GENERALIZED BIPED WALKING CONTROL

Presented by
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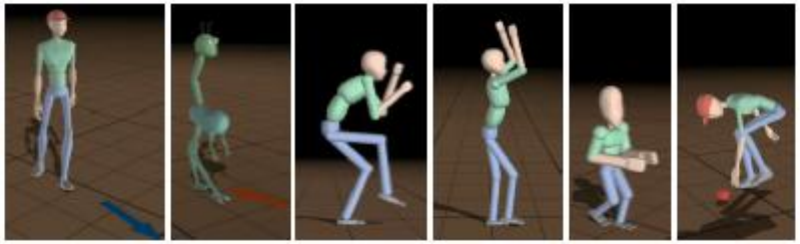
INTRODUCTION

- Control strategy for physically simulated walking motions
- Generalizes well
- Real-time, no tuning required
- Author some properties interactively



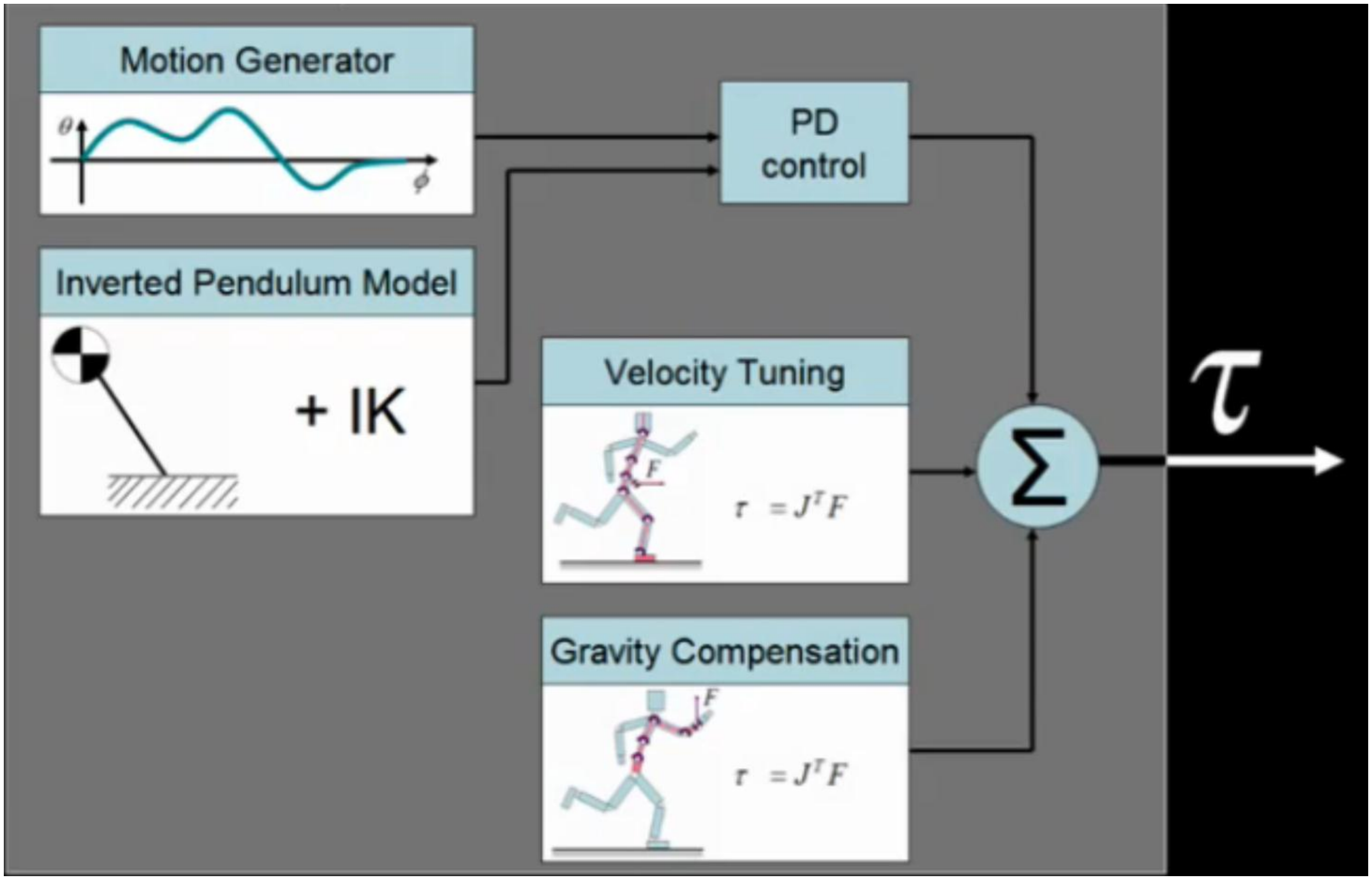
INTRODUCTION

- **Physics-based character animation strives for creating “natural” motion**
