Generic Collision Detection for Games Using Ellipsoids

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Preface

This latest revision (October 5, 2000) outlines a set of changes since the September 25 revision of this document. These changes outline some corrections but primarily it is an improvement of the original algorithm, which includes a simplification for using ellipsoids, and also allows for oriented ellipsoids.

If you've already read this document in the past and want to skip right to the meat of the update, then re-read the section titled "**Making it ellipsoidal**". This section was completely re-written and the pseudo-code was updated to reflect this change.

Since this article was originally written, I've received a number of emails and comments; many of which were from people who have successfully implemented the technique, including a few professional game developers. But also, I've heard from a number of people that had some difficulty understanding certain concepts. So many clarifications have also been included in this update.

Introduction

I'm often asked about collision detection for games, where a player can collide with a static environment. I figured it was time to write a document, so I present you with this, very informal and in my own words.

This document will describe a collision technique that allows you to move an ellipsoid (a sphere with three different radii, one for each axis) through a world that not only properly detects collisions, but also reacts in a way that gamers would expect from the common first person shooter.

This technique also allows for sliding along surfaces as well as easy implementation of gravity, which includes sliding downhill when standing stationary. This technique also allows automatic climbing of stairs and sliding over bumps in walls (like door frames) and any other randomly oriented "stair-like topography".

Defining some terms

Just so we're all on the same starting page, I'll define three basic terms:

Source – The source point where a colliding object starts. Every colliding object travels from the source to a collision on its way to the destination.

Destination – This is where the colliding object wants to go to, but can't get there, because it's too busy bumping into stuff.

Velocity vector – This is the vector that defines the direction and speed that the colliding object is traveling. If a colliding object is traveling two feet forward, then the direction of this vector is forward, and the length of this vector is two feet.

Starting simple: spheres and planes only

I'm going to start simple by dealing with spheres and planes only. We'll get to ellipsoids and polygons soon enough.

Before we can really dig in, we'll need to determine the intersection of a ray with a plane. Here's some pseudo code:

```
// Inputs: plane origin, plane normal, ray origin ray vector.
// NOTE: both vectors are assumed to be normalized

double intersect(Point pOrigin, Vector pNormal, Point rOrigin, Vector rVector)
{
       double d = -(planeNormal * planeOrigin);
       double numer = planeNormal * rayOrigin + d;
       double denom = planeNormal * rayVector;
       return -(numer / denom);
}
```

Colliding a sphere with a plane

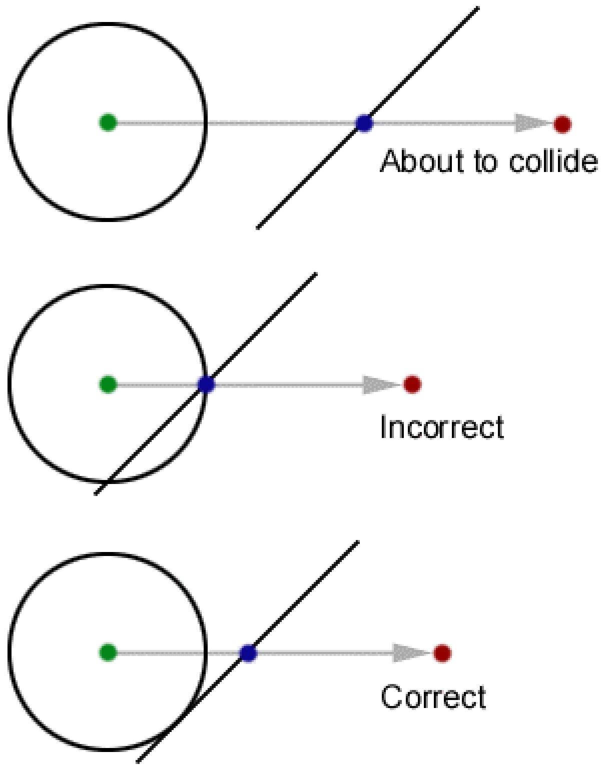


Figure 1: A sphere collides with a plane

Figure 1 shows that our task isn't as simple as determining where the velocity vector intersects the plane. As you can see, this causes an incorrect collision because the sphere passes through the plane at a point other than the ray/plane collision point. Let's take a closer look at the correct collision:

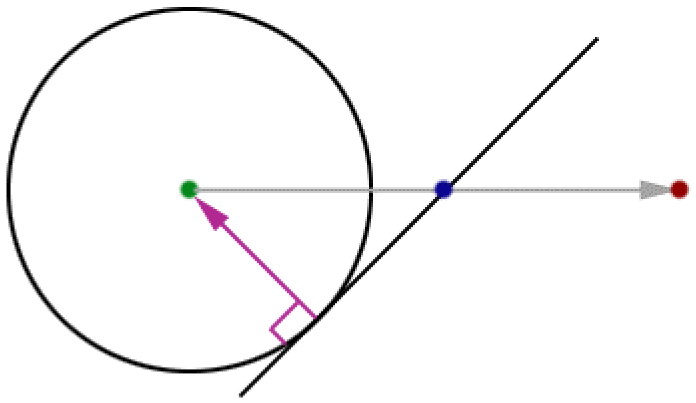


Figure 2: A sphere correctly collides with a plane

In figure 2, you can clearly see that the vector formed by the point of intersection and the center of the sphere, is coincident with the plane's normal. We can reverse this process to determine the point on the surface of the sphere that will intersect with the plane before we even do the collisions. That's a bit confusing, so here's a helping of visual aid:

