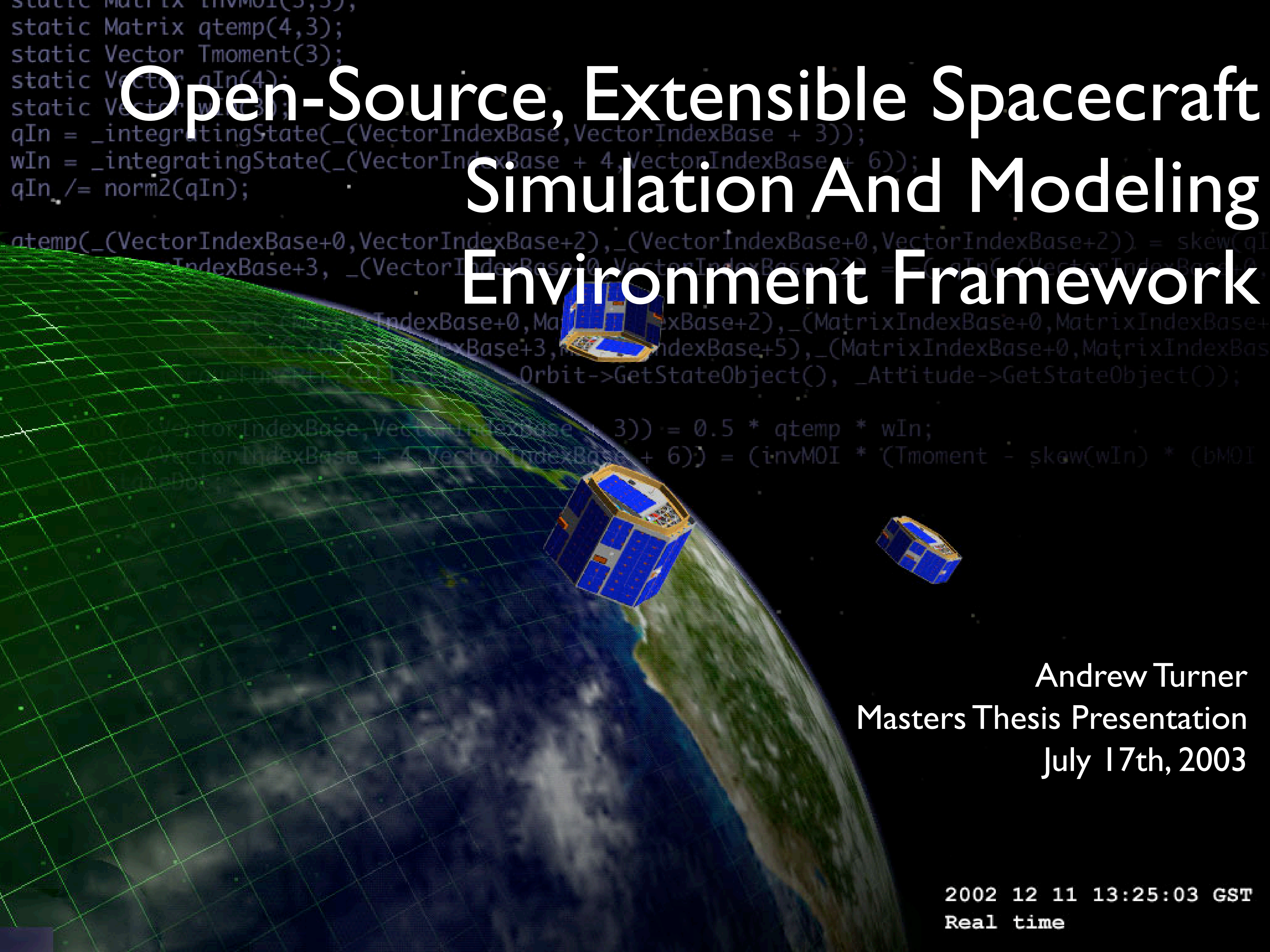
Open-Source, Extensible Spacecraft Simulation And Modeling Environment Framework



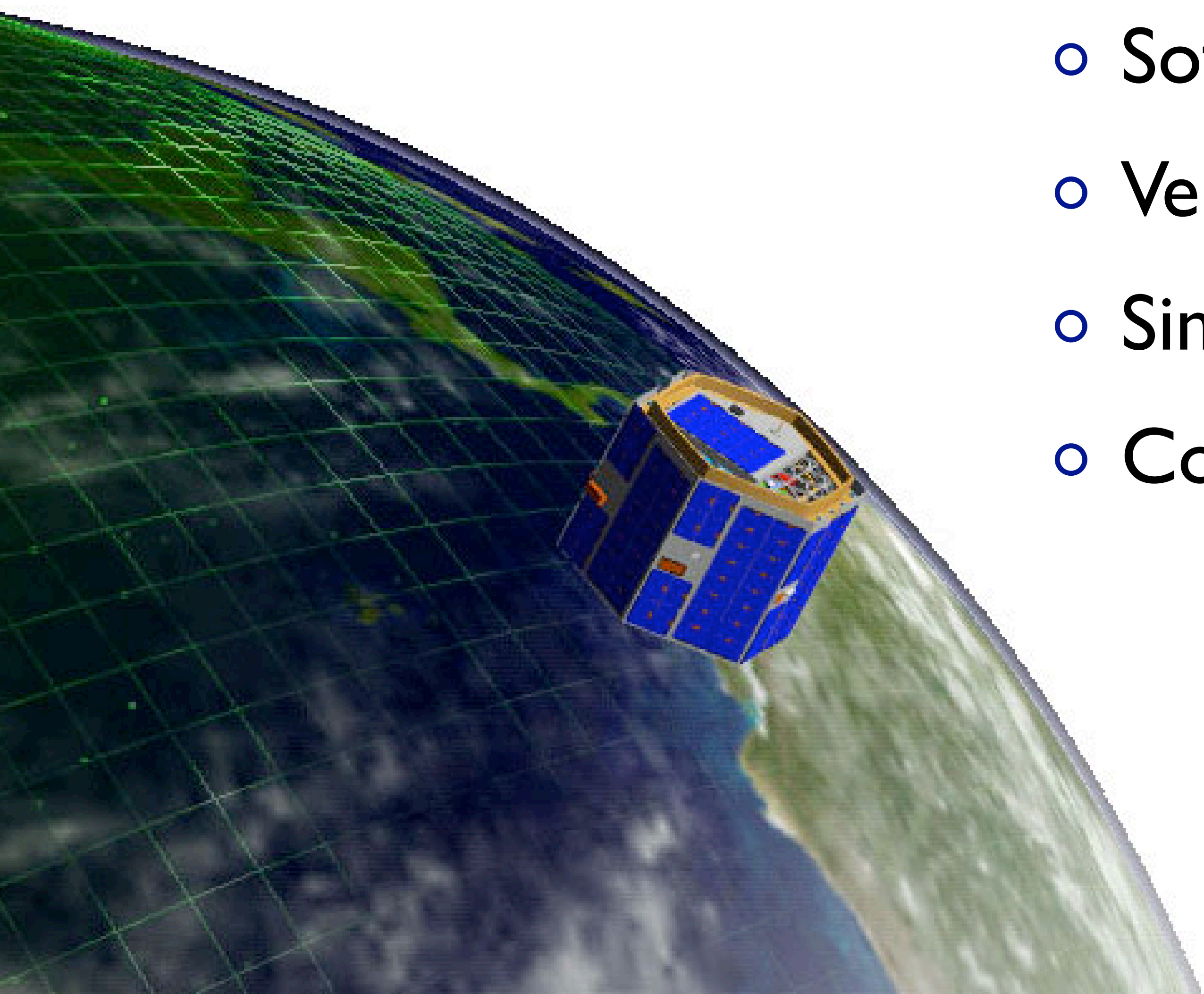
Andrew Turner

Masters Thesis Presentation

July 17th, 2003

Outline of Presentation

- Introduction
- Background
- Purpose
- Architecture Design
- Software Implementation
- Verification and Validation
- Simulation Examples
- Conclusions



Introduction

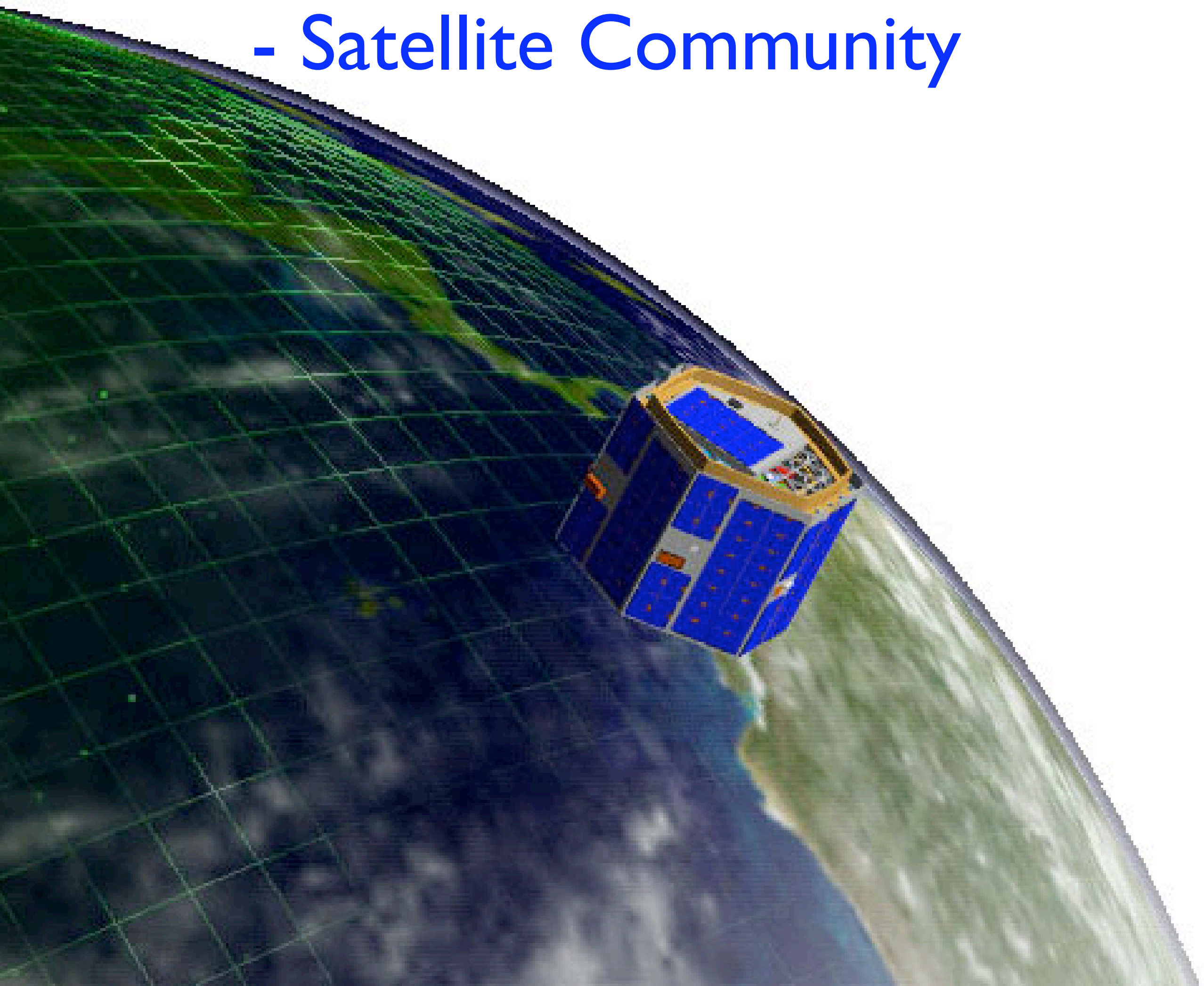
- Open-SESSAME Framework
  - Open-Source
  - Extensible
  - Spacecraft
  - Simulation And Modeling
  - Environment
  - Framework

