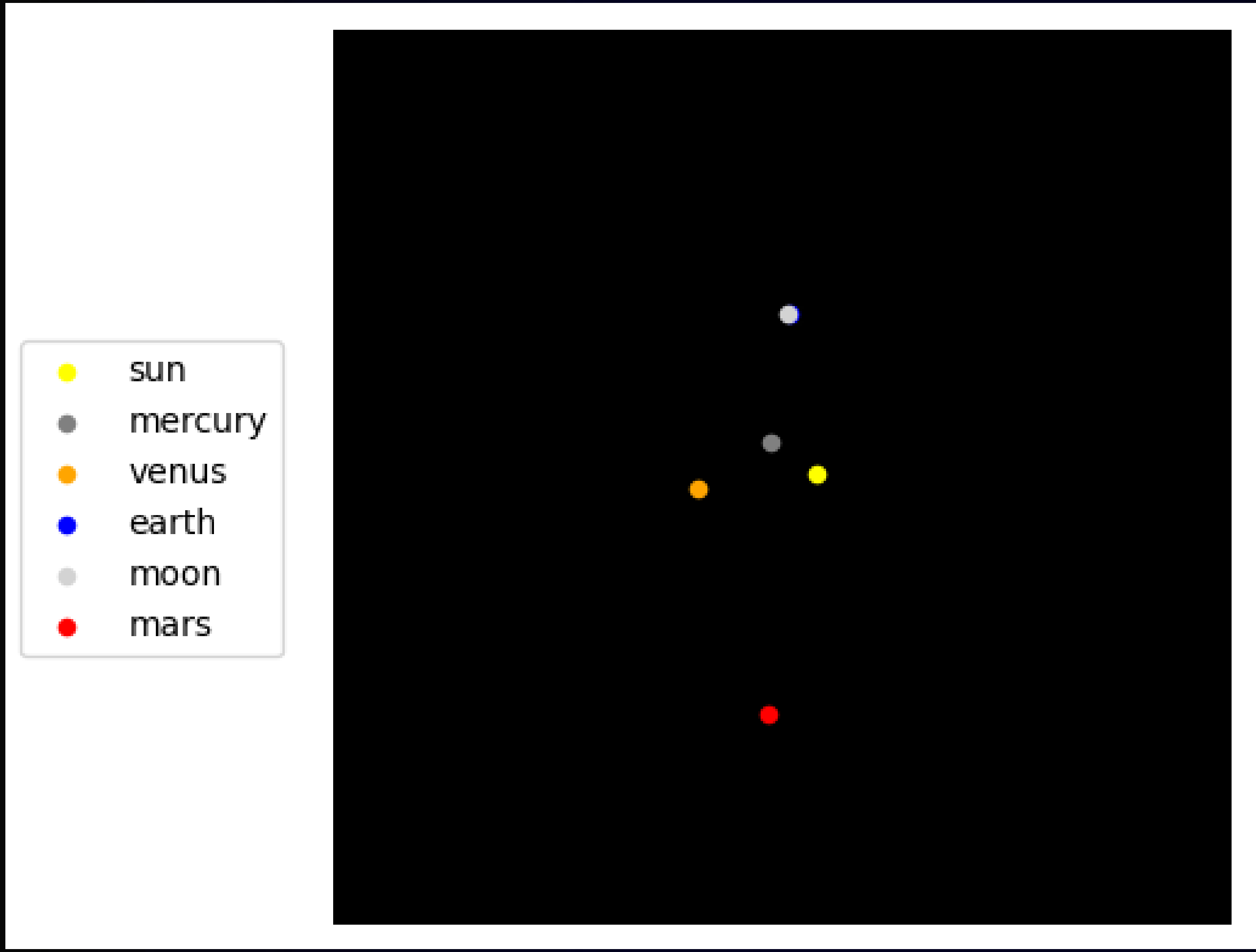
```
phases = ['New Moon', 'Wanning Crescent',
          'Last Quarter', 'Wanning Gibous',
          'Full Moon', 'Waxing Gibbous',
          'First Quarter', 'Waxing Crescent']
```

```
#  Assign the correct Moon Phase name, give

if theta <= 10*rad and theta > 0:
    phase = phases[0]
elif 10*rad<theta<=80*rad and sign <0:
    phase = phases[1]
elif 80*rad<theta<=100*rad and sign <0:
    phase = phases[2]
elif 100*rad<theta<=170*rad and sign <0:
    phase = phases[3]
elif 170*rad<theta<=180*rad:
    phase = phases[4]
elif 100*rad<theta<=170*rad and sign >0:
    phase = phases[5]
elif 80*rad<theta<=100*rad and sign >0:
    phase = phases[6]
elif 10*rad<theta<=80*rad and sign >0:
    phase = phases[7]
# print(phase)
```

