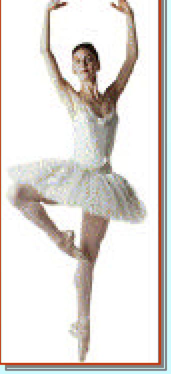
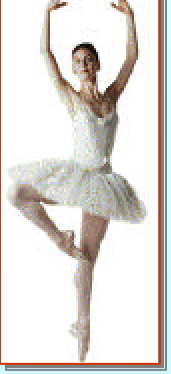


Physics of Dance

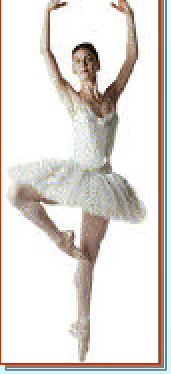
- Basic physics definitions we'll need
- Balance
- Turns
- Jumps
- Why are dancers so slim? The physics behind the body size!



Basic physics definitions we'll need

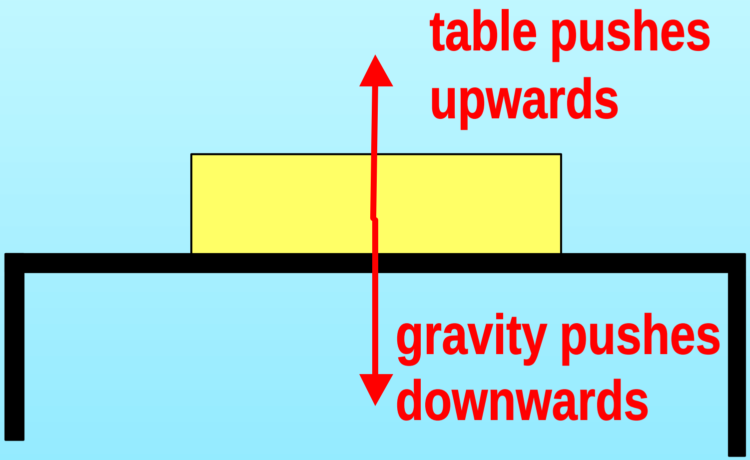
- **Velocity** is how fast and in what direction an object is moving
  - It's basically rate = distance/time + direction
- **Momentum** is mass times velocity
  - If an object has a large momentum, it's hard to stop it!
- **Force** is basically a push or a pull
  - To change an object's momentum, you have to apply some kind of force for some time! So

change in momentum = force x duration of time the force was applied

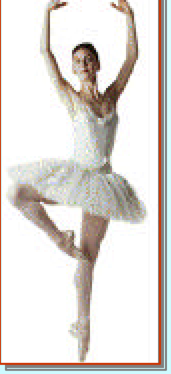


A force is a vector quantity

- A force is a <u>vector</u> quantity, meaning that it has both magnitude and direction.
  - This is why forces are often graphically represented as arrows

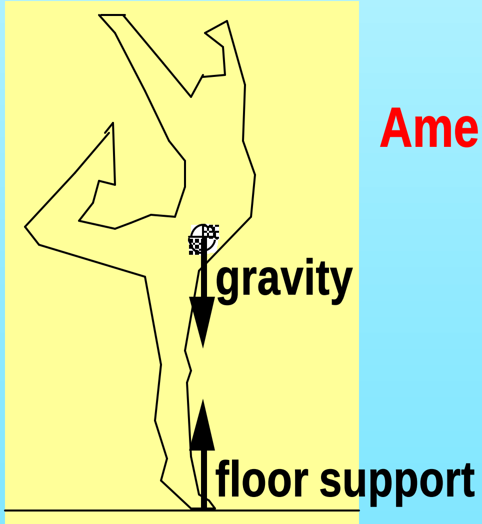


- Forces add! It's the **total** force that counts!



What forces act on a dancer?

