Verifying Safety for a Hopping, Straight-Legged Bipeded Robot

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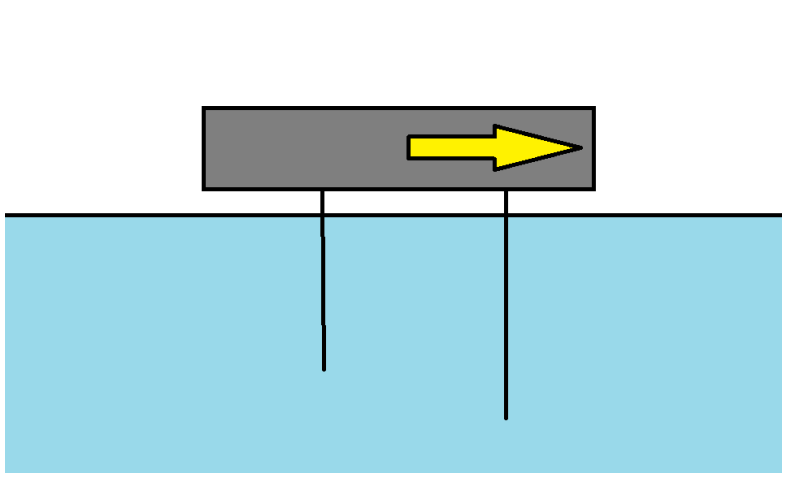
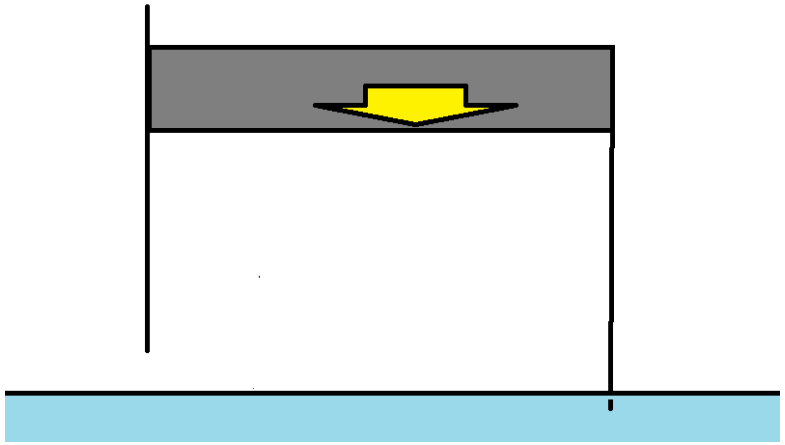
Background

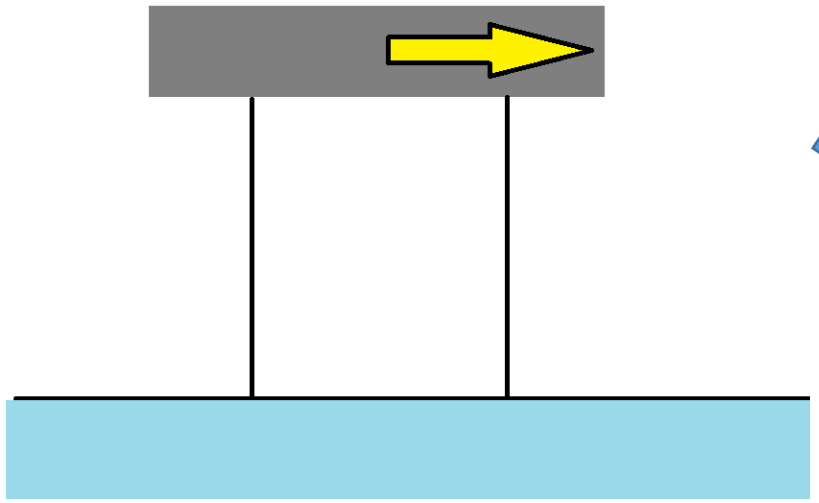
- Studied a lot, by primarily but controls examined separately from dynamics
- Testing controller and machine usually done by simulation or real-life tests
- d/dt tool closest related work, but focused on dynamics, not controls

