Karma Glossary

Acceleration Rate of change of velocity with respect to time, or how fast velocity is increasing.

Actuator A mechanical device for moving or controlling something, such as a motor, a lever, a piston, and so on. Actuators can be implemented with forces and torques or with velocity constraints.

Angular Velocity The rate of rotation about an axis. This is a vector quantity whose direction points along the instantaneous axis preserved by the rotation and whose magnitude is the rate of rotation about this axis.It is usually expressed in radians per second or revolutions per second.

Ballistics Ballistics is the science of the motion and behavior of projectiles, missiles, bullets and other similar objects in flight submitted to a gravitational field and air resistance.

Ballistic Objects In a games development environment, ballistic objects are usually single rigid body projectiles that are subject to ballistic calculations without contacts or impulses.

BSP Tree Binary Space Partitioning (BSP) tree. BSP trees are tools used in 3D graphics for organizing the geometry of objects and extracting information about geometrical relationships. In 3D worlds they are often used for visibility determination and hidden surface removal.

Cartesian Coordinates A coordinate system which is based on orthogonal axes. This is the standard x, y and z coordinate system, in contrast to polar coordinates on a sphere. In 3D graphics applications, x usually stands for left-right position, y describes vertical position and z gives the position along the line of sight, (i.e., depth). Traditionally, graphics viewers use a Left Handed system where x increases to the right, y increases towards the top, and z increases further along the line of sight i.e., into the screen.

Center of Mass The point in a body or system of bodies at which the whole mass may be considered as concentrated. For the purpose of dynamics calculations, a body or system of bodies can be abstracted to a point mass located at its center of mass coordinates.

Collision Detection A calculation which determines if two objects are intersecting, and if so, also computes the location and the local geometry of the object near the intersection. Collision detection may determine the spatial relationships between objects, such as the approximate separation distance between them.

Collision Model A geometrical representation of an object used for collision detection. Karma supports a variety of primitives such as sphere, box, plane, cylinder and cone as well as more complicated objects such as convex primitives and unstructured lists of triangles. The collision model may be identical to the model used for rendering or maybe an approximation that allows for faster collision detection. Collision models can also be made up of a combination of collision primitives.

Collision Response The change of motion of an object which occurs when it collides with another object, or when a joint limit is reached. Note that collision response is related to the dynamics properties of the objects in contact. Collision response is determined by the degree of restitution and the friction properties at the point of impact.

Constraint An external restriction on the motion of an object or body. There are equality and inequality constraints, constraints on positions and velocities, ideal constraints and non-ideal ones, and further constraints on forces resulting from constraints. There are constraints involving a single rigid body and others involving more. Constraints are maintained by computing a force that must be applied to all involved bodies so that the constraint remains satisfied. An example of an equality constraint could be that a joint attached to a specific location of a body should not be allowed to wander off a preset location, that is, the body may move as long as that point remains where it was initially (this still allows object rotation about that point). An *inequality* restriction could be a ball placed in a room: allowed to move freely on the floor as long as it stays inside the area bordered by the walls.

These restrictions are used to connect objects together, such as connecting two rigid bodies with a hinge, or to impose motion in a joint by applying a force limited velocity constraint which is used to model a motor. Constraints are called ideal or non-ideal according to whether or not they dissipate energy, i.e.: whether or not the constraint force does work on the system. A ball and socket joint is an ideal constraint but a box friction contact constraint is non-ideal.

Constraint Equation A mathematical relation between the coordinates of several bodies.

Culling Culling is the process of selectively removing items from a collection. For example, the process of eliminating certain polygons that shouldn't be seen before drawing a scene.

