the gamedesigninitiative at cornell university

Lecture 19

Physics Engines

Physics in Games

- **Moving** objects about the screen
  - **Kinematics**: Motion ignoring external forces (Only consider position, velocity, acceleration)
  - **Dynamics**: The effect of forces on the screen
- **Collisions** between objects
  - **Collision Detection**: Did a collision occur?
  - **Collision Resolution**: What do we do?

Physics in Games

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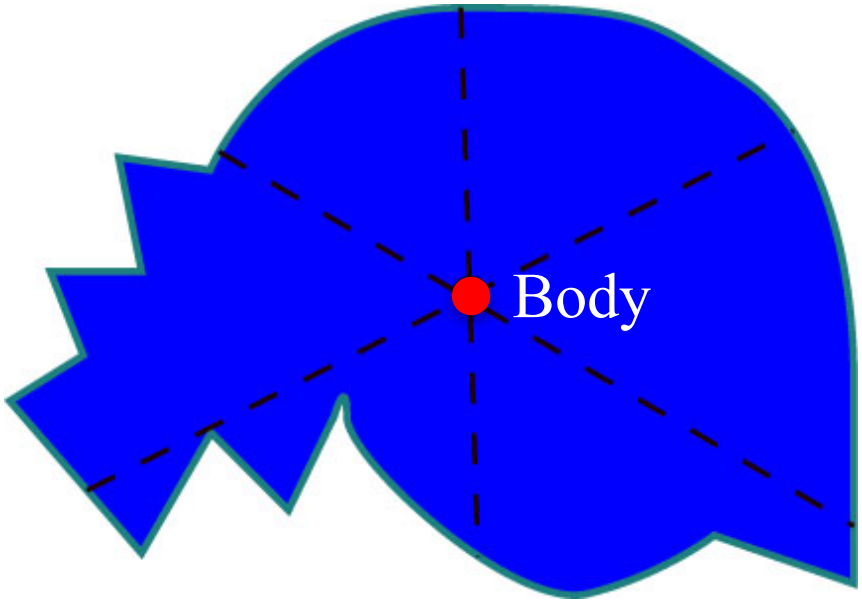
    (C ration)
  - **Dynamics**: The effect of forces on the screen
- **Collisions** between objects
  - **Collision D** ur?
  - **C**

Class Body

Class Fixture

Body in Box2D

- Represents a single point
  - Center of the object's mass
  - Object must move as unit
- Properties in class Body
  - Position
  - Linear Velocity
  - Angular Velocity
  - Body Type
- There are 3 body types
  - **Static**: Does not move
  - **Kinematic**: Moves w/o force
  - **Dynamic**: Obeys forces



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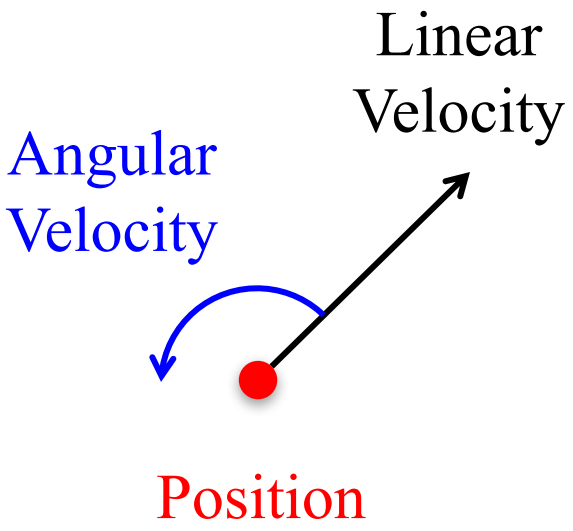

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- There are **3 body types**
  - **Static**: Does not move
  - **Kinematic**: Moves w/o force
  - **Dynamic**: Obeys forces
- Kinematic is rarely useful
  - Limited collision detection
  - Only collides w/ dynamics
  - Does not bounce or react
- **Application**: Bullets
  - Light, fast-moving objects
  - Should not bounce

Forces vs. Impulses

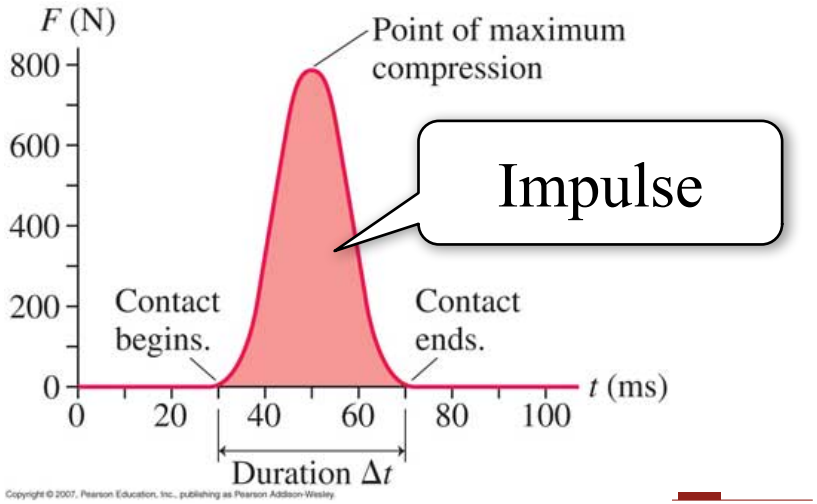
Forces

- Instantaneous push
  - To be applied over time
  - Gradually accelerates
  - Momentum if sustained

Impulses

- Push with duration
  - To be applied in one frame
  - Quickly accelerates
  - Immediate momentum

Impulse = Force x Time



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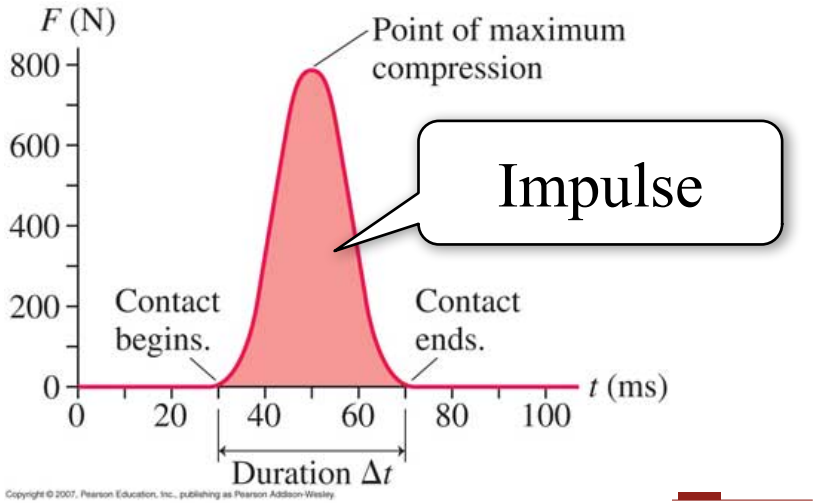
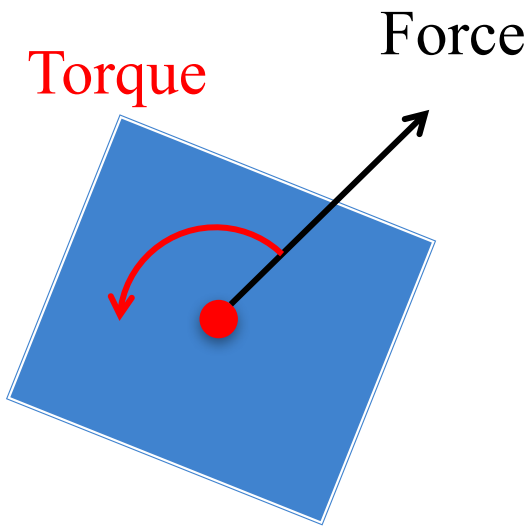
Impulse = Force x **1 Sec**

in Box2D



Four Ways to Move a Dynamic Body

- **Forces**
  - applyForce (linear)
  - applyTorque (angular)
- **Impulses**
  - applyLinearImpulse
  - applyAngularImpulse
- **Velocity**
  - setLinearVelocity
  - setAngularVelocity
- **Translation**
  - setTransform