Adapted by J. Schwartz from http://www.jenn98.com/bugs/1957-1.html

Spacecraft Simulation

Aerospace Engineering

- Attitude dynamics
- Orbit dynamics
- Satellite environment
- Terminology
- Aerospace tools
- Typical use cases
- Satellite Community



Computer Science / Software Engineering

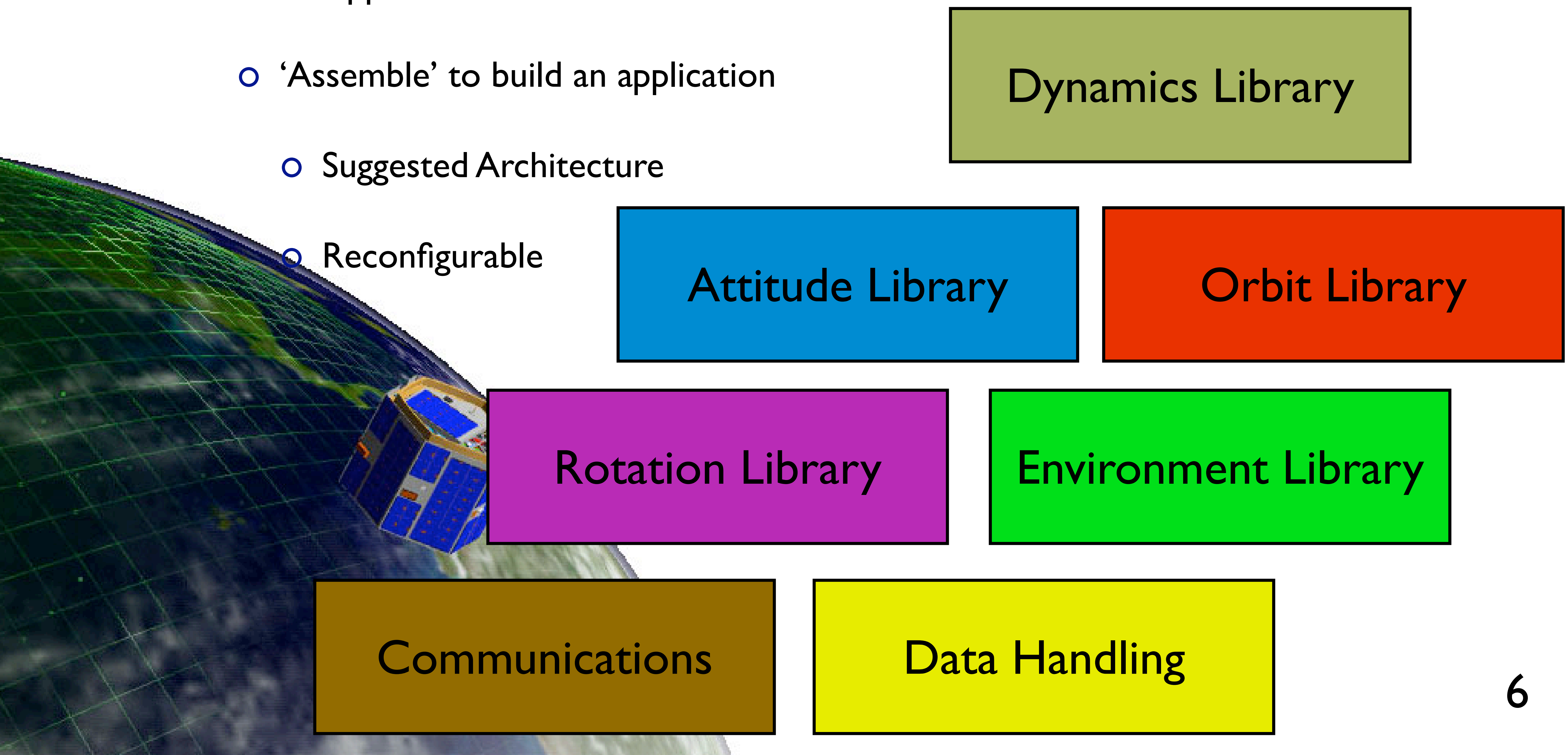
- Object-Oriented Design
- Computational Speed
- Networking
- Data Handling
- Extensibility
- Software development tools
- Open-Source Community

Purpose

- Provide a useful spacecraft simulation modeling tool to engineers
  - Complement existing engineering tools
  - Include underdeveloped methodologies
  - Allow for infinite extensibility
- Educate students and other users how to design and implement simulation in software
  - Readable and useful documentation and software
  - Logical architecture design
- Develop an open-source framework that can be maintained and extended longer than the original project's lifetime
  - Host on a public repository and include developers in the community
  - Foster communication between developers and users

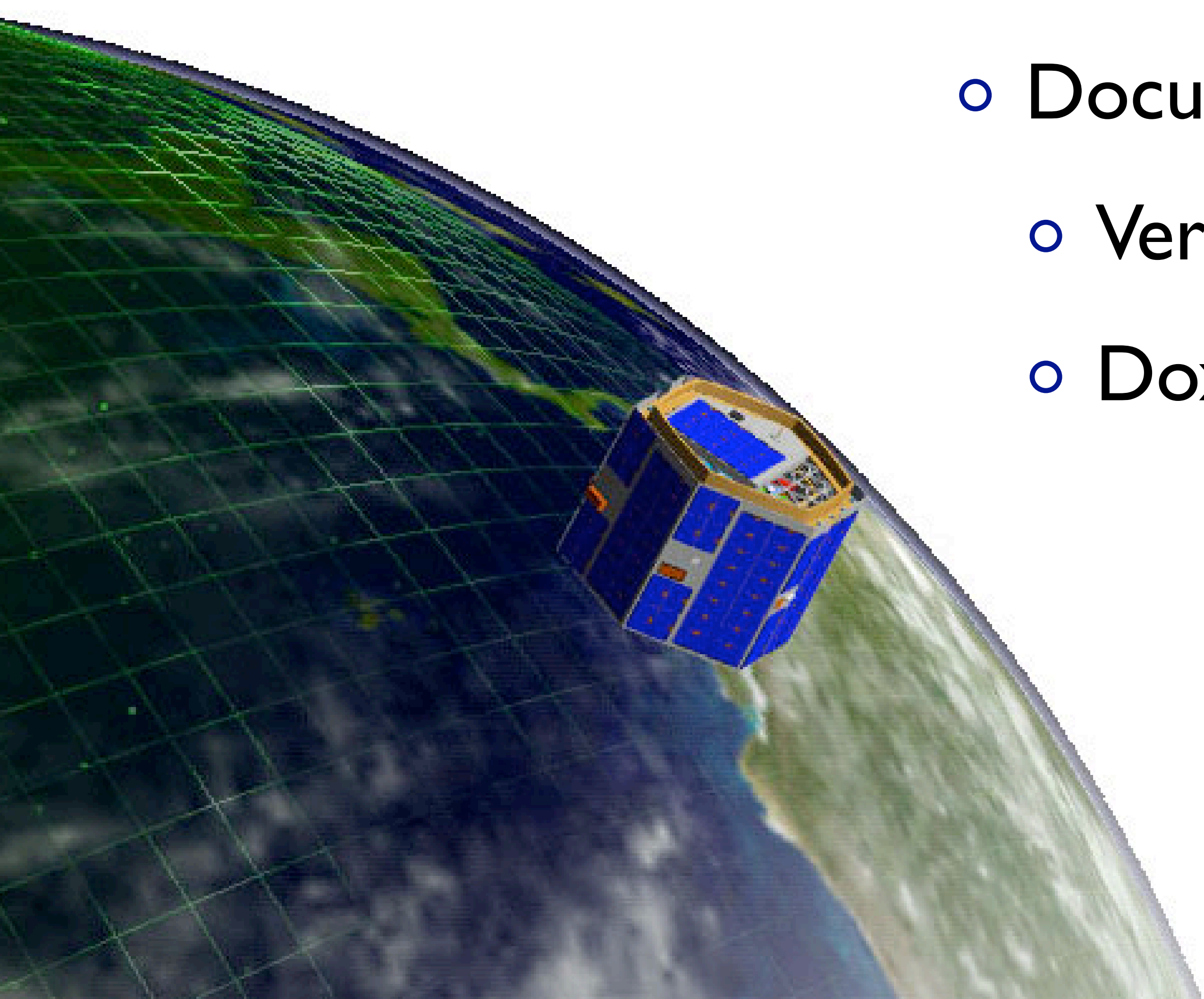
Architecture Design

- Collections of libraries
  - Interchangeable components
  - Application framework
- 'Assemble' to build an application
  - Suggested Architecture
  - Reconfigurable

