the gamedesigninitiative at cornell university

Lecture 18

Box2D Physics

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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  - **Dynamics**: The effect of forces on the screen
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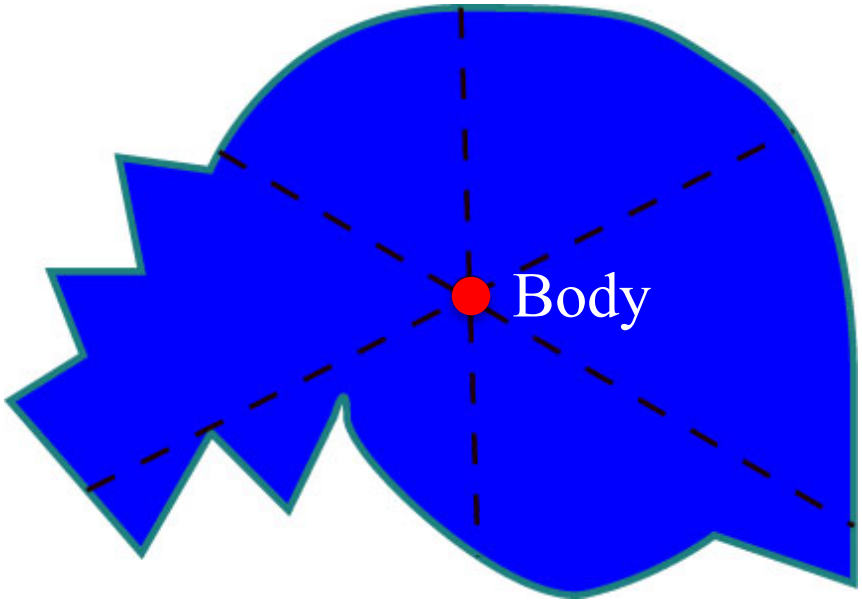
  - **Collision Detection**: Class Fixture ur?
  - **C** we do?

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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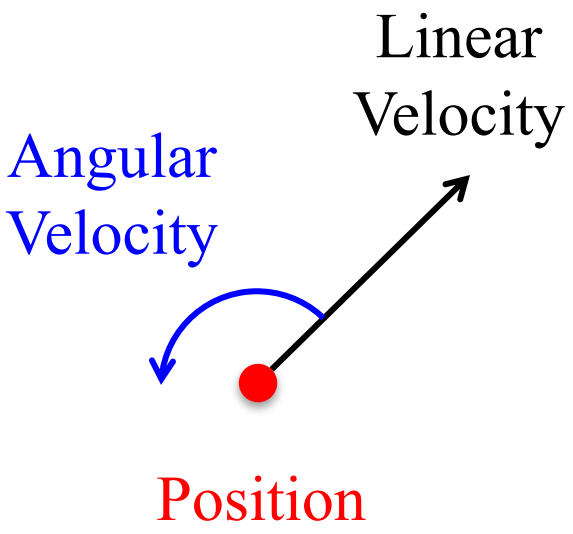

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  - **Static**: Does not move
  - **Kinematic**: Moves w/o force
  - **Dynamic**: Obeys forces

- 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

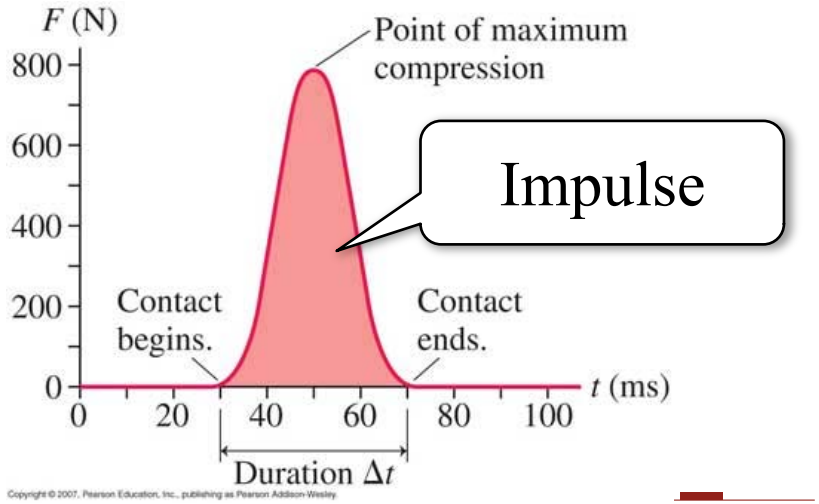
Forces

- 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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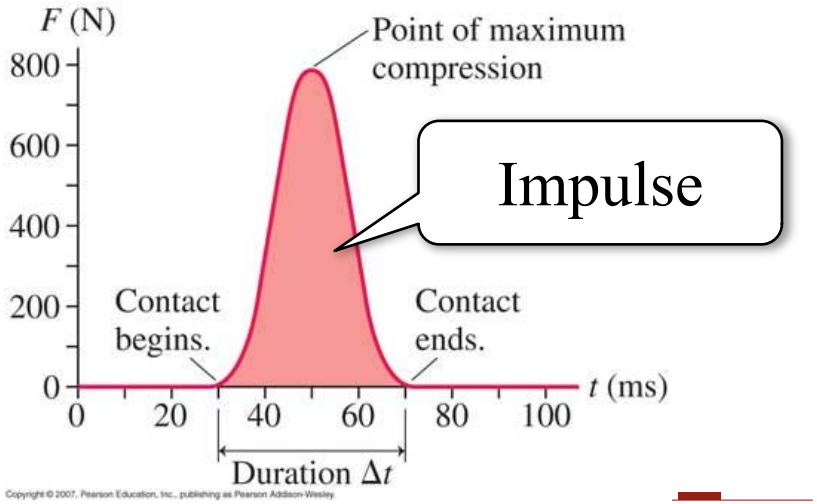
Impulse = Force x **1 Sec**

in Box2D



Force and Acceleration

- What do we need to compute motion?
  - $\Delta p = v\Delta t = v_0\Delta t + \frac{1}{2}a(\Delta t)^2 = v_0\Delta t + \frac{1}{2}(F/m)(\Delta t)^2$
  - So depends on Force, current velocity and **mass**
- Where does that mass come from?
  - Class Body has a getter, but no setter!
  - It comes from the Fixture class
  - Fixture gives *volume* to body
- Will revisit this later with collisions

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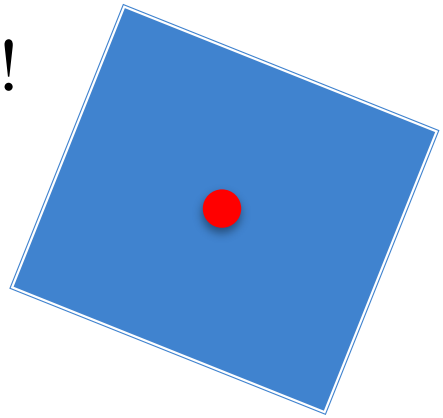
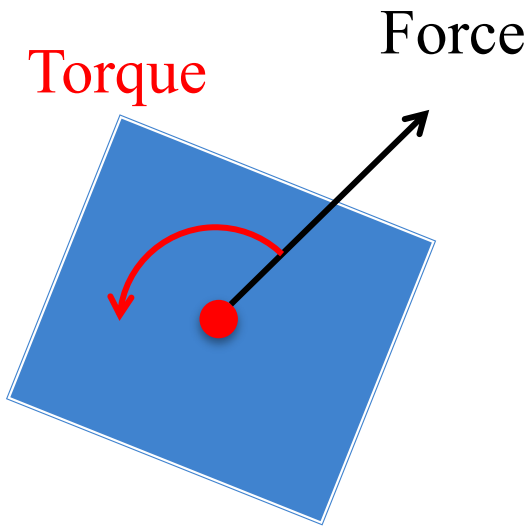