- **Product of muscles, gravity, and other external forces acting on a skeleton**
- **Existing authoring motions are difficult to use**
  - Motions are an indirect end-product of what can be controlled, namely the forces and torques
- **Characters need to be balance aware if they are not to fall over**
  - Balance is the vexing problem

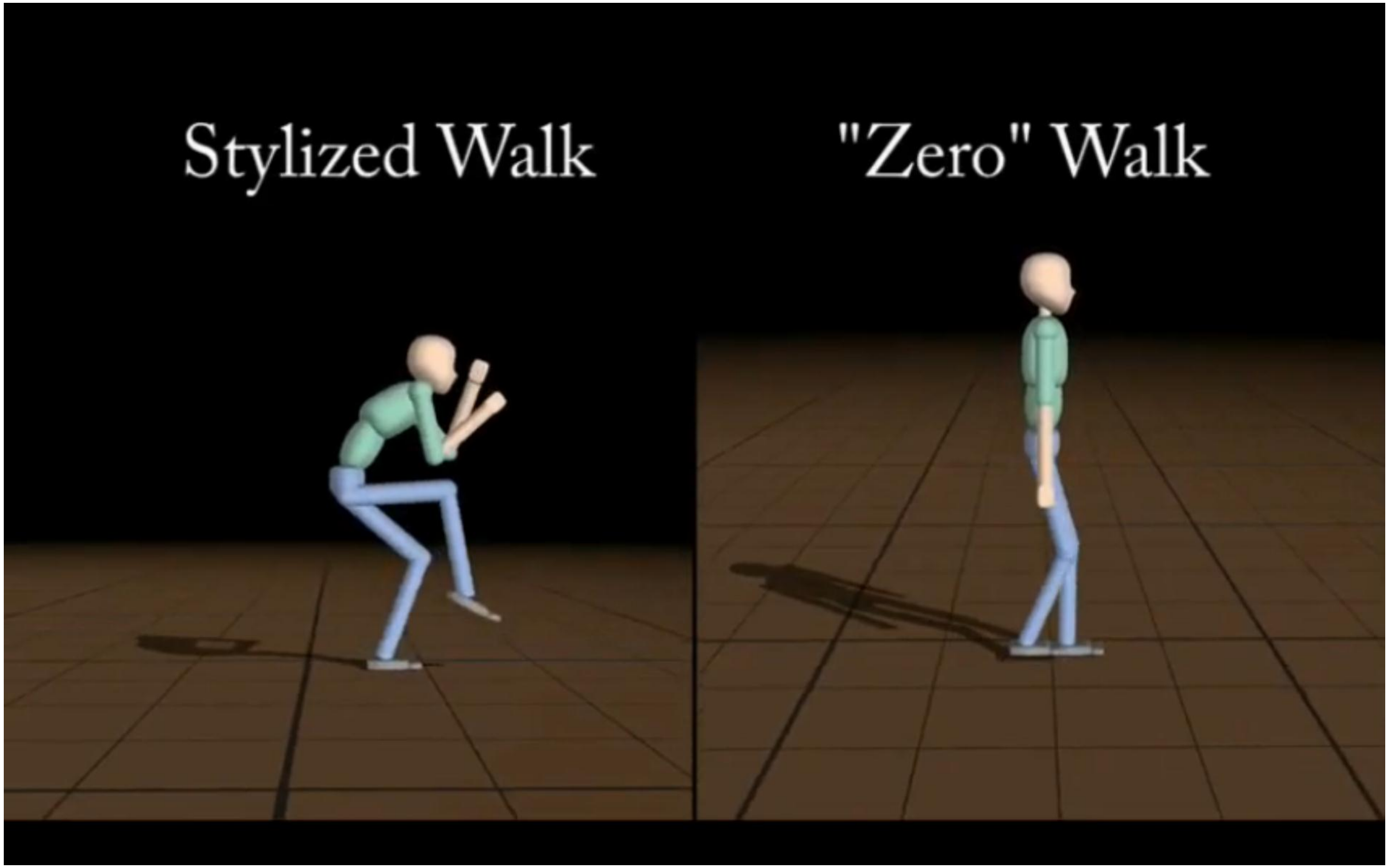
WHY ANOTHER SIMULATOR?