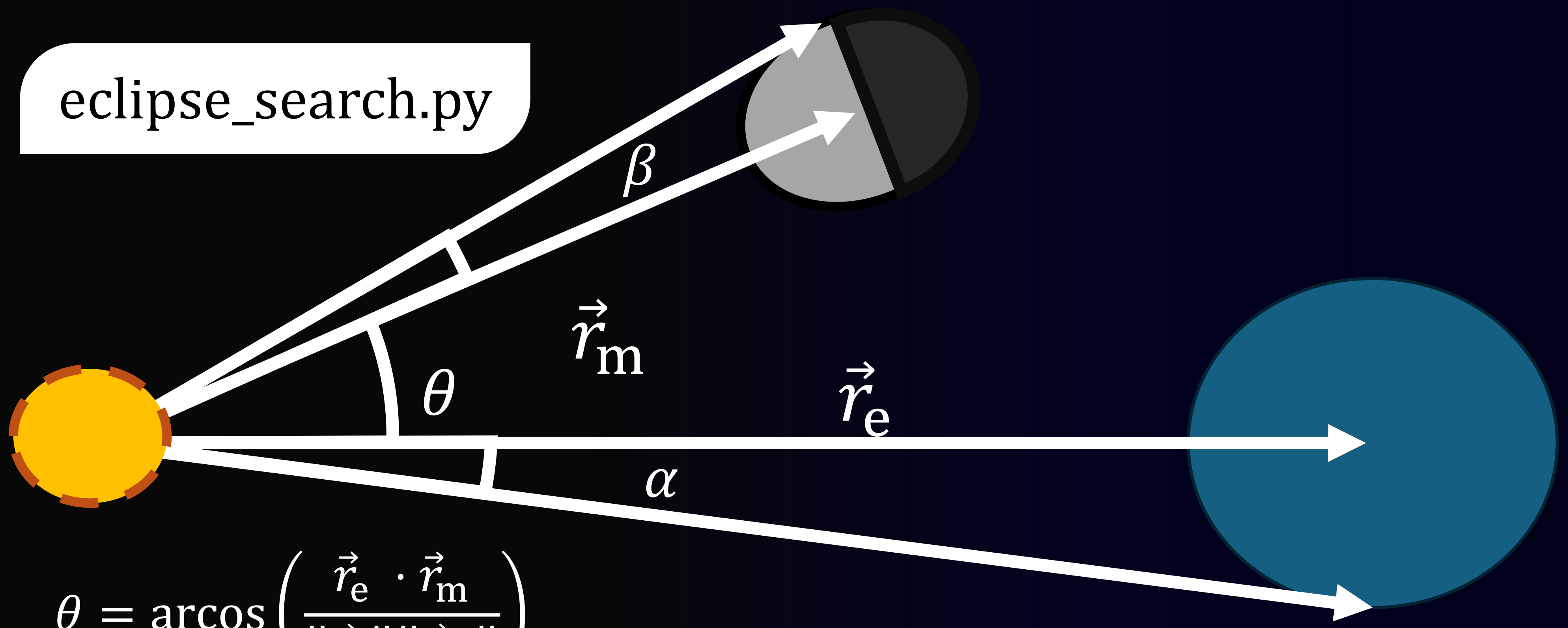
Animation

animation.py



2. The Code up to Today — Eclipse check

eclipse_search.py



$$\theta = \arccos\left(\frac{\vec{r}_{\mathrm{e}} \cdot \vec{r}_{\mathrm{m}}}{\|\vec{r}_{\mathrm{e}}\|\,\|\vec{r}_{\mathrm{m}}\|}\right)$$

$$\alpha \approx \frac{R_{\mathrm{e}}}{\|\vec{r}_{\mathrm{e}}\|} \qquad \beta \approx \frac{R_{\mathrm{m}}}{\|\vec{r}_{\mathrm{m}}\|}$$