- Will revisit this later with collisions

Four Ways to Move a Dynamic Body

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



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- **Translation**
  - setTransform

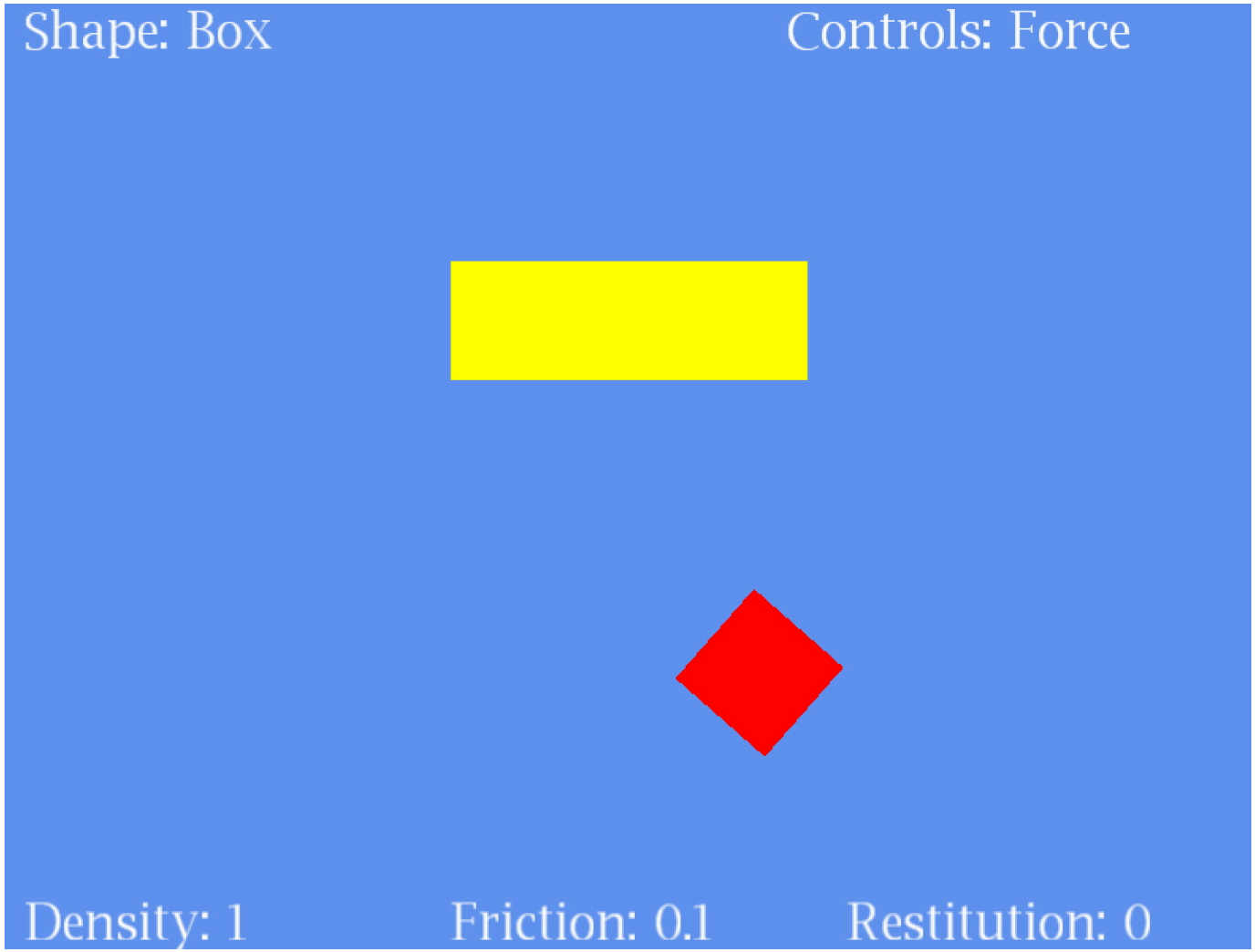
- Great for joints, complex shapes
- Laggy response to user input
- A bit hard to control

- 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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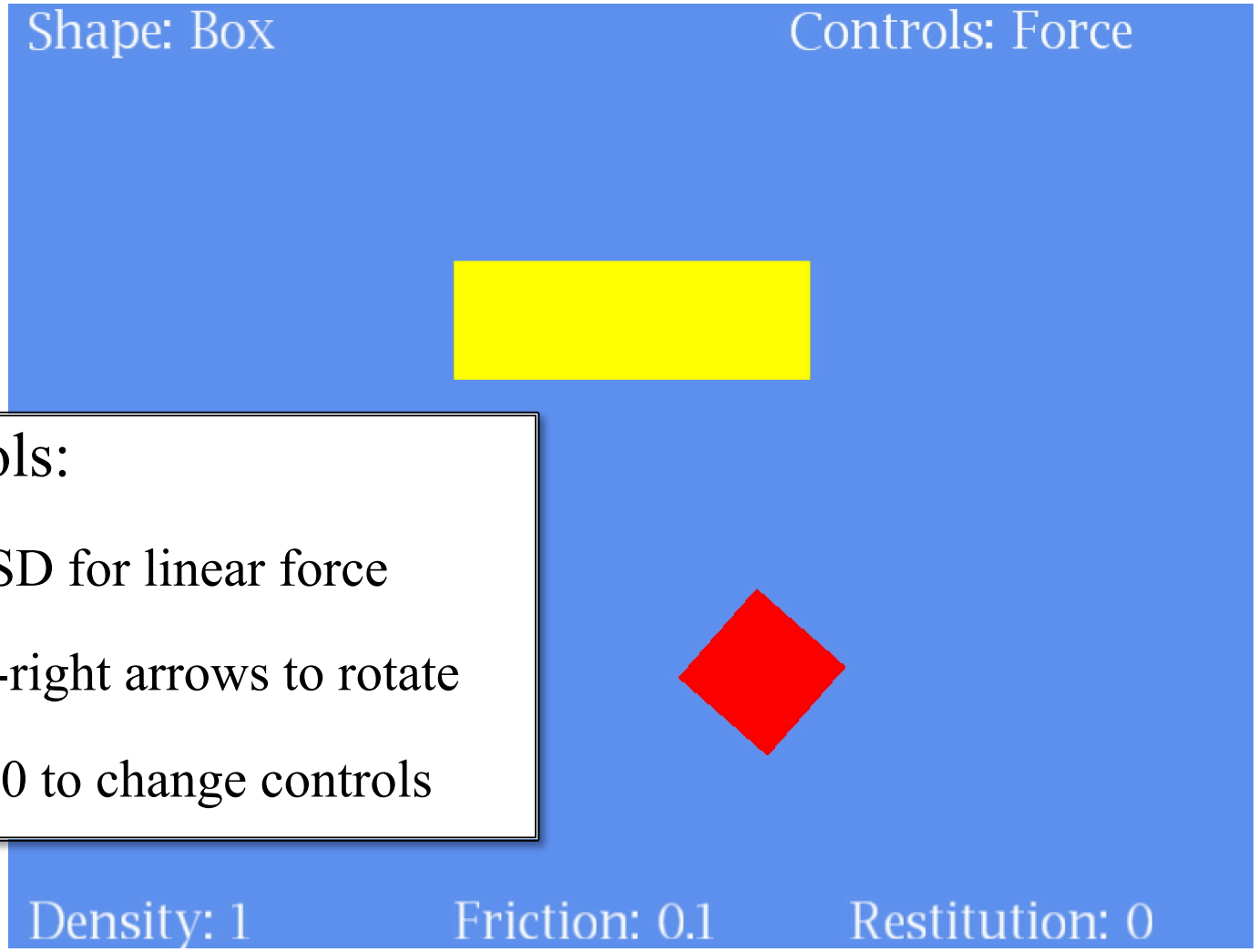