What we are trying to model

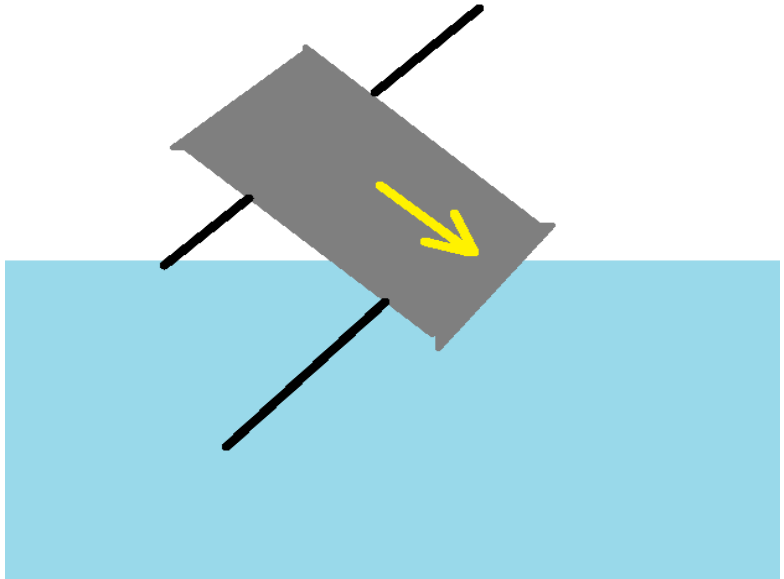


Front View



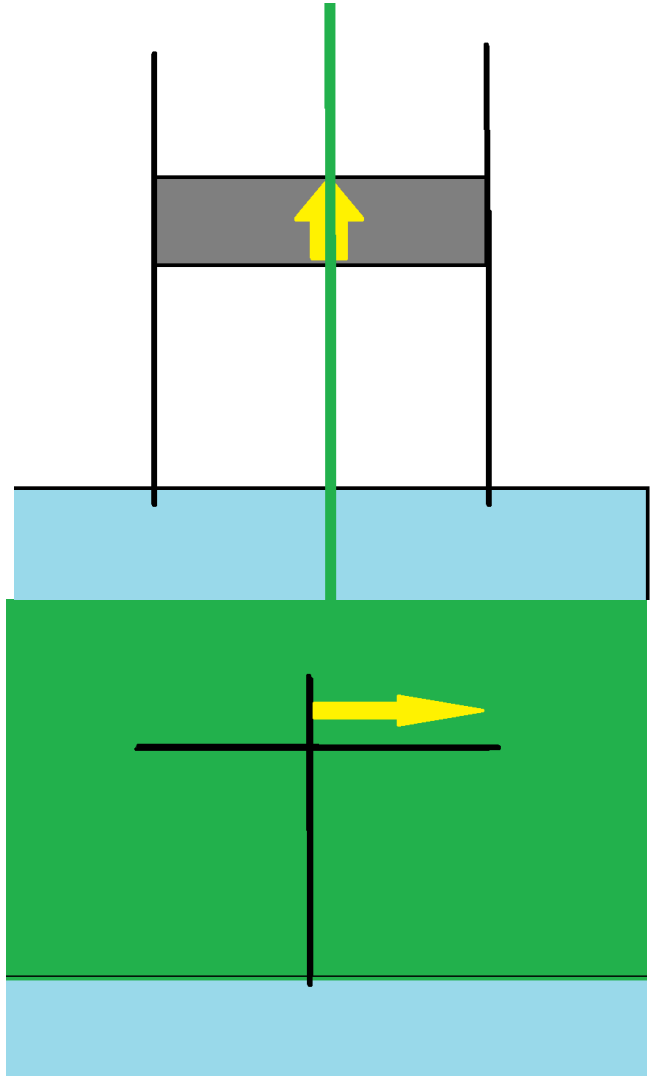


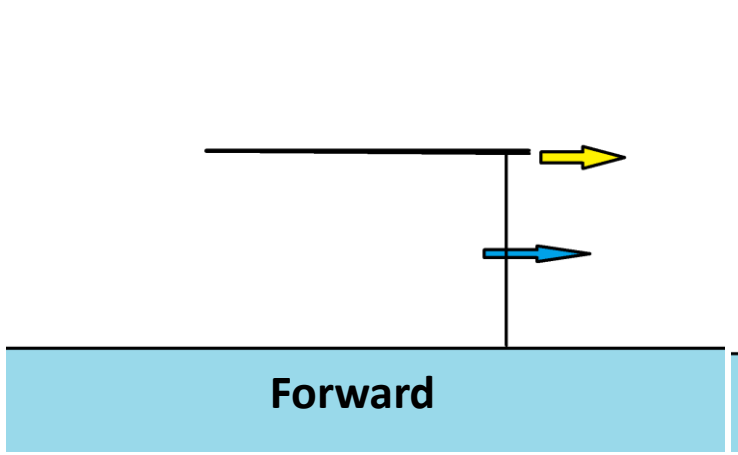
Side View

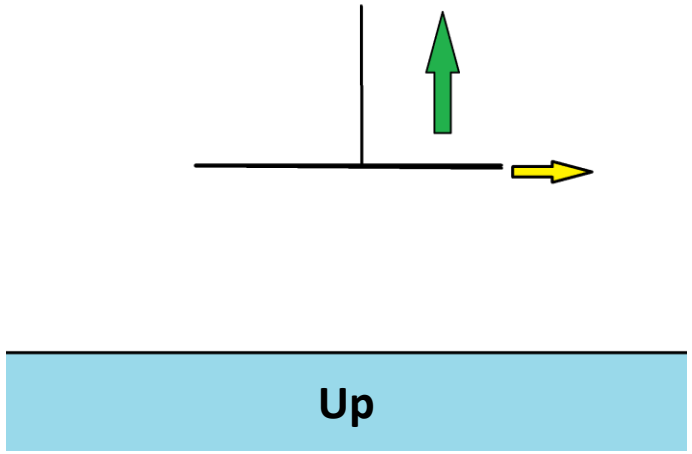