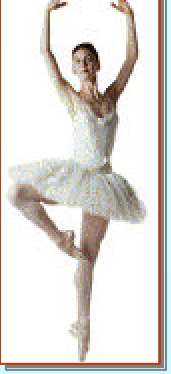
- Gravity (downwards)
- Support from floor (upwards)
- Friction from floor (sideways)
  - Friction is the force that resists relative motion between two bodies in contact



Keith Roberts

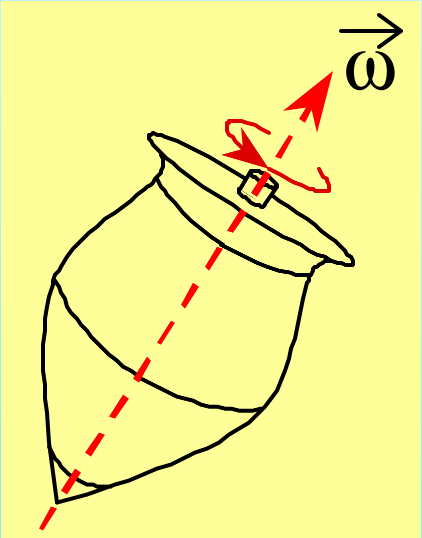
American Ballet Theatre principal

(photo by Roy Round)

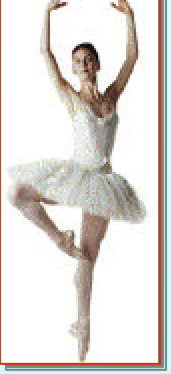


Some more physics definitions: spins

- **Angular velocity** is how fast an object spins
  - It is also a vector, characterized not only by magnitude but also by the direction of the rotation axis.
- **Rotational inertia** is the inertia of a rotating object
  - Inertia in general is the tendency of an object to keep doing whatever it is doing

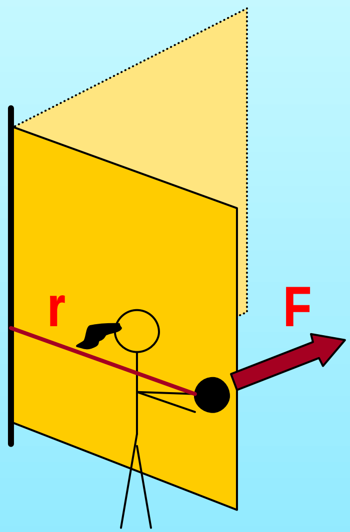


- **Angular momentum** is rotational inertia times angular velocity
  - If an object has a large angular momentum, it's hard to stop its spinning!



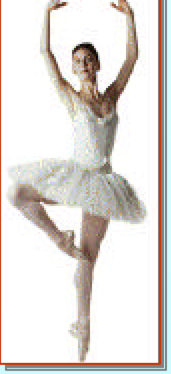
Torque

- **Torque** is a measure of how much a force acting on an object causes that object to rotate.
- You are applying a torque to doors every day of your life!



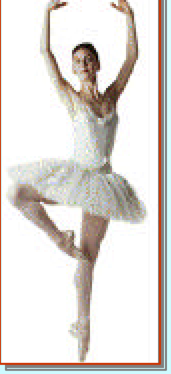
Torque = distance (r) times force (F)

change in angular momentum = torque x duration of time the torque was applied



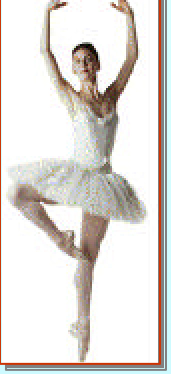
Analogies

Motion without spins		Motion with spins
Velocity	⟷	Angular velocity
Mass	⟷	Rotational inertia
Momentum	⟷	Angular momentum
Force	⟷	Torque



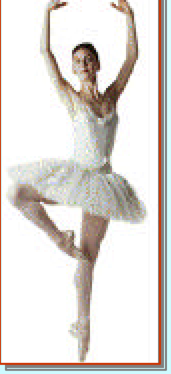
What's balance?