Controls:

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

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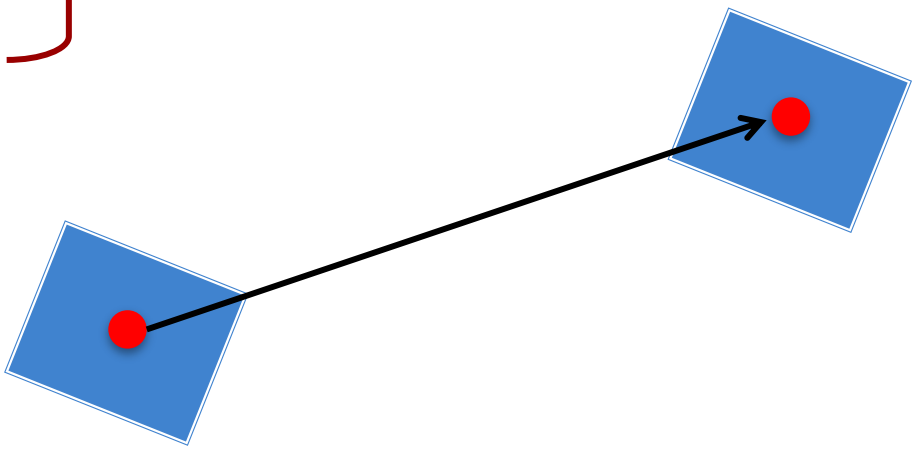
Must Cap Velocity



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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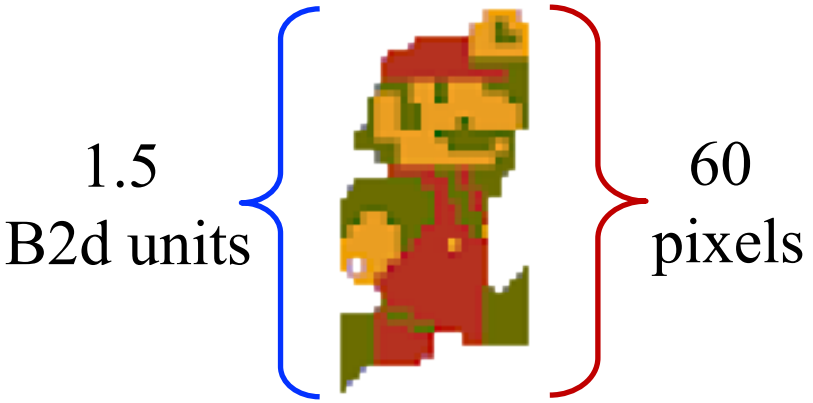
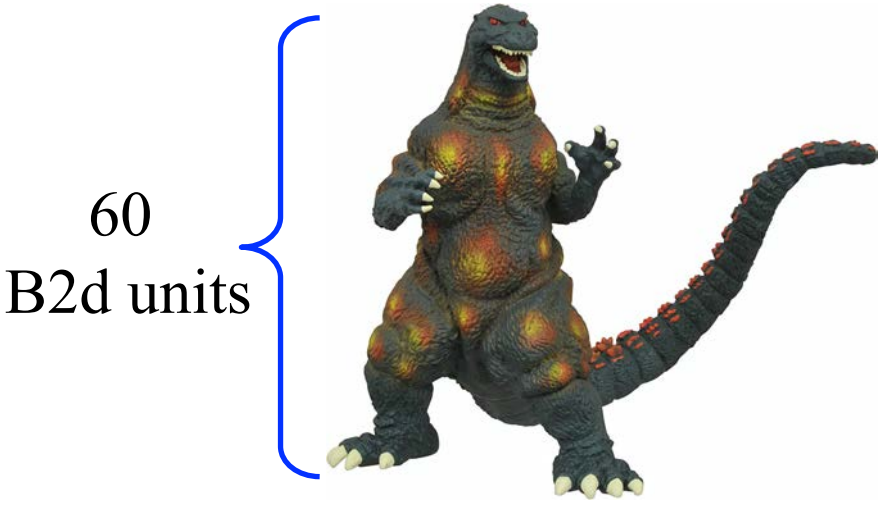
Observations on Fixture Parameters

- **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

A Word on Units

- Size is **not** in pixels
  - 1 Box2D unit = 1 meter
  - Also 1 density = 1 kg/m^2
  - Drawing scale in Lab 4
- This is **rescalable**
  - Could say 1 unit = 10 m
  - But must be consistent
- Box2d likes units *near* 1
  - Best if objects same size
  - Adjust scale so 1 default