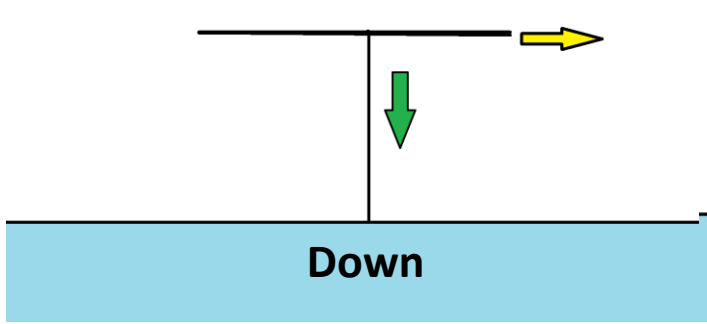
Modeling Robot

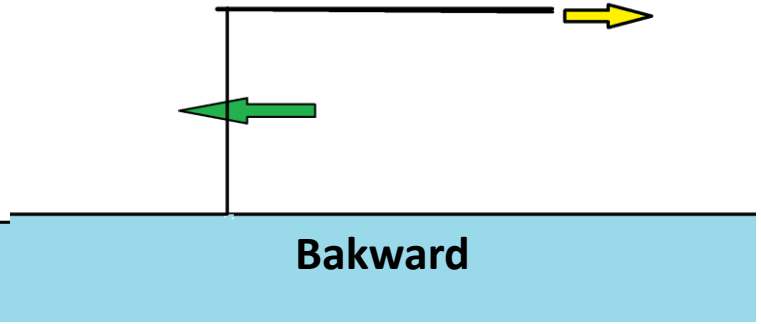
“Projection” to 2 Dimensions









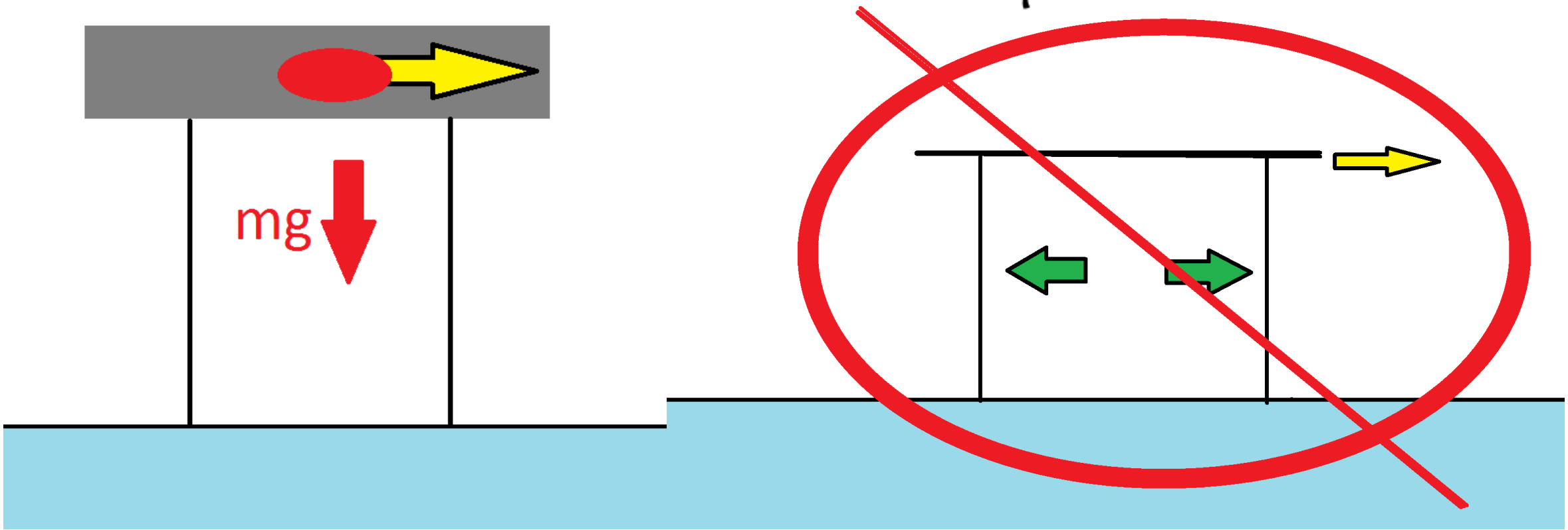


Modeling Robot, cont.

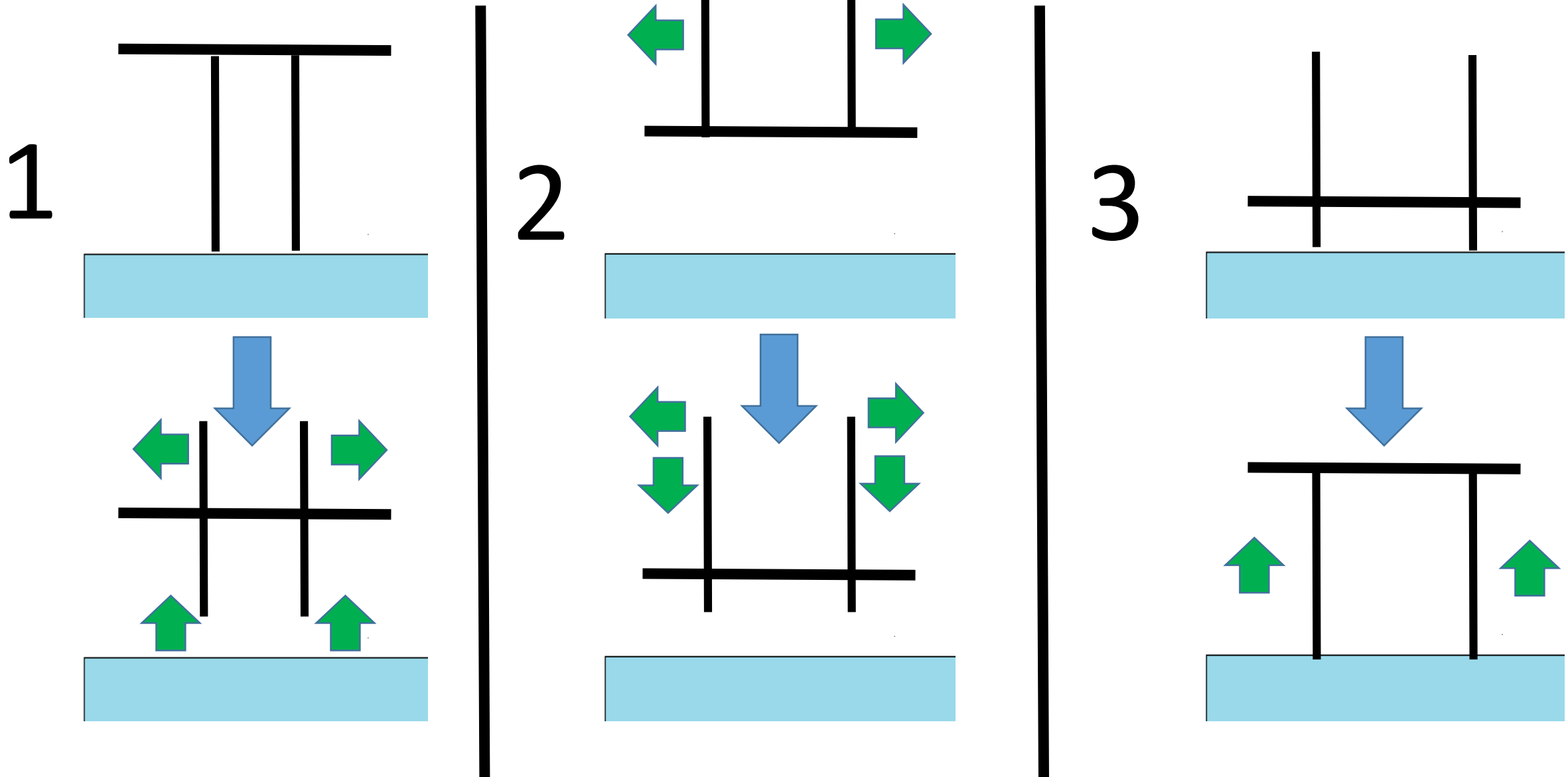
Massless legs –
Only mass at center

Infinite Friction

$$\mu = \infty$$

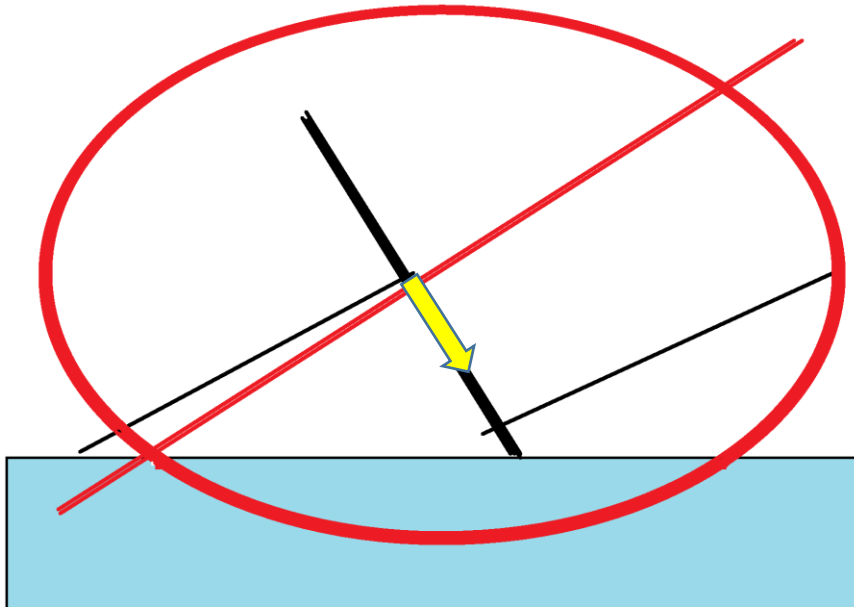


Hopping

