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

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Overlap Testing: Useful Results

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

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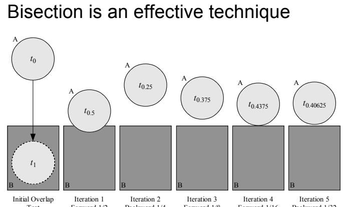
Overlap Testing: Collision Time

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



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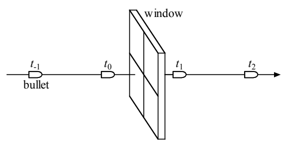
Overlap Testing: Limitations

- 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



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Intersection Testing

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

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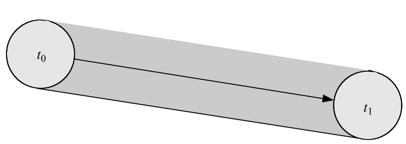
Intersection Testing: Swept Geometry

- Extrude geometry in direction of movement
- Swept sphere turns into a “capsule” shape



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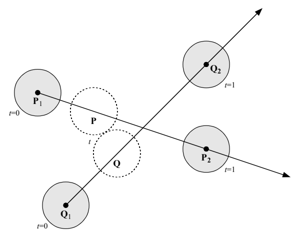
Intersection Testing: Sphere-Sphere Collision

$$t = \frac{-(\acute{\mathbf{A}} \cdot \hat{\mathbf{A}}) - \sqrt{(\mathbf{A}\cdot\mathbf{B})^2 - B^2\left(\acute{A}^2 - (r_P + r_Q)^2\right)}}{B^2}, \qquad \mathbf{A} = \mathbf{P}_1 - \mathbf{Q}_1, \quad \mathbf{B} = (\mathbf{P}_2 - \mathbf{P}_1) - (\mathbf{Q}_2 - \mathbf{Q}_1).$$



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Intersection Testing: Sphere-Sphere Collision

- Smallest distance ever separating two spheres:

$$d^2 = A^2 - \frac{(\mathbf{A}\cdot\mathbf{B})^2}{B^2}$$

- If $d^2 > (r_P + r_Q)^2$ there is a collision

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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

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Dealing with Complexity

Two issues

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

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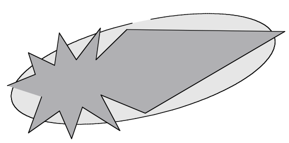
Dealing with Complexity: Simplified Geometry

- Approximate complex objects with simpler geometry, like this ellipsoid



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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

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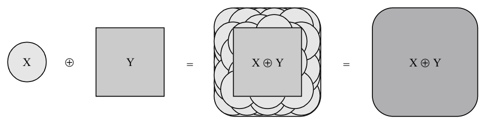
Dealing with Complexity: Minkowski Sum

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



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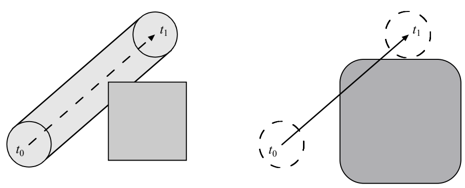
Dealing with Complexity: Minkowski Sum



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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

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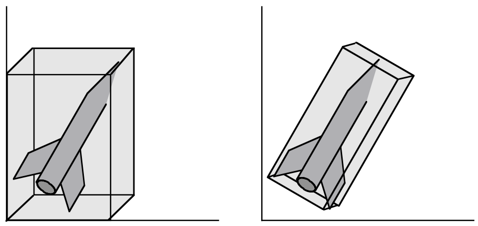
Dealing with Complexity: Box Bounding Volumes



Axis-Aligned Bounding Box   Oriented Bounding Box

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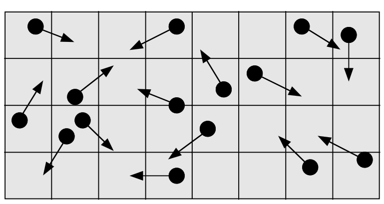
Dealing with Complexity: Achieving O(n) Time Complexity

One solution is to partition space



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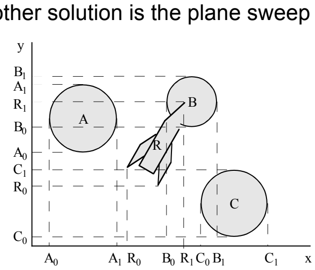
Dealing with Complexity: Achieving O(n) Time Complexity