- **Develop control solutions for locomotion that provide robust control over balance**
- **Easy to author new motions**
- **Generalizations across gait parameters, character proportions, motion style and walking skills**
- **Authors offer a method that addresses these issues**
- **Caveat: the method is best suited for dynamically-balancing but slower motions**

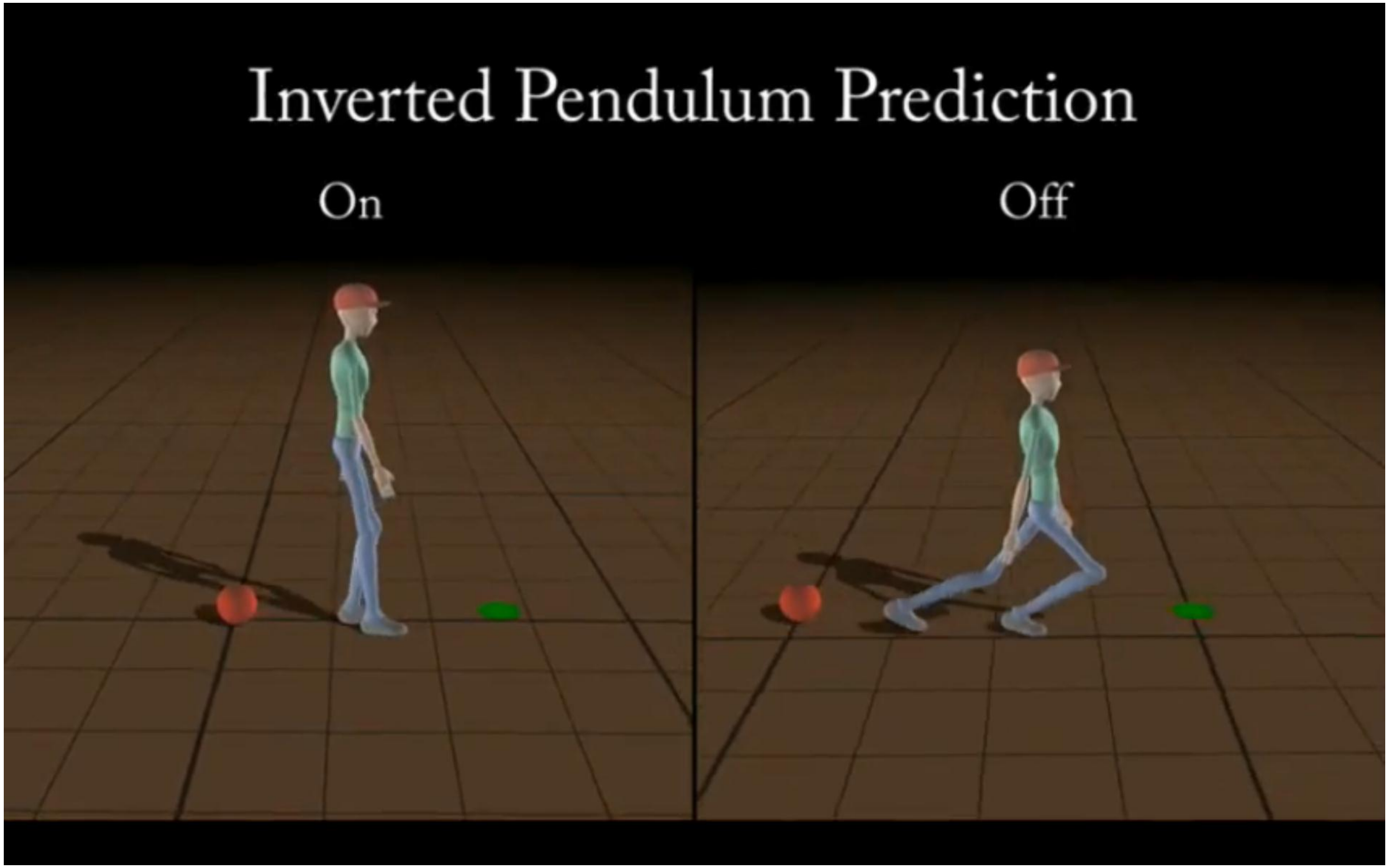
CONTROLLER


Motion Generator
θ
φ
PD
control
Inverted Pendulum Model
+ IK
Velocity Tuning
F
τ = J^T F
Σ
τ
Gravity Compensation
F
τ = J^T F