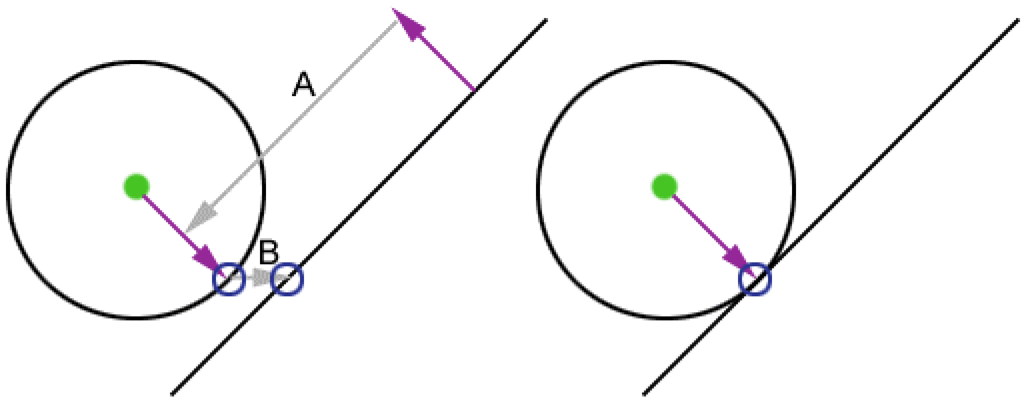


Figure 3: Using the plane's normal to find the *sphere intersection point*

Figure 3 shows that the plane's normal can be used to determine the point on the surface of the sphere that will eventually intersect the plane. We'll call this point the *sphere intersection point.*

We do this by first setting the length of the plane's normal to the radius of the sphere, and then we invert it. Following the gray line (labeled 'A') you can clearly see that the result is a vector that (when added to the center point of the sphere) results in the *sphere intersection point*.

From this point, we move along our velocity vector (the gray line labeled 'B'), until we intersect the plane. The latter half of the example shows the final result – our sphere sits nicely on the plane.

If the plane bisects the sphere, we'll end up with a *sphere intersection point* that is on the backside of the plane.

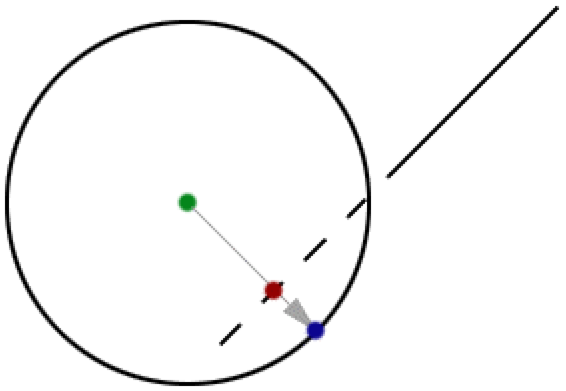


Figure 3a: Dealing with embedded planes

Figure 3a shows an embedded plane. Because of this, our *sphere intersection point* is beyond the plane, causing our collisions to fail.

To solve this problem, we first need to detect this case. We do so by determining the distance from the origin of the sphere to the plane. We trace a ray from the origin of the sphere toward the plane, along the plane's inverted normal (the gray vector shown in Figure 3a.) This results in the *plane intersection point* (the red point in Figure 3a.) If the distance from this point to the origin of the sphere is less than the radius of the sphere, we have an embedded sphere, and this becomes our plane intersection point. We then continue as normal and determine the *polygon intersection point*.

Colliding with multiple planes

At this point in time (it's a point as good as any :), I should mention that if you are colliding with a plane, and the *source* point is behind the plane, it can safely be ignored (unless you don't do back-face culling in your visuals.)

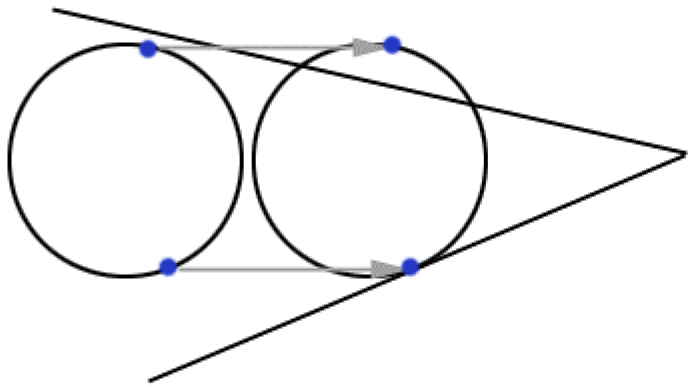


Figure 4: The problem of colliding with multiple planes

Figure 4, aside from being an optical illusion (both circles really are the same size), shows us that we need to be careful when there is more than one potentially colliding plane in our path.

The solution to this is simple… we merely need to consider all *potential colliders* and determine which one collides first…

Determining potential colliders

The method by which you chose to do this depends on your dataset, how it's organized, how you deal with collisions, and a whole lot more. But here's a simple solution that covers most cases:

1. Find the bounding box of your sphere, centered on the source position
2. Find the bounding box of your sphere, centered on the destination position
3. Find the bounding box of those two bounding boxes
4. Find all polygons that intersect that final bounding box

Be careful on #4! Finding a polygon that intersects the bounding box is not as simple as it seems… you can't just look for vertices in the box, since there will often be times when a polygon's vertices are all outside of a box, yet the polygon still intersects the box (consider a huge polygon with a tiny box that intersects the polygon near its center.) Properly doing this requires clipping the polygon to the box.