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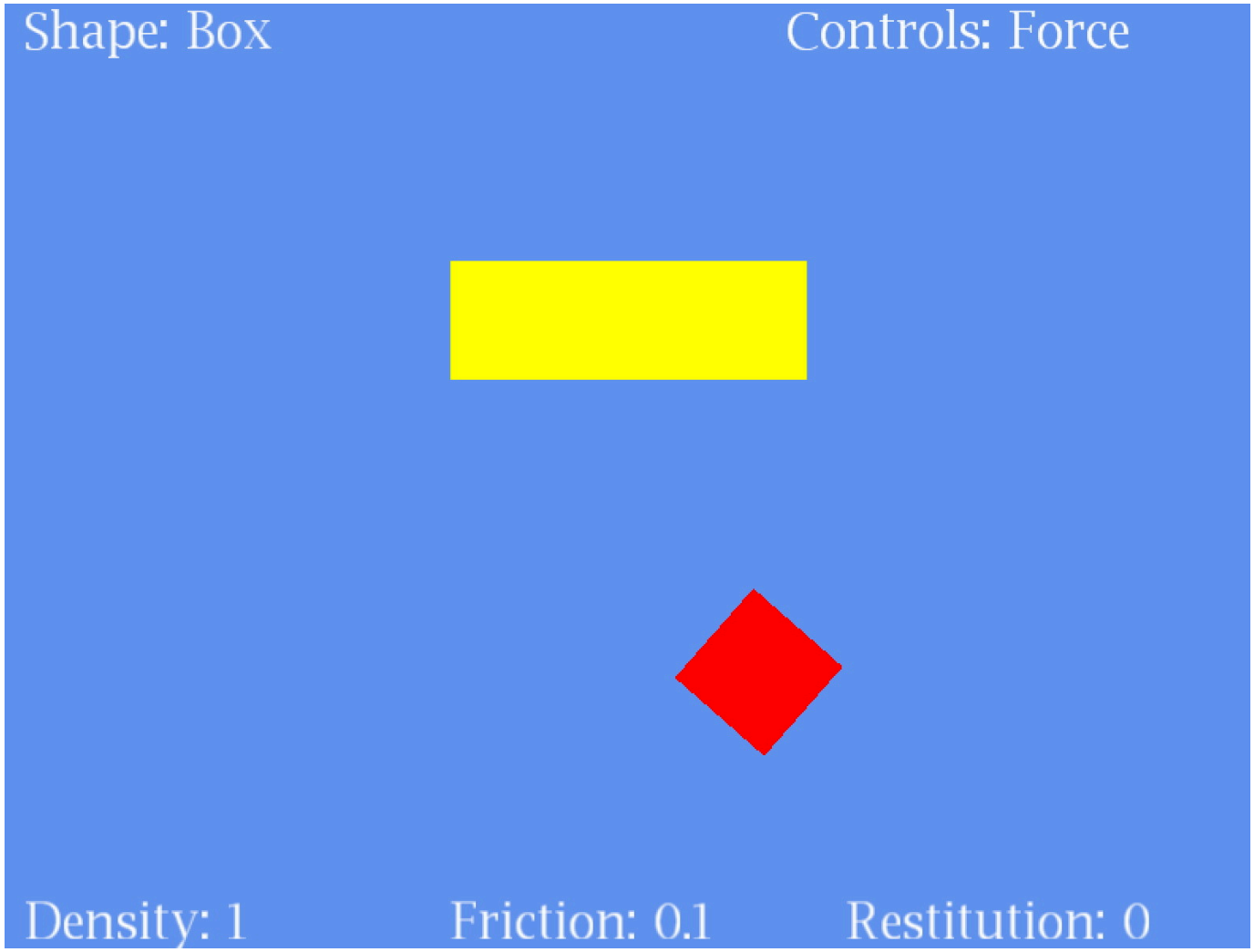

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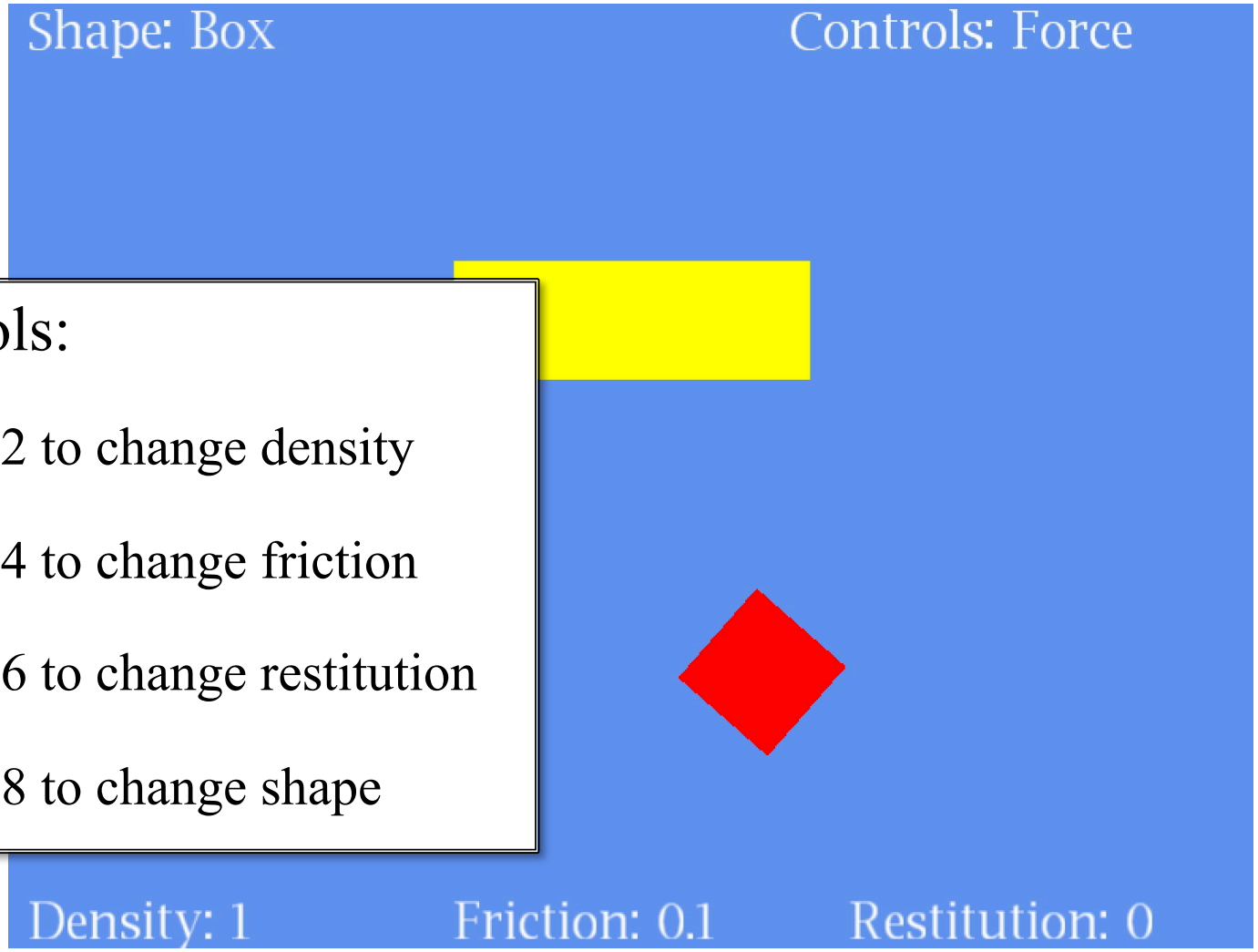
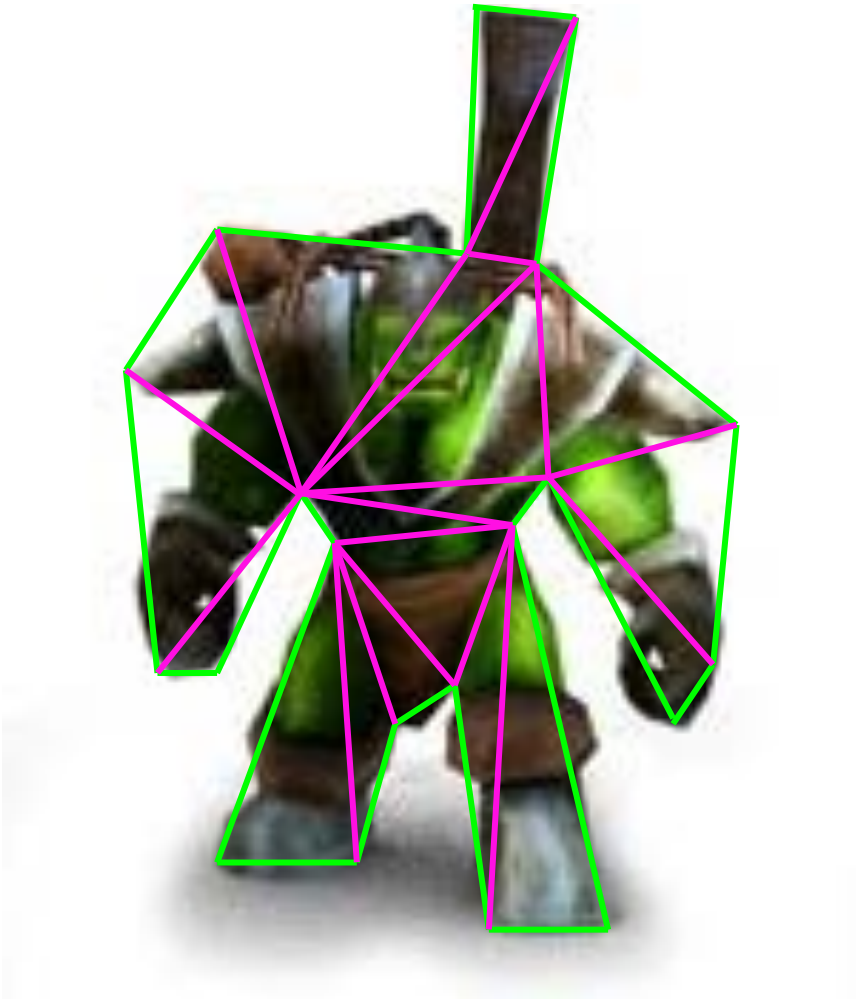