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  - setTransform

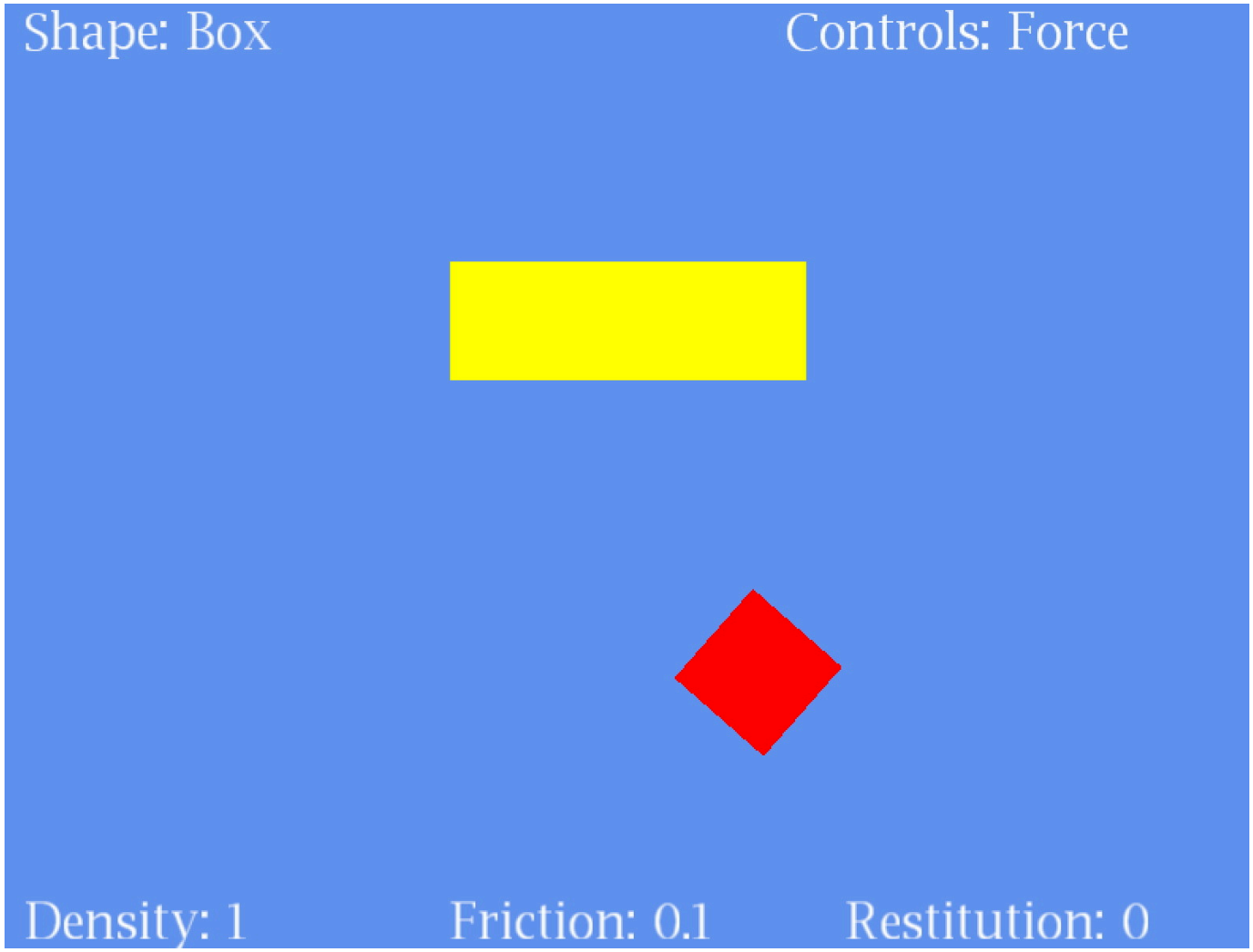
- Great for joints, complex shapes
- Laggy response to user input
- A bit hard to control

- Great for joints, complex shapes
- Good response to user input
- Extremely hard to control

- Bad for joints, complex shapes
- Excellent response to user input
- Very easy to control

- **Completely ignores physics!**
- Very easy to control

Example: Box2D Demo



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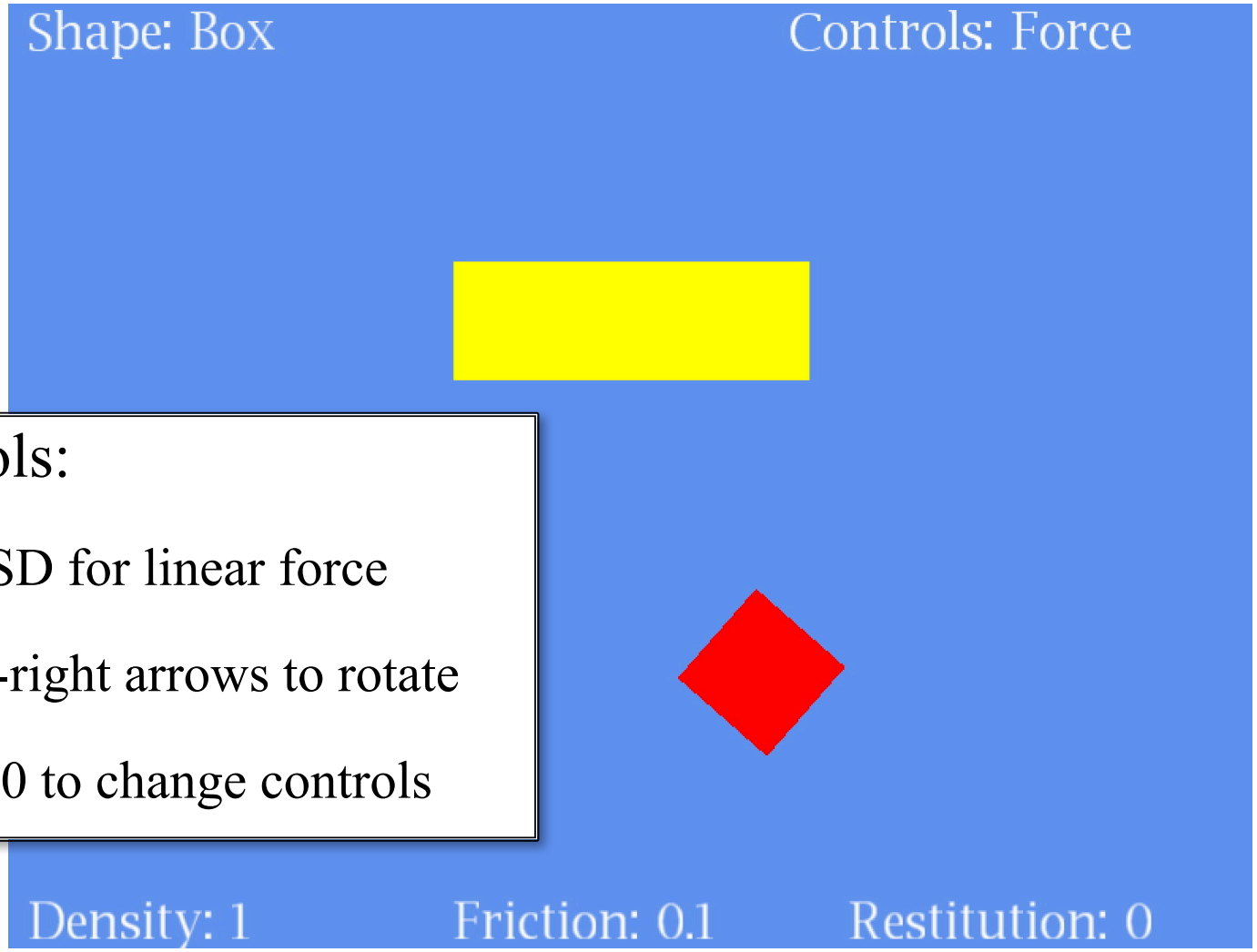