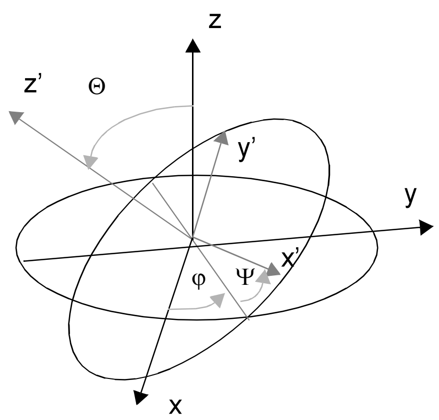
Convex Object A geometrical object with no holes in it, such as a sphere or a cube. More precisely, an object is convex if given any two points of the interior or the surface of the object, all the points that lie on the line segment between those two points are also inside or on the surface of the object. A doughnut is not convex for instance.

Damping This is a rate of energy loss of a body. It results in the body slowing down and being gradually brought to rest. Rate of energy loss is proportional to velocity.

Dynamics Dynamics is the part of mechanics (which, of course is a branch of physics) that is concerned with the causes of accelerating motion. It describes the change in motion of objects or particles using the concepts of force, momentum, energy, and mass. It is governed by the three basic laws of motion, called Newton's laws. See Newton's Laws.

Euler Angles

The Euler angles are the three angles Ψ, Θ and φ (for yaw, pitch and roll) used to describe the orientation of a body's reference frame relative to the world reference frame.



The resulting rotation matrix R_{ij} would be written as:

$$\begin{bmatrix} \cos\Psi\cos\varphi - \cos\Theta\sin\varphi\sin\Psi & \cos\Psi\sin\varphi + \cos\Theta\cos\varphi\sin\Psi & \sin\Psi\sin\Theta \\ -\sin\Psi\cos\varphi - \cos\Theta\sin\varphi\cos\Psi & -\sin\Psi\sin\varphi + \cos\Theta\cos\varphi\cos\Psi & \cos\Psi\sin\Theta \\ \sin\Theta\sin\varphi & -\sin\Theta\cos\varphi & \cos\Theta \end{bmatrix}$$

Another way of representing a body's rotation is with a *quaternion.*

Force

A force is what causes the state of motion (momentum) of an object to change. If you to change the way something is moving (change its direction or make it go faster, for example) you must apply a force to it. Forces are vector quantities with orientation and magnitude. The bigger the force, the faster the motion will change. In 3D games' worlds, forces typically include gravity and wind.

Force-limited Motor

This is a special model for controlling the remaining degree of freedom in either a hinge or a prismatic joint in the Karma Dynamics Library. It allows you to control the relative linear velocity of two bodies connected by a prismatic joint or the relative angular velocity of two bodies connected with a hinge joint. You set the desired target velocity, which will be achieved provided that the force required to do so is less than the limit specified, otherwise, the maximum force is applied. You may control the desired velocity using a mouse or a joystick input signal. Force limited actuators respond very quickly and are inherently stable; they are the best way to introduce user controlled motion in a joint in the Karma Dynamics Library.

Frame A single rendered screen of graphics,

Frame Rate The number of screen images displayed per second, usually abbreviated by *fps* (frame per second). Common frame rates are 60fps for games consoles, 25fps for PAL video, and 30fps for NTSC video, although other speeds may be used

Friction Force The force that resists relative motion between two bodies in contact. Viscous friction imposes a force which is proportional to the relative velocity and opposed to it. Dry friction has two modes: sliding mode and stick mode. When bodies are sliding, this force directly opposes the relative motion and has a magnitude proportional to the normal force which keeps the two bodies from interpenetrating. Otherwise, this force prevents the bodies from sliding, in which case it does not dissipate energy.

GJK Algorithm A fast method of doing collisions between a set of convex objects invented by Gilbert, Johnson and Keerthi and described in: "A Fast Procedure for Computing the Distance between Complex Objects in Three-Dimensional Space" by E. G. Gilbert, D. W. Johnson and S. S. Keerthi, IEEE Trans. Robotics and Automation 4(2):193-203, April 1988.

GJK Engine The part of the collision detection software that implements the GJK algorithm.