- No total force and no total torque
  - No total force is needed so that the momentum does not change
  - No total torque is required so that the angular momentum does not change



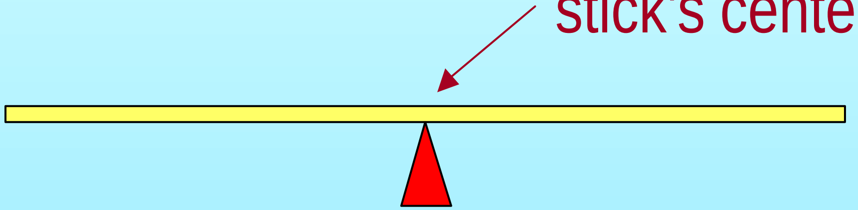
Amazing examples of balance…

Paloma Herrera
American Ballet Theatre principal
(photo by Roy Round)

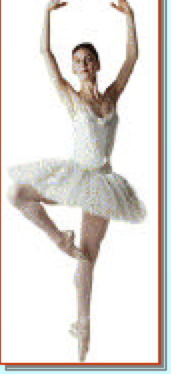


Center of gravity

- **The center of gravity** of an object is that point at which the object will balance.

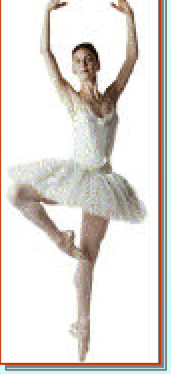


- The entire weight may be considered as concentrated at this point, hence the name.



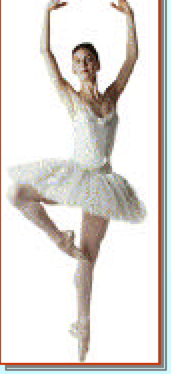
A trick to know about center of gravity

- In order to stay balanced, the center of gravity must remain directly above the area of contact with the floor!
  - Then gravity's downward push and floor's upward push will go through the dancer's center of gravity and there is no total force and no total torque
  - If this area is very small (e.g., a dancer is en pointe), it's harder to balance



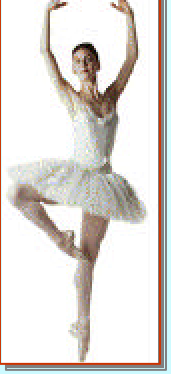
Balancing *en pointe*…

Sylvie Guillem
Royal Ballet principal



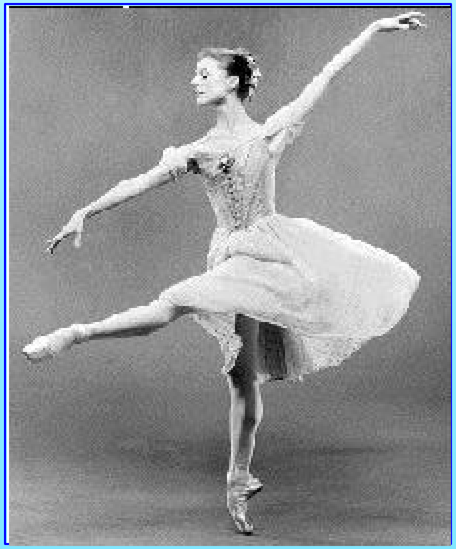
Area covered while *en pointe*

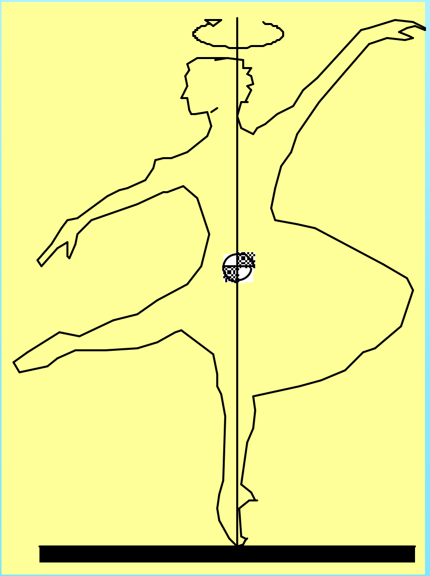
Demo with graph paper, etc.

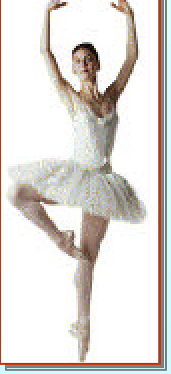


How can a dance keep a balance while turning?