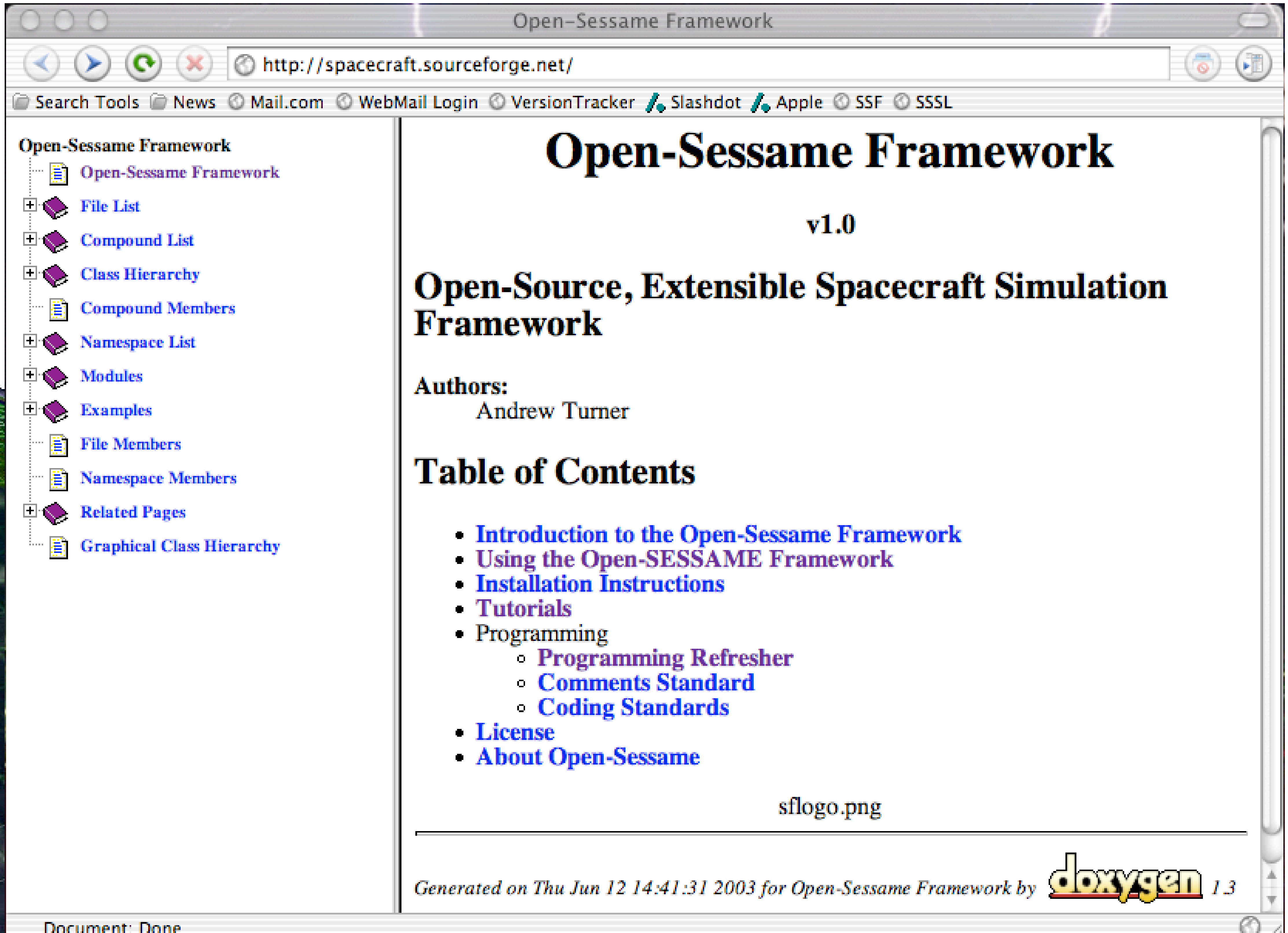


Software Implementation

- C++ software language
- Open-source libraries and toolkits
  - Matrix
  - Network Communications
- Documentation
  - Verbose coding
  - Doxygen