Getting ready to collide with polygons

Until now, I've tried to stick to dealing only with collisions with planes. If our scene was as simple as a single convex space we could stop here, but few scenes are. Here's an example of what you might run into if you only try to collide with planes rather than polygons, in a non-convex space:

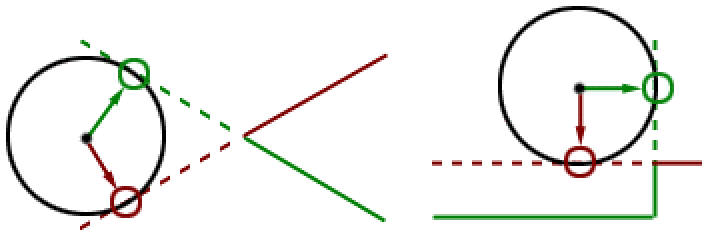


Figure 5: Collisions with planes in a concave world just doesn't work

Figure 5 is a clear example of two cases that show the difference between polygon and plane collisions.

At some point, we'll need to know which point inside the polygon is closest to our intersection point on the plane. Since the polygon and the intersection point both lie on the plane, this problem may be as simple as determining if our intersection point is within the polygon. If so, then our intersection point *is* the closest point in the polygon. However, often times, our intersection point will lie beyond the extents of the polygon (as shown in both cases of figure 5). In this case, the closest point in the polygon will lie on its perimeter.

So, it's time to find the closest point on a polygon's perimeter to a point.

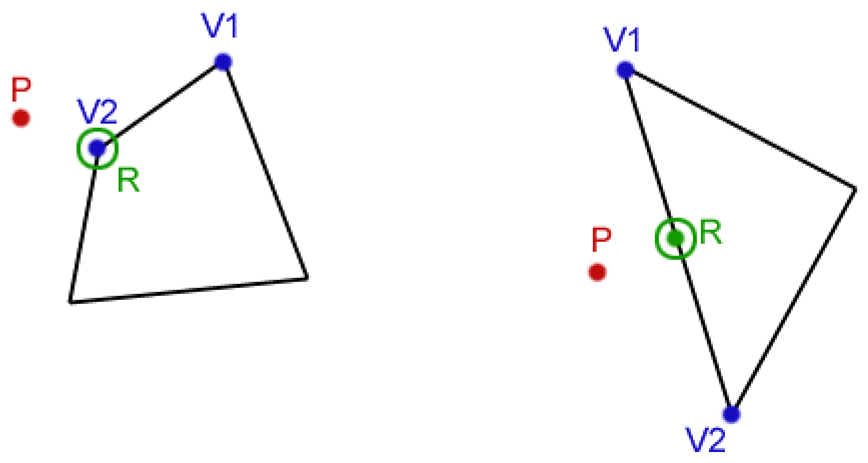


Figure 6: Finding the closest point on a polygon's perimeter

In the above example we show the closest point (R) to P. R is always on the perimeter of the polygon. The first step in solving this problem is to determine the closest point on a line to P. This is performed for each edge of the polygon and the closest resulting point from each edge is the winner. We call this resulting point 'R'. Here's an example that shows how to determine the closest point on a triangle's perimeter to a point on its plane:

```
Point  closestPointOnTriangle(Point a, Point b, Point c, Point p)
{
       Point  Rab = closestPointOnLine(a, b, p);
       Point  Rbc = closestPointOnLine(b, c, p);
       Point  Rca = closestPointOnLine(c, a, p);
       return closest [Rab, Rbc, Rca] to p;
}

Point  closestPointOnLine(Point a, Point b, Point p)
{
       // Determine t (the length of the vector from 'a' to 'p')

       Vector c = p - a;
       Vector V = Normalized vector [b – a];
       double d = distance from a to b;
       double t = V * c;

       // Check to see if 't' is beyond the extents of the line segment

       if (t < 0) return a;
       if (t > d) return b;

       // Return the point between 'a' and 'b'

       set length of V to t;
       return a + V;
}
```

Our goal

Let's take brief a look at our goal: a sphere that interacts with an environment in a natural way:

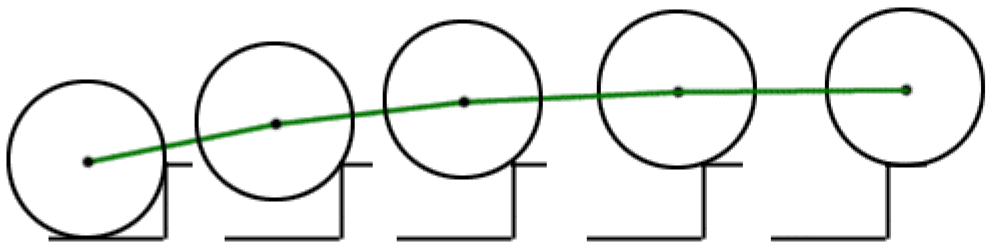


Figure 7: A sphere climbs a stair

Figure 7 shows five consecutive samples of a sphere climbing stairs. Note the green curve showing the path of the sphere. This curve allows our sphere to move about the environment in a smooth way, not jumping up stairs but rather *rolling* up them, in a way that a ball naturally would. Consider the following example:

> *If you were to place a beach ball in front of a wall that was taller than the ball, you would not be able to push the ball forward (the wall's height is taller than half the ball's height.) However, if you were to place the ball in front of a stair that was slightly less than half the ball's height and push the ball directly at the stairs (horizontally) you would notice that as you pushed the ball, it would begin to slowly move forward, climbing the stair as it did. Yet as the ball started to crest the top of the stair, you wouldn't have to push quite as hard to keep the ball moving. By the time the ball reaches the top of the stair, it will roll freely.*

The movement doesn't only follow a curve, but so does the amount of force required to push the ball up the stair.