Controls:

- 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

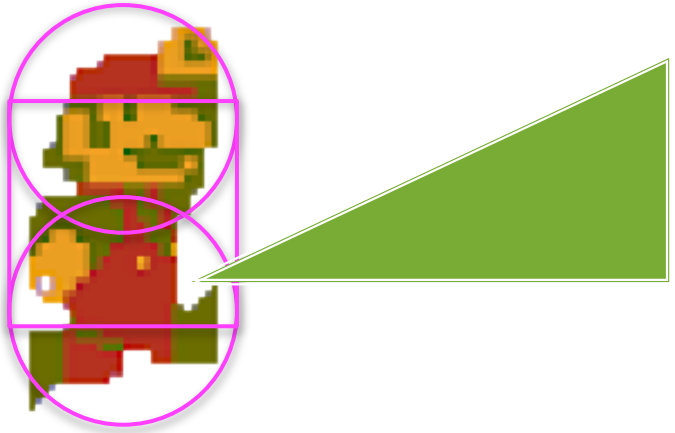
character.shape

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

Collision is About Fixtures!



- Capsule obstacle is two circles and rectangle
  - Allows smooth motion while walking
  - Feet do not get hung up on surfaces
- But may register **multiple collisions**!

Collision Filtering

- FixtureDef has a Filter attribute
  - `categoryBits`: Defines what can collide with it
  - `maskBits`: Defines what it can collide with
  - `groupIndex`: Collision group (overrides bits)
- **Example:**
  - Fixture A category `x001`, Fixture B category `x010`
  - Mask `x101` or `x001` only collides with A
  - Mask `x011` collides with both A and B

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- **Example:**
  - Fixture A category x001 Fi[illegible]10
  - [illegible]
  - [illegible] both A and B

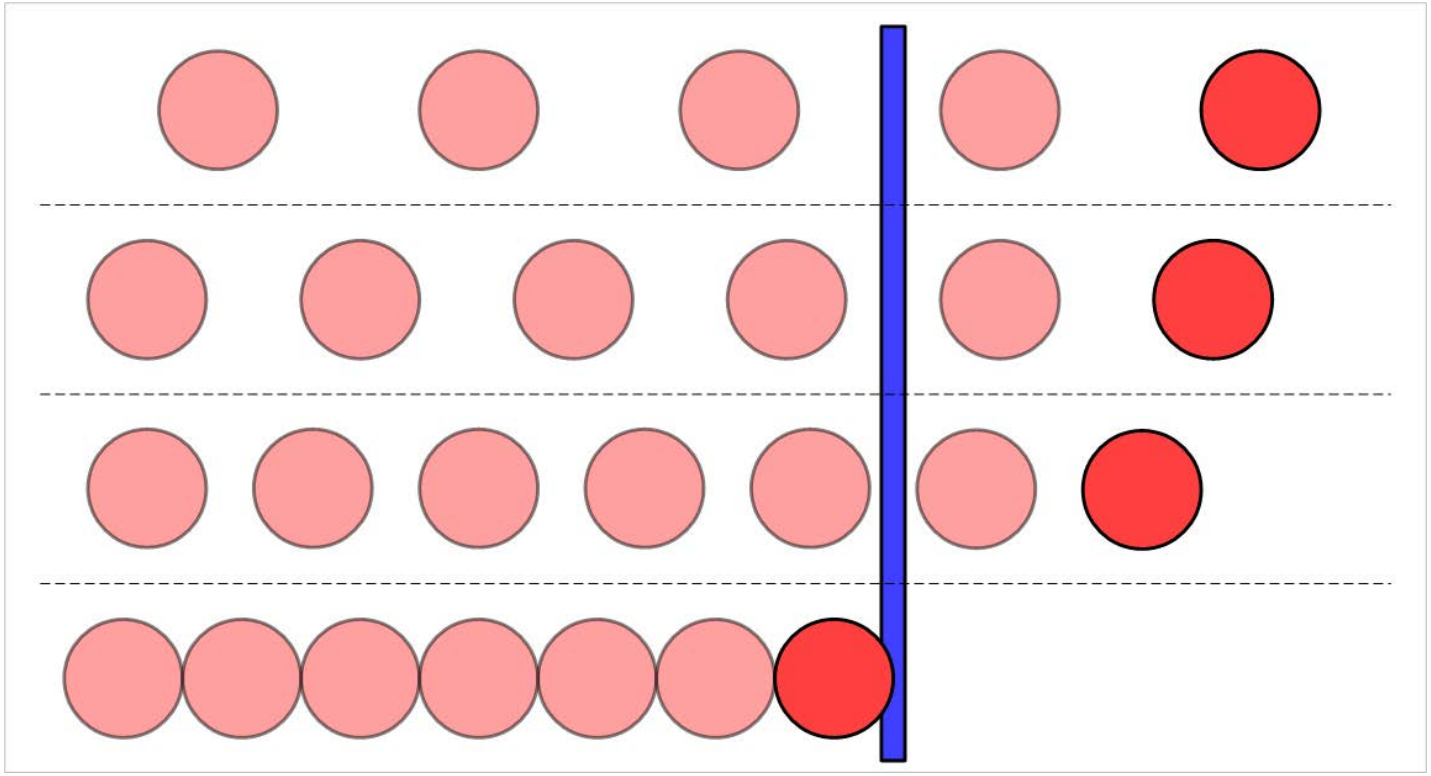
Filtering means is never detected!

How about Sort-of-Filtering?