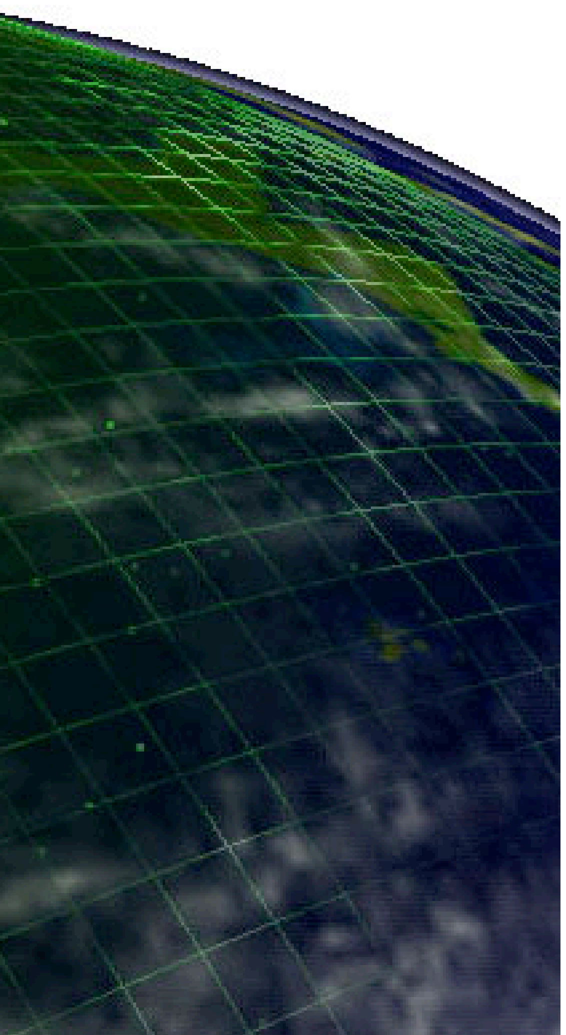


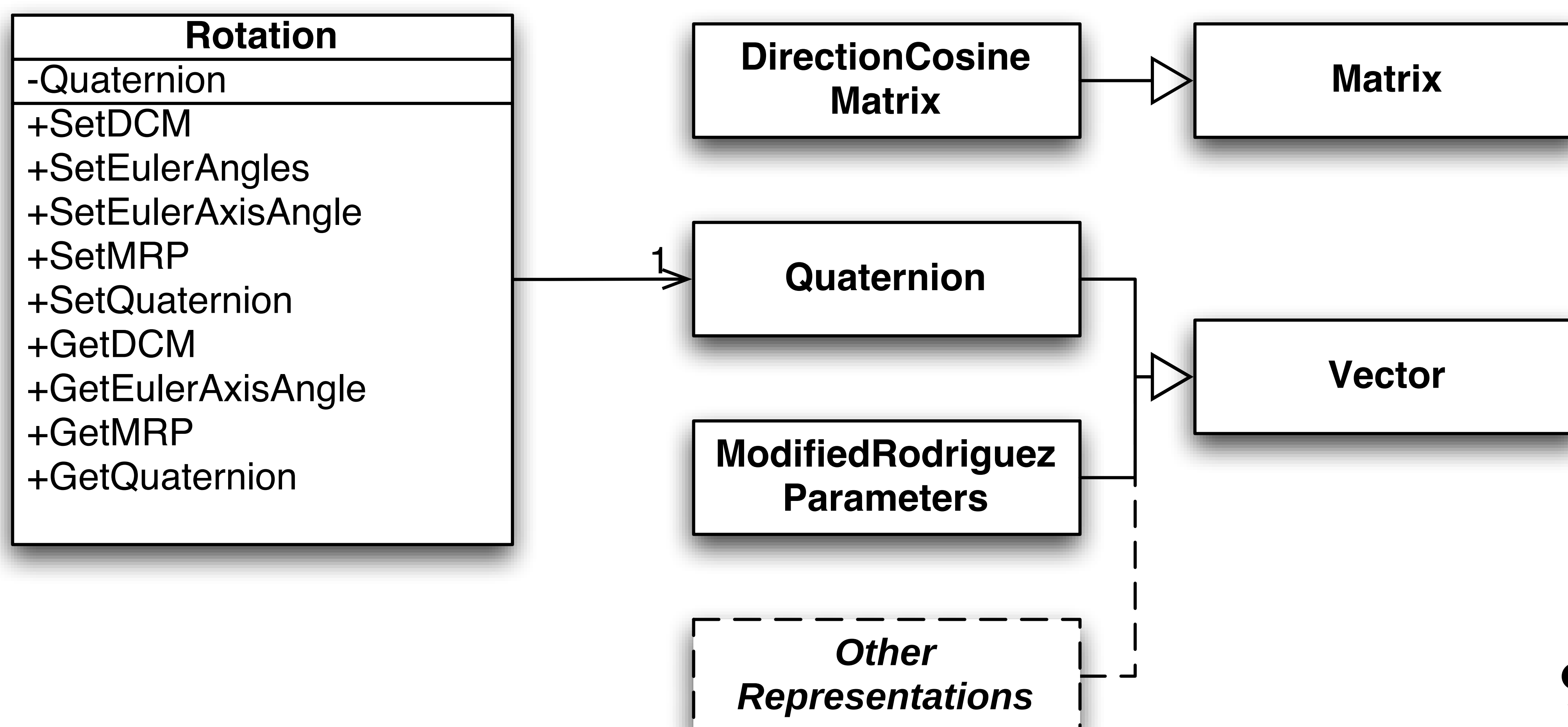
Documentation

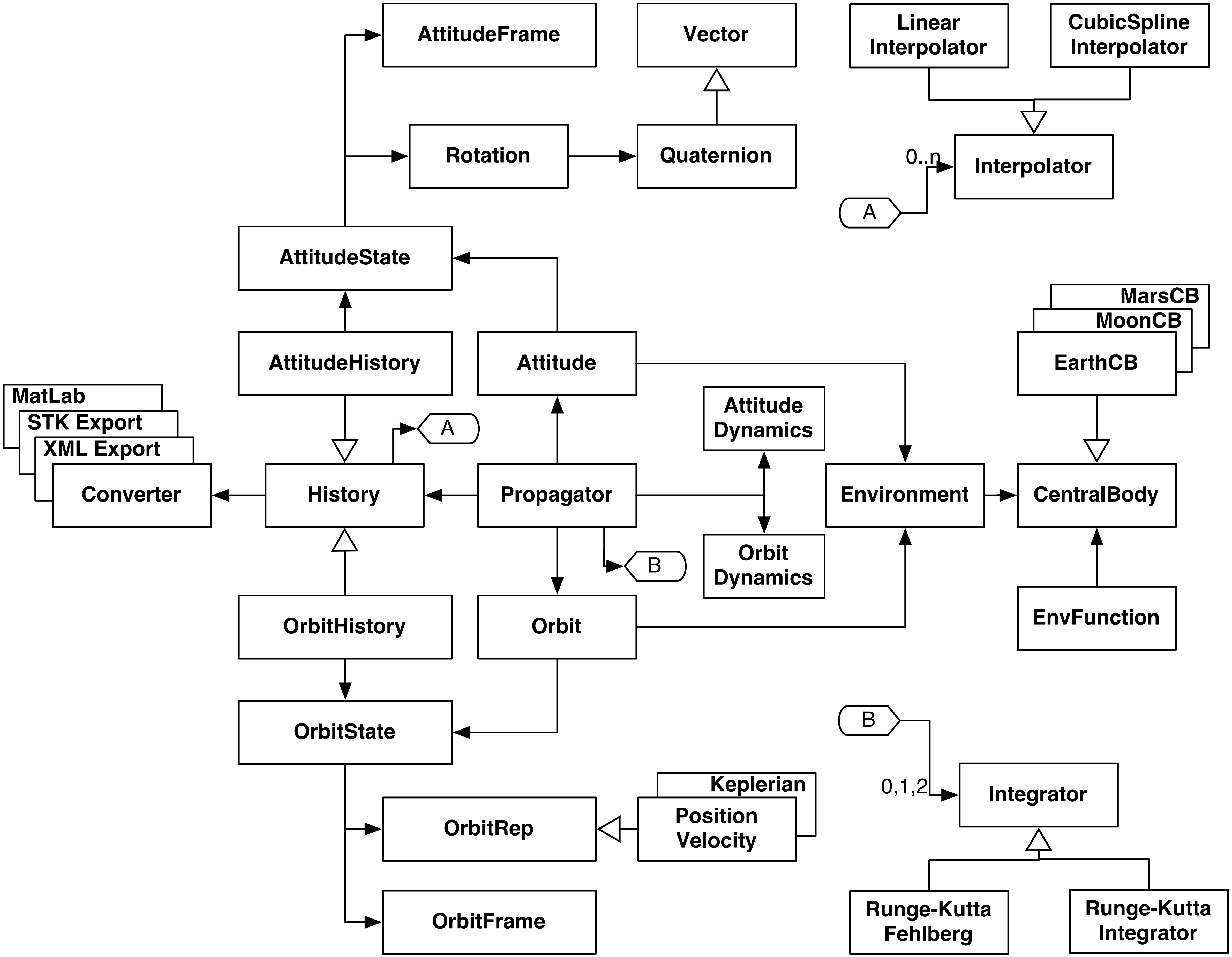


Example: Rotation Library

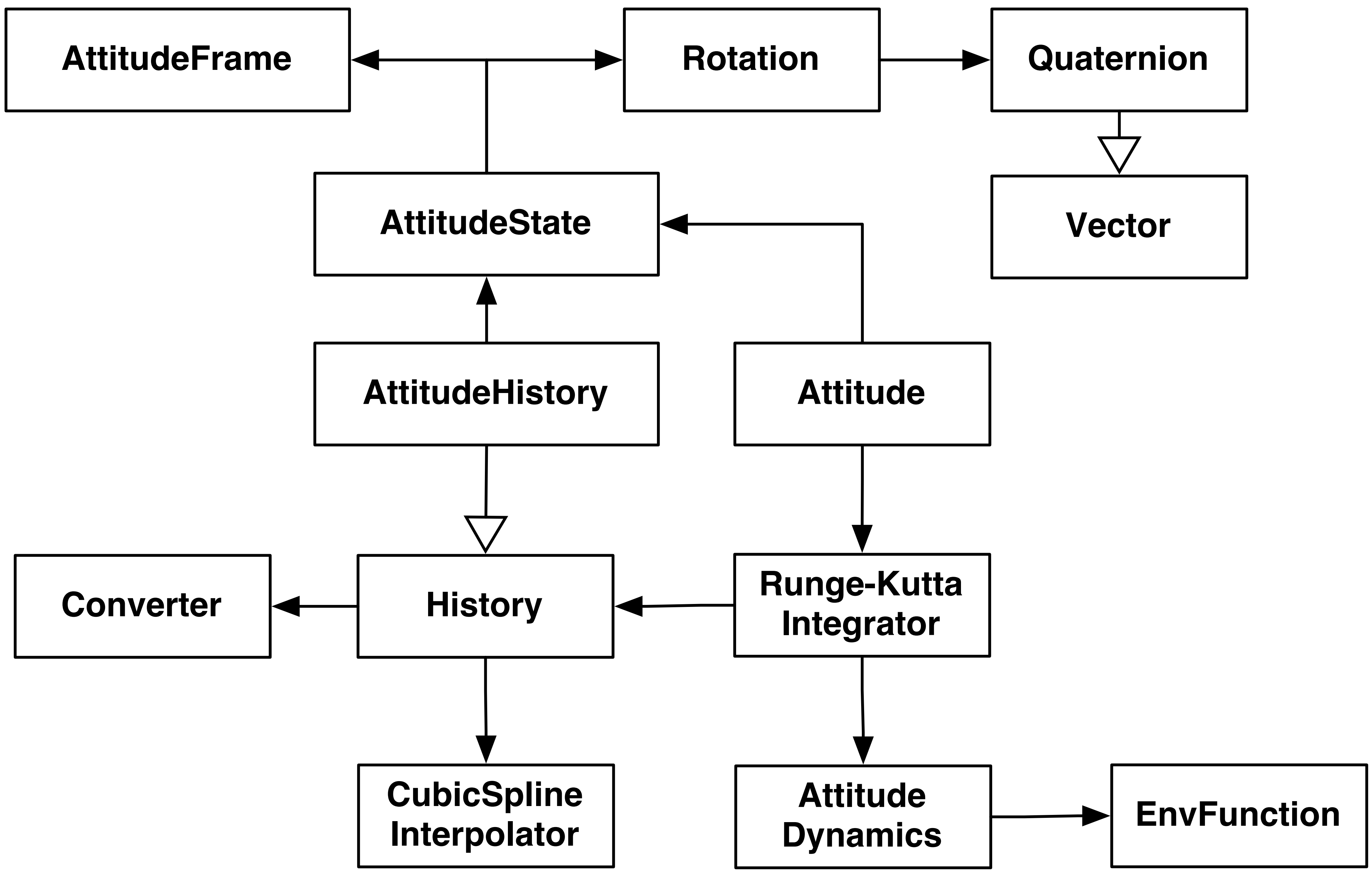
- **Rotation** Class
  - Abstract
  - Conversion Routines
  - Stored as a **Quaternion**



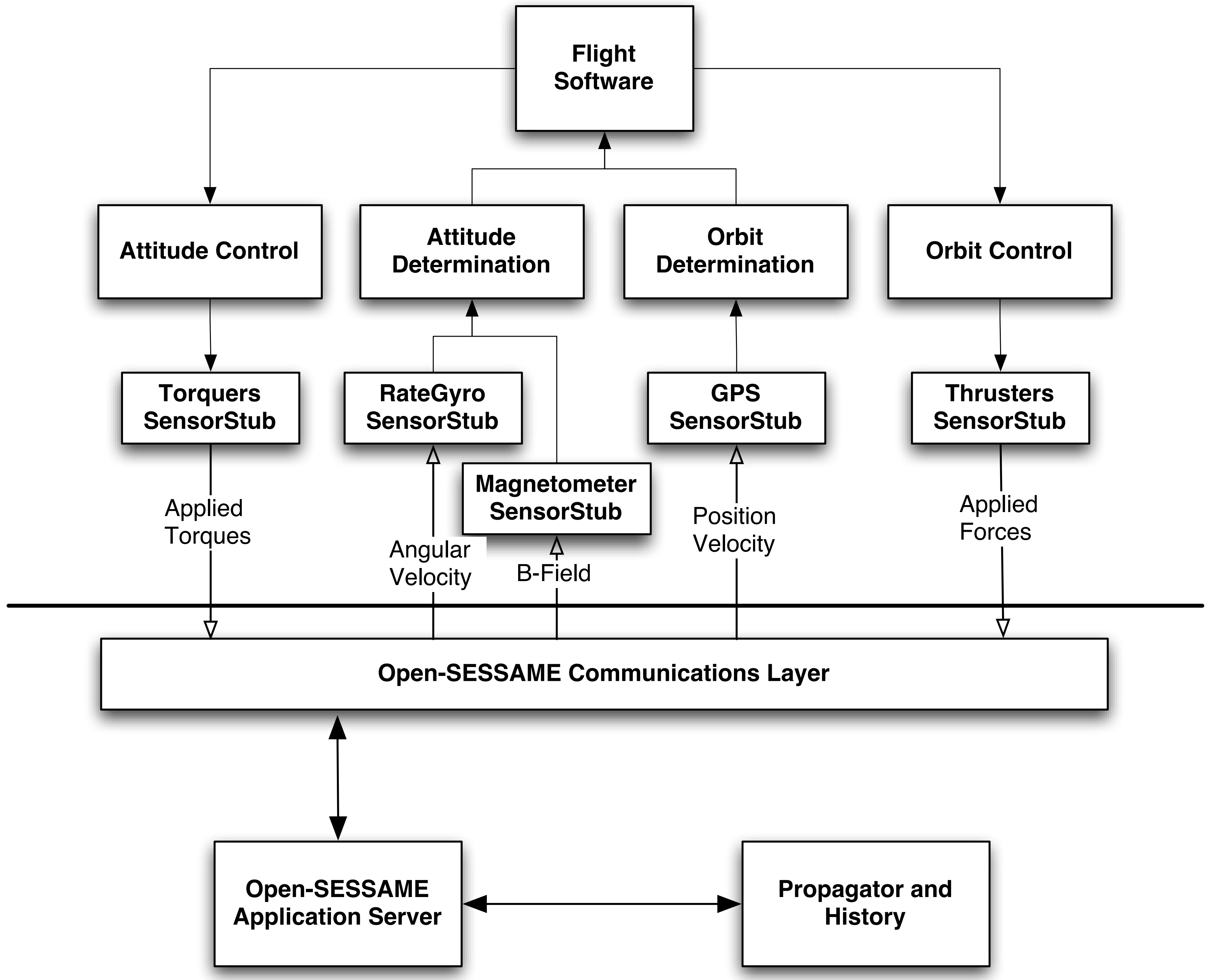



AttitudeFrame
Vector
Linear Interpolator
CubicSpline Interpolator
Rotation
Quaternion
0..n
Interpolator
A
AttitudeState
MarsCB
MoonCB
EarthCB
AttitudeHistory
Attitude
MatLab
STK Export
XML Export
Converter
A
History
Propagator
Attitude Dynamics
Environment
CentralBody
B
Orbit Dynamics
OrbitHistory
Orbit
EnvFunction
OrbitState
B
0,1,2
Integrator
Keplerian
OrbitRep
Position Velocity
OrbitFrame
Runge-Kutta Fehlberg
Runge-Kutta Integrator

Attitude Integration



Hardware-in-the-Loop



Conclusions

- No prior solution for configurable, extensible, coupled spacecraft simulation
- Open-SESSAME fulfills goals and requirements
  - Speed and accuracy comparable to commercial packages
  - Used to ease development and testing of HokieSat flight code
- Future
  - Multiple extension points for added functionality
  - Integrate software into curriculum
  - Publish use cases and include in lab activities
  - Increase connectivity with other programs
  - Optimize operation

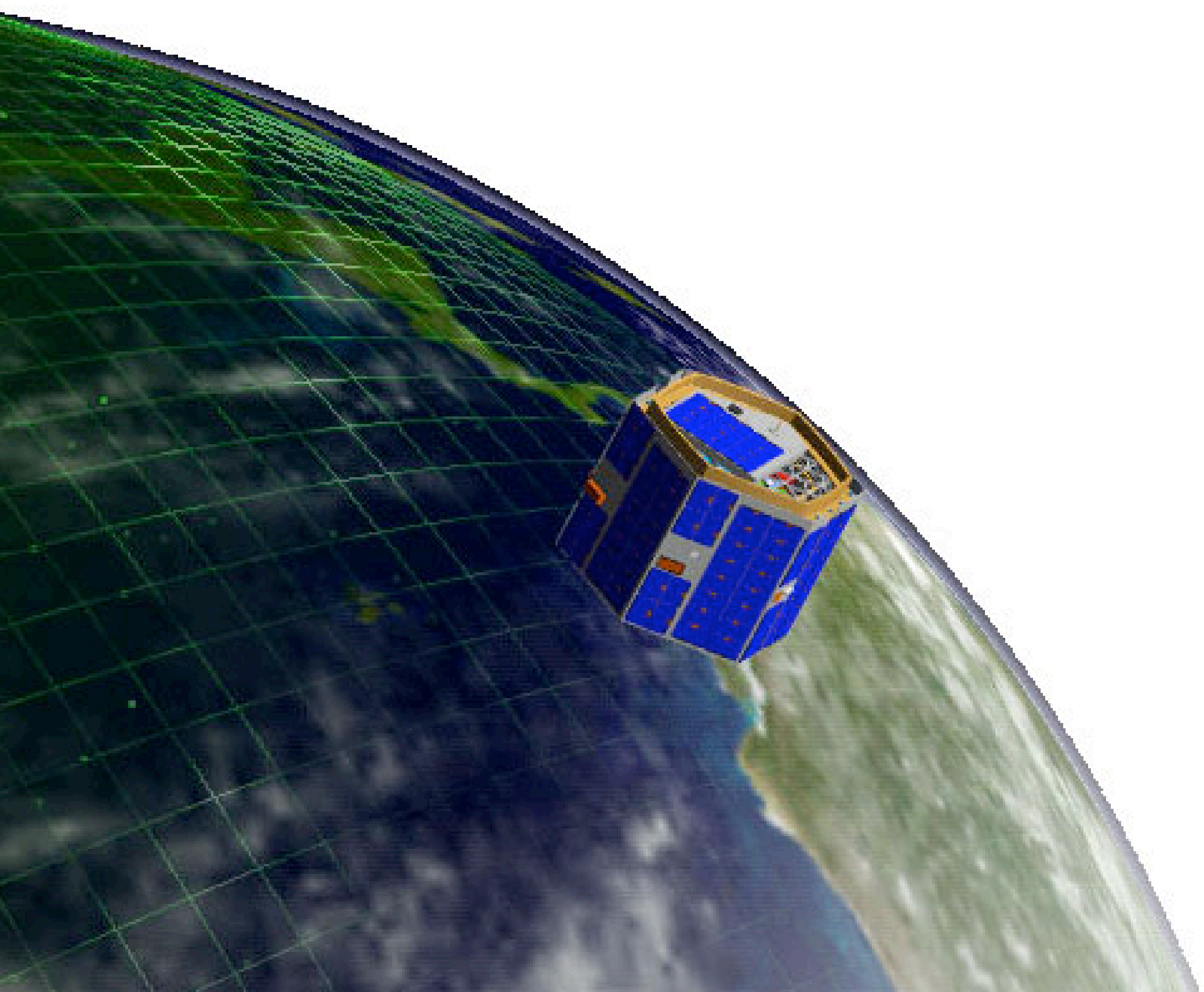
Thank you

- Space Systems Simulation Laboratory
- Dr. Christopher Hall
- Sourceforge.net
- ION-F & HokieSat