Controls:

- WASD for linear force
- Left-right arrows to rotate
- 9 or 0 to change controls

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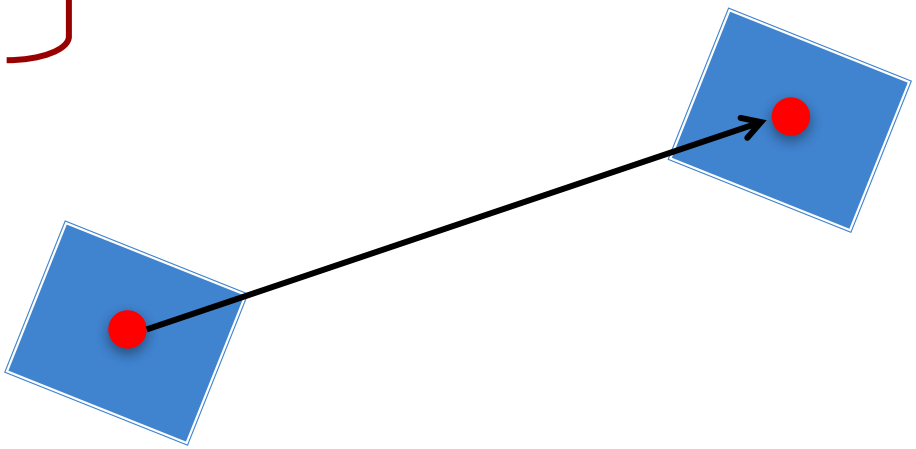
Must Cap Velocity



Basic Structure of a Update Loop

```
public void update(float dt) {
   // Apply movement to relevant bodies
   if (body above or equal to max velocity) {
      body.setLinearVelocity(maximum velocity);
   } else {
      body.applyForce(force)
      body.applyTorque(torque)
   }
   // Use physics engine to update positions
   world.step(dt,vel_iterations,pos_iterations);
}
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Multiple times to improve accuracy

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```

Only before first iteration!

Multiple times to improve accuracy

Collision Objects in Box 2D

Shape

- Stores the object geometry
  - Boxes, circles or polygons
  - **Must be convex**!
- Has own coordinate space
  - Associated body is origin
  - Unaffected if body moved
  - Cannot be resized later
- Also stores object **density**
  - Mass is area x density

Fixture

- Attaches a shape to a body
  - Fixture has only one body
  - Bodies have many fixtures
- Cannot change the shape
  - Must destroy old fixture
  - Must make a new fixture
- Has other properties
  - **Friction**: stickiness
  - **Restitution**: bounciness

Making a Box2D Physics Object

```
// Create a body definition
// (this can be reused)
bodydef = new BodyDef();
bodydef.type = type;
bodydef.position.set(position);
bodydef.angle = angle;

// Allocate the body
body1 = world.createBody(bodydef);

// Another?
bodydef.position.set(position2);
body2 = world.createBody(bodydef);
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Normal Allocation

Optimized Allocation

Making a Box2D Physics Object

```
// Create two triangles as shapes
shape1 = new PolygonShape().;
shape2 = new PolygonShape();
shape1.set(verts1); shape2.set(verts2);

// Create a fixture definition
fixdef = new FixtureDef();
fixdef.density = density;

// Attach the two shapes to body
fixdef.shape = shape1;
fixture1 = body1.createFixture(fixdef);
fixdef.shape = shape2;
fixture2 = body1.createFixture(fixdef);
```

Making a Box2D Physics Object

Other shapes possible

```
// Create two triangles as shapes
shape1 = new PolygonShape().;
shape2 = new PolygonShape();
shape1.set(verts1); shape2.set(verts2);
```

Also set friction and restitution parameters

```
// Create a fixture definition
fixdef = new FixtureDef();
fixdef.density = density;
```