- Want a non-sensor object where
  - We always **detect** the collision
  - But sometimes ignore the **restitution**
- Method **beginContact** has a `Contact` parameter
  - Manages the physics while it resolves collision
  - Can call the method `contact.isEnabled(false)`
  - Turns off collision; **endContact** is never called
- See tutorials for "anatomy of a collision"
  - https://www.iforce2d.net/b2dtut/collision-anatomy

Recall: Tunneling

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

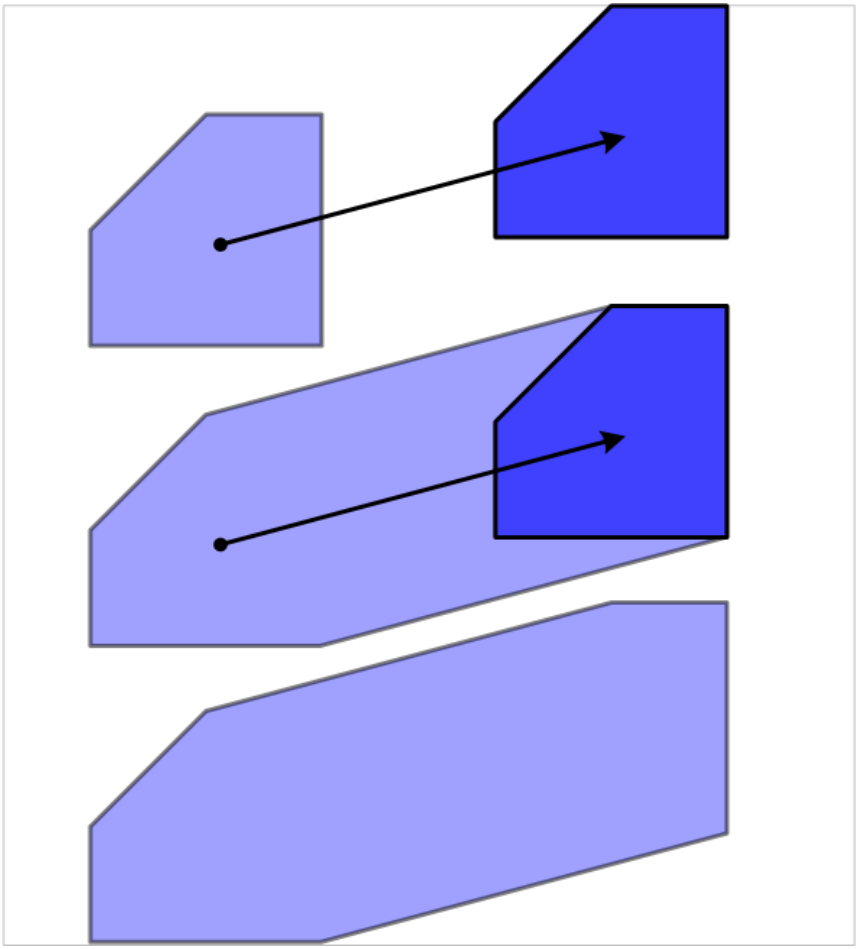


Possible Solutions to Tunnelling

- 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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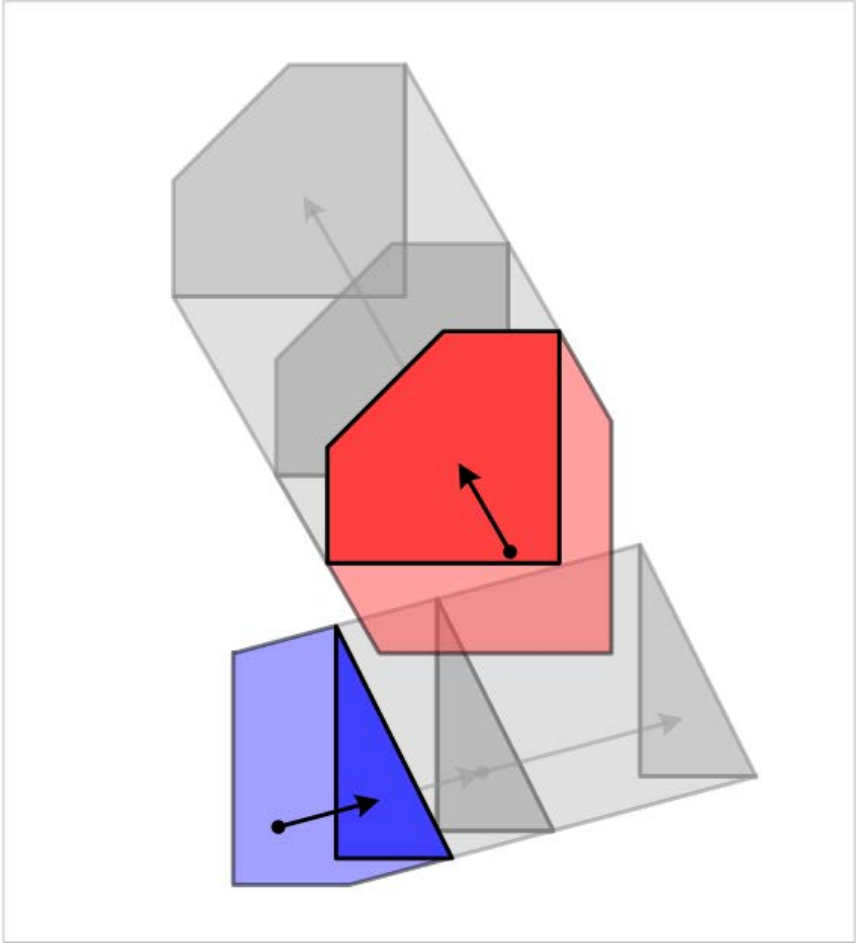
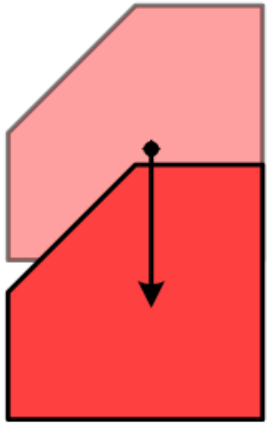
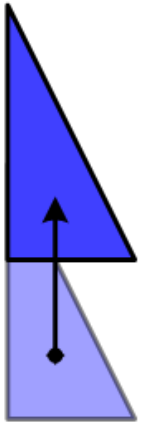


Swept Shapes & Relative Coordinates

- **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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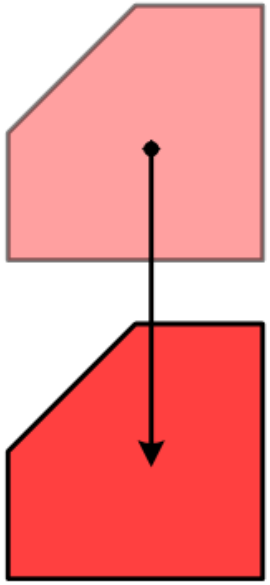
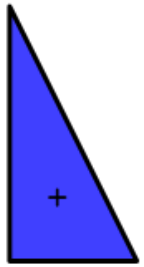


Blue Frame



Swept Shapes & Relative Coordinates

- **False positives** happen if:
  - Two objects are moving
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- What if only
  - Swept in
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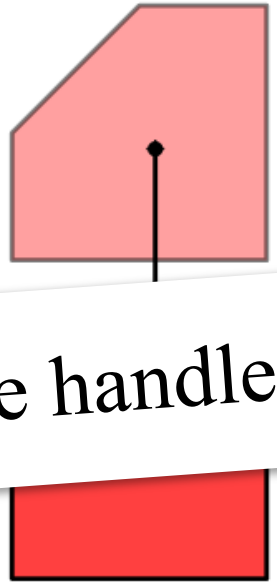
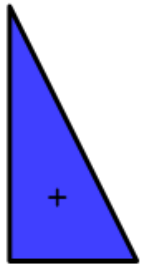
  -
  - s



