Chapter 4.2
Collision Detection and Resolution

From Steve Rabin’s Introduction to Game Development

Collision Detection
Complicated for two reasons
1. Geometry is typically very complex, potentially requiring expensive testing
2. Naïve solution is $O(n^2)$ time complexity, since every object can potentially collide with every other object

Collision Detection
Two basic techniques
1. Overlap testing
   - Detects whether a collision has already occurred
2. Intersection testing
   - Predicts whether a collision will occur in the future
## Overlap Testing

**Facts**
- Most common technique used in games
- Exhibits more error than intersection testing

**Concept**
- For every simulation step, test every pair of objects to see if they overlap
- Easy for simple volumes like spheres, harder for polygonal models

## Overlap Testing: Useful Results

Useful results of detected collision
- Time collision took place
- Collision normal vector

## Overlap Testing: Collision Time

Collision time calculated by moving object back in time until right before collision
- Bisection is an effective technique
Overlap Testing: Limitations

- Fails with objects that move too fast
  - Unlikely to catch time slice during overlap
- Possible solutions
  - Design constraint on speed of objects
  - Reduce simulation step size

Intersection Testing

- Predict future collisions
- When predicted:
  - Move simulation to time of collision
  - Resolve collision
  - Simulate remaining time step

Intersection Testing: Swept Geometry

- Extrude geometry in direction of movement
- Swept sphere turns into a "capsule" shape
Intersection Testing: Sphere-Sphere Collision

Smallest distance ever separating two spheres:
\[ d^2 = A^2 - \left( \frac{A \cdot B}{B^2} \right)^2 \]

If \[ d^2 > \left( r_a + r_b \right) \]
there is a collision

Intersection Testing: Limitations

- Issue with networked games
  - Future predictions rely on exact state of world at present time
  - Due to packet latency, current state not always coherent

- Assumes constant velocity and zero acceleration over simulation step
  - Has implications for physics model and choice of integrator
Dealing with Complexity

Two issues
1. Complex geometry must be simplified
2. Reduce number of object pair tests

Dealing with Complexity: Simplified Geometry

Approximate complex objects with simpler geometry, like this ellipsoid

Dealing with Complexity: Minkowski Sum

By taking the Minkowski Sum of two complex volumes and creating a new volume, overlap can be found by testing if a single point is within the new volume
Dealing with Complexity: Minkowski Sum

\[ X \oplus Y = \{ A + B : A \in X \text{ and } B \in Y \} \]

Dealing with Complexity: Minkowski Sum

Dealing with Complexity: Bounding Volumes

- Bounding volume is a simple geometric shape
- Completely encapsulates object
- If no collision with bounding volume, no more testing is required
- Common bounding volumes
  - Sphere
  - Box
Dealing with Complexity: Box Bounding Volumes

Axis-Aligned Bounding Box

Oriented Bounding Box

Dealing with Complexity: Achieving O(n) Time Complexity

One solution is to partition space

Another solution is the plane sweep algorithm
Terrain Collision Detection: Height Field Landscape

Terrain Collision Detection: Locate Triangle on Height Field

Terrain Collision Detection: Locate Point on Triangle

- Plane equation: \( Ax + By + Cz + D = 0 \)
- \( A, B, C \) are the \( x, y, z \) components of the plane’s normal vector
- \( D = -N \cdot P_o \)
- with one of the triangles vertices being \( P_o \)
- Giving: \( N_x(x) + N_y(y) + N_z(z) + (-N \cdot P_o) = 0 \)
Terrain Collision Detection: Locate Point on Triangle

- The normal can be constructed by taking the cross product of two sides:
  \[ \mathbf{N} = (\mathbf{P}_1 - \mathbf{P}_o) \times (\mathbf{P}_2 - \mathbf{P}_o) \]
- Solve for \( y \) and insert the \( x \) and \( z \) components of \( Q \), giving the final equation for point within triangle:
  \[ Q_y = -\mathbf{N}_x Q_x - \mathbf{N}_z Q_z + (\mathbf{N} \cdot \mathbf{P}_o) \]

Terrain Collision Detection: Locate Point on Triangle

Triangulated Irregular Networks (TINs)
- Non-uniform polygonal mesh
- Barycentric Coordinates

Point = \( w_0 \mathbf{P}_0 + w_1 \mathbf{P}_1 + w_2 \mathbf{P}_2 \)
\[ Q = (0)\mathbf{P}_0 + (0.5)\mathbf{P}_1 + (0.5)\mathbf{P}_2 \]
\[ R = (0.33)\mathbf{P}_0 + (0.33)\mathbf{P}_1 + (0.33)\mathbf{P}_2 \]

Terrain Collision Detection: Locate Point on Triangle

- Calculate barycentric coordinates for point \( Q \) in a triangle’s plane

\[
\begin{bmatrix} w_0 \\ w_1 \\ w_2 \end{bmatrix} = \frac{1}{V_1 \mathbf{P}_2 - (V_1, V_2)} \begin{bmatrix} 1 \\ V_1^2 - V_1 \mathbf{V}_2 \\ V_1 \mathbf{V}_2 \end{bmatrix} \begin{bmatrix} S \mathbf{V}_2 \\ S \mathbf{V}_1 \\ \mathbf{V}_1 - \mathbf{P}_2 \end{bmatrix} = S \mathbf{Q} - \mathbf{P}_2
\]
\[ w_0 = 1 - w_1 - w_2 \]
- If any of the weights \( (w_0, w_1, w_2) \) are negative, then the point \( Q \) does not lie in the triangle
Collision Resolution:
Examples

- Two billiard balls strike
  - Calculate ball positions at time of impact
  - Impart new velocities on balls
  - Play “clinking” sound effect
- Rocket slams into wall
  - Rocket disappears
  - Explosion spawned and explosion sound effect
  - Wall charred and area damage inflicted on nearby characters
- Character walks through wall
  - Magical sound effect triggered
  - No trajectories or velocities affected

Collision Resolution:
Parts

Resolution has three parts
1. Prologue
2. Collision
3. Epilogue

Collision Resolution:
Prologue

- Collision known to have occurred
- Check if collision should be ignored
- Other events might be triggered
  - Sound effects
  - Send collision notification messages
Collision Resolution:

Collision
- Place objects at point of impact
- Assign new velocities
  - Using physics or
  - Using some other decision logic

Collision Resolution:

Epilogue
- Propagate post-collision effects
- Possible effects
  - Destroy one or both objects
  - Play sound effect
  - Inflict damage
- Many effects can be done either in the prologue or epilogue

Collision Resolution:

Resolving Overlap Testing
1. Extract collision normal
2. Extract penetration depth
3. Move the two objects apart
4. Compute new velocities
Collision Resolution:

Extract Collision Normal

- Find position of objects before impact
- Use two closest points to construct the collision normal vector

Collision Resolution:

Extract Collision Normal

Sphere collision normal vector
- Difference between centers at point of collision

Collision Resolution:

Resolving Intersection Testing

- Simpler than resolving overlap testing
- No need to find penetration depth or move objects apart
- Simply
  1. Extract collision normal
  2. Compute new velocities