Reason for separating Fixture & Body classes

```
// Attach the two shapes to body
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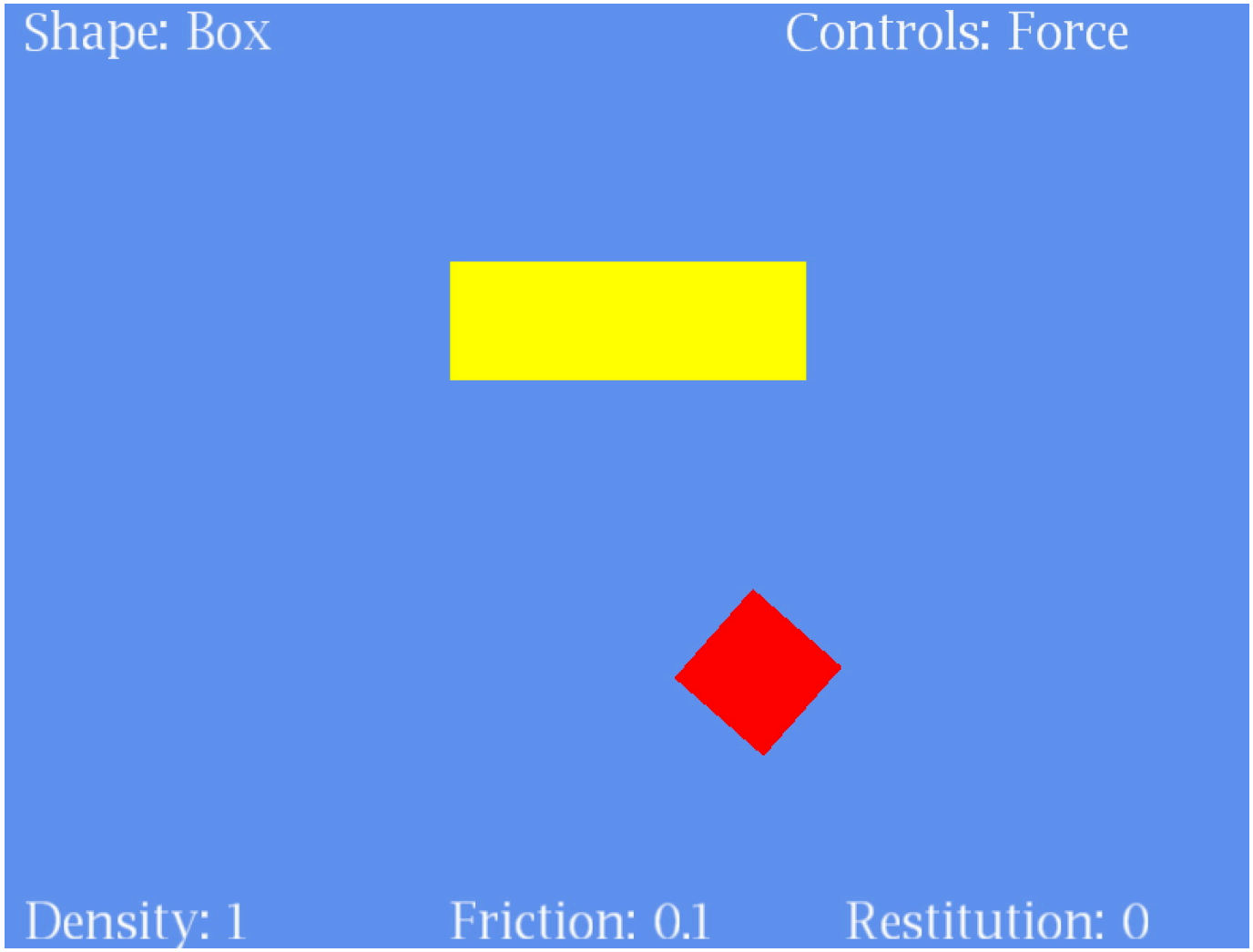
Observations on Fixture Parameters

- **Density** can be anything **non-zero**
  - The higher the density the higher the mass
  - Heavier objects are harder to move
- **Friction** should be within **0 to 1**
  - Can be larger, but effects are unpredictable
  - Affects everything, even manual velocity control
- **Restitution** should be within **0 to 1**
  - A value of 0 means no bounciness at all
  - Unpredictable with manual velocity control

Example: Box2D Demo



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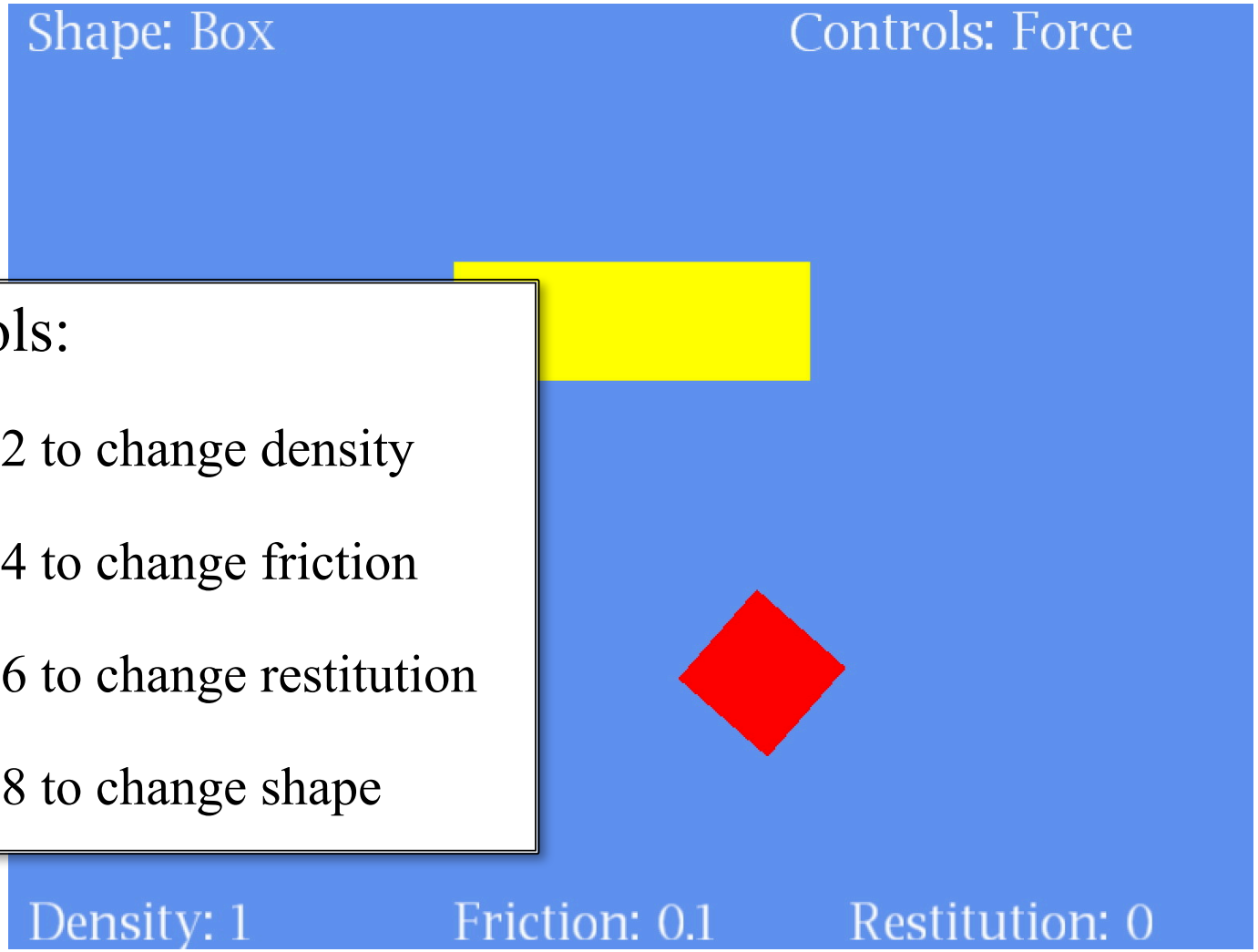
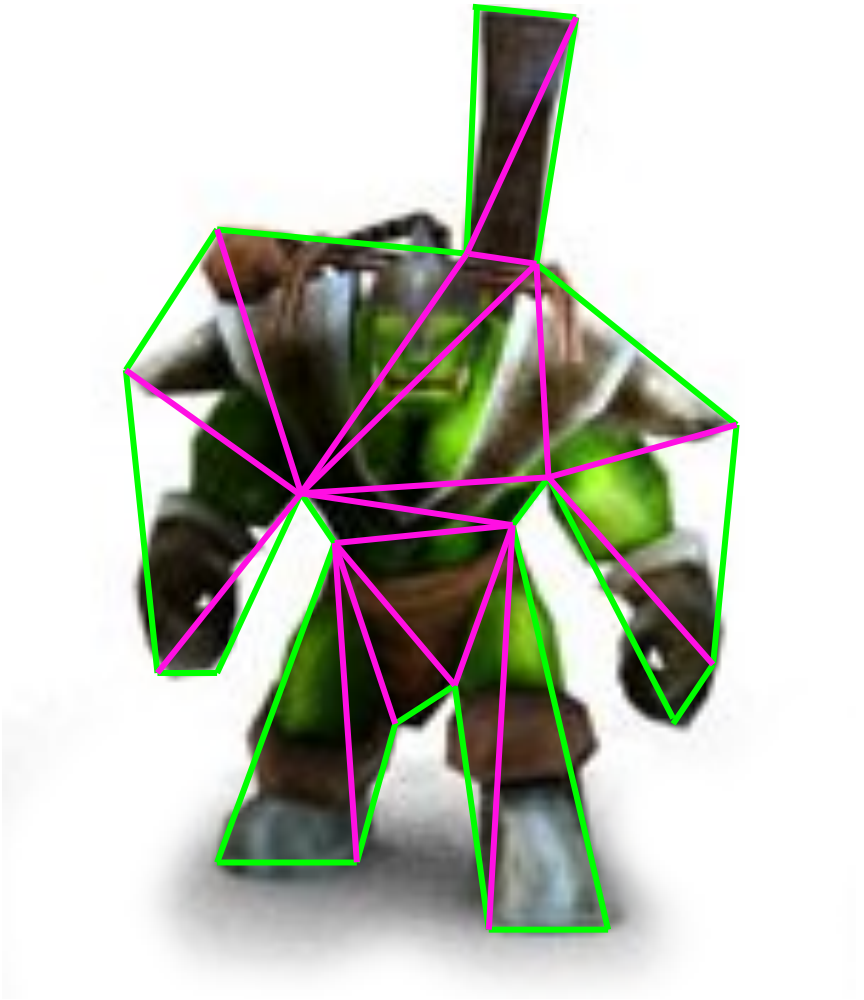


Controls:

- 1 or 2 to change density
- 3 or 4 to change friction
- 5 or 6 to change restitution
- 7 or 8 to change shape

How Do We Find the Shape?

- Do not try to *learn* boundary
  - Image recognition is hard
  - Hull will have **many** sides
- Have artists draw the shape
  - Cover shape with triangles