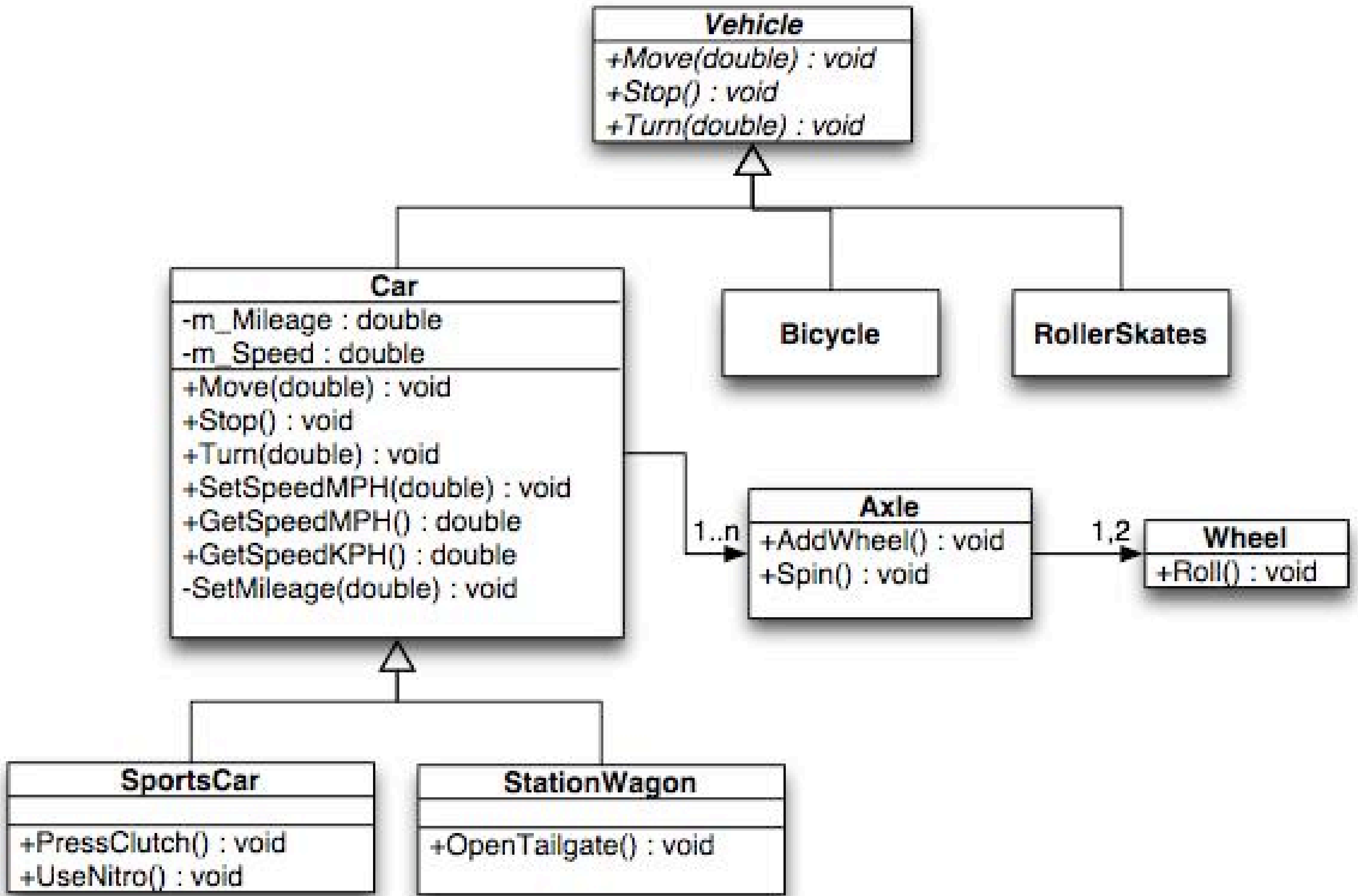
the Space Systems Simulation laboratory

Virginia Tech Department of Aerospace & Ocean Engineering

Questions?



Object-Oriented Programming



Section: Architecture Design

- Software Architecture
- Component Libraries
- Building an Application

Introduction
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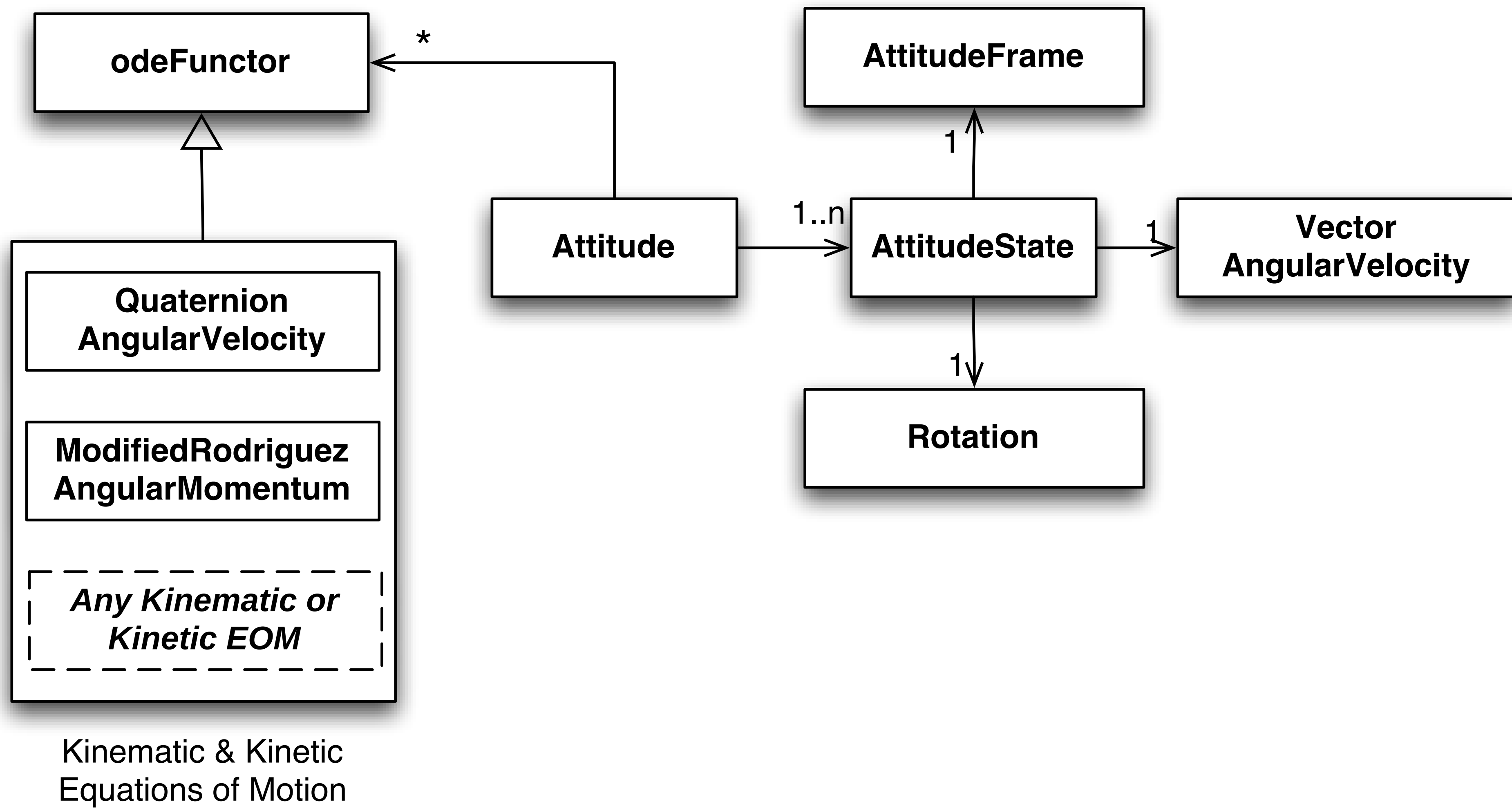
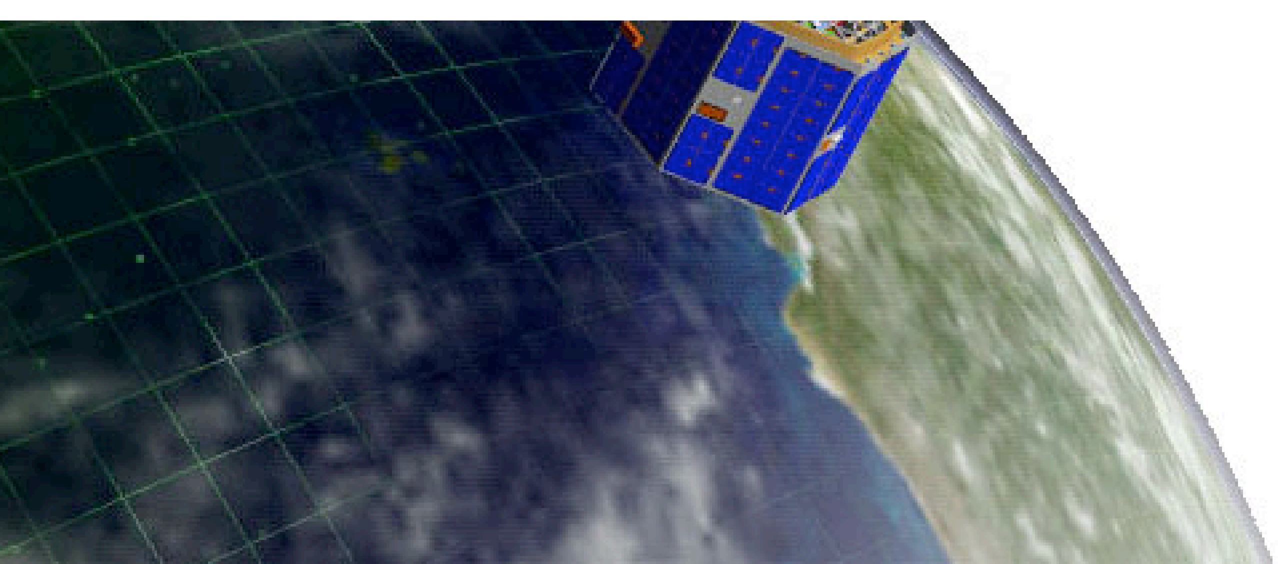
Attitude Library

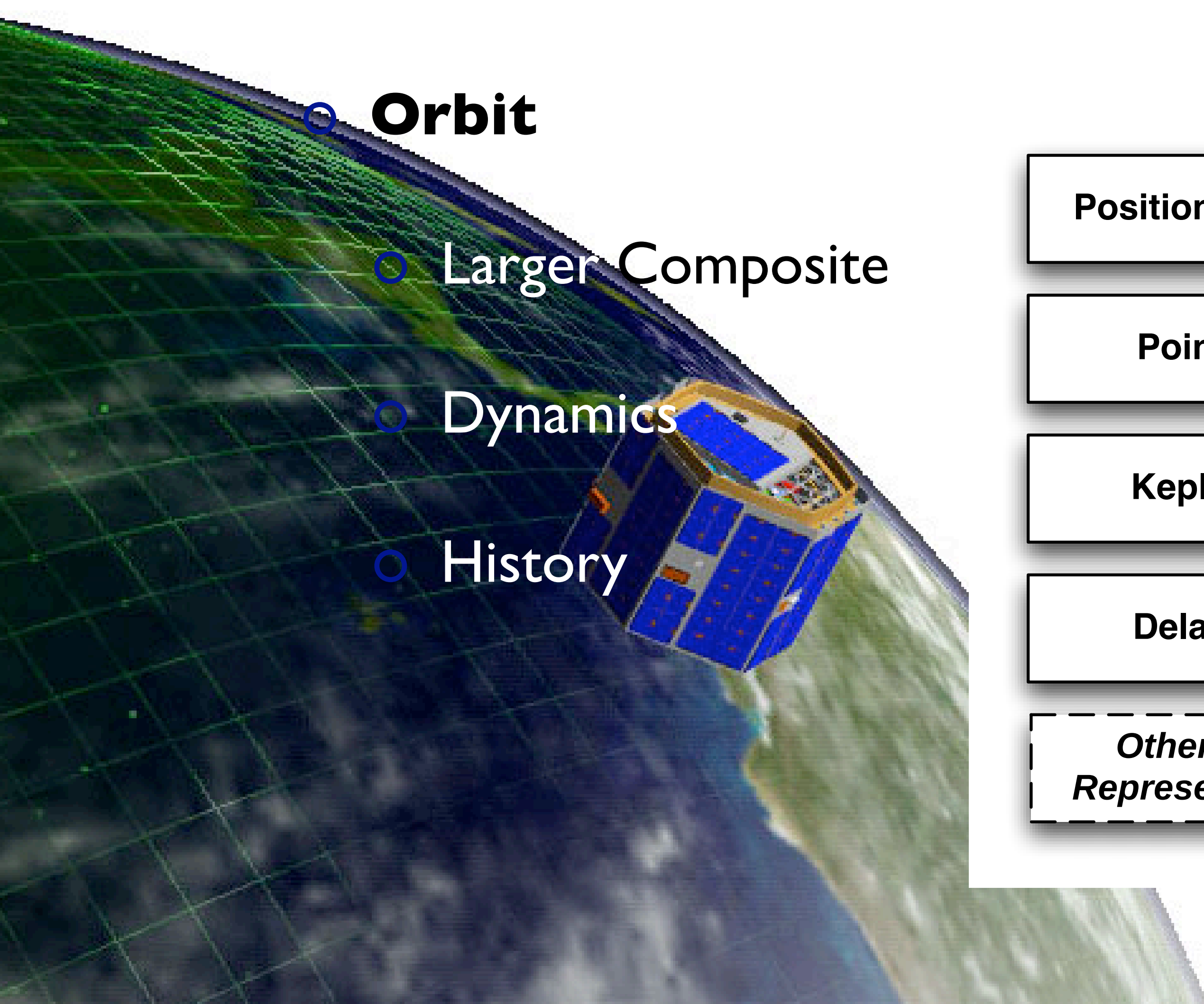


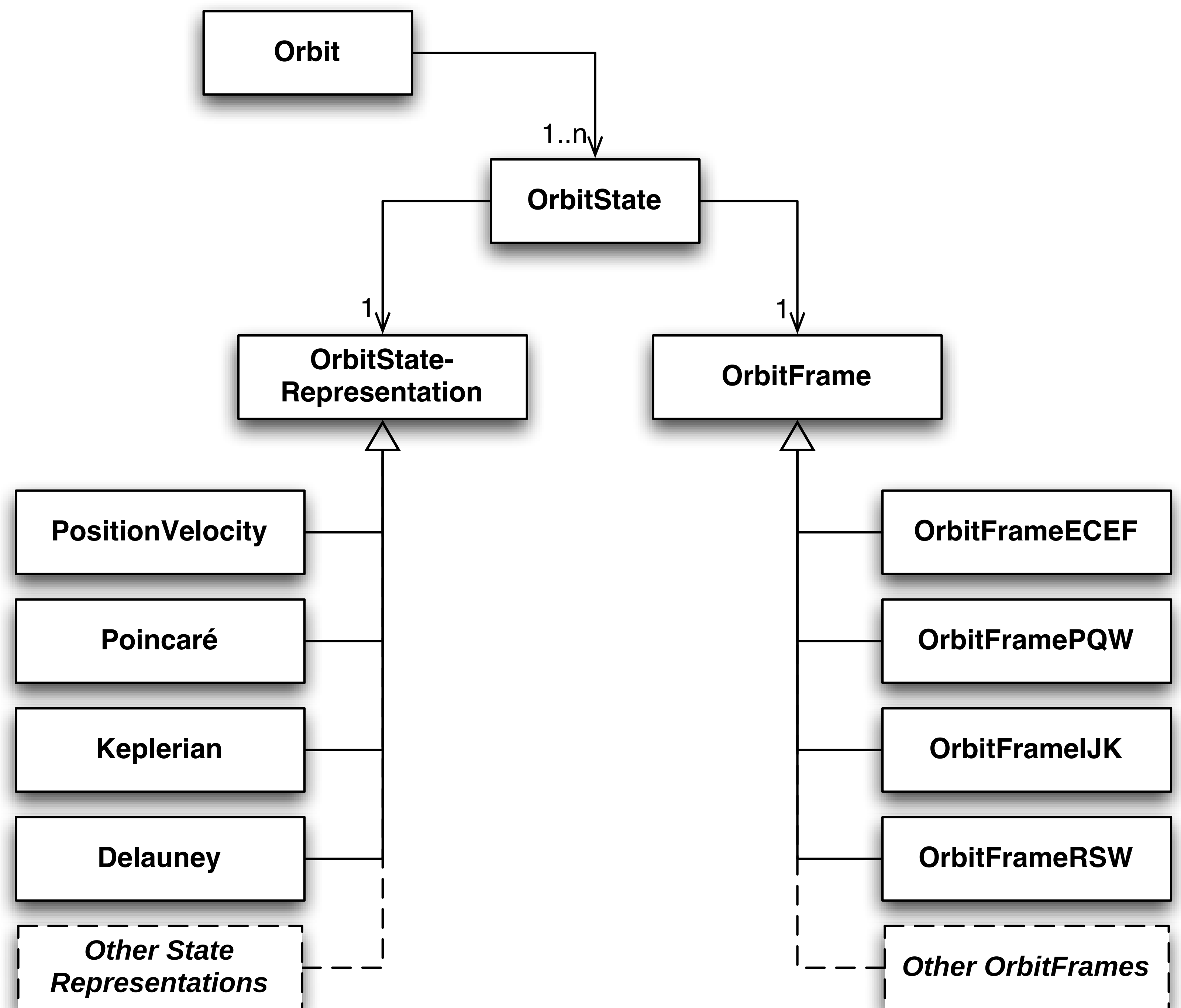
- AttitudeState
  - Composition
  - Rotation, Frame, AngVel
- Attitude
  - Larger composition
  - AttitudeState
  - Kinematics & Dynamics
  - History



Orbit Library

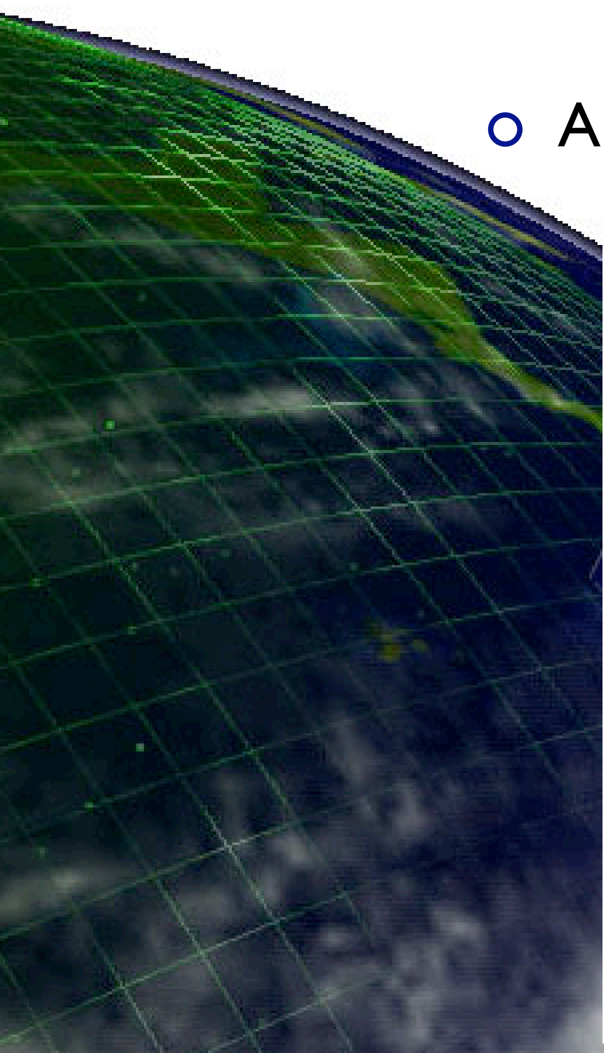
- OrbitState
  - Local Composite
  - **OrbitStateRep**
  - **OrbitFrame**
- Orbit
  - Larger Composite
  - Dynamics
  - History

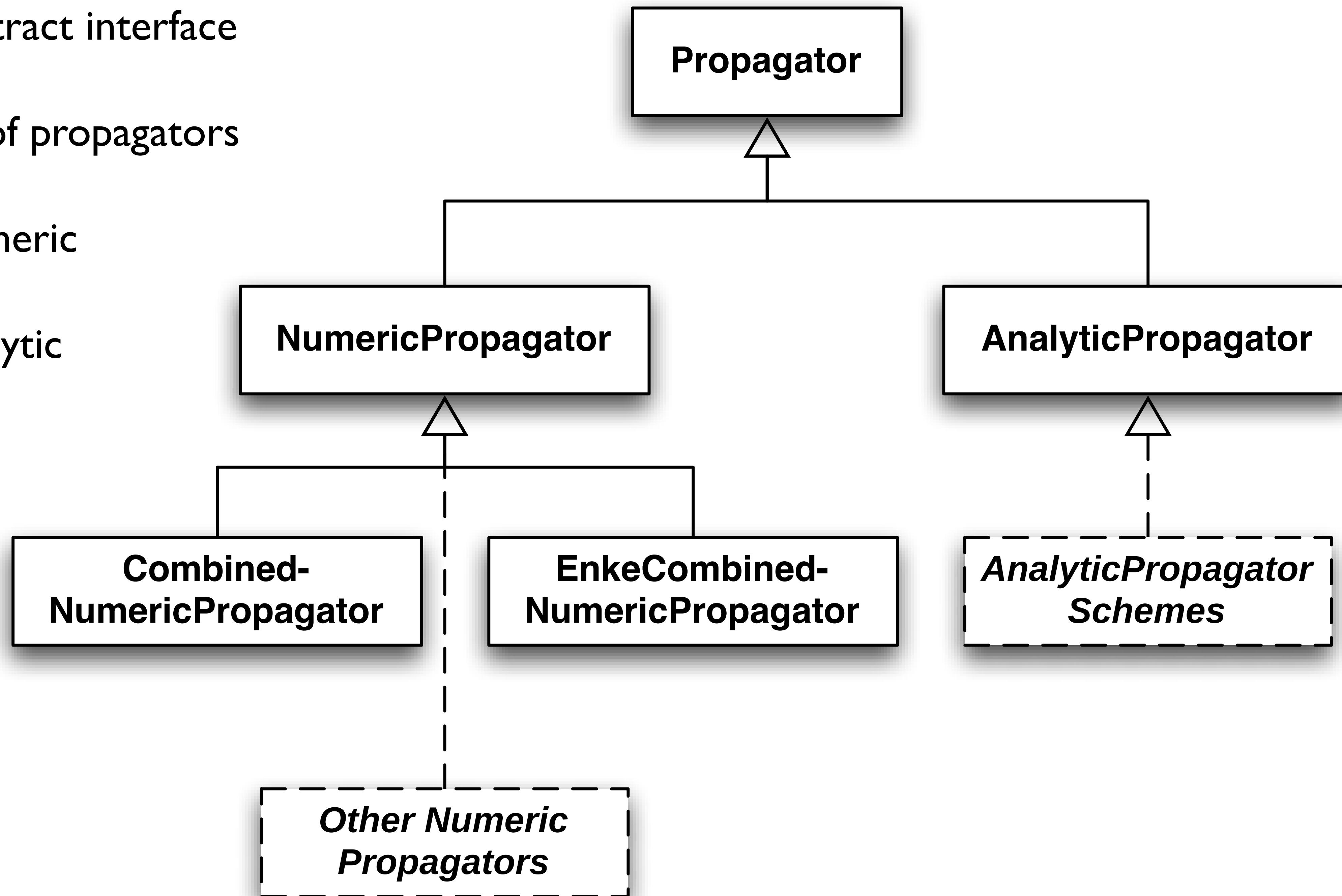




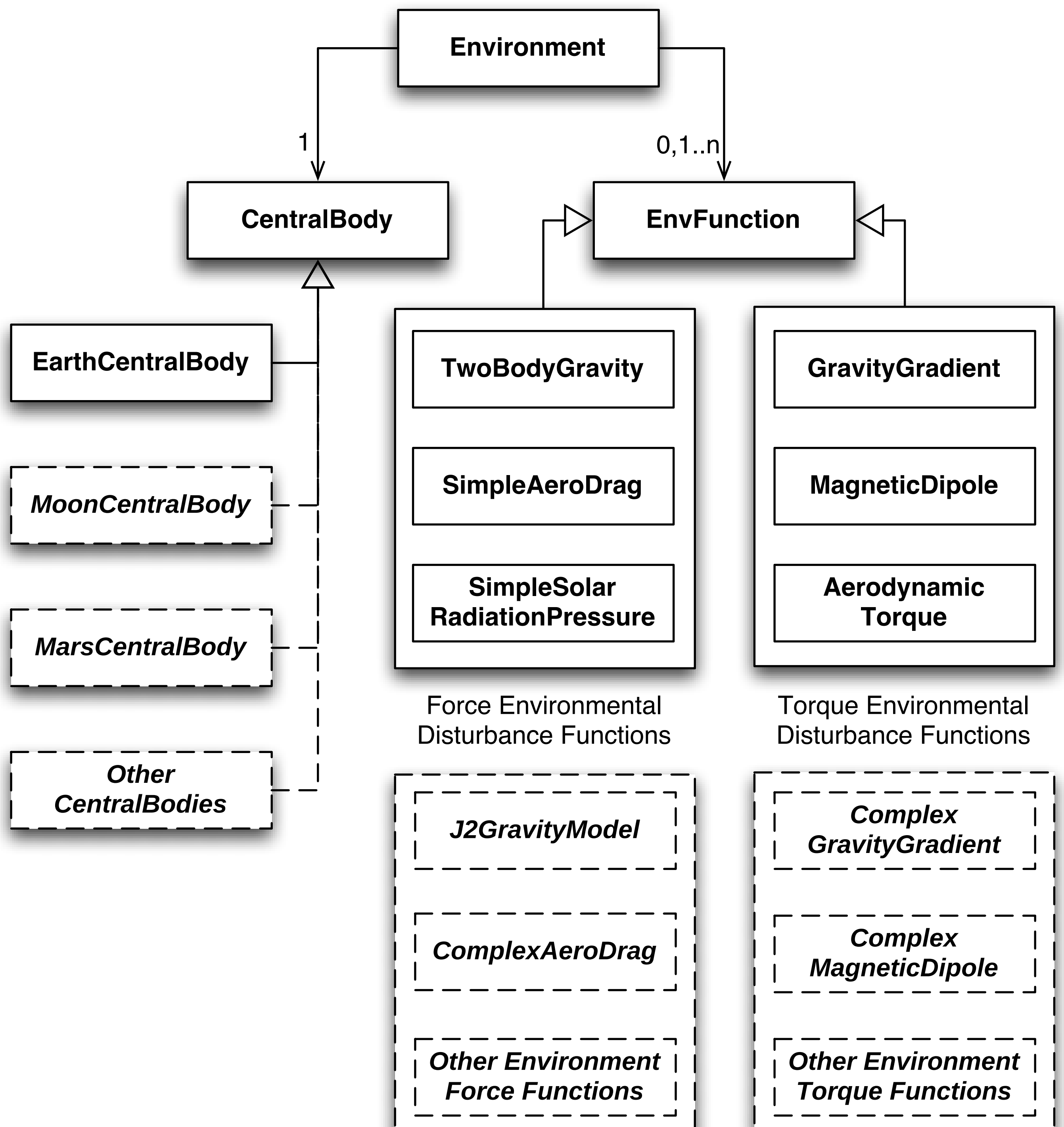
Dynamics Library

- **Propagator**
  - Abstract interface
- Types of propagators
  - Numeric
  - Analytic





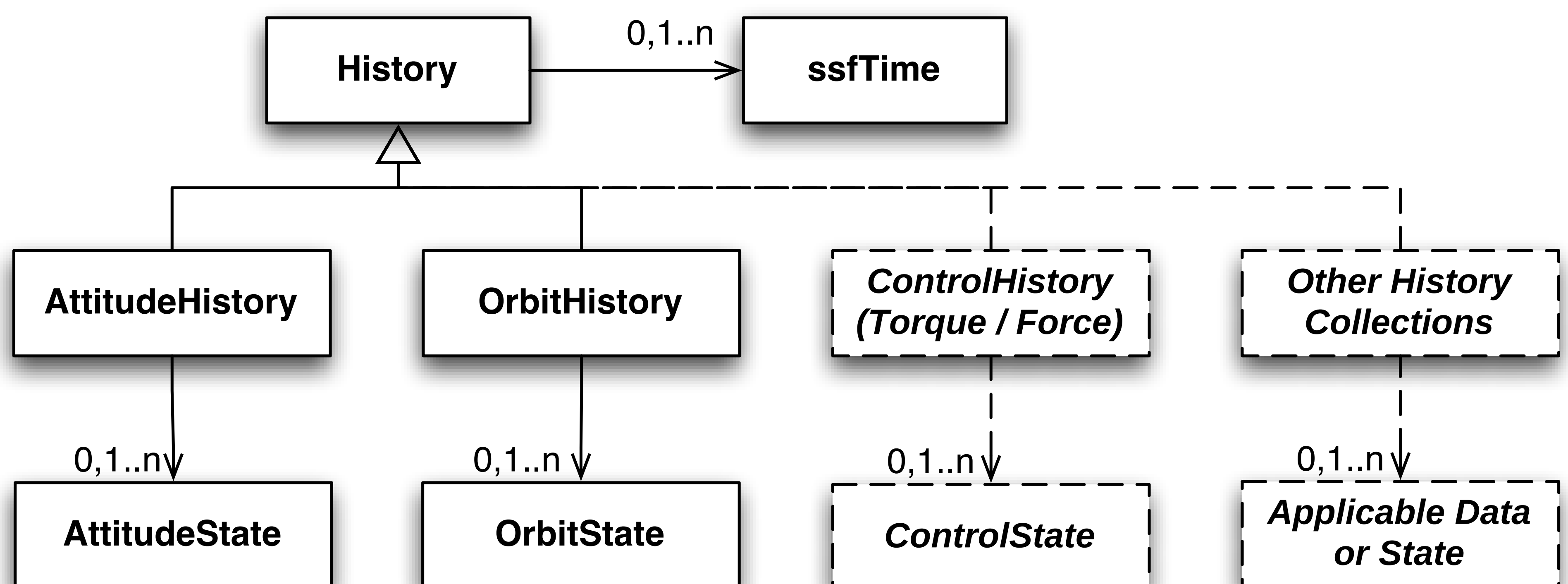
Environment Library



- Environment
  - Composition and interface
- CentralBody
  - Physical parameters
  - Defines frames
  - Location with respect to other celestial bodies
- EnvFunctions
  - Interface to force and torque functions
  - Parameters: time, orbit state,