Let's now extend this to a common game environment scenario, with a 6-foot ball, and a 1-foot stair. Referring to our real-world example, the ball would roll up the stairs with a nice smooth motion as it crested each stair, because the ball is so much taller than the stair. This is the effect we plan to achieve.

Colliding with polygons

Finding the intersection of the ray/plane doesn't give us enough information, since (as shown in figure 5) that point may not lie within the polygon (thus, it is termed the *Plane Intersection Point*.) We'll need to determine if this collision point is within the polygon and if not, determine the nearest point on the polygon's perimeter to this point. This will become our *Polygon Intersection Point*.

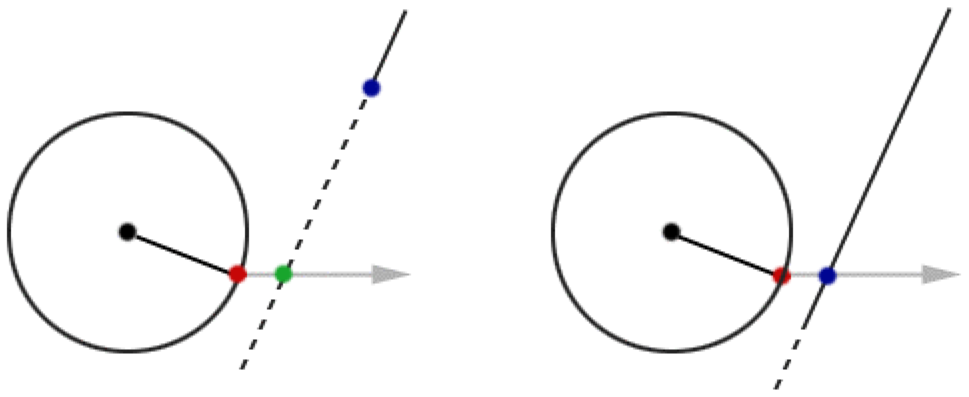


Figure 8: collisions and non-collisions with a sphere

Figure 8 (left) shows us that if we use the *sphere intersection point* to determine the intersection with the plane (along the direction of the *velocity vector*) we get a point, which lies on the polygon's plane yet lie outside the polygon (the *plane intersection point*.) What we really want is the *polygon intersection point.* To find this, we must determine the point on the polygon's perimeter that is nearest to the *plane intersection point*.

Figure 8 (right) shows us that the intersection with the polygon's plane results in a point within the polygon, so there is no need to determine the nearest point on the polygon's perimeter. In this case, the *plane intersection point* and the *polygon intersection point* are one in the same.

Also note that the *polygon intersection point* in figure 8 (left) will never intersect our sphere. So our next step is to determine where the sphere will intersect our *polygon intersection point* (if at all.)

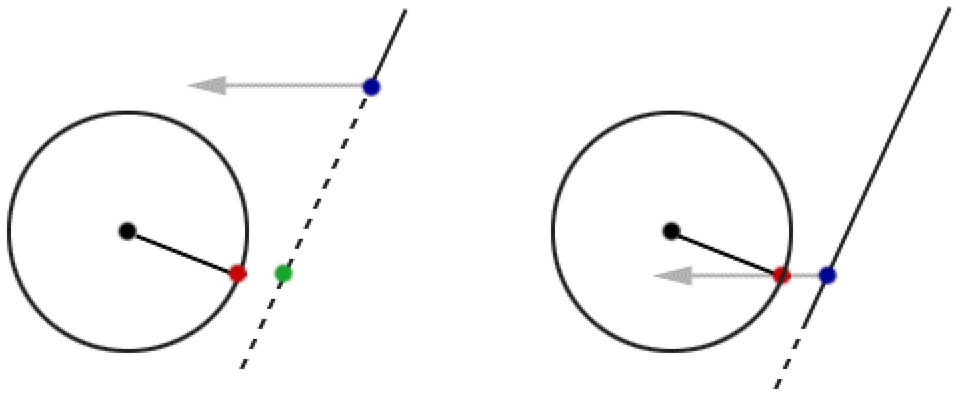


Figure 9: using the *polygon intersection point* to collide with the sphere

Figure 9 shows us that if we reverse the direction of the *velocity vector*, we can detect the point of collision with the sphere – we'll call this *reverse intersection*. To do this, we will need a ray/sphere intersection routine. In each case, our ray will originate from the *polygon intersection point.* Also note that in figure 9 (left) it has become clear that our sphere will never intersect the polygon.

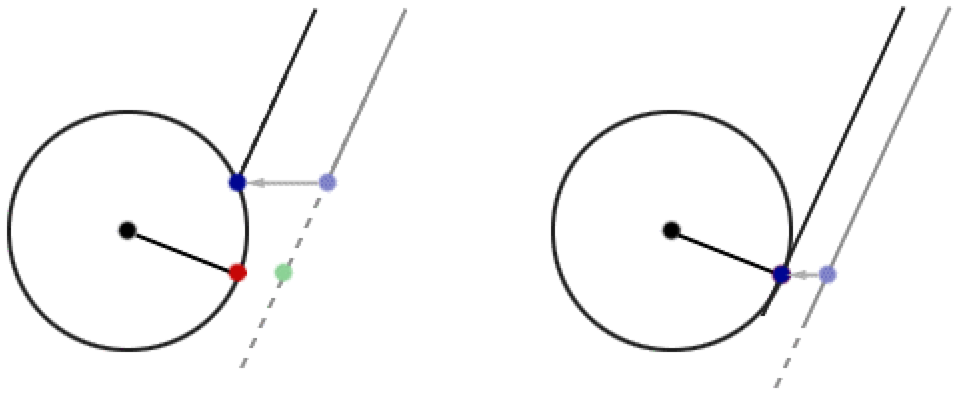


Figure 10: reverse-intersecting the sphere

Figure 10 shows two cases in which the polygon intersection point is used for reverse intersection to locate the point at which a collision with the sphere occurs. Note that in figure 10 (right) this point is the same point as the *sphere intersection point*; yet figure 10 (left) it is not.

Here's an example of the ray/sphere intersection (the inputs are the ray's origin and normalized direction vector, as well as the sphere's origin and radius):

```
double intersectSphere(Point rO, Vector rV, Point sO, double sR)
{
       Vector Q = sO - rO;
       double c = length of Q;
       double v = Q * rV;
       double d = sR*sR - (c*c – v*v);

       // If there was no intersection, return -1

       if (d < 0.0) return -1.0;

       // Return the distance to the [first] intersecting point

       return v - sqrt(d);
}
```

Sliding

Until now, we've only talked about how to deal with collisions. Any physics expert will tell you that the *velocity vector* represents energy in the form of momentum. Once a collision happens, there is leftover energy (the remaining distance to the destination.) Some of that energy is absorbed in the collision (this varies with the angle of incidence of the collision.) You can do whatever you want with this leftover energy, like bouncing and sliding. I'll cover sliding since it's the most popular.

Sliding, at its simplest form is done along a *sliding plane*.

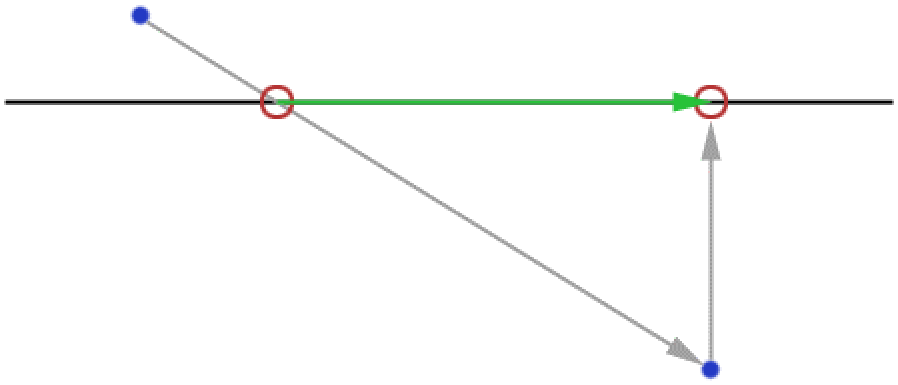


Figure 11: the effect of sliding along a *sliding plane*

Figure 11 illustrates the process of sliding. First, a collision is detected, and the velocity vector (the long diagonal gray line) is cut short at the point where it collides with the plane. The remainder (the leftover energy – everything behind the plane) is not thrown away. Rather, the destination point is projected onto the plane along the plane's normal. This new point, subtracted from our collision point results in a new *velocity vector* that can be used for sliding.

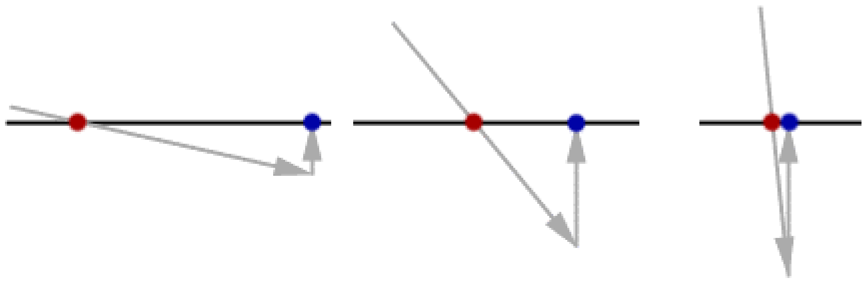


Figure 12: Slide distance varies based on angle of incidence

Figure 12 shows us that, as stated earlier, the distance to slide will vary with the angle of incidence, even thought the initial velocity vectors are very similar in length.

We can't merely slide right along, oblivious to the rest of the world. If our velocity vector is long enough, we may slide for quite a distance, in which case we may collide with more geometry. So rather than sliding right along, we'll simply pass this new vector (the *slide vector*) through our entire collision routine.

Before we can determine the sliding vector, we need to calculate our *sliding plane*.