  - But can ignore interiors
  - Keep # sides small!
- Store shape in another file
  - Do not ruin the art!
  - Need coordinates as data



Data-Driven Design

character.jpg

character.shape

120,2
130,4
125,50
150,65
160,100
150,110
125,80
140,200
130,200
120,110
...

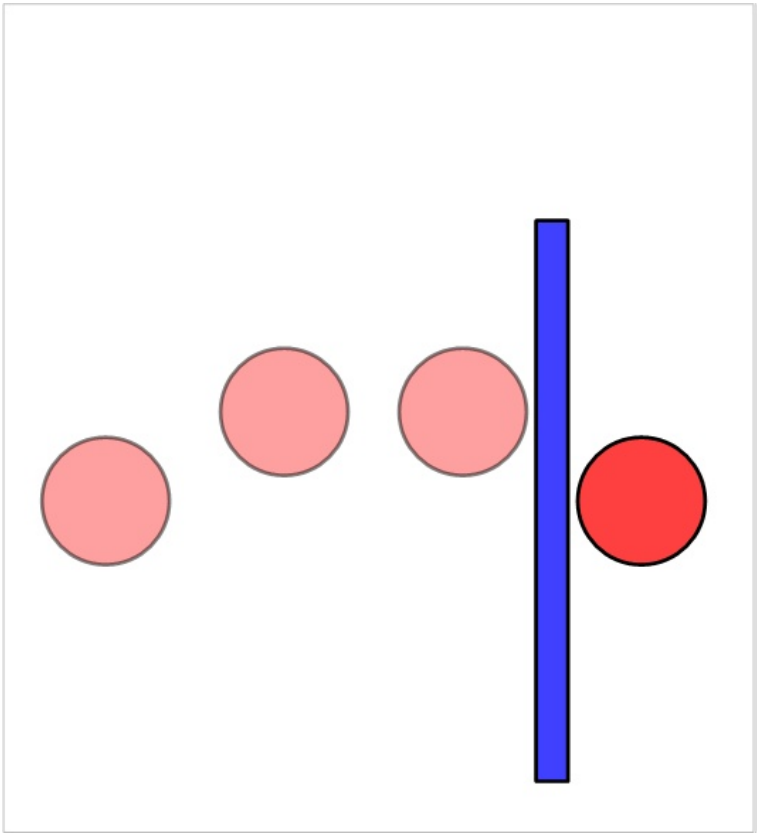
Custom Collisions: ContactListeners

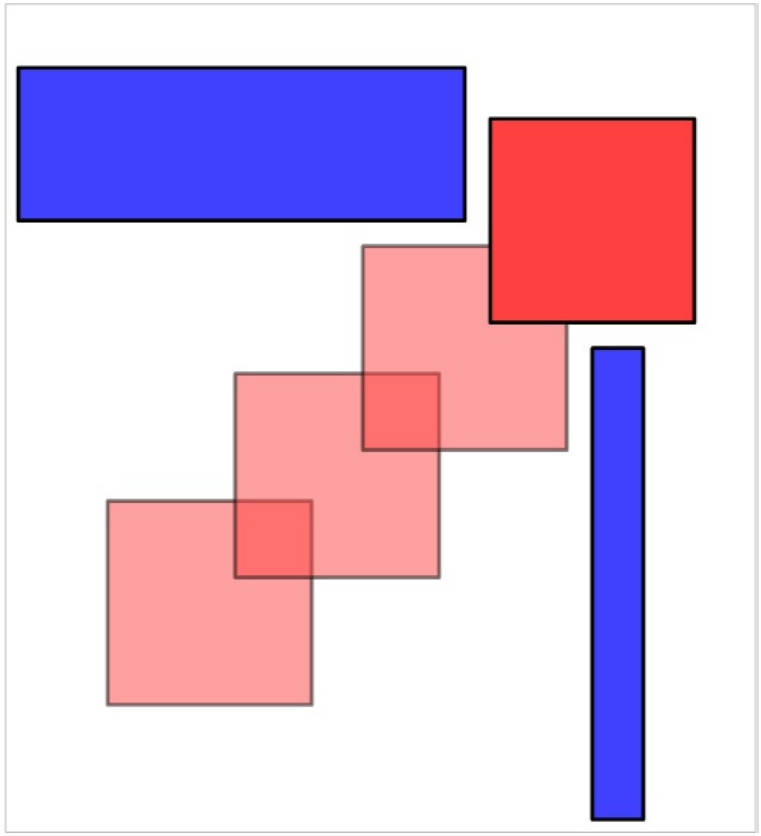
- Special listener attached to world object
  - Reacts to any two **fixtures** that collide
  - Allow you to *override* collision behavior
  - Or you can *augment* collision behavior
- Two primary methods in interface
  - **beginContact**: When objects first collide
  - **endContact**: When objects no longer collide
- **Example**: Color changing in Box2D demo

Issues with Collisions: Tunneling

- Collisions in midstep can lead to **tunneling**
  - Objects that "pass through" each other
    - Not colliding at start or end of simulation
    - But they collided somewhere in between
  - This is an example of a *false negative*
- This is a **serious** problem; cannot ignore
