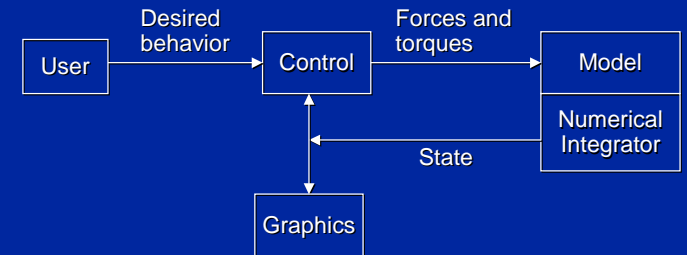


## Robot Controllers in Animation

## Control Systems



## Where do the control laws come from?

- Observation
- Biomechanical literature
- Optimization
- Intuition

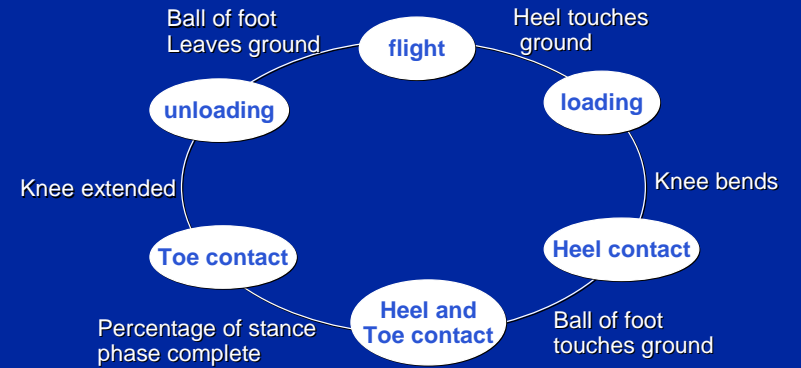
## Hierarchy of control laws

1. State machine
2. Control actions
3. Low level control

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1. **State machine**
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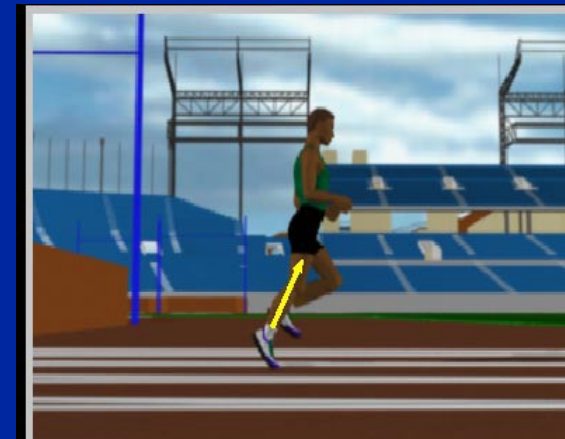
## Running state machine



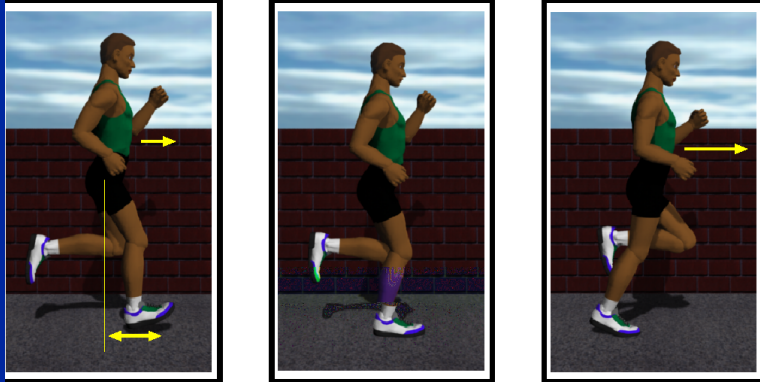
## Hierarchy of control laws

1. State machine
2. **Control actions**
3. Low level control

## Flight duration



## Forward Velocity



## Ground speed matching



## Balance: roll, pitch, yaw



## Mirroring: hips and shoulders



## Control laws for all states

- Neck: turn in desired facing direction
- Shoulder: mirror hip angle
- Elbow: mirror magnitude of shoulder
- Wrist: constant angle
- Waist: keep body upright

## Control laws for flight phase

### Active leg:

- Swing leg forward for touchdown
- Straighten knee

### Idle leg:

- Mirror hip angles of active leg
- Hold knee and ankle at flight angle

## Control laws for heel contact phase

### Active leg:

- Pitch control with hip
- Allow ankle to extend
- Knee acts as a spring

### Idle leg:

- Mirror hip angles of active leg
- Shorten knee to prevent foot contact
- Hold at flight angle

## Control laws for heel/toe contact and toe contact

### Active leg:

- Pitch control with hip
- Extend ankle for thrust
- Extend knee for thrust

### Idle leg:

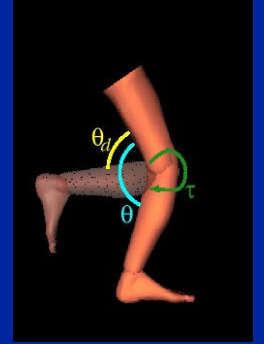
- Mirror hip angle of active leg
- Shorten knee to prevent foot contact
- Hold ankle at flight angle

## Hierarchy of control laws

1. State machine
2. Control actions
3. **Low level control**

## Low level control

$$\tau = k(\theta_d - \theta) + k_v(\dot{\theta}_d - \dot{\theta})$$



## Difference between walking and running

- Walking: double support
- Running: flight phase
- Energy transfer patterns
  - Inverted pendulum
  - Pogostick

## Walking state machine