Another solution is the plane sweep algorithm



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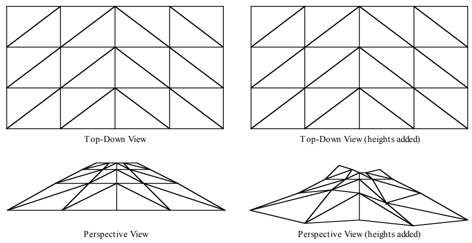
Terrain Collision Detection: Height Field Landscape



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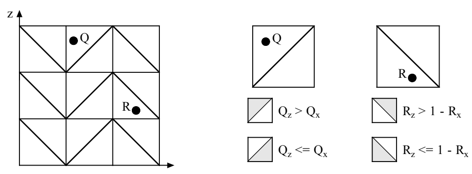
Terrain Collision Detection: Locate Triangle on Height Field



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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
- Where $D = -\mathbf{N} \cdot \mathbf{P}_0$
  with one of the triangles
  vertices being $\mathbf{P}_0$
- Giving: $\mathbf{N}_x(x) + \mathbf{N}_y(y) + \mathbf{N}_z(z) + (-\mathbf{N} \cdot \mathbf{P}_0) = 0$

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Terrain Collision Detection: Locate Point on Triangle

- The normal can be constructed by taking the cross product of two sides:

$$\mathbf{N} = (\mathbf{P}_1 - \mathbf{P}_0) \times (\mathbf{P}_2 - \mathbf{P}_0)$$

- Solve for *y* and insert the *x* and *z* components of Q, giving the final equation for point within triangle:

$$\mathbf{Q}_y = \frac{-\mathbf{N}_x\mathbf{Q}_x - \mathbf{N}_z\mathbf{Q}_z + (\mathbf{N} \cdot \mathbf{P}_0)}{\mathbf{N}_y}$$

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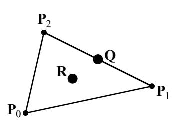
Terrain Collision Detection: Locate Point on Triangle

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



$$\text{Point} = w_0\mathbf{P}_0 + w_1\mathbf{P}_1 + w_2\mathbf{P}_2$$

$$\mathbf{Q} = (0)\mathbf{P}_0 + (0.5)\mathbf{P}_1 + (0.5)\mathbf{P}_2$$

$$\mathbf{R} = (0.33)\mathbf{P}_0 + (0.33)\mathbf{P}_1 + (0.33)\mathbf{P}_2$$

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Terrain Collision Detection: Locate Point on Triangle

- Calculate barycentric coordinates for point Q in a triangle's plane

$$\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} = \frac{1}{V_1^2 V_2^2 - (\mathbf{V}_1 \cdot \mathbf{V}_2)^2} \begin{bmatrix} V_2^2 & -\mathbf{V}_1 \cdot \mathbf{V}_2 \\ -\mathbf{V}_1 \cdot \mathbf{V}_2 & V_1^2 \end{bmatrix} \begin{bmatrix} \mathbf{S} \cdot \mathbf{V}_1 \\ \mathbf{S} \cdot \mathbf{V}_2 \end{bmatrix}$$

$$\mathbf{S} = \mathbf{Q} - \mathbf{P}_0$$
$$\mathbf{V}_1 = \mathbf{P}_1 - \mathbf{P}_0$$
$$\mathbf{V}_2 = \mathbf{P}_2 - \mathbf{P}_0$$

$$w_0 = 1 - w_1 - w_2$$

- If any of the weights (w_0, w_1, w_2) are negative, then the point Q does not lie in the triangle

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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

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Collision Resolution: Parts

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

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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

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Collision Resolution: Collision

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

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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

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Collision Resolution: Resolving Overlap Testing

1. Extract collision normal
2. Extract penetration depth
3. Move the two objects apart
4. Compute new velocities

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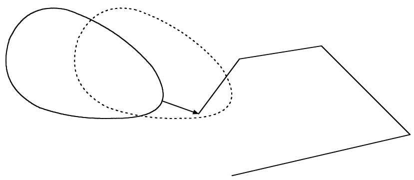
Collision Resolution: Extract Collision Normal

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



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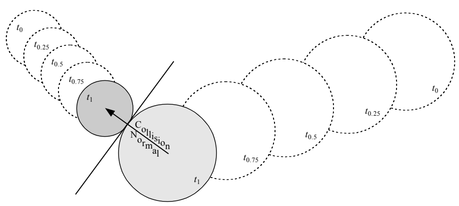
Collision Resolution: Extract Collision Normal

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



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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

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