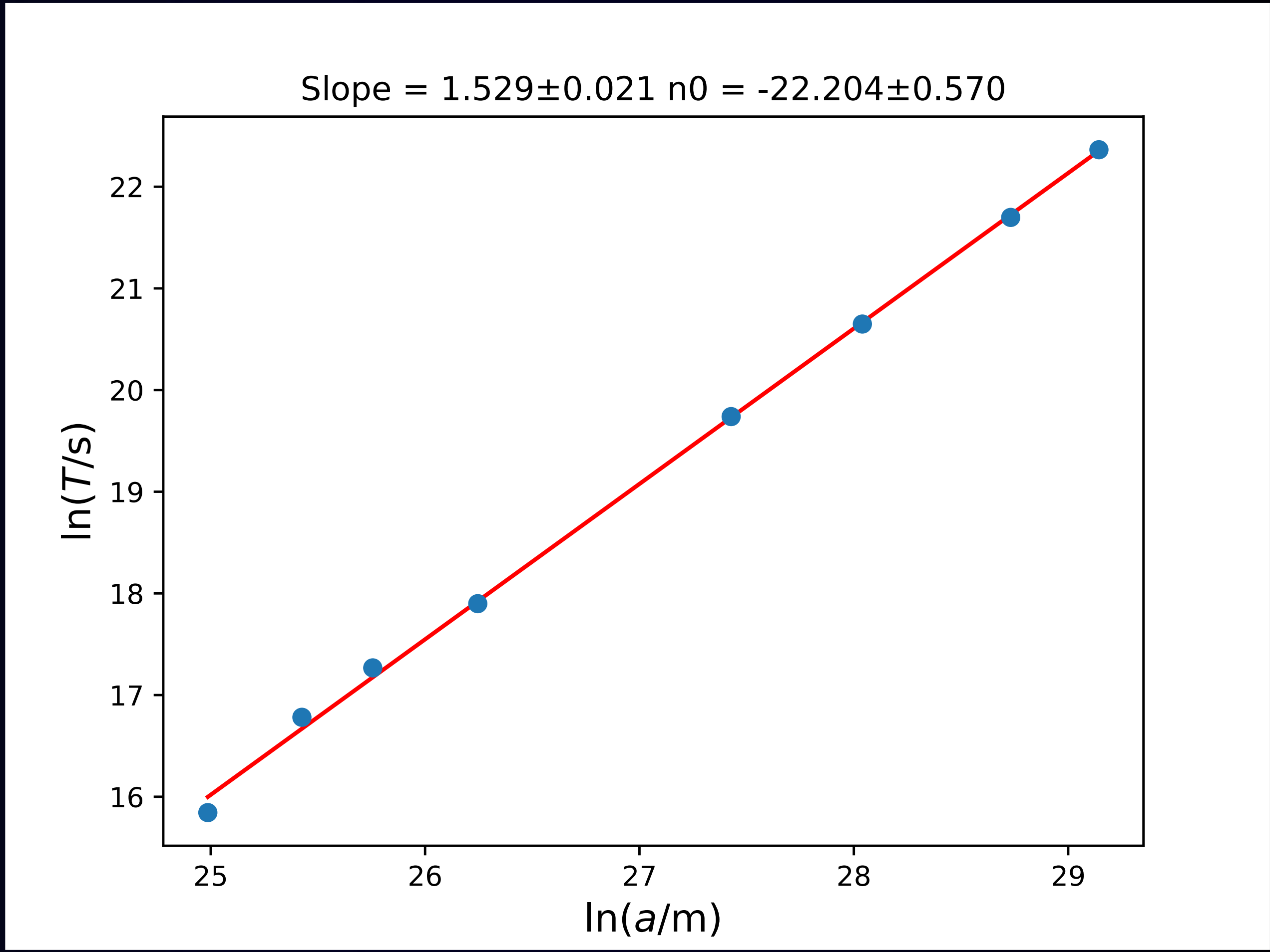
Eclipse? $\longrightarrow \theta < \alpha + \beta$