  - Players getting places they shouldn't
  - Players missing an event trigger boundary

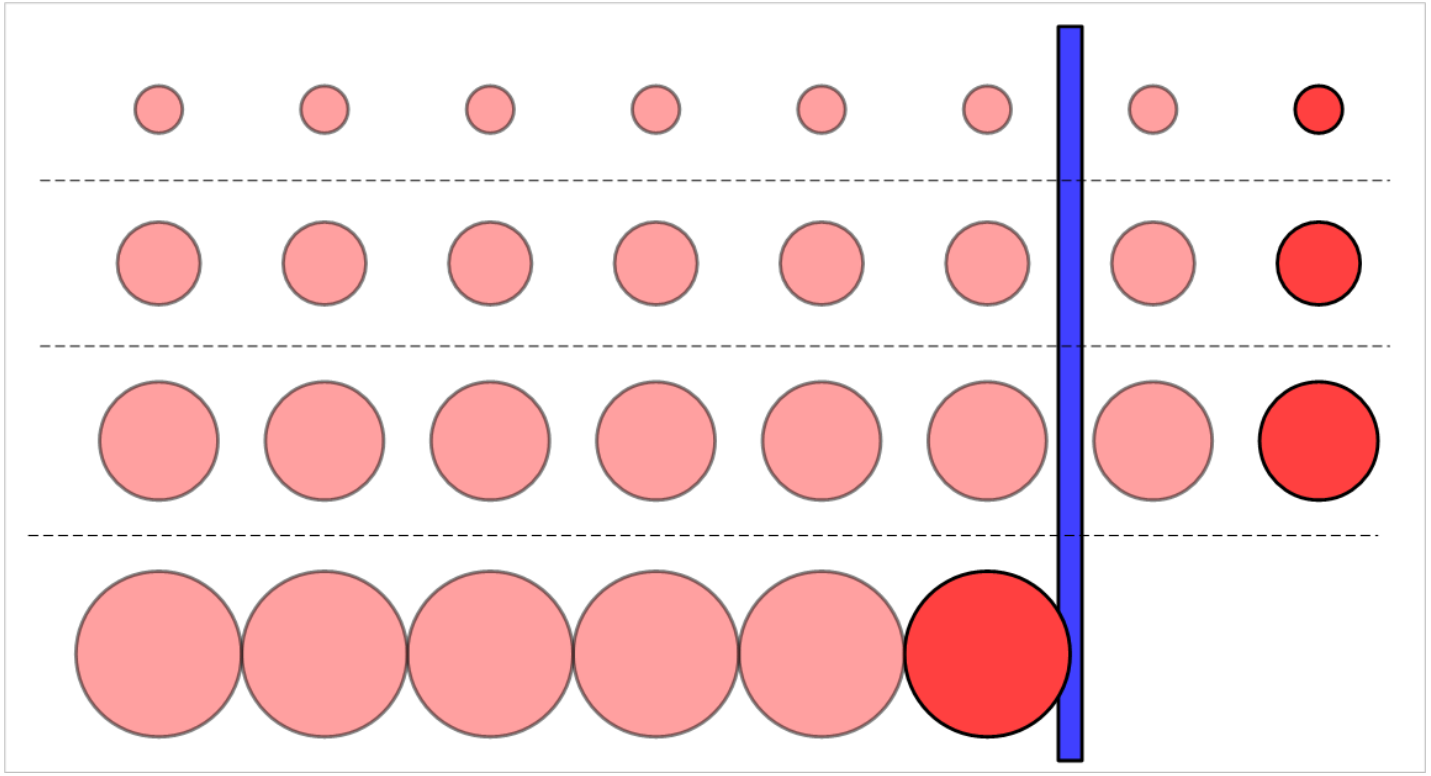
Tunneling





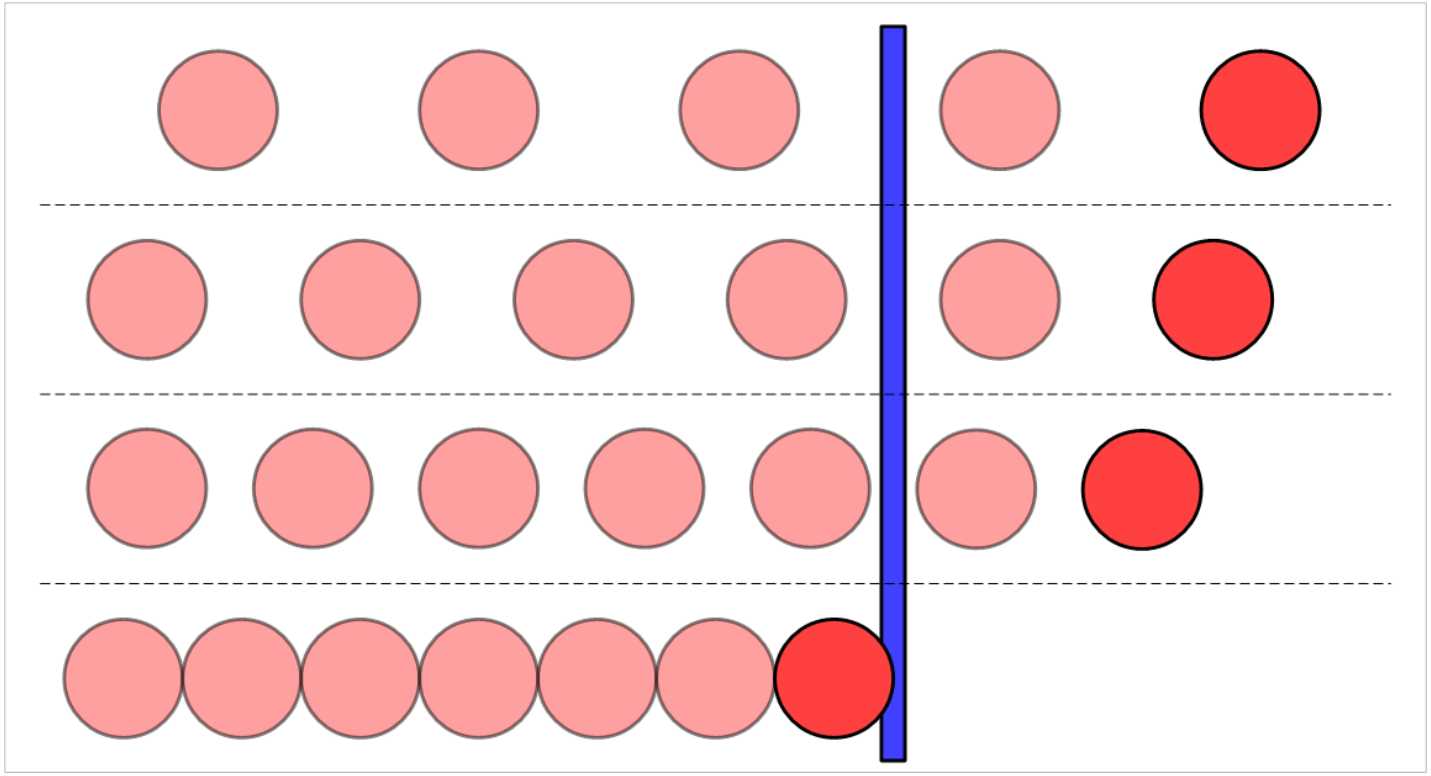
Tunneling: Observations

- Small objects tunnel more easily



Tunneling: Observations

- Small objects tunnel more easily
- Fast-moving objects tunnel more easily

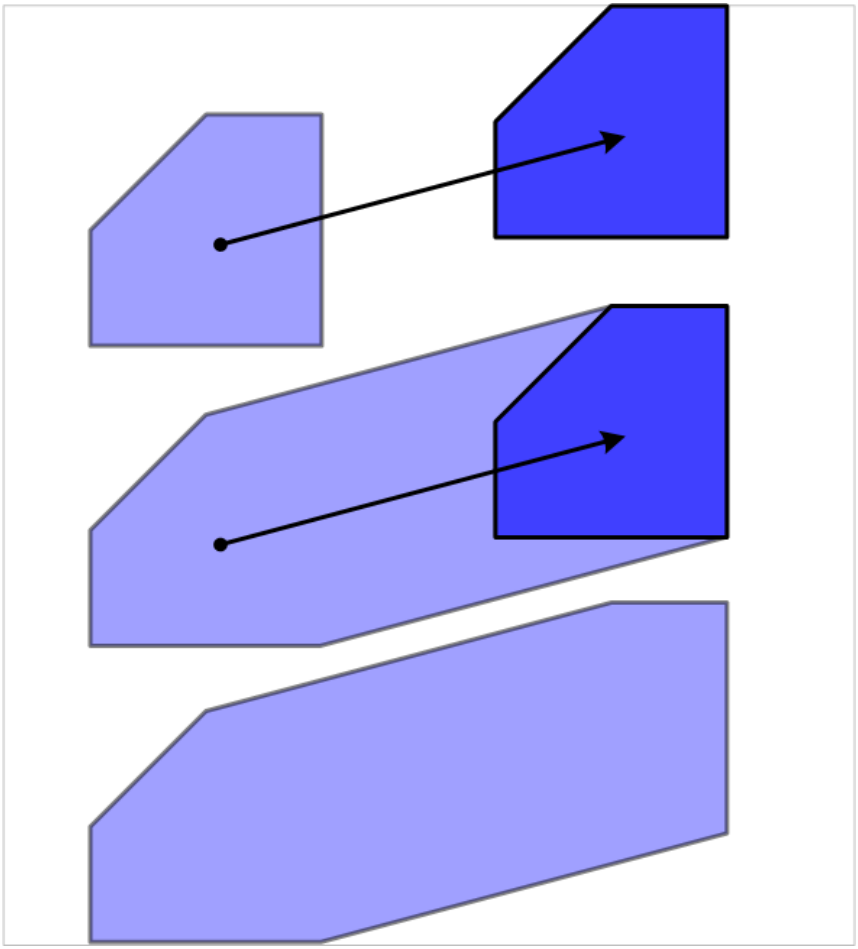


Possible Solutions to Tunnelling

- Minimum size requirement?
  - Fast objects still tunnel
- Maximum speed limit?
  - Speed limit is a function of object size
  - So small & fast objects (bullets) not allowed
- Smaller time step?
  - Essentially the same as a speed limit
- All of these solutions are **inadequate**

Swept Shapes

- Bounds contain motion
  - "Cylinder" w/ shape at ends
  - Object always in bounds
  - Convex if shape is convex
- New collision checking
  - Put shapes at start and end
  - Create swept shape for pair
  - Check for collisions
- Can have **false positives**
  - Swept shape ignores time



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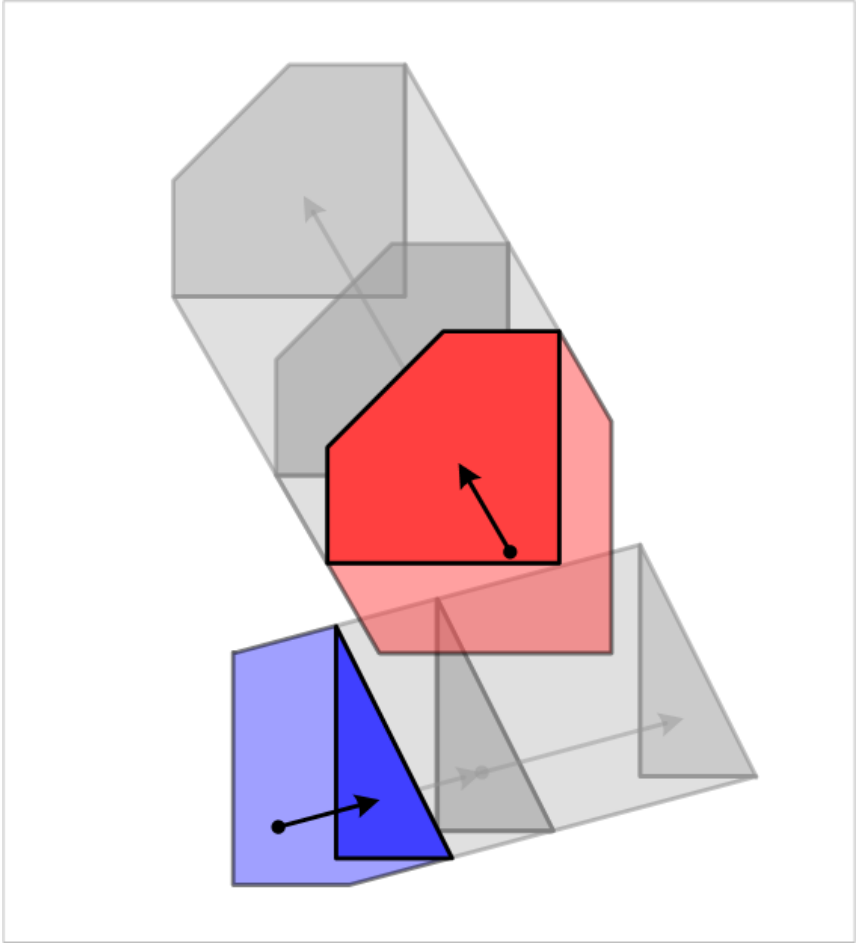