Blue Frame

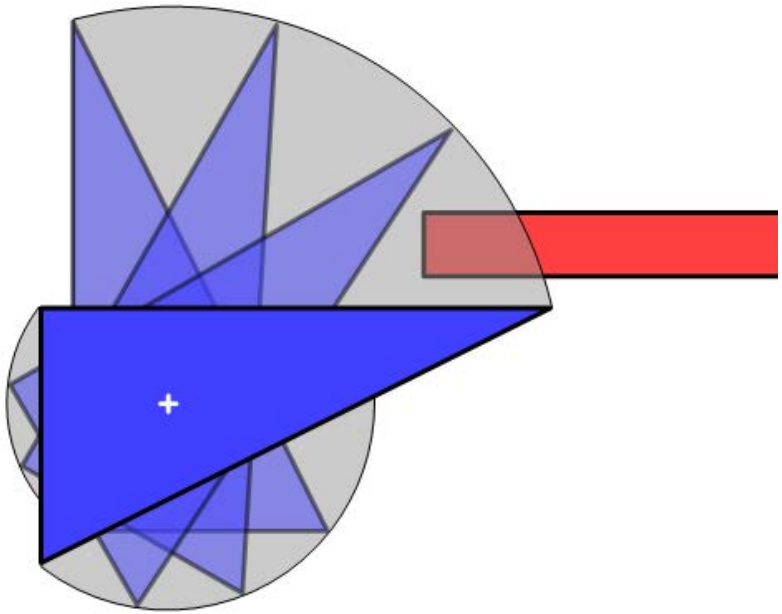
How "Bullets" are handled



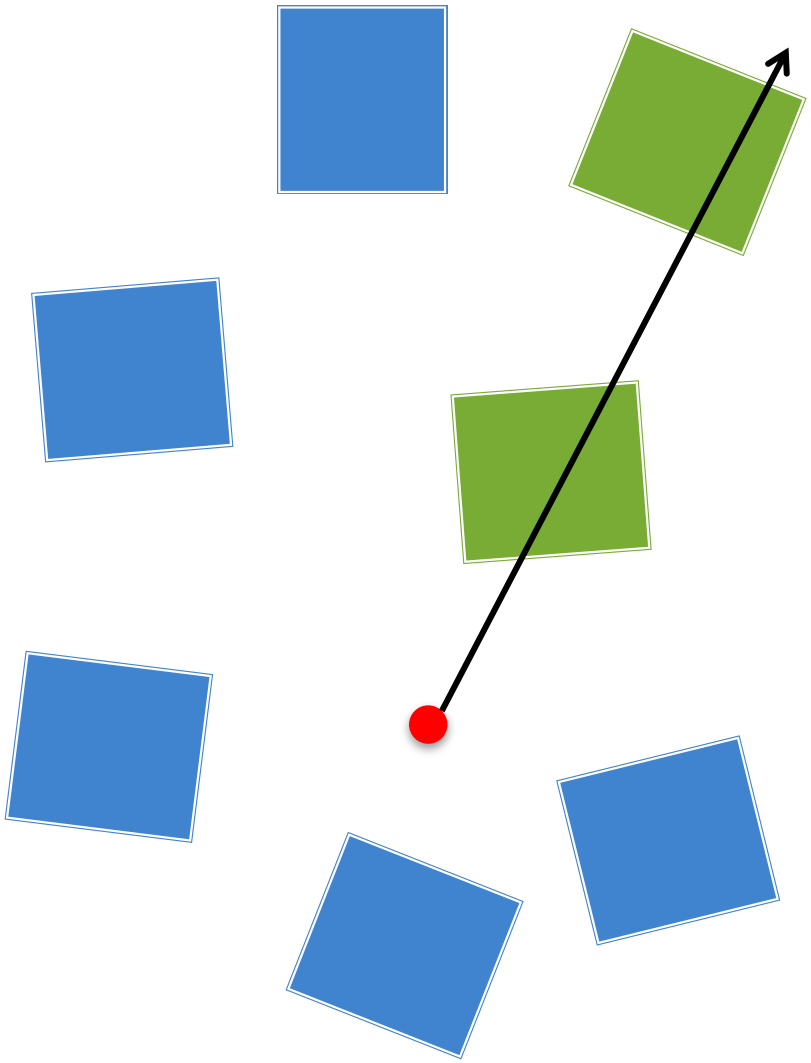
Expensive!

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



More Collisions: RayCasting



- Method `rayCast` in `world`
  - Give it start, end of ray
  - Also a `RayCastCallback`
  - Executed when call step
- Invoked on **all collisions**
  - Not just the first on
  - Does not return in order!
  - This is for optimization
- Sight-cones = many rays

The RayCastCallback Interface

```
float reportRayFixture(Fixture fixture,  // Fixture found
                       Vector2 point,    // Collision point
                       Vector2 nom,      // Collision normal
                       float fraction    // Fraction of ray
                       )
```

- Fraction is how far along ray (0 = start, 1 = end)
  - First collision is one with **lowest fraction**
  - But be prepared for larger fractions first
- Return value is optimization to **limit search**
  - Ignores collisions with fraction later than return

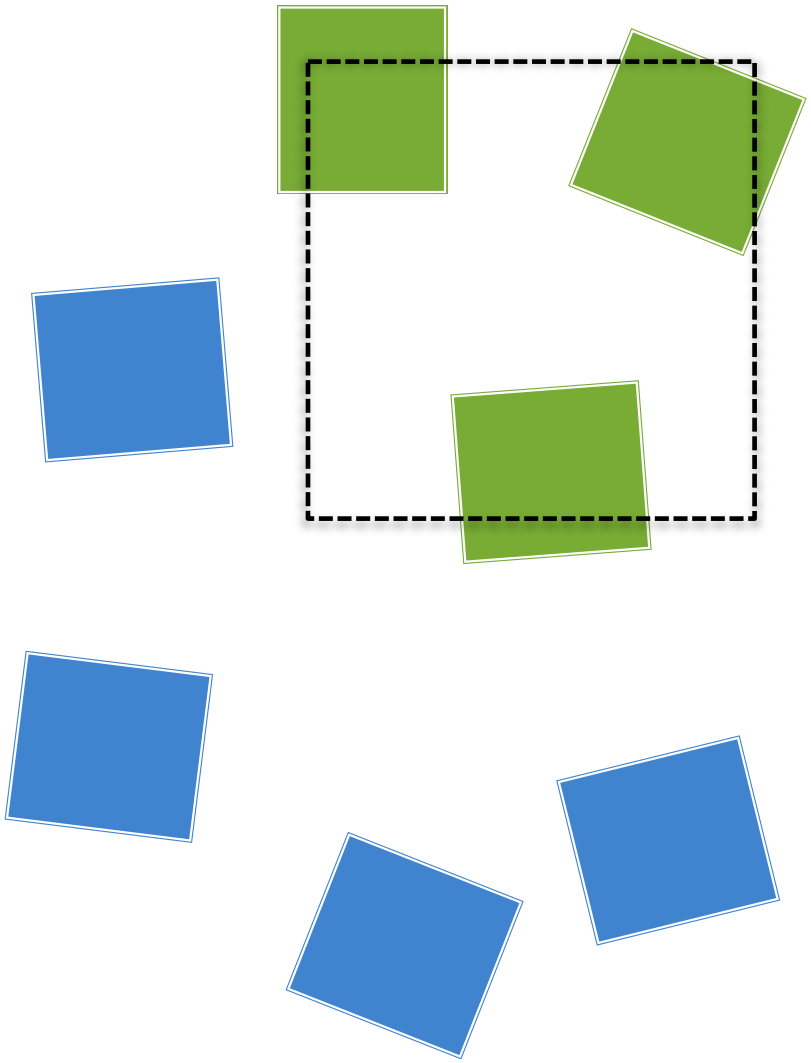
The RayCastCallback Interface

```
float reportRayFixture(Fixture fixture,  // Fixture found
                       Vector2 point,    // Collision point
                       Vector2 nom,      // Collision normal
                       float fraction    // Fraction of ray
                       )
```