- What's the trick that keeps the dancer balanced when she is turning?
  - The rotation axis shouldn't wobble around much!
- There's a lot of neat physics in turns!

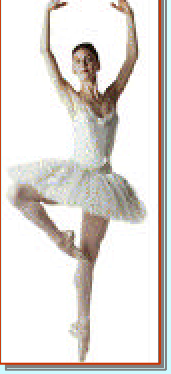






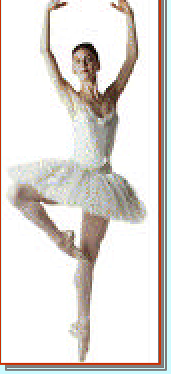
What describes turns?

- The relevant quantities that describe turns are:
  - **Angular velocity** is how fast an object spins
  - **Rotational inertia** is the inertia of a rotating object
  - **Angular momentum** is rotational inertia times angular velocity
  - A change in angular momentum is equal to the **torque** exerted on an object times the duration of time the torque was acting

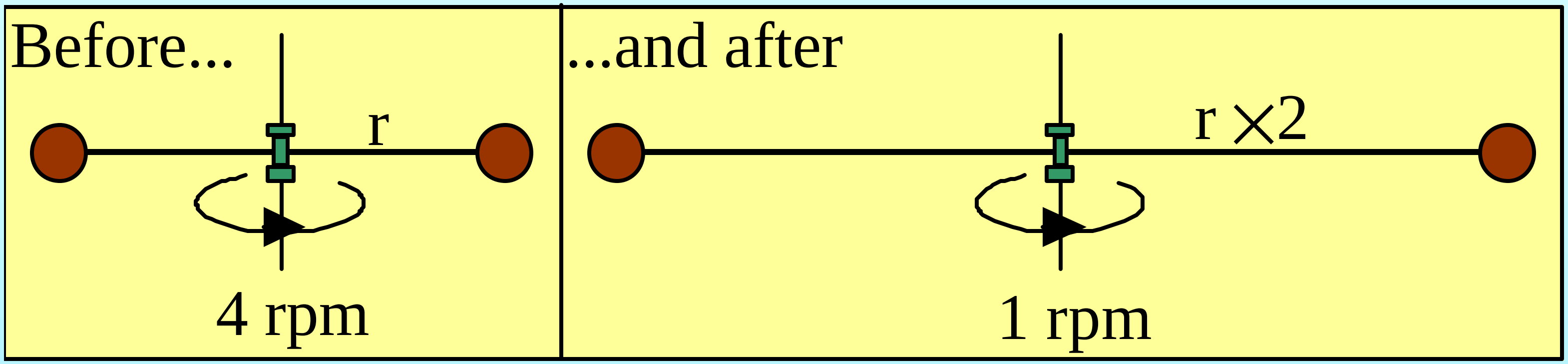


Rotational inertia

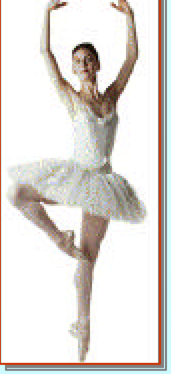
- Rotational inertia indicates how difficult it is to start an object spinning (or to stop it, if it's already spinning)
  - It depends on the mass of the object
    - The greater the mass, the greater the rotational inertia
  - It also depends on how far the mass of the object is placed from the rotation axis
    - If this distance is doubled, the rotational inertia gets quadrupled!
- If no torque is applied, the angular momentum stays the same
- So since angular momentum = rotational inertia times angular velocity, the greater the rotational inertia, the smaller the angular velocity!