Gravity In a Newtonian world, gravity is a force that attracts all objects to each other. Gravitational force between any two given objects is proportional to the products of their masses and inversely proportional to the square of the distance that separates them.

However, we are mostly interested in constant and uniform gravity which is the force that keeps your chair on the floor. For objects near the surface of the earth, gravity causes objects to accelerate downward at a constant rate of 9.81 m/sec^2, independent of their mass. This means that gravity causes an object's velocity to change by 9.81 m/sec^2 downward for every second the object is under the influence of gravity.

Hooke's Law This law states that the force on a object displaced from a point of equilibrium is proportional to the displacement and in the direction opposite to the displacement.

Impulse The change in momentum of an object. This can happen over either a finite time interval or over a vanishingly small time interval as in the case of collisions. Most of the time, people mean the latter when referring to impulses i.e., forces which act over a very small amount of time and which cause sudden changes in the velocity of an object.

Inertia The tendency of an object to maintain its state of rest or of uniform motion. The resistance to change in the quantity of linear motion (linear momentum) is given by the mass of the object. Resistance to change in the quantity of angular motion (angular momentum) about an axis is the moment of inertia about that axis.

Inertia Tensor The set of numbers that describe the resistance to change in angular motion. This consists of several numbers because, in any given orientation, a body may have different inertia to rotation about all three axes, x, y and z. This quantity also changes with the orientation of the body, which is why it is a tensor.

The inertia tensor can be represented as a 3x3 matrix which is symmetric and positive definite.

Inertial Reference Frame

A reference system in which Newton’s laws of motion hold. See *Newton’s Laws*.

Joint An equality constraint or connection between objects or bodies. When two or more bodies or objects are connected by joints, they form a multi-body system which is also called a jointed body or an articulated body.

Kinematics Kinematics is the study of how things move in relation with time. It describes the different types of motion a body can undergo: translational (change of position), rotational (change of orientation), vibrational (change of shape and size).

Local Coordinates The origin of the local coordinate system of a body is usually located at its center of mass.

Jacobian Matrix Given any vector function of several variables with components

$F_1(x_1, x_2, ..., x_n)$,

$F_2(x_1, x_2, ..., x_n)$,

....

$F_n(x_1, x_2, ..., x_n)$,

the Jacobian matrix is defined as:

$$J_{ij} = \frac{\partial F_i}{\partial x_j}$$

In the case where the functions F_j represent a coordinate transformation between x_i and $q_j = F_j$, the Jacobian matrix is the linear approximation of the coordinate transformation in the neighborhood of the point where the derivatives of F_j are evaluated.

In a more general way, the Jacobian matrix is the local linear approximation of a non-linear function in the neighborhood of a point x_0:

$$F(x) = F(x_0) + J(x-x_0)$$

In Kea, we use the Jacobians of the constraint functions in the computation of the constraint forces, i.e. the forces required to maintain the constraint.

Mass

Mass is the measure of the amount of material contained within a body. It is independent of the location of the body.

Mechanics

A branch of physics that deals with the analysis of motion of physical objects. This includes the study of the equations of motion derived in dynamics.

Momentum

This is a quantitative measure of the state of motion of an object. Linear momentum is the product of mass and velocity: $\vec{p} = m\vec{v}$ and is a vector quantity. Angular momentum is a measure of the rotational motion of an object around some point.

Newton

The SI unit of force, derived from 3 basic units: mass, length and time.

Newtons' Laws

Newton's first law of motion: In an inertial frame, an object that is free of interaction has constant momentum. An object at rest remains at rest, and if it is in motion, that motion will be uniform and constant, that is, the center of mass will move on a straight line and the motion about the center of mass will be uniform. The tendency of an object to resist any change in motion is called the **inertia** of the object. **Mass** is a measure of inertia.

Newton's second law states the relationship between an acting force, the momentum of a body, and its acceleration, as follows:

$$\frac{d\vec{p}}{dt} = \vec{F}$$

where p is the momentum of the object and F is the applied force. In words, this means that the force exerted on a body is equal to the rate of change of momentum of that body. For point masses with constant mass, this simplifies to:

$$m\frac{d\vec{v}}{dt} = \vec{F}$$

the familiar F = ma. As such, Newton's second law only applies to point masses and further analysis is required to derive the equations of motion for rigid bodies and composite objects.

Newton's third law states that for every action there is an equal and opposite reaction. If two bodies interact, the magnitude of the force exerted by body 1 on body 2 is equal to the magnitude of the force exerted on body1 by body 2. These two forces are also opposite in direction.

Normals

Normals are unit vectors. The normal to a plane is a unit vector perpendicular to the plane. In 3D graphics, they indicate the visible side of an object.

Object

We use this term to describe virtually any entity that can move—a point mass, rigid body, articulated body, multi-body system, and so on. We use it as a general term when what is being discussed is not restricted to rigid bodies. Object does not refer to object-oriented programming constructs.

Ordinary Differential Equation

A differential equation is a relationship between the rate of change for the variables of a system and the state of that system. The term *ordinary* means that the derivatives are taken with respect to an independent variable which is often labelled as time. When there is more than one independent variable, such as space for instance, the equations are called partial differential equations.

Orientation

Describes a body’s direction relative to the world or reference frame coordinates.

Power

The time rate at which work is performed (energy is transformed) by a system.

Quaternion

Quaternions form a four-dimensional algebra which is an extension of normal complex numbers. They can be used to represent rotations of coordinate axes in 3D worlds in a way that is free of singularity, in contrast to Euler angles, for example. With Euler angles there are difficulties when the pitch angle reaches 90 degrees - a problem that never occurs when quaternions are used.

The four components of a unit quaternion which represents a 3D rotation can be thought of as a set of parameters for 3D rotations, as an alternative to Euler angles.

Because they lack the singularities that Euler systems have, quaternions allow for smooth interpolations between rotations. It is possible to convert *Euler Angles* to a quaternion *Q* using the following equation:

$$Q = q_o + q_x\mathbf{i} + q_y\mathbf{j} + q_z\mathbf{k}$$

where:

$$q_o = \cos\left(\frac{\Psi}{2}\right)\cos\left(\frac{\Theta}{2}\right)\cos\left(\frac{\varphi}{2}\right) + \sin\left(\frac{\Psi}{2}\right)\sin\left(\frac{\Theta}{2}\right)\sin\left(\frac{\varphi}{2}\right)$$

$$q_x = \cos\left(\frac{\Psi}{2}\right)\cos\left(\frac{\Theta}{2}\right)\sin\left(\frac{\varphi}{2}\right) + \sin\left(\frac{\Psi}{2}\right)\sin\left(\frac{\Theta}{2}\right)\cos\left(\frac{\varphi}{2}\right)$$

$$q_y = \cos\left(\frac{\Psi}{2}\right)\sin\left(\frac{\Theta}{2}\right)\cos\left(\frac{\varphi}{2}\right) + \sin\left(\frac{\Psi}{2}\right)\cos\left(\frac{\Theta}{2}\right)\sin\left(\frac{\varphi}{2}\right)$$

$$q_z = \sin\left(\frac{\Psi}{2}\right)\cos\left(\frac{\Theta}{2}\right)\cos\left(\frac{\varphi}{2}\right) + \cos\left(\frac{\Psi}{2}\right)\sin\left(\frac{\Theta}{2}\right)\sin\left(\frac{\varphi}{2}\right)$$

Restitution (coefficient of)

When designing your game, think of restitution as bounciness. In physics terms it is the ratio of the relative speeds of two bodies just after and just before a collision between them along their direction of impact; it ranges from 0, for perfectly inelastic collisions (no bounce), to 1 (maximum bounce), for completely elastic ones. If you increase the value to a number greater than one, you'll get an effect like a pinball machine. It is a constant at moderate speeds.

Right—Hand Rule

A useful visual aid to represent a right-handed coordinate system. Here's how it works: orient your right hand so that your thumb is perpendicular to the plane defined by the x and y axes, and so that you can curl your fingers in the direction from the x axis towards the y axis. Your thumb will be pointing in the direction of the z axis.

Rigid Body

A solid object that doesn't change its shape or size, despite any forces being applied to it.

Rotation

In a 3D world, rotation of an object is its motion about an internal axis of symmetry relative to an internal coordinate system.

SI Units and Prefixes

SI stands for *Systeme International*. It is a standardized set of units for scientific measurement. Examples of SI units include: the Newton, metre, Hertz, second and Watt. Examples of SI prefixes include: mega, milli, tera and giga.

Stiff Springs

Stiffness is a measure of how a spring resists stretching. A very stiff spring will hardly move at all—even if you pull very hard, whereas a spring with very little stiffness will stretch easily even if you pull it gently.

The stiffness is related to the 'spring constant' usually represented by the letter *K*. Writing this down as a formula called Hooke's law for the extension of springs we get;

Force = - (spring constant) X (length increase)

Stiff springs create very large forces for short times and this can be a problem in a simulation. The reason is that the force is never very large for very long. For a small mass attached on a stiff spring, the resulting motion for the mass is to stay *very* near the point of equilibrium. The force from the spring will change very rapidly from large to small to keep the mass in place. An integrator that is using a time step larger than half the period of the spring might overestimate the magnitude of the force and this can lead to an "explosion" i.e., a situation where the mass moves further and further away from the equilibrium point.

Note also that the frequency of a spring is dependent on the mass attached on it and if you drop a small mass on a stiff spring, that will produce a very high frequency which might be difficult for the integrator.

The constraint solver uses a first order integrator for user forces which doesn't check if forces are getting very large. This means that you should avoid stiff springs altogether. If you want to simulate a stiff spring, you should use a "relaxed" constraint instead i.e., a constraint that is allowed to be violated.

Time-Step

Time, like mass, is another of those rather undefined measures in physics. Everybody knows what it is, and agrees to measure it in seconds.

A time step is an interval of time, typically of the order of the frame rate. If you run a simulation at 60 fps, your time step should be 1/60 s or shorter; if it is shorter, you will need to perform several steps between frames if you want to create a real-time simulation in which everything seems to move at the same rate as in the real world.

The simulation computes what the state of the system will be after an interval of time equal to the time step has elapsed, using current state and derivative information. Essentially, the simulator uses current velocities and forces and extrapolates them to compute an approximation of the state into the future. The correctness of the approximation is related to the time step: the bigger the time step the worse the approximation.

Tracking Problem

The problem of keeping track of the distance between objects as simulated time is stepped forward. This is useful to estimate when objects will collide.

Torque

A torque can be described as a turning or twisting force. It’s the measure of a force's tendency to produce a rotation about an axis, which also produces a change in the angular momentum of a body. For an extended body—one that is not just a single point mass - a torque is generated by applying a force at a point other than at the center of mass. The distance between the point where the force is

	applied and the center of mass acts like a lever: the greater the distance, the bigger the resulting change in angular momentum.
Velocity	The rate of change of position along a straight line with respect to time. A velocity has speed and direction; it is a vector quantity whose magnitude is expressed in units of distance over time, such as kilometers per hour.
Work	Work is the product of force, and the distance moved by the point of application of the force in the direction that the force was applied. Work is directly related to the change in the energy of the system.
World Reference Frame	A coordinate system that is used to locate an object in relation to a world origin. This is sometimes referred to as a Global Coordinate system.
XYZ axes	In a Cartesian coordinate system, these are the three orthogonal axes which represent three-dimensional space.