Feedback Control for Rotational Movements in Feature Space

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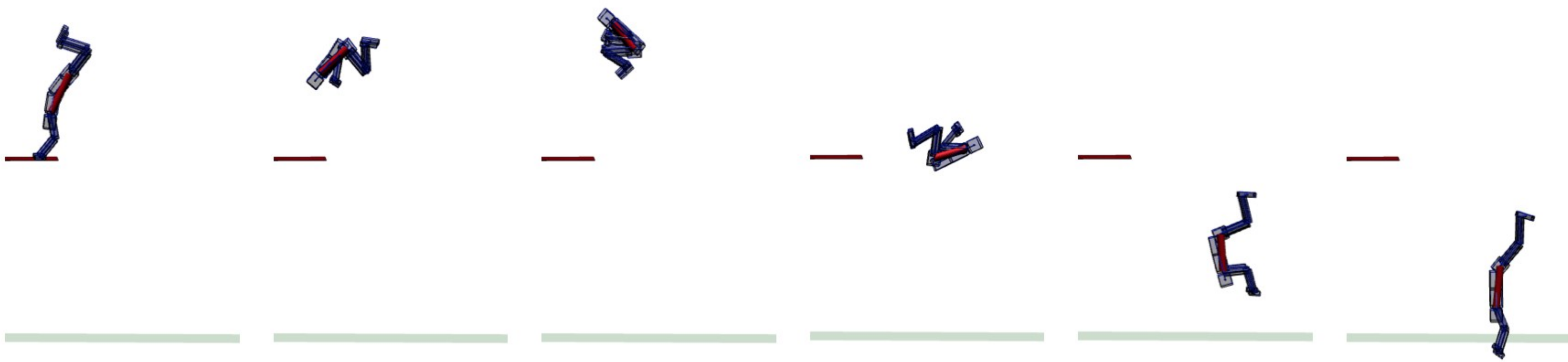
Main problem:

- global orientation
- angular momentum
- inertia

- run computation at interactive rates
- do not rely on any input motion or offline optimization
- time-invariant
- generality



$\mathbf{q}$ - generalized joint positions (vector)

$\mathbf{q}_i$ - controlled variable

$$\left.\begin{aligned} &\mathbf{q}_i \neq \mathbf{q}_i(t) \\ &\mathbf{q}_i = h_i(\theta) \end{aligned}\right\}$$

θ - phase variable
- strictly monotonic with respect to time
- time-invariant controller

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Feature space :

- i.e. Center-of-Mass (COM), angular momentum, end-effector
- output of a map of the character's state: $\mathbf{y} = f(\mathbf{q},\mathbf{q'})$ $\mathbf{q'}$ – velocity
- feature-based control

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Let's take it all together : $\mathbf{y}_i = h_i(\theta,\mathbf{q},\mathbf{q'})$ $\mathbf{y}_i$ - desired feature

Note: - In rotational movements θ is an angle in the plane perpendicular to the axis of rotation of the revolution.
- θ increases as the revolution progresses

<u>Benefits of phase variable (parametrizing controllers)</u> :

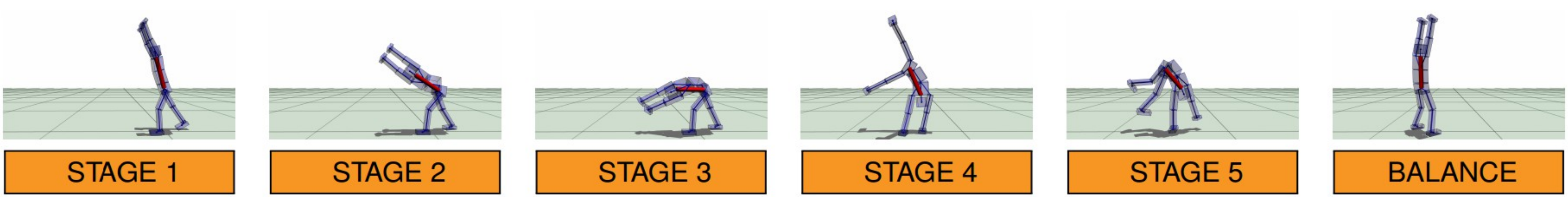
- make the controllers more general
  - i.e. in a flip, the character roughly completes a full revolution, no matter how far, high or fast the character jumps
- make the controllers more robust because of feedback
  - i.e. character performing a cartwheel (no disturbances vs. strong wind forces)

Rotational movements of characters (controllers) :

- Cartwheel
- Flips
- Diving
- Backhandspring
- Pirouette
- Front Aerial
- ...