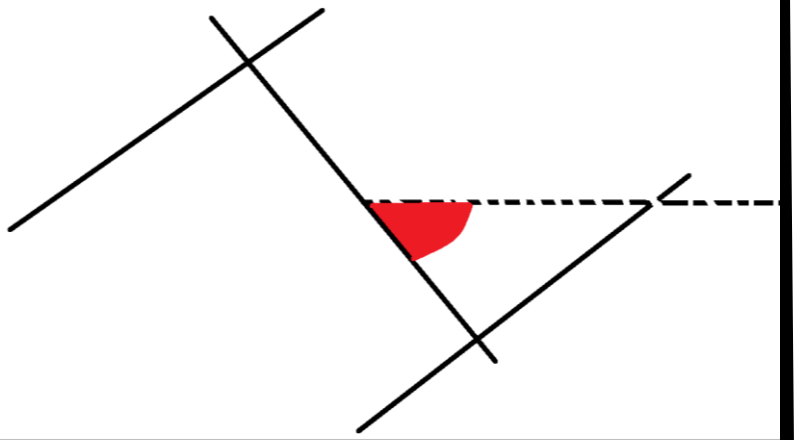


Postconditions

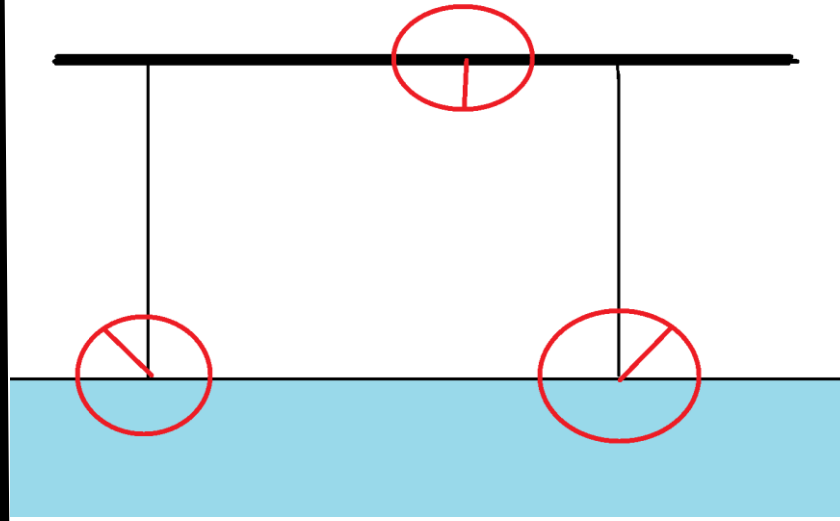
Don’t Fall



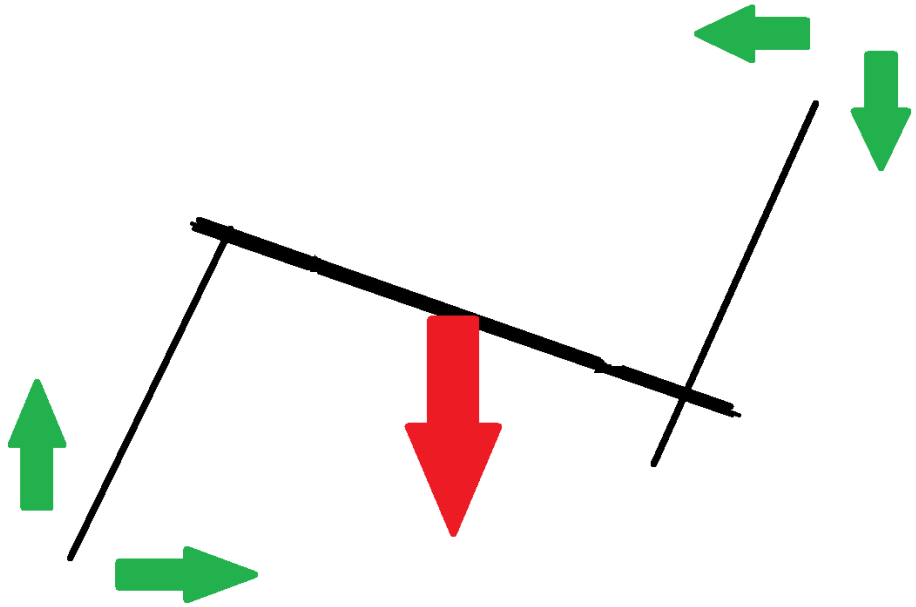
Don’t tilt too far

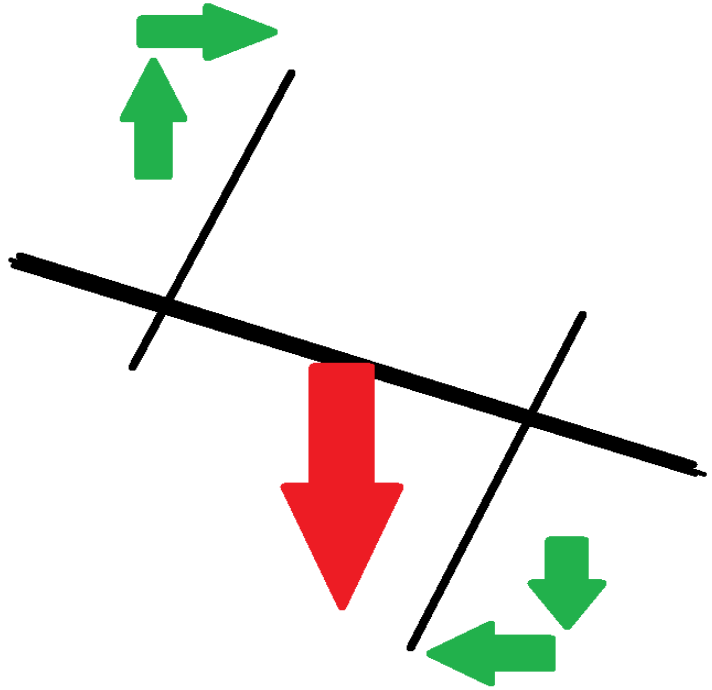