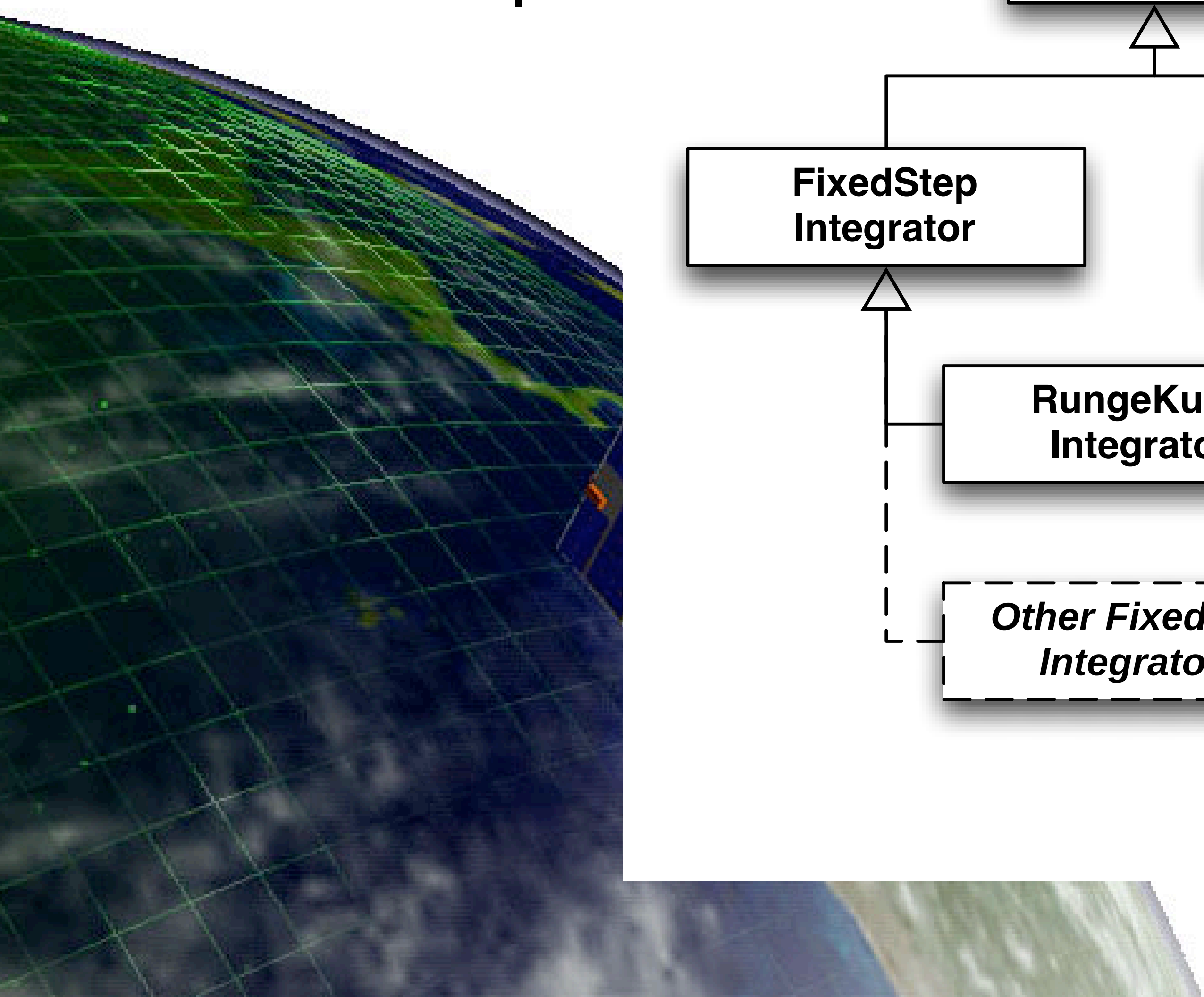
Data Handling Utilities

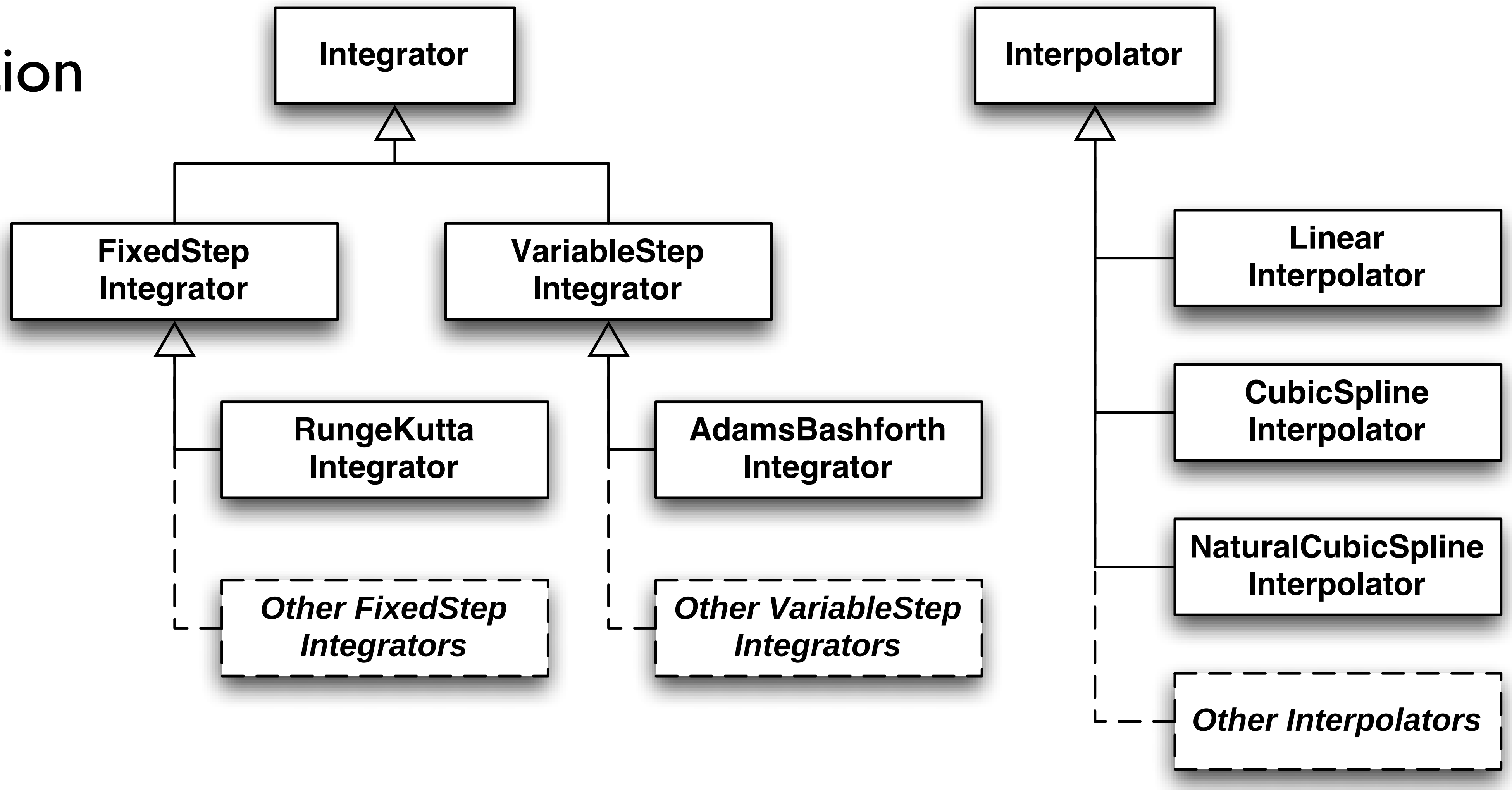
- **History**
  - Vectors of data
  - Associated with times
  - Interpolation
- Data Conversion



Math Library

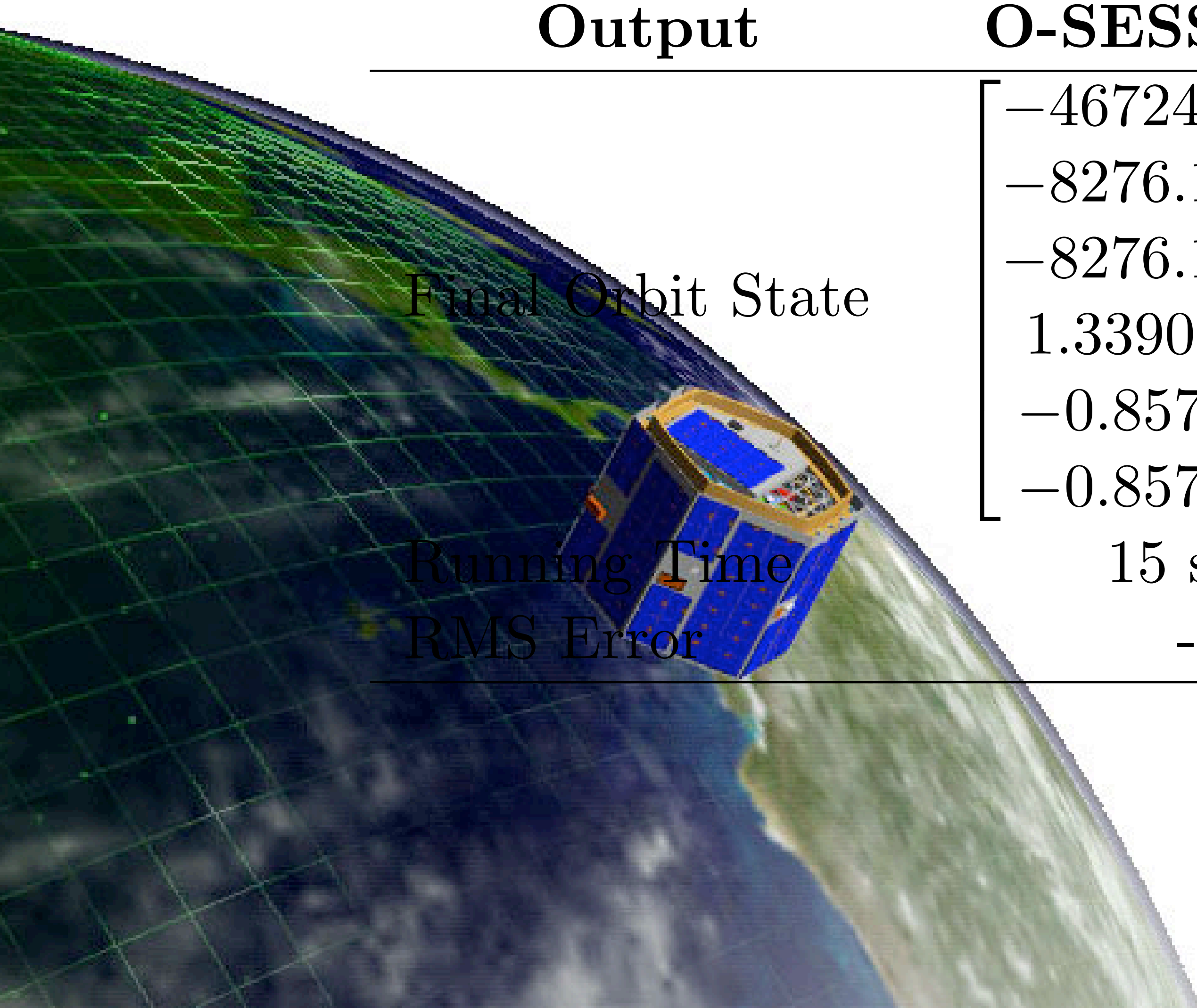
- Numerical Integration
  - Fixed step
  - Variable step
- Data Interpolation





High Eccentricity

Parameter	Value		
Initial Orbit State	$\mathbf{r}_0 = \begin{bmatrix} 7500 & 0 & 0 \end{bmatrix}^T$		
	$\mathbf{v}_0 = \begin{bmatrix} 0 & 6.819333903 & 6.819333903 \end{bmatrix}^T$		
Disturbances	Two-Body Gravity		
Integrator	Runge-Kutta-Fehlberg 4(5)		
Simulation Time	20 days		
Output	**O-SESSAME**	**STK**	**FreeFlyer**
Final Orbit State	$\begin{bmatrix} -46724.94751 \\ -8276.177337 \\ -8276.177337 \\ 1.339061791 \\ -0.85741544 \\ -0.85741544 \end{bmatrix}$	$\begin{bmatrix} -46727.35881 \\ -8275.048124 \\ -8275.048124 \\ 1.338824 \\ -0.857447 \\ -0.857447 \end{bmatrix}$	$\begin{bmatrix} -46713.96349 \\ -8283.620519 \\ -8283.620519 \\ 1.340490327 \\ -0.857151194 \\ -0.857151194 \end{bmatrix}$
Running Time	15 sec	4 sec	48 sec
RMS Error	-	2.72×10^{-4}	1.73×10^{-3}



Accumulation of Error