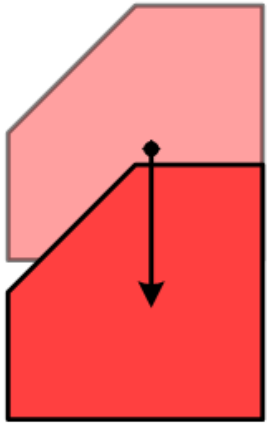
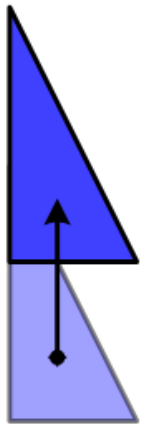


Swept Shapes & Relative Coordinates

- **False positives** happen if:
  - Two objects are moving
  - Swept shapes intersect at different intersection times
- What if only one moving?
  - Swept intersects stationary
  - So no false positives
- Change **reference frames**
  - Keep one shape still
  - Move other in new coords



Inertial Frame



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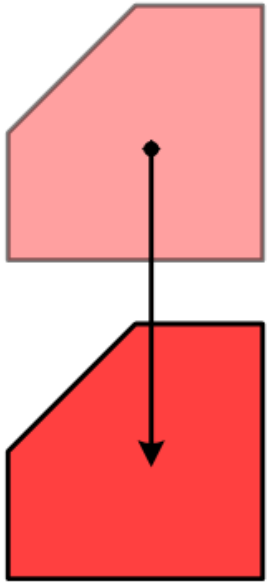
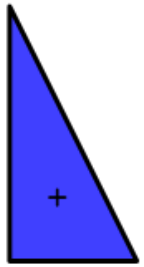


Blue Frame



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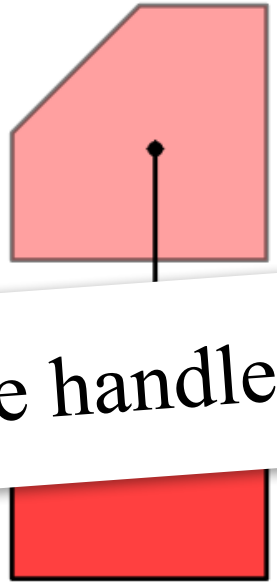
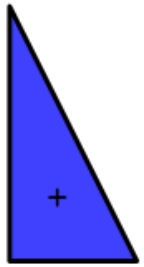


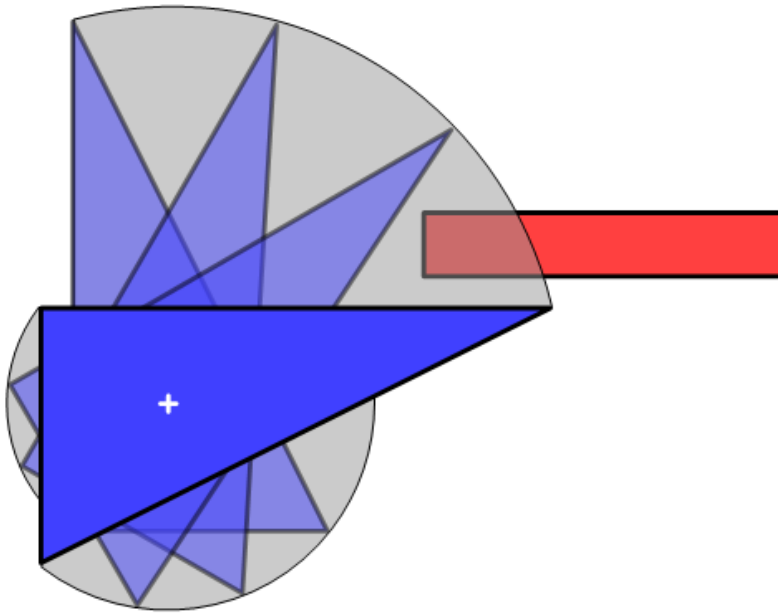
Blue Frame

How "Bullets" are handled



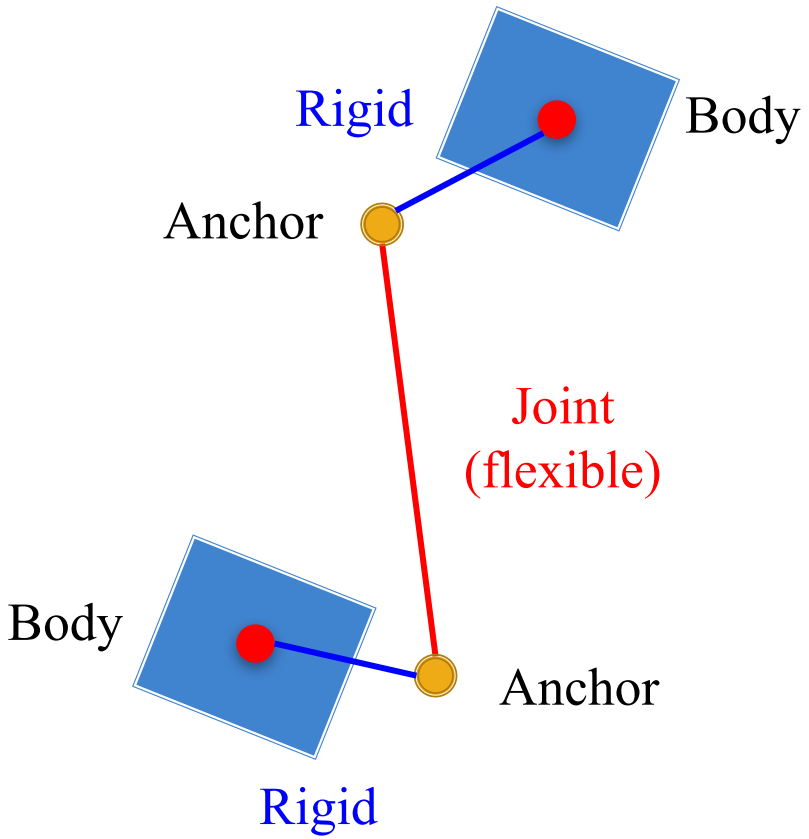
Rotations Suck

- Relative coordinates no help
  - Cannot use swept shapes
  - Actual solution is hard!
- But not so bad…
  - Angular tunneling looks ok
  - Speed limits are feasible
  - Do linear approximations