Keep feet and body from colliding – keep safe radius away



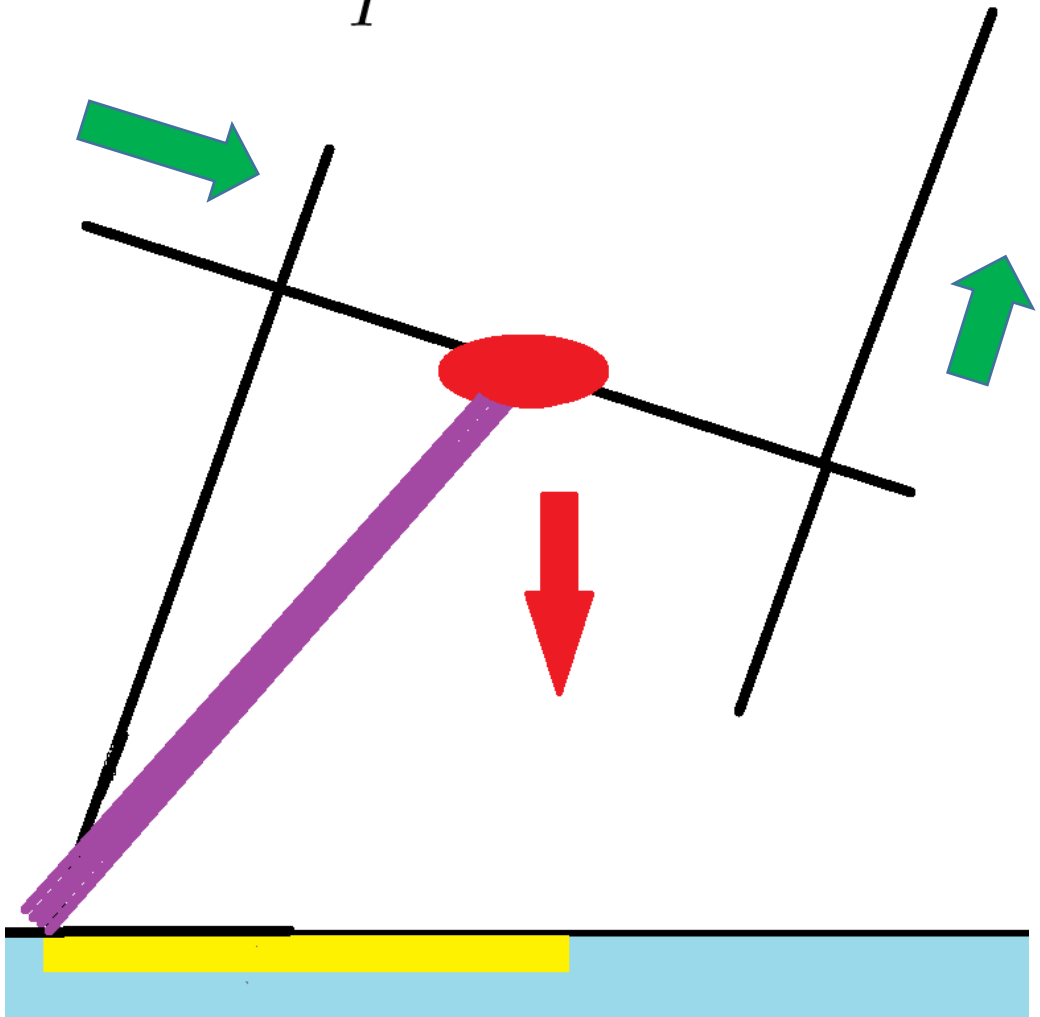
No-Legs-On-Ground Dynamics: Freefall



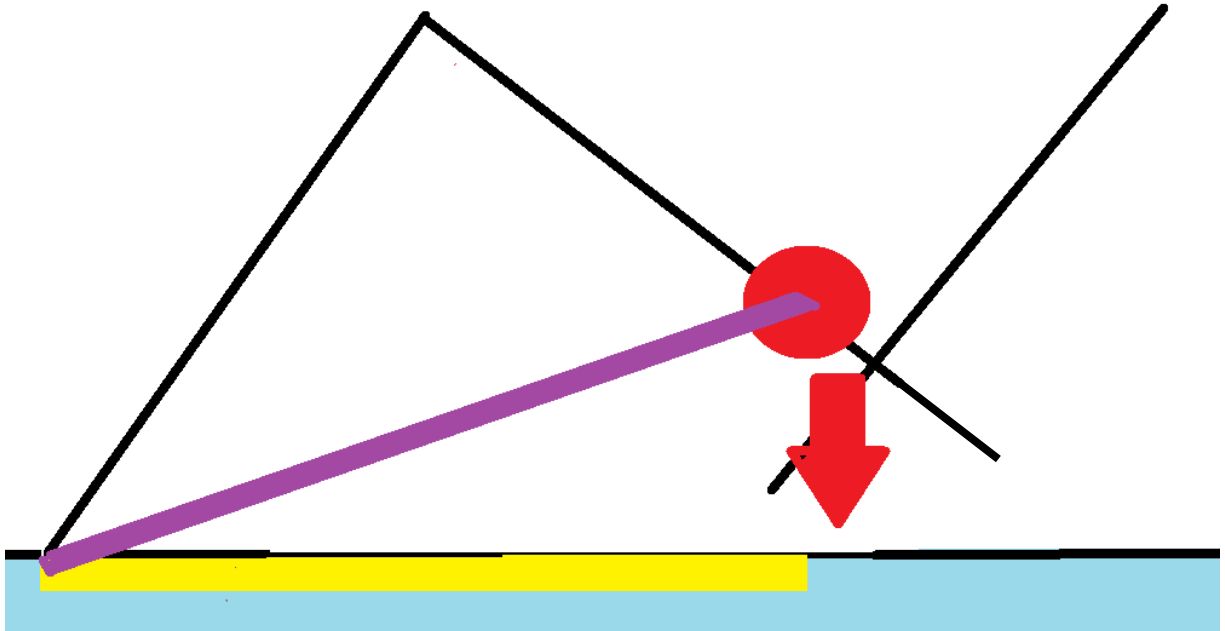