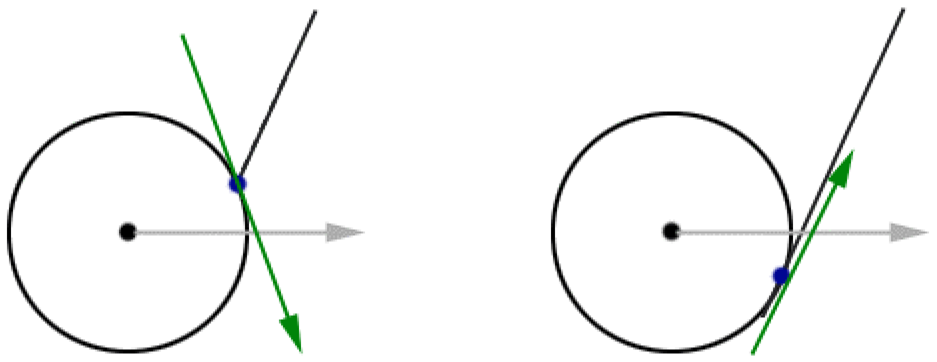


Figure 13: The sliding plane

The *sliding plane*, like any plane, is defined by an origin (a point) and a normal. The origin to the sliding plane is the point of intersection with the sphere. The normal of this plane is the vector from the intersection point to the center of the sphere. More specifically, you'll notice that this plane is the tangent plane of the sphere that intersects the *sphere intersection point*.

As stated earlier, we will need to project our destination point onto the *sliding plane*. This can be done with a simple ray/plane intersection, where the ray's origin is the destination point, and the ray's normal is the normal of the *sliding plane*.

There is a pretty cool effect that we can achieve by doing this. If our velocity vector is long enough, we can slide along multiple surfaces. This is possible if our sliding vector so long, that it causes a collision with another angular surface, which in turn, causes us to slide along it. If the initial velocity vector was long enough, we could end up sliding right around the inside of a rounded corner. This is similar to a hockey puck traveling at a high velocity, sliding around the back corner in a hockey rink.

A quick note about friction

You can take friction into account by simply shortening the slide vector to some degree. One way to do this is to associate a friction with each surface in the scene. When you collide with a surface, keep track of its friction. Before you slide, apply that friction to the sliding vector.

You'll find that in many cases, you'll be using very short velocity vectors because sliding is hard to control, like everything is made of ice. Well, in a frictionless environment, everything is a lot like ice. So if you're not interested in modeling friction, the quickest solution is to apply a constant friction.

Gravity

Adding gravity is a no-brainer. Start by determining your gravity vector. In the case of a standard world, your gravity vector might be [0, -1, 0] (straight down). You can increase or decrease your gravity by lengthening or shortening the gravity vector. In this case, [0, -1000, 0] would be quite a lot of gravity, and [0, -0.00001, 0] would be very little gravity. Of course, the amount of gravity you apply needs to be directly proportional to your unit system.

To apply gravity, simply add it to the initial velocity vector that gets passed into your collision routines. Be careful not to add it to the sliding vectors, or you'll get perpetual motion, because you'll always have "leftover energy" and will end up perpetually sliding.

At times, you may find that your sphere will have problems climbing stairs (due to the angle of the sliding plane and the amount of energy required to climb that plane.) This problem can potentially be compounded with ellipsoids. So be careful not to make your ellipsoids too tall and narrow (in relation to the height of a single stair), or you'll never climb anything.

Although this is the correct physical behavior, this may not necessarily be what you want to happen in your game. So, even if you're careful, you may still find stairs difficult to climb because of a required shape of an ellipsoid, or a required stair-height. If this happens, there's a simple solution that may help: run the collision code twice.

On the first run, perform collisions as normal, but do not include the gravity vector. Once that is complete, use the new destination as your new *source* and run through the routines a second time, with the gravity vector.

The effect of this is to allow the sphere to climb a difficult stair without the hindrance of gravity, but then to apply gravity once the sphere reaches the top of the stair.

In many cases, this costs no overhead. Consider moving along a level ground with a straight-down gravity vector. If you were to combine the gravity vector with a directly forward *velocity vector*, you would pass through the routine twice (once for the collision with the ground, and the second pass to slide along the ground.) But if you were to break the calls up into two (using a forward *velocity vector*, and a separate call for the gravity vector) no sliding would actually take place (you would just 'skim' over the ground without colliding with it on the first pass.) In both cases, the result is two passes through the collision code.

There are some issues to be considered if you decide to do this. First, if you consider the previous example (moving along a level ground), using two separate passes would allow you to travel further than a single, combined pass. This is the case, because the combined pass includes sliding, which shortens the overall length traveled.

Also without using a combined pass (i.e. without actually sliding), friction (as described in the previous section) will have no effect.

In short, this solution will affect virtually every distance traveled, including distance adjustments caused by friction. However, if you are willing to adjust your velocities and find a different solution for friction (or if you don't need friction at all) then this solution can be quite handy. For example, this solution would work perfectly well for your typical first-person shooter.

For the sake of purity, the pseudo-code at the bottom of this document will not include this trick, but hopefully I have described it clearly enough for you to implement on your own.

Gravity vectors also don't need to point straight down. If you're an Escher fan, you might consider pointing them up, or at some other angle. ✍

Sliding downhill is automatic

The gravity vector, just like real gravity, is constant. It's always present, even when the colliding object is standing still.

Because of this, if the colliding object is on a slanted ground, there is still a force of gravity being applied. This, combined with proper sliding will cause the player to slide down slopes automatically.

If you don't like this, you can prevent it with the use of friction (as mentioned earlier) or by not applying gravity when the colliding sphere is stationary.