- Many physics systems **never** handle this well

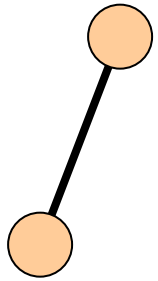


Some Words on Joints

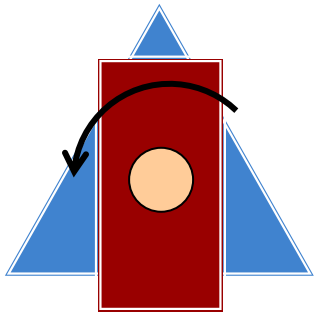
- Joints connect **bodies**
  - Anchors can be offset body
  - Coordinates relative to body
- Are affected by **fixtures**
  - Fixtures prevent collisions
  - Limit relative movement
- Must control with forces
  - Manual velocity might violate constraints
  - Use force or impulse



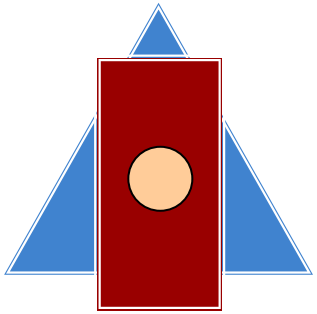
Sample Joint Types



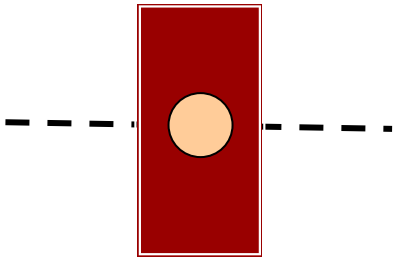
Distance (soft)
Rope (hard)



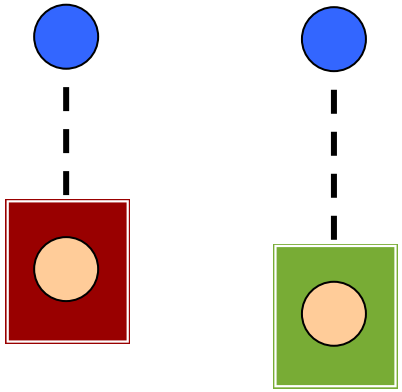
Revolute



Weld
(rigid)



Prismatic



Pulley

Summary

- Physics engines support motion and collisions
  - `Body` class provides the motion
  - `Fixture`, `Shape` classes are for collisions
- Multiple ways to control a physics object
  - Can **apply forces** or manually **control velocity**
  - Joint constraints work best with forces
- Physics engines do not solve all your problems
  - You have manually compute your shapes
  - May need to tune parameters to prevent tunneling