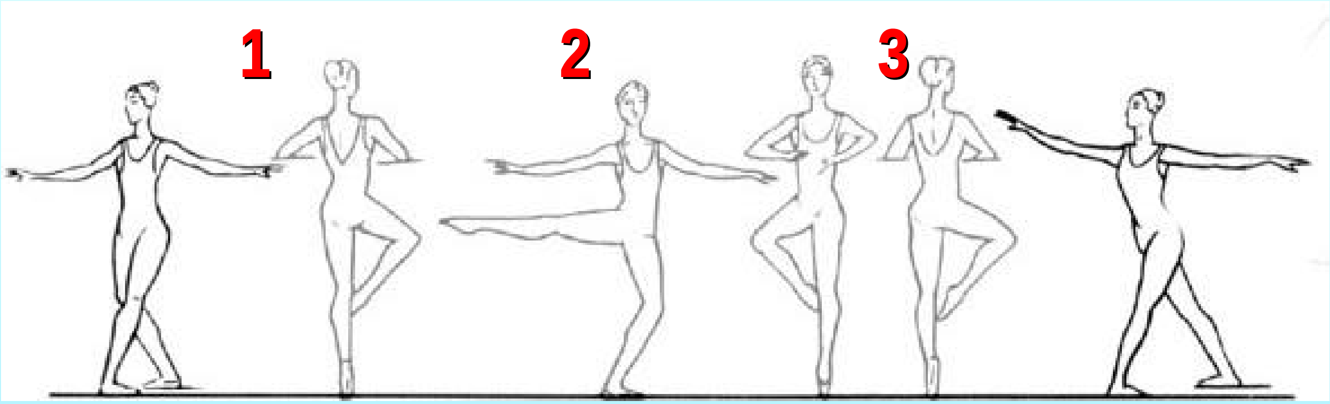
Rotational Inertia (2)



- The masses were at a distance r from the rotation axis before
- Then the distance doubled => rotational inertia quadrupled, so the angular velocity became smaller by a factor of four.
- A number of ballet movements is based on this principle.



Fouette



1) Dancer starts turning -- arms brought together

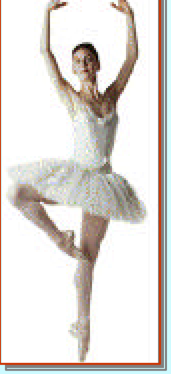
(r small, rotational inertia small, so large angular velocity)

2) Dancer stops for a moment by extending arms and leg

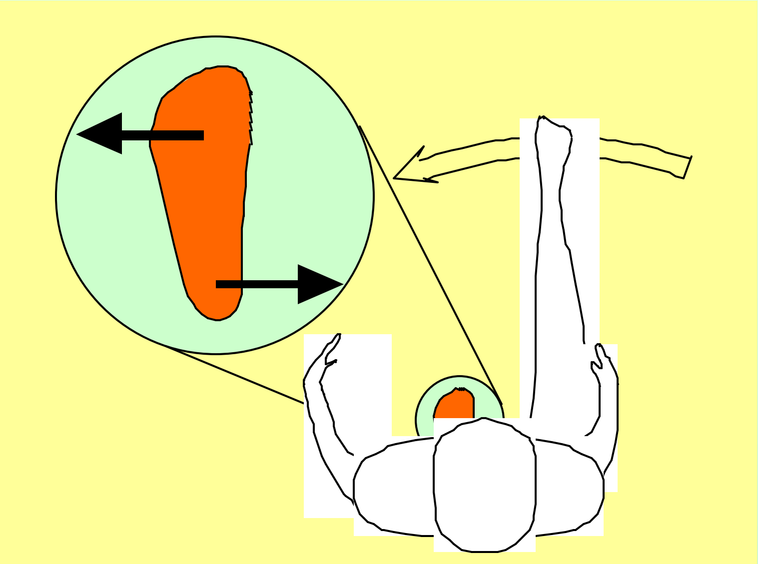
(r large, rotational internal large, so small angular velocity)

3) Dancer continues turning -- arms brought togethe

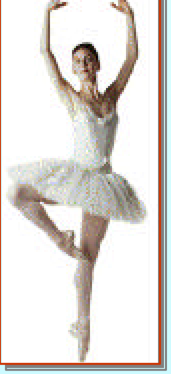
(r small, rotational inertia small, so large angular velocity)



Friction can create torque, too!



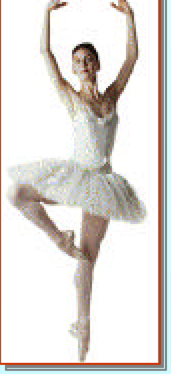
When the dancer pushes the floor one way, the friction between the leg and the floor creates the push the other way.

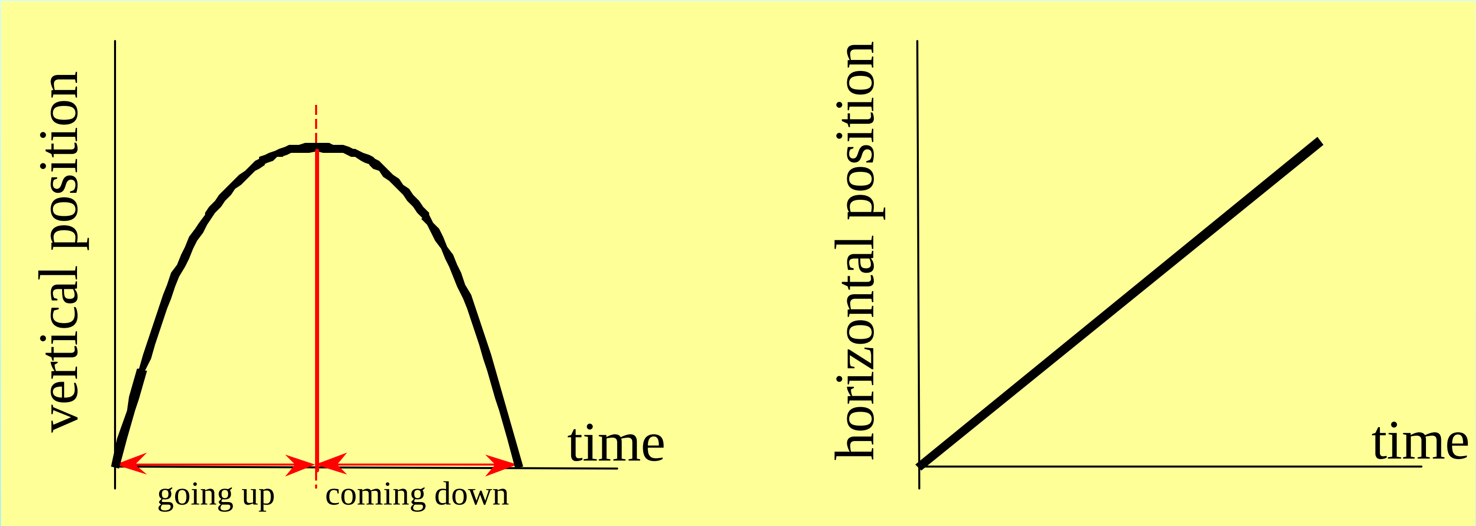


The physics of jumps

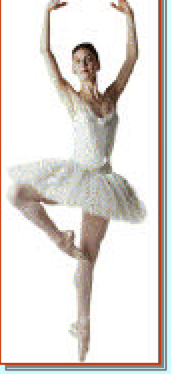
- Gravitational force plays a major role in jumps
- The total effect of gravity is the same as if it were acting on the dancer's center of gravity only
- Gravity only affects vertical (not horizontal) motion
- Gravitational force is proportional to an object's mass
  - So double the mass, and the gravitational pull will double too!

Horizontal vs. vertical motion

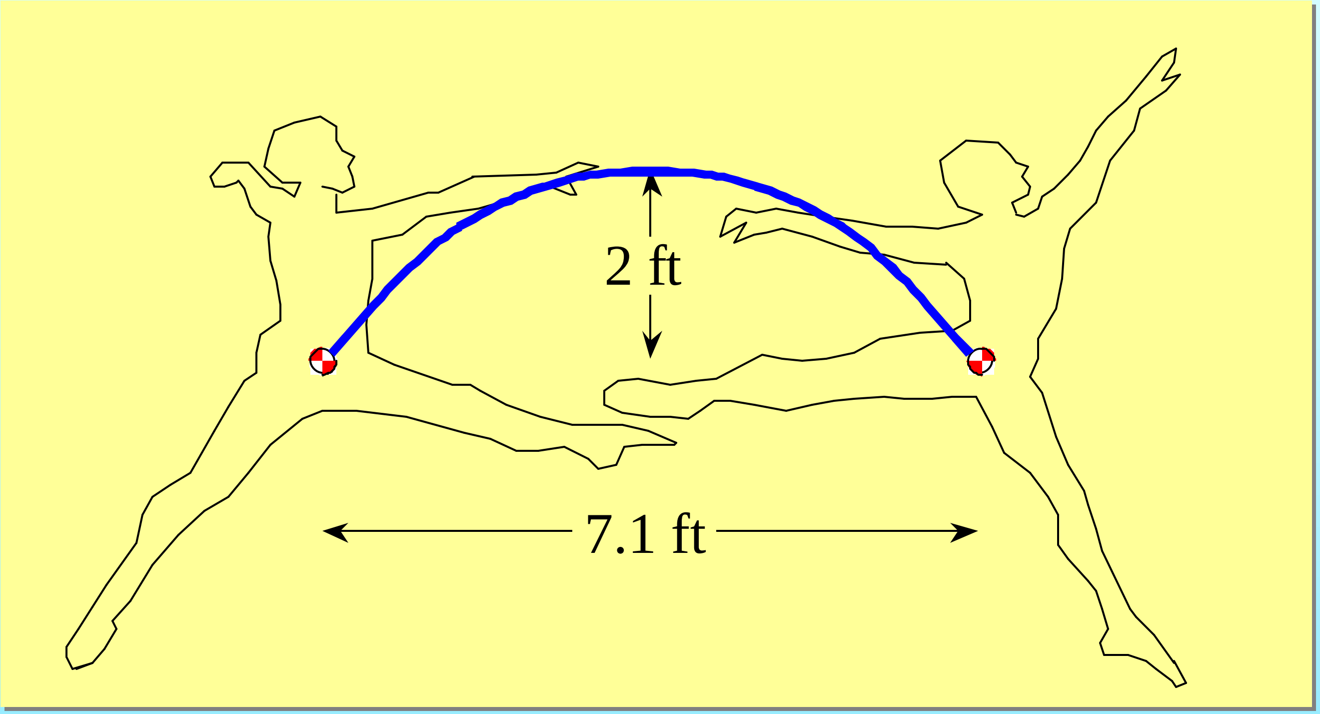




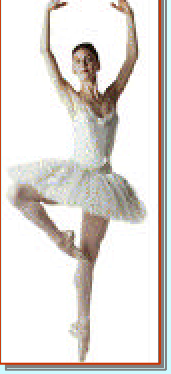
- The vertical position of the dancer's center of gravity vs. time describes a parabola
- There's no force in the horizontal direction, so the horizontal position is a straight line if we plot it vs. time



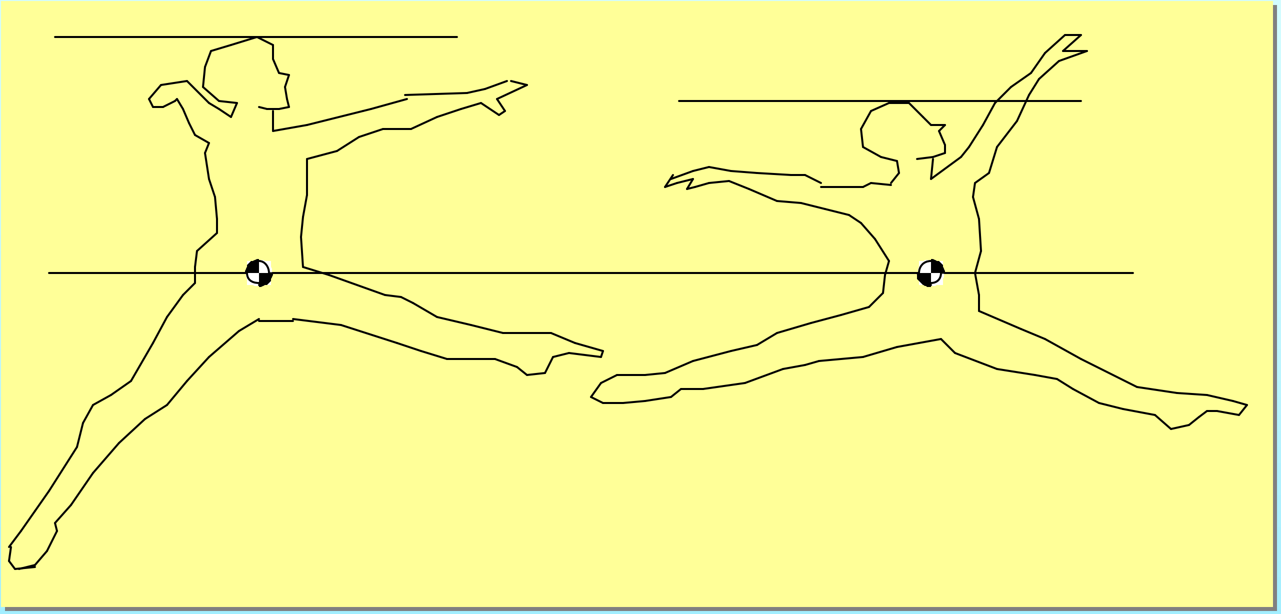
Trajectory in a jump



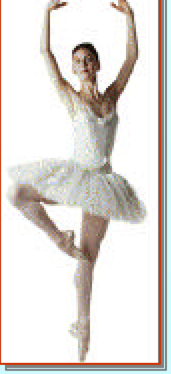
- If a dancer jumps so that their center of gravity rises by 2 feet, and the horizontal velocity is 10 ft/sec, this is what we would see.



Floating?

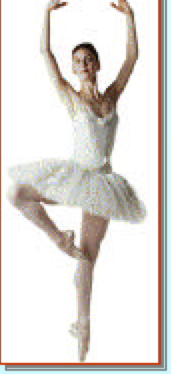


- While the trajectory is always the same, some dancers can create an illusion of floating in space.
- This is done by raising the legs, arms, adjusting the head
  - The vertical motion of the head is smaller than the vertical motion of the center of gravity



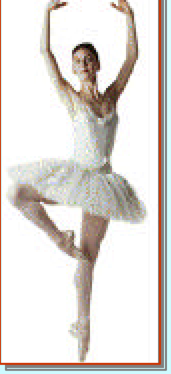
Beautiful jumps

Yulia Makhalina
Farukh Ruzimatov
Kirov Ballet principals
(photo by Marc Haegemar



Body size effects

- Rotational inertia is proportional to the mass of an object and to the square of the distance from the rotation axis to the object's edge
- In order to rotate faster, need to decrease rotational inertia
- This can be done in two ways:
  - Decrease mass
  - Make sure most of the body is very close to the rotation axis
  - Most dancers go for both…

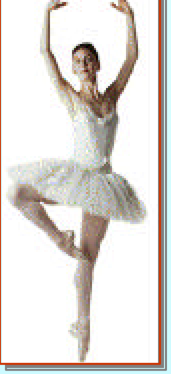


A dancer's body evolution

- It is curious to see how the way dancers look changed over time
  - Increased technical demands required new body looks
  - And it's nothing but physics that's behind it!

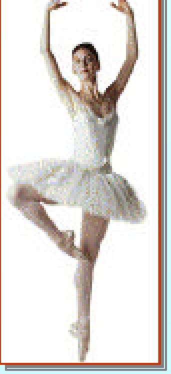
Pierina Legnani
(1863 - 1923).

Sylvie Guillem
Royal Ballet Principal



Never exaggerate!

- Sometimes the demand for a perfect dancer's body leads to really ugly results…



Conclusions and acknowledgements

- Physics does not "explain" dance, of course!
  - Dance is an art form, and as such is rather outside the realm of science
- However, it may help the dancer to know the physics behind the movements she is performing.

- I'd like to acknowledge George Gollin, UIUC

http://www.uiuc.edu/ph/www/g-gollin/dance/dance_physics.html