Making it ellipsoidal

The radius for an ellipsoid cannot be defined by a single value. Rather, it is defined by something called the *radius vector*. For an ellipse (the 2D version of an ellipsoid), the *radius vector* might look something like this:

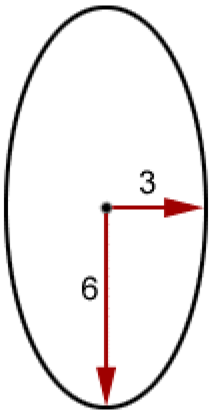
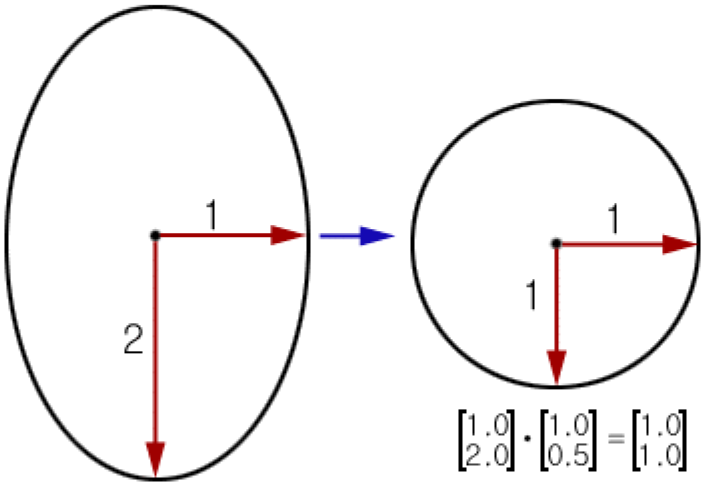


Figure 14: An ellipse with its *radius vector*

When lighting an object, you have the choice of either lighting that object in world space (by transforming the object into world-space) or you can just as well transform the light source into object space. Either way, the results are the same. The purpose of transformations is to put everything into the *same* space. We'll apply this methodology to the collision detection.

Let's take the example of an environment stored in world space. The ellipsoid moves through world space where collisions are performed. Both the ellipsoid and the environment are in the same space. But what if we were to transform both (the environment and the ellipsoid) into "sphere space"? In order for this to work, we have to run them both through the same transformation so they both end up in the same space.

We can do this by crafting a transform that simply scales everything (including the ellipsoid.)



$$\begin{bmatrix}1.0\\2.0\end{bmatrix}\cdot\begin{bmatrix}1.0\\0.5\end{bmatrix}=\begin{bmatrix}1.0\\1.0\end{bmatrix}$$

Figure 15: An ellipse being scaled into a circle

Figure 15 shows a 2D example our scale transform that resizes our ellipsoid into a sphere. The components of this transform are the reciprocal of the *radius vector* (the [1.0/1.0, 1.0/2.0] becomes [1.0, 0.5]). In other words, we're dividing (scaling) all of the inputs by the *radius vector*.

This transform has another noteworthy side effect. The ellipsoid is scaled into a unit-sphere (i.e. a sphere with a radius of 1.0), which simplifies our calculations even further.

We don't need to transform the entire environment just to perform collision detection. We will simply transform the inputs into our collision detection code: The *source,* the *velocity vector*, the polygons from the set of *potential colliders* and the *radius vector*. We'll perform our collisions using these scaled values, and when the collisions are complete we simply un-transform our final destination point, placing it back into the space from whence it came.

It's important that, while scaling your geometry, you also scale the surface normals which will be used by the collision detection. Once the normals have been scaled, however, make sure to re-normalize them (i.e. set their length back to 1.0).

Though I won't cover it here, I would like to mention that this transform could be any transformation (i.e. a 4x4 matrix if you so desire) allowing oriented ellipsoids as well as other effects. These transforms are only performed on a small subset of the data and a few input parameters, so the overhead of doing this is still minimized.

Clever readers might be tempted to consider an "animated transform", one that changes each frame, simulating collisions with a "pulsating" or spinning ellipsoid. Before you try this, be warned that this collision detection scheme is reactive, not proactive. In other words, it will only react to movement of the ellipsoid. It will not, for example, push the ellipsoid away from a wall that was too close to a growing ellipsoid.

Thus, we are now able to collide with ellipsoids as if they were simple spheres. Sliding, gravity and everything else continues to work the same.

Summary: Tying it all together

At this point, we've discussed all the tools needed for collision detection. Now we're going to pull all these pieces together to make one coherent concept, which accomplishes our goal. I've chosen pseudo code for the task.

There are a couple notes about the following code:

1. The intersect() routine assumes that the input direction vector for the ray is not normalized (thus, it does the normalization within itself.)
2. For clarity, all Points and Vectors can be multiplied, divided, added or subtracted with the use of their operators. These operations are component-based operations (i.e. a multiply consists of [x1*x2], [y1*y2] and [z1*z2].)

```
// The collision detection entry point

collisionDetection(Point sourcePoint, Vector velocityVector, Vector gravityVector)
{
       // We need to do any pre-collision detection work here. Such as adding
       // gravity to our velocity vector. We want to do it in this
       // separate routine because the following routine is recursive, and we
       // don't want to recursively add gravity.

       // Add gravity

       velocityVector += gravityVector;

       // At this point, we'll scale our inputs to the collision routine

       sourcePoint /= radiusVector;
       velocityVector /= radiusVector;

       // Okay! Time to do some collisions

       call collideWithWorld(sourcePoint, velocityVector);

       // Our collisions are complete, un-scale the output

       sourcePoint *= radiusVector;
}

// The collision detection's recursive routine

collideWithWorld(Point sourcePoint, Vector velocityVector)
{
       // How far do we need to go?

       Double distanceToTravel = length of velocityVector;

       // Do we need to bother?

       if (distanceToTravel < EPSILON) return;

       // Whom might we collide with?

       List   potentialColliders = determine list of potential colliders;

       // If there are none, we can safely move to the destination and bail

       if (potentialColliders is empty)
       {
              sourcePoint += velocityVector;
              return;
       }

       // You'll need to write this routine to deal with your specific data

       scale_potential_colliders_to_ellipsoid_space(radiusVector);

       // Determine the nearest collider from the list potentialColliders

       bool   collisionFound = false;
       Double nearestDistance = -1.0;
       Point  nearestIntersectionPoint = NULL;
Point  nearestPolygonIntersectionPoint = NULL;

for (each polygon in potentialColliders)
{
       // Plane origin/normal

       Point  pOrigin = any vertex from current poly;
       Vector pNormal = surface normal (unit vector) from current poly;

       // Determine the distance from the plane to the source

       Double pDist = intersect(pOrigin, pNormal, source, -pNormal);
       Point  sphereIntersectionPoint;
       Point  planeIntersectionPoint;

       // Is the source point behind the plane?
       //
       // [note that you can remove this condition if your visuals are not
       //  using backface culling]

       if (pDist < 0.0)
       {
              continue;
       }

       // Is the plane embedded (i.e. within the distance of 1.0 for our
       // unit sphere)?

       else if (pDist <= 1.0)
       {
              // Calculate the plane intersection point

              Vector temp = -pNormal with length set to pDist;
              planeIntersectionPoint = source + temp;
       }
       else
       {
              // Calculate the sphere intersection point

              sphereIntersectionPoint = source - pNormal;

              // Calculate the plane intersection point

              Double t = intersect(pOrigin, pNormal,
                         sphereIntersectionPoint, Velocity with
                         normalized length);

              // Are we traveling away from this polygon?

              if (t < 0.0) continue;

              // Calculate the plane intersection point

              Vector V = velocityVector with length set to t;
              planeIntersectionPoint = sphereIntersectionPoint + V;
       }

       // Unless otherwise noted, our polygonIntersectionPoint is the
       // same point as planeIntersectionPoint

       Point  polygonIntersectionPoint = planeIntersectionPoint;

       // So… are they the same?

       if (planeIntersectionPoint is not within the current polygon)
       {
              polygonIntersectionPoint = nearest point on polygon's
                     perimeter to planeIntersectionPoint;
       }

       // Invert the velocity vector
```

```
        Vector negativeVelocityVector = -velocityVector;

        // Using the polygonIntersectionPoint, we need to reverse-intersect
        // with the sphere (note: the 1.0 below is the unit-sphere’s
        // radius)

        Double t = intersectSphere(sourcePoint, 1.0,
               polygonIntersectionPoint, negativeVelocityVector);

        // Was there an intersection with the sphere?

        if (t >= 0.0 && t <= distanceToTravel)
        {
               // Where did we intersect the sphere?

               Vector V = negativeVelocityVector with length set to t;
               Vector intersectionPoint = polygonIntersectionPoint + V;

               // Closest intersection thus far?

               if (!collisionFound || t < nearestDistance)
               {
                      nearestDistance = t;
                      nearestIntersectionPoint = intersectionPoint;
                      nearestPolygonIntersectionPoint =
                             polygonIntersectionPoint;
                      collisionFound = true;
               }
        }
}

// If we never found a collision, we can safely move to the destination
// and bail

if (!collisionFound)
{
       sourcePoint += velocityVector;
       return;
}

// Move to the nearest collision

Vector V = velocityVector with length set to (nearestDistance - EPSILON);
sourcePoint += V;

// What's our destination (relative to the point of contact)?

Set length of V to (distanceToTravel – nearestDistance);
Point  destinationPoint = nearestPolygonIntersectionPoint + V;

// Determine the sliding plane

Point  slidePlaneOrigin = nearestPolygonIntersectionPoint;
Vector slidePlaneNormal = nearestPolygonIntersectionPoint - sourcePoint;

// We now project the destination point onto the sliding plane

Double time = intersect(slidePlaneOrigin, slidePlaneNormal,
       destinationPoint, slidePlaneNormal);

Set length of slidePlaneNormal to time;

Vector destinationProjectionNormal = slidePlaneNormal;

Point  newDestinationPoint = destination + destinationProjectionNormal;

// Generate the slide vector, which will become our new velocity vector
// for the next iteration

Vector newVelocityVector = newDestinationPoint –
```

```
                        nearestPolygonIntersectionPoint;

                // Recursively slide (without adding gravity)

                collideWithWorld(sourcePoint, newVelocityVector);
        }
```

Conclusion

If you have trouble with a topic in this document and you want more information on it (such as clipping a polygon to a bounding box) don't fret, there are plenty of references on the Internet. A good place to start is *Paul Bourke's Geometry Page* (http://www.swin.edu.au/astronomy/pbourke/geometry/).

I would like to thank Shimon Shvartsbroit (a.k.a. "MasterBoy") for his willingness to prove this algorithm in code ***twice*** (and along the way, helping me clarify and work out the kinks in this document.) Thanks to his effort, you can count on the fact that this document explains a technique that has been proven to work in practice. If you wish to contact Shimon, email him at cobra11@netvision.net.il or ICQ him at 14054887.

Finally, I would like to thank Kasper Fauerby (a.k.a. "Telemachos") for pointing out a few issues in the original algorithm, which led to this update. Kasper was also kind enough to include a note about how to climb difficult stairs (see the section on gravity) and has provided other useful input that has led to overall improvements of this document. Kasper has been working on "Ultima I – a legend is reborn", which can be found here: http://www.peroxide.dk/ultima/

Happy coding,
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