One-Leg-On-Ground Dynamics: Pivoting

$\alpha = \frac{T}{I}$ = -g(length) / (length)



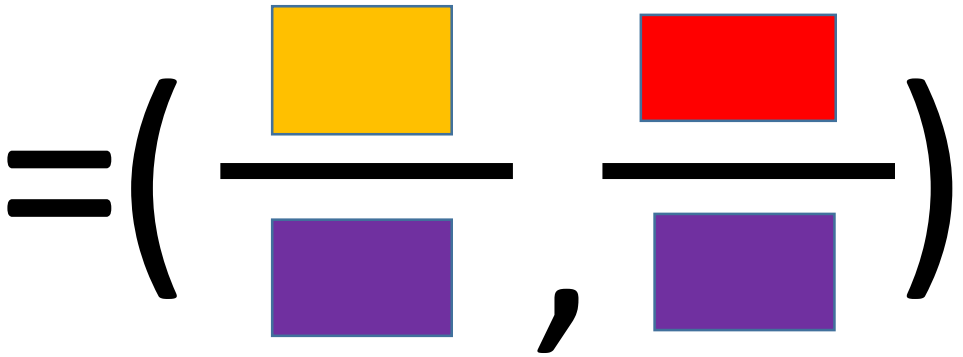
Legs can move while falling, which might move center