Allowed fraction for future matches

- Fraction is how far along ray (0 = start, 1 = end)
  - First collision is one with **lowest fraction**
  - But be prepared for larger fractions first
- Return value is optimization to **limit search**
  - Ignores collisions with fraction later than return

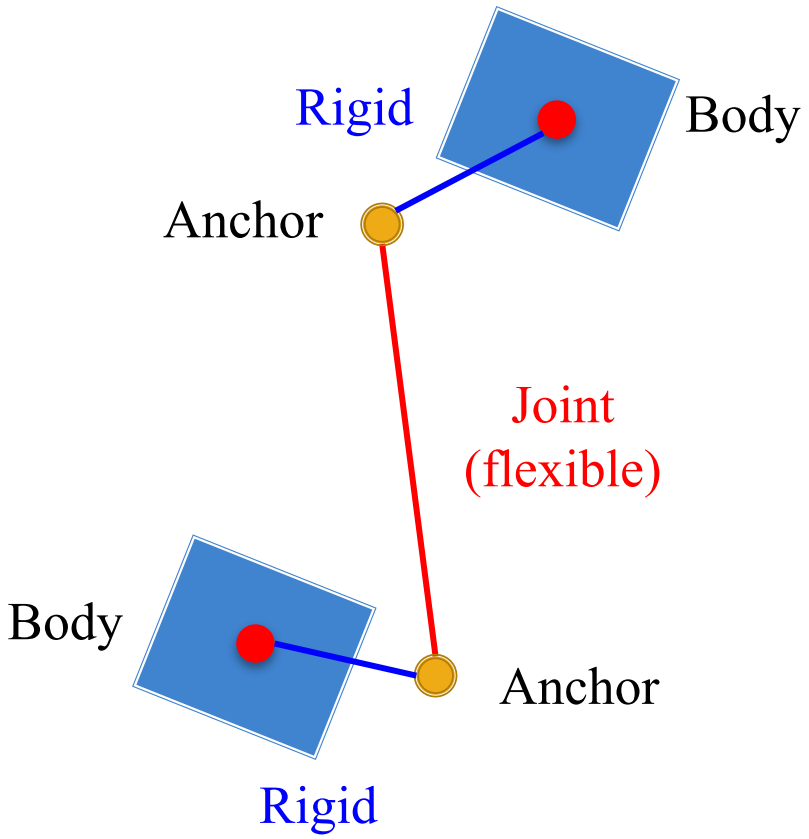
AABB Queries



- **Bounding Box** queries
  - Find all fixtures in box
  - Must be *axis aligned*
  - Rotation not allowed
- Similar to raycasting
  - Provide callback listener
  - Call step method in world
  - Prepare for many matches
- **Application:** selection
  - See Ragdoll Demo

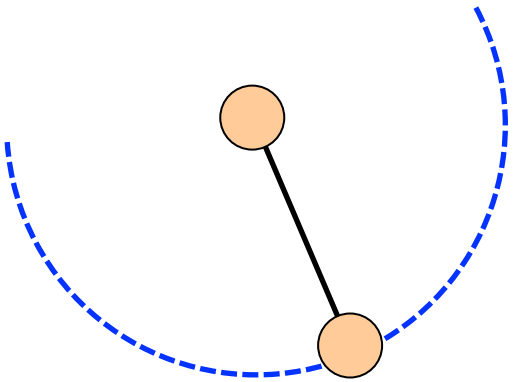
Some Words on Joints

- 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



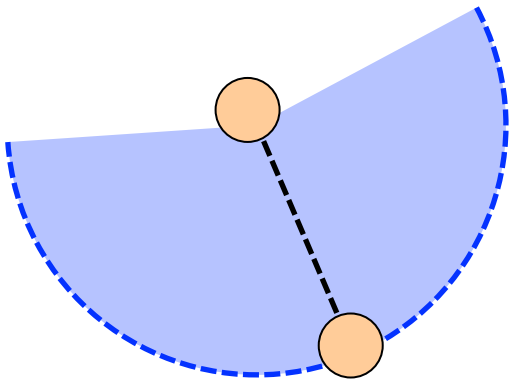
Sample Joint Types

Distance Joint



- Hard constraint
- **Strong** but very **brittle**
- Primary chain/rope joint

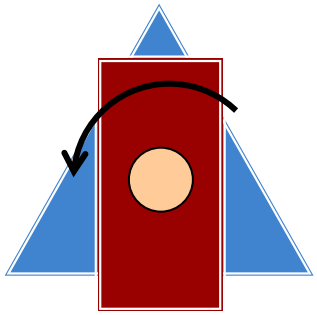
Rope Joint



- Soft constraint
- **Stretchy** but very **weak**
- More for *reinforcement*

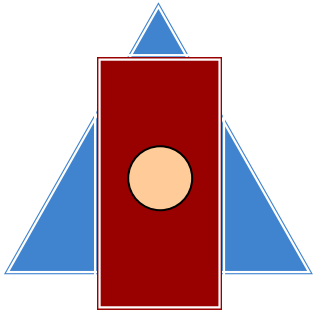
Sample Joint Types

Revolute



- Joint binds at one point
- Both translate together
- But rotate **independently**

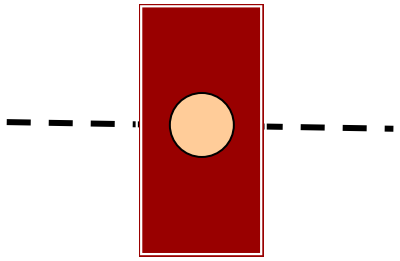
Weld



- Joint binds at one point
- Both translate together
- Both rotate together

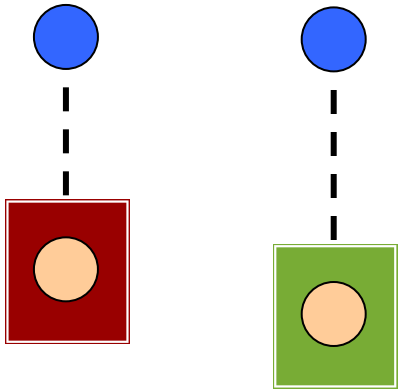
Sample Joint Types

Prismatic



- Joint binds with a "track"
- Both rotate together
- But **translate along track**

Pulley



- Joint binds through portals
- Pulling one raises the other
- **Distance** w/ "teleportation"

Summary

- Box2d 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
- Collisions are managed by callback functions
  - Invoked once you call the world step method
  - Collisions are processed per fixture, not per body