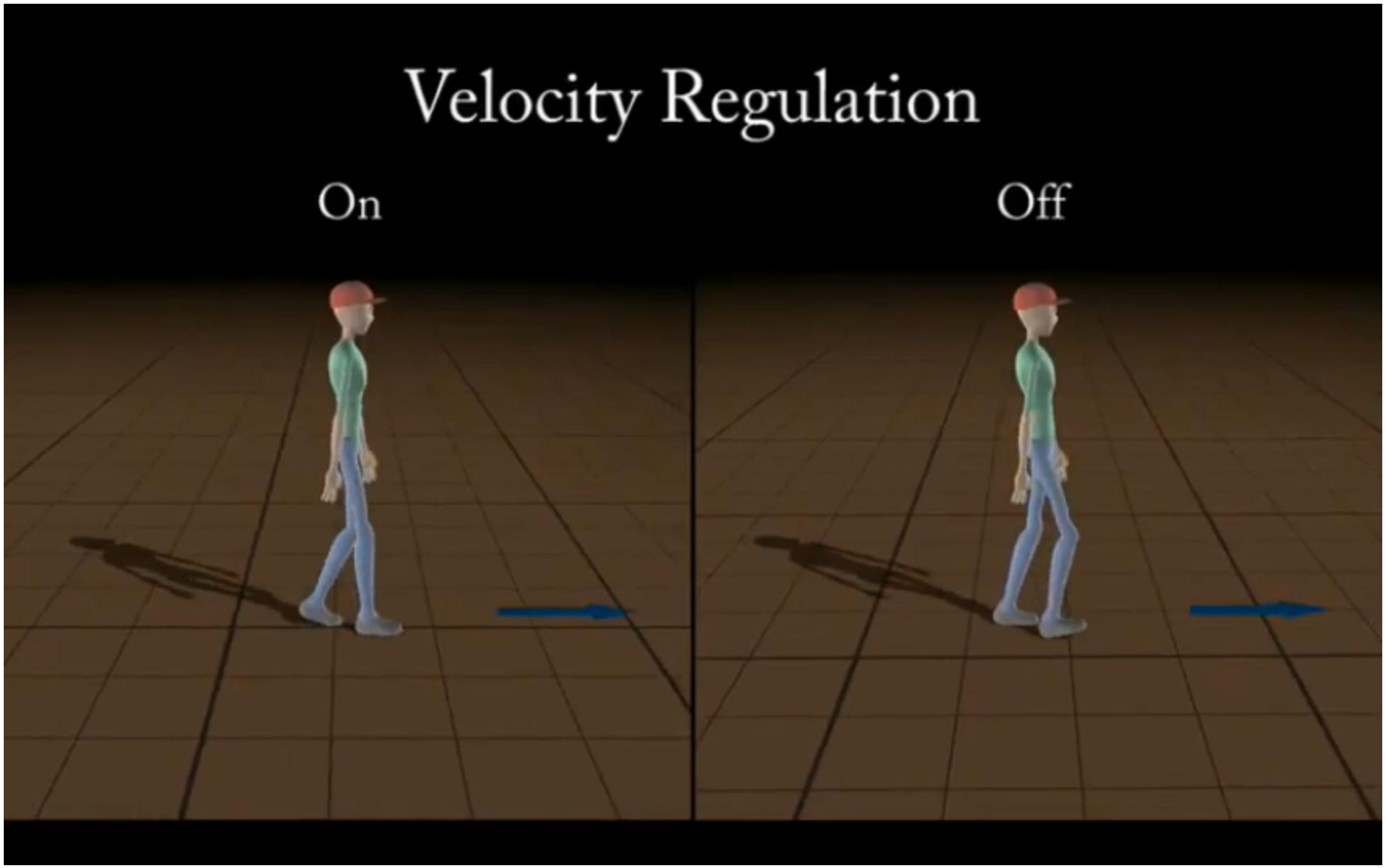
MOTION GENERATOR

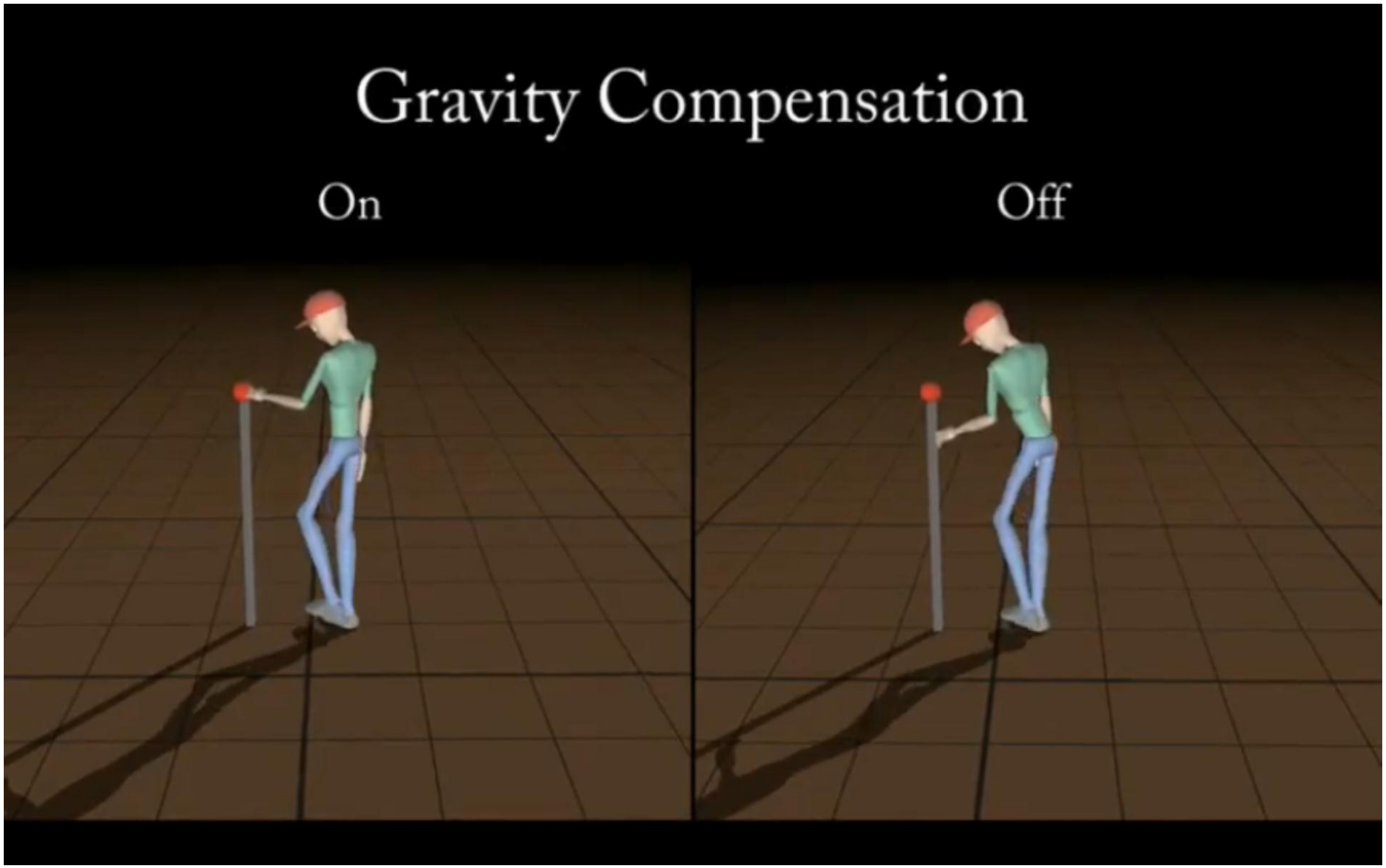


INVERTED PENDULUM MODEL



VELOCITY TUNING




Gravity Compensation
On
Off

SYSTEM OVERVIEW

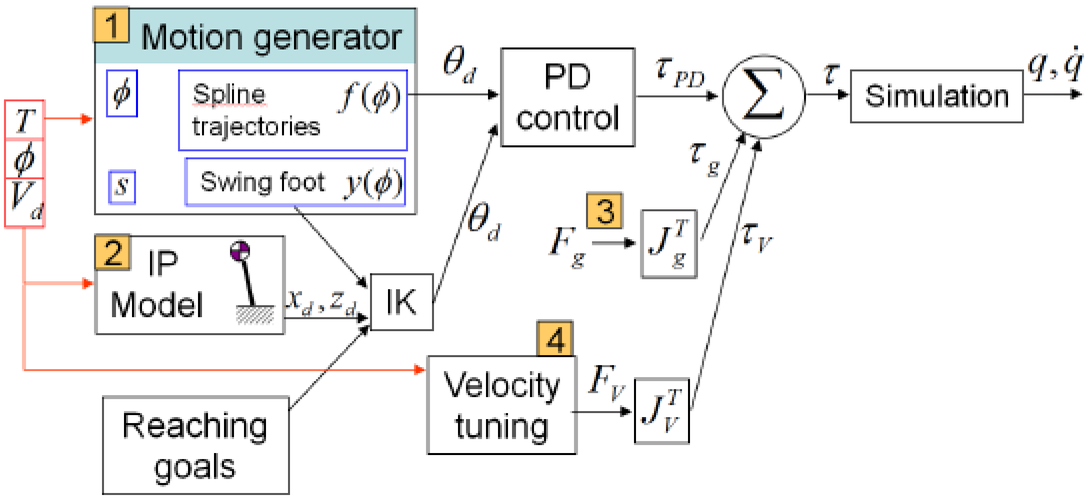
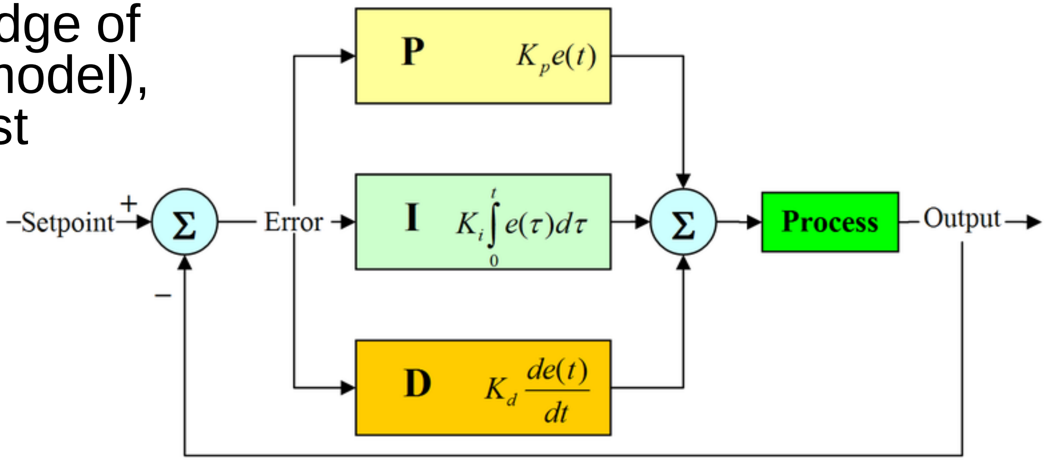


Figure 2: *System Overview. Key components of the model are: (1) a motion generator for producing desired trajectories; (2) an inverted pendulum model for predictive foot placement; (3) a gravity compensation model for all links; and (4) velocity tuning for fine balance corrections.*

CONTROL THEORY

- A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller)
- PID controller
  - Calculates an "error" value as the difference between a measured process variable and a desired setpoint
  - Attempts to minimize the error by adjusting the process control inputs
- In the absence of knowledge of the underlying process (model), a PID controller is the best controller



PID CONTROLLER

- ***P****roportional* value determines the reaction to the current error
- ***I****ntegral* value determines the reaction based on the sum of recent errors
- ***D****erivative* value determines the reaction based on the rate at which the error has been changing
- Any component can be set to zero to disable it
- Heuristically, these values can be interpreted in terms of time
  - *P* depends on the *present* error,
  - *I* on the accumulation of *past* errors
  - *D* is a prediction of *future* errors, based on current rate of change

MOTION GENERATOR

- **Produces the various desired trajectories that help create desired motion styles**
- **The joint angle trajectories are modeled as spline functions over time relative to**
  - Their parent-link coordinate frame (elbows, shoulders, stance knee, and toes)
  - The character coordinate frame(CCF)
- **Trajectories are modeled are a function of the phase of a step by Catmul-Rom splines (3 segments chosen)**

INVERTED PENDULUM MODEL (IPM)

- The IPM helps achieve motion that is highly robust to disturbances such as pushes
- Does not require parameter tuning because the relevant parameters are captured by the model

IPM

- *Current state = balanced state*

$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv'^2 + mgh'$$

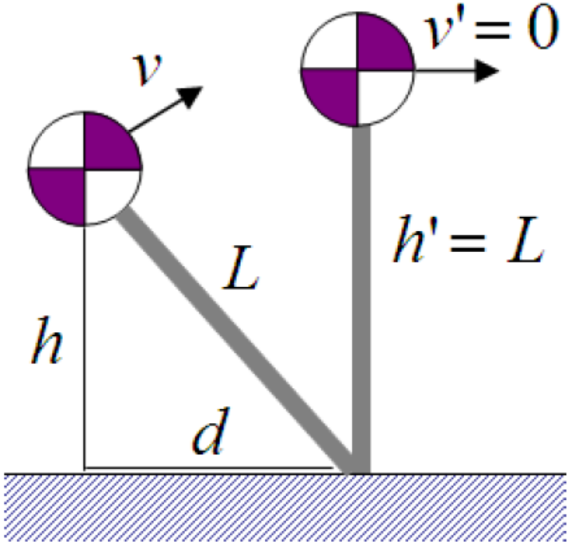
- *Compute **d** to reach zero velocity at the next step*

$$d = v\sqrt{\frac{h}{g} + v^2/(4g^2)}$$

- *Compute*

$$d' = d - \alpha V_d$$

- *Compute **d** for coronal and sagittal planes*

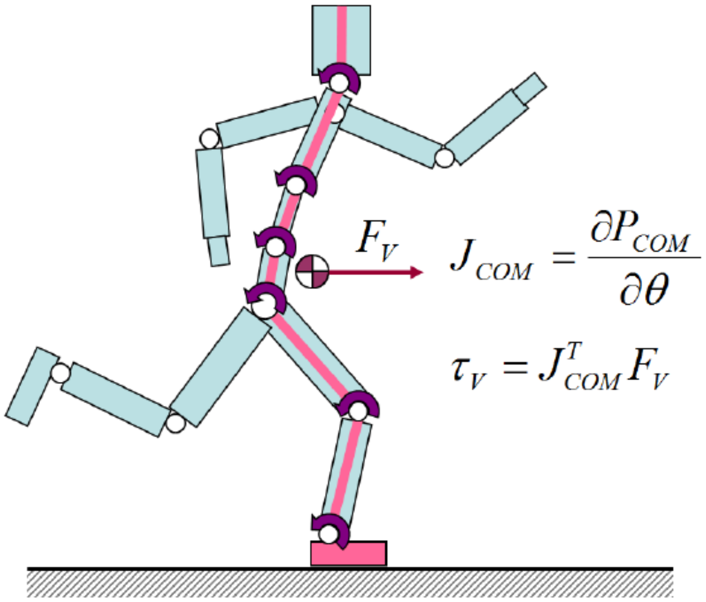


IPM

- Drive the motion of the swing leg by synthesizing a desired trajectory for the swing ankle relative to the ground and in the character coordinate frame
- Use inverse kinematics to compute target joint angles for the swing hip and knee, which are then tracked using PD controllers and augmented by gravity compensation torques
- The inverse kinematics problem has a remaining degree of freedom which allows for knock-kneed, normal, or bowlegged walking variations

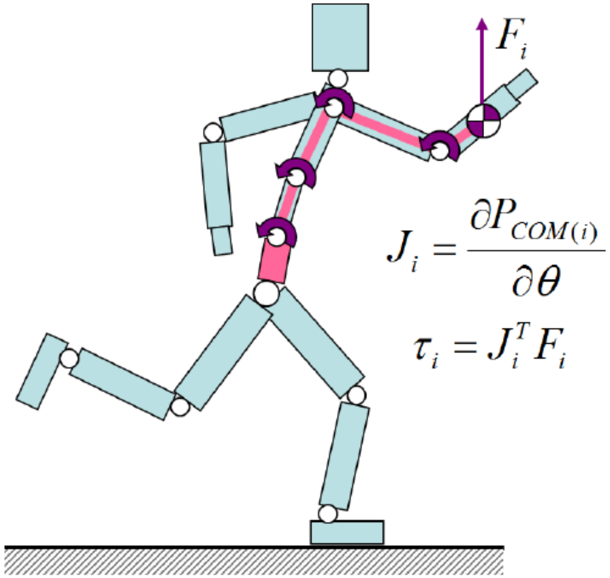
VELOCITY TUNING

- Shifting the COP towards the toes helps in slowing the forward progression of the body, while shifting it back helps accelerate
- We first compute the center of mass velocity of the biped, V
- Compute virtual forces in the sagittal $F_v = k_v(V_d - V)$ and analogously in the coronal planes



GRAVITY COMPENSATION

- Apply virtual force $F_i = -m_i g$ at the center of the mass of every link i
- Any given joint j thus sees the sum of the GC torques required by all links that are distal to it
- The compensation is applied to all links, with the exception of those in the stance leg

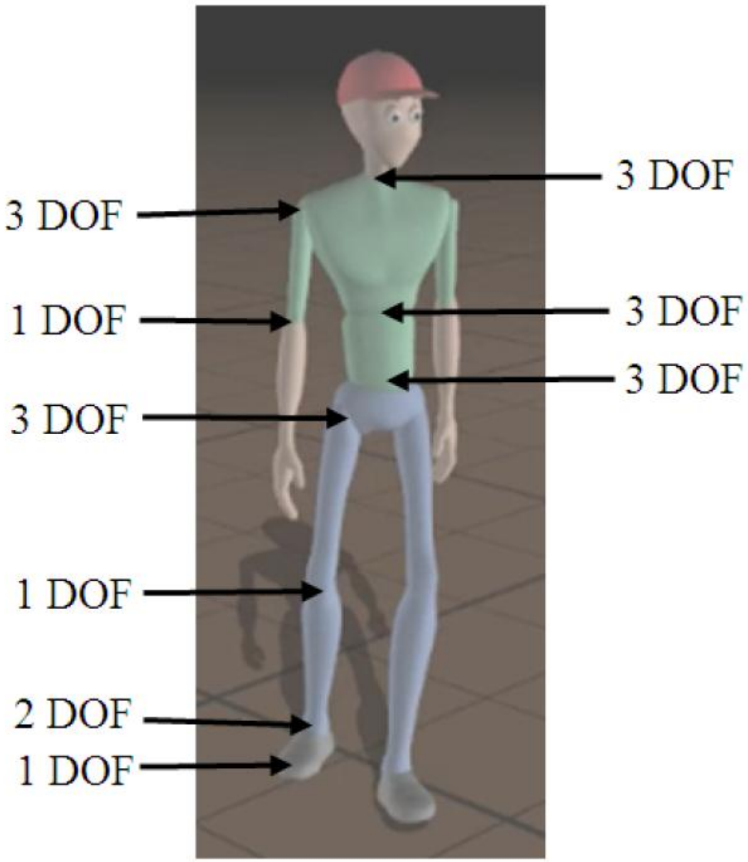


TURNING AND LIMB GUIDANCE

- Turning is achieved using the stance hip
- Rotate the torso and the head according to linearly weighted functions of the turning phase $\emptyset_{turn}$-fraction of the turn completed
- Use reverse kinematics for the swing hip and knee
  - Use analytic solution to the two-link inverse kinematic problems
  - For the unique solution force an elbow to lie in the same plane as shoulder and hand (same for leg, the hip and ankle)

IMPLEMENTATION

- Use Open Dynamics Engine (ODE) as the forward dynamics simulator
- All balance control parameters are kept fixed across all our simulations
- PD gains
  - k_p - *scale with various mass M*
  - $k_d = 2\sqrt{k_p}$
- Humanoid character has total 37 DOF (6 DOF = position and orientation)
- Real-time simulation



LIMITATIONS

- Does not allow for the authoring of a ‘push recovery style’, which is governed by the inverted pendulum foot-placement
- Self-intersection between the swing and stance legs still occurs in some situations
- Do not demonstrate generalization across terrain, with the exception of climbing steps
- Not explored extending the method to non-biped morphologies
- Have not demonstrated high-speed agility

RESULTS

CONCLUSIONS

- Developing the control required for physics-based skills is a significant challenge
- The authors have presented a simple and general method for biped walking control
  - The method generalizes across gait parameters, motion styles, character proportions, and locomotion tasks
  - Demonstrated that naive users can interactively author the character proportions, gait parameters, and motion styles
  - The technique may enable the wider adoption of physics-based characters in games and film