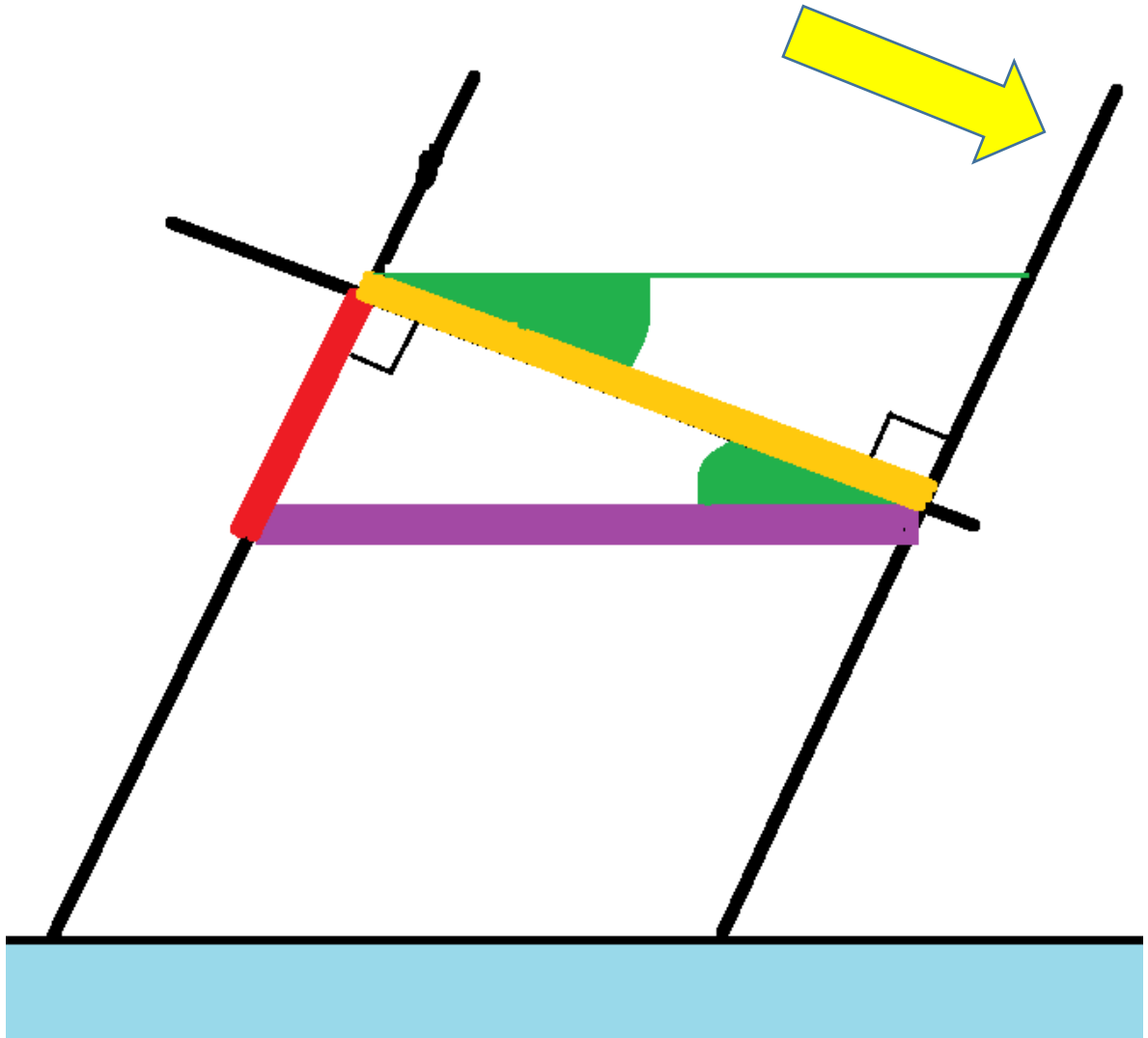


Two-Legs -(Stably)-On-Ground Dynamics

Dynamics determined by leg movements and initial conditions

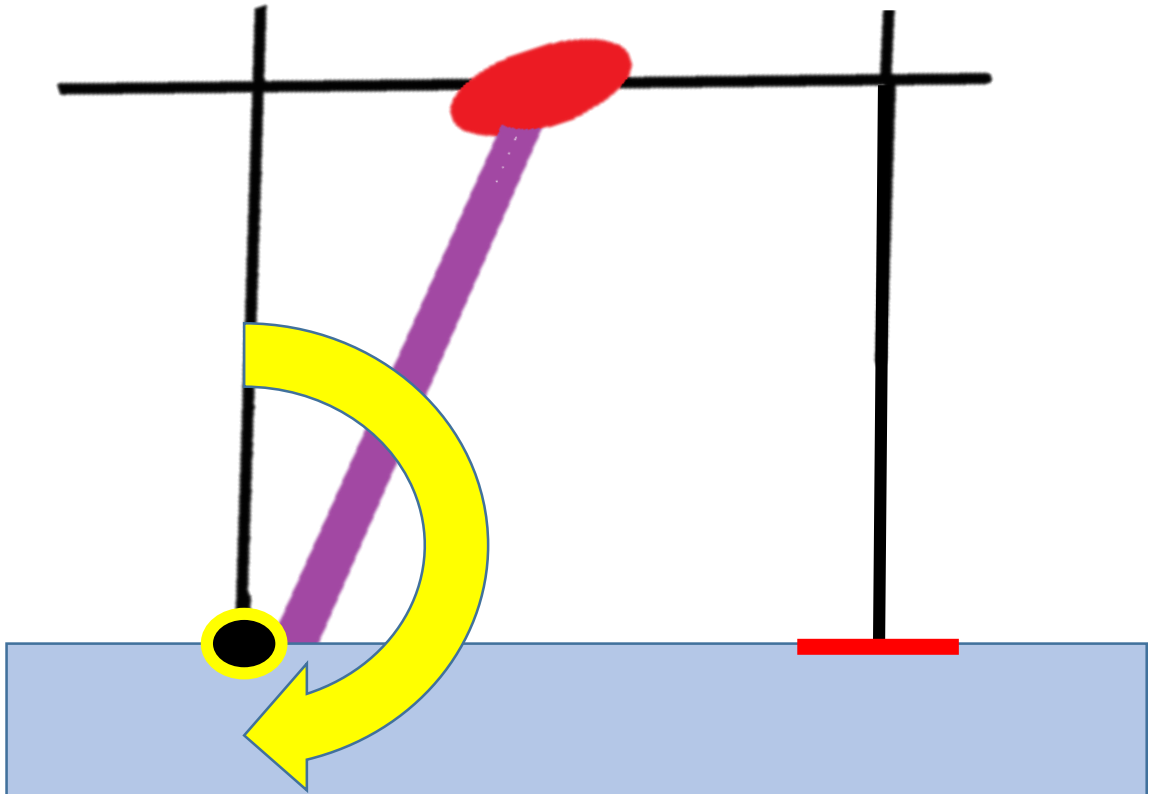
 = (F_x, F_y)





Verifying Hopping Motion

- Two-leg dynamics and free fall have solvable ODEs : use DiffSolve
- One Legged Case: must use invariants



Challenges to verification

- Large model – ran into computer-based difficulties
  - Finite length legs, friction stopping motion, etc.
- Manually translated trivial section
- Doing DiffSolve alone (for basic dynamics) took hours