Solar or lunar? $\longrightarrow \|\vec{r}_{\mathrm{e}}\| > \|\vec{r}_{\mathrm{m}}\|$

Kepler third law

kepler.py

$$T^2 \propto a^3 \Rightarrow \ln(T) = \frac{3}{2}\ln(a) + k$$

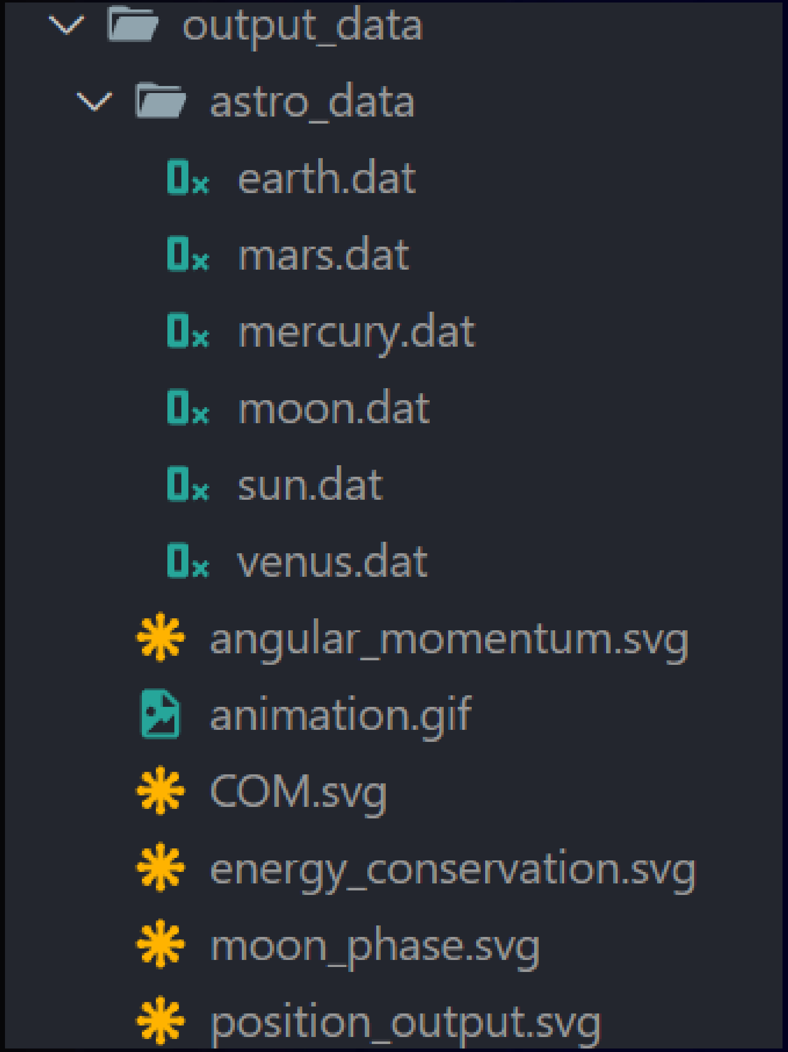


Working
Pegasus
Software

3. Results

Program Output

save_state.py



Future Implementations

Nice things for the future

Future implementations…

Solid base:

- ✓ Fast
- ✓ Efficient
- ✓ Precise
- ✓ User-friendly

[2]
[3]

Bibliography

[1] Project: https://github.com/asaltanubes/pegasus

[2] Background Images were AI Generated: *pixlr.com*

[3] Pegasus Helicopter: *diariomotor.es*

[4] Pegasus Chase video: *twitter_DGT*

[3]

[4]