Rotational movements of characters (controllers) :

- Cartwheel
  - Stage i is triggered when: $\theta \in (l_i, u_i)$
  - Stage 1: $\mathbf{y}_{COM} = \mathbf{c} + \eta\mathbf{d} + [0,l,0]^T$
    - the character tilts towards its left/right side
    - **d** – direction of characters move
    - **c** – position of the COM
    - η and l – scalars: η > 0 and l < 0 (y axis to the ground)
    - active until both hands touch the ground



Rotational movements of characters (controllers) :

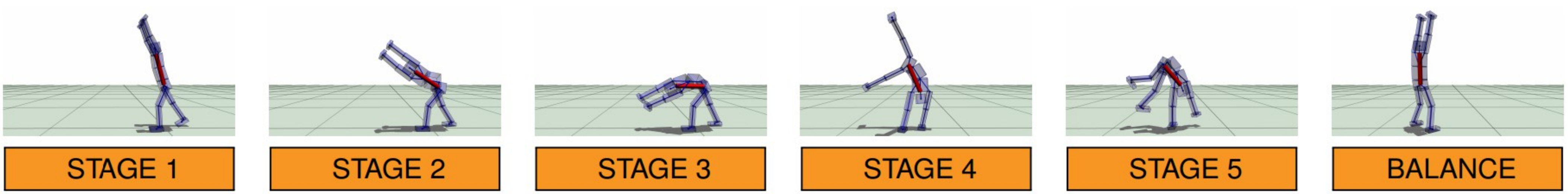
- Cartwheel
  - Stage 2
    - move left character's hand
    - left hand: $y_{lhand}^{xz} = c^{xz} + \eta \cdot d^{xz}$

      $y_{lhand}^{y} = y_{lhand}^{y} \cdot \left(1 - \frac{\theta - \theta_i}{\theta_f - \theta_i}\right)$

      Θ_i - the value of θ when the character should begin to lower its hand

      Θ_f - is the value of θ when the hand should be on the ground
  - Stage 3
    - place the right hand
    - right hand: $y_{rhand}^{y} = y_{rhand}^{y} \cdot \left(1 - \frac{\left|y_{rhand}^{xz} - y_{lhand}^{xz}\right|^2}{s}\right)$

      s – desired distance between the hands when in contact



<u>Rotational movements of characters (controllers)</u> :

- Cartwheel
  - Stage 4
    - hands are deactivated – foots are activated
    - left foot:

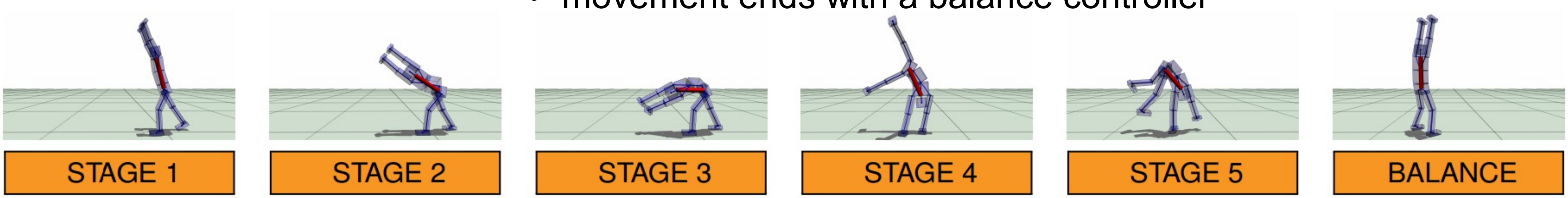
$$y_{lfoot} = R_{\Phi} \cdot (c^{xz} + p^{loff})$$

Φ - is an estimate of the character's global orientation

R_{Φ} - rotation matrix associated with Φ

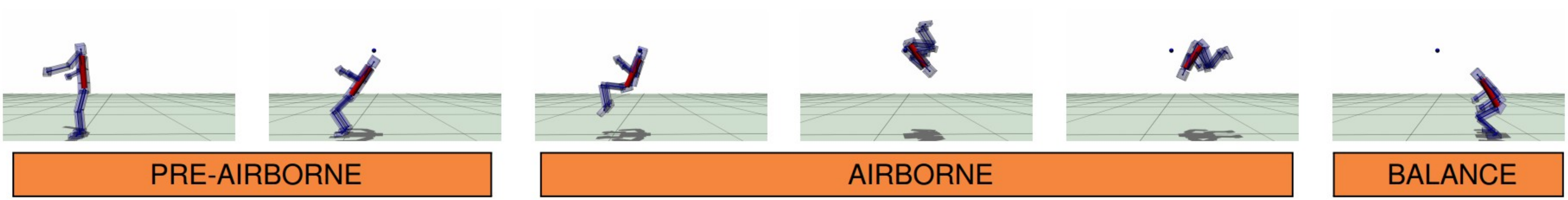
p^{loff} - fixed horizontal offset term for the left foot

    - analogous feedback law applies for right foot
      - orientation of the lumbar joint is a good choice for Φ
  - Stage 5
    - oposite to stage 2 and stage 1 – straighten character
    - movement ends with a balance controller



<u>Rotational movements of characters (controllers)</u> :

- Flips
  - two main stages: pre-airborne & airborne
  - pre-airbone stage:
    - place the character in a crouch position that is slowly tilting on its back
    - generate the necessary angular momentum for the character to flip
    - avoid insufficient or excessive angular momentum



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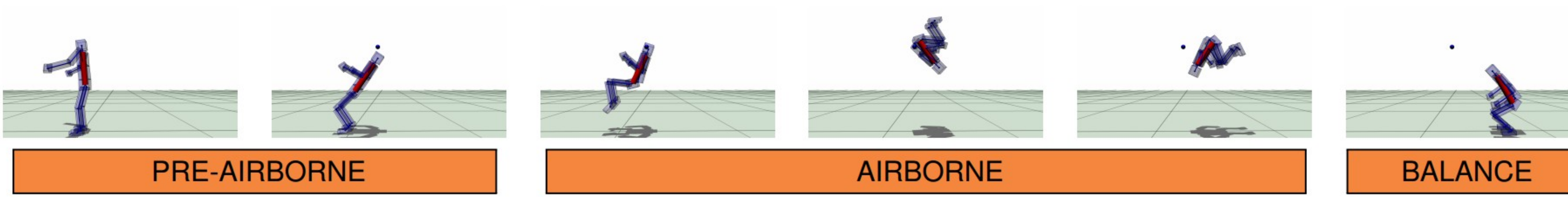
estimate the duration of the airborne stage of the flip:

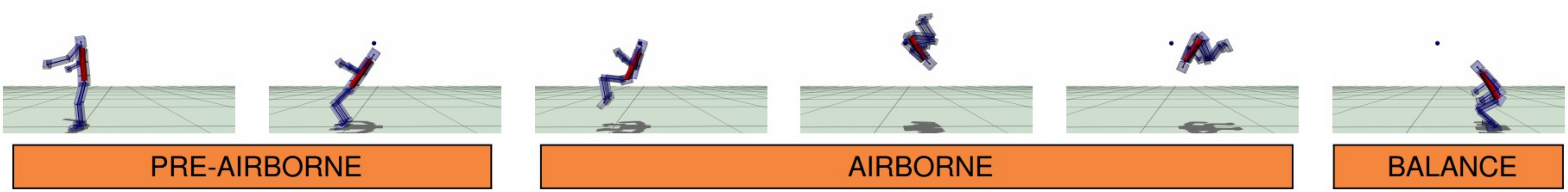
$$t_{air} = \frac{2 \cdot \varepsilon}{g}$$

ε - estimated velocity of the COM
g - gravitational constant



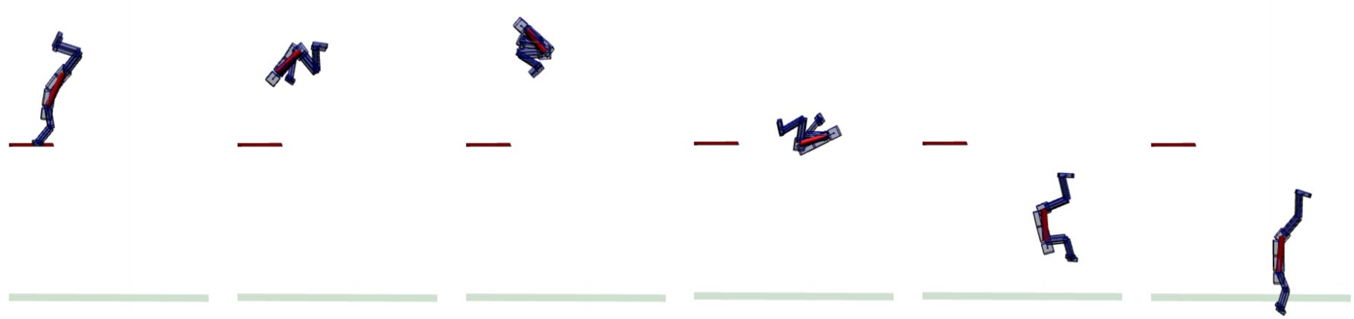
Rotational movements of characters (controllers) :

- Flips
  - two main stages: pre-airborne & airborne
  - airbone stage:
    - land with a desired orientation (θ_{land}) and inertia (I_{land})
    - current angular velocity: $w = \frac{|M|}{I}$ M - angular momentum, I - Inertia
    - desired angular velocity at landing: $w_{land} = \frac{|M|}{I_{land}}$
    - character is rotating too slowly – decrease the character's inertia to increase the angular velocity
    - character is rotating too quickly – increase the character's inertia to decrease the angular velocity



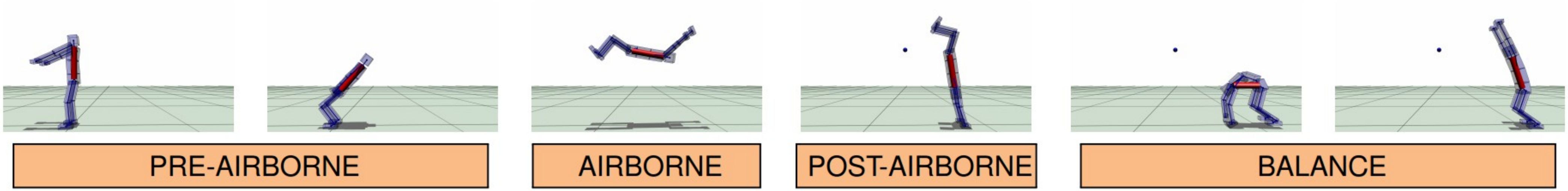
Rotational movements of characters (controllers) :

- Diving
  - The goal is to have the character enter the water with a straight posture and with its arms raised upwards
  - for generality – input can contain desired number of complete revolutions before entry
  - almost identical to flip controller
    - Θ_{land} , I_{land} - different because of the different desired landing positions
    - take into account the number of complete revolutions when calculating the desired average angular velocity
    - shoulders are now included in computation because of arms raising
  - identical airborne controller can generate forward, backward, straight and armstand dives



<u>Rotational movements of characters (controllers)</u> :

- Backhandspring
  - pre-airborne stages is different to backflip controllers only in the values of θ_{land} and I_d
  - not significant change of the inertia in the airborne stage
  - rest pose of the shoulders vary when the character is airborne
    - the character raises its arms as a function of θ in order to land on its hands
    - the character enters a post-airborne stage when its hands are close enough to the ground



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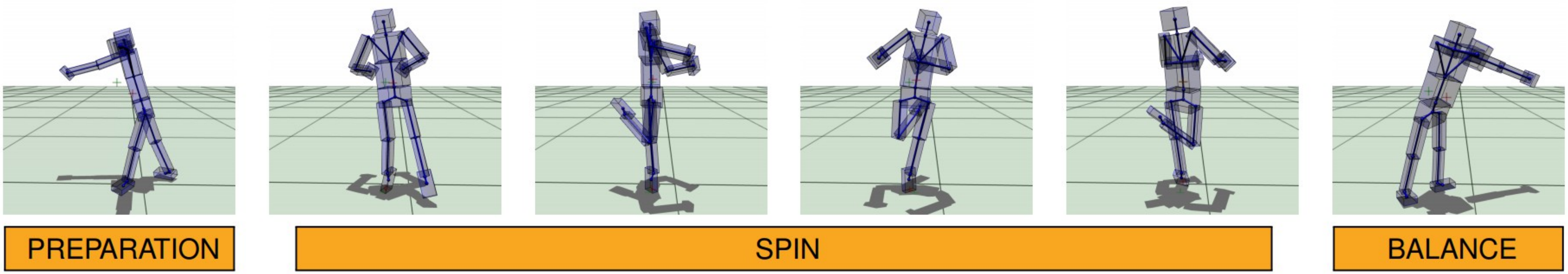
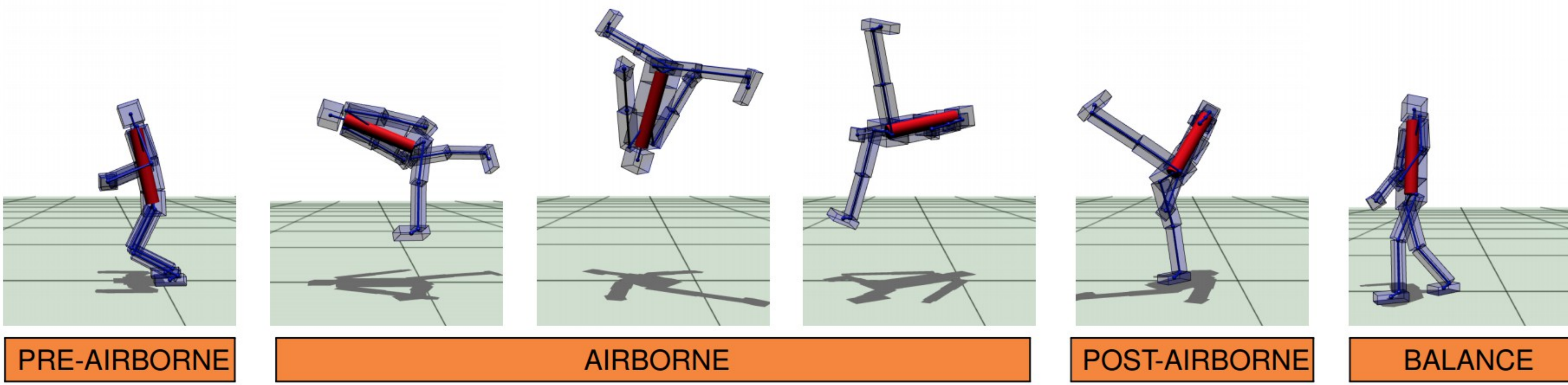


- Piroutte

- Front Aerial



RESAULTS

- feature-based control algorithms for a wide variety of rotational movements (aerials, cartwheels, dives, and flips), that do not require any input motion or offline optimization
- most of these movements have not previously been generated by physics-based methods without prior data
- controllers are general and robust

- results lack some aspects of natural human motion
- most of the rotations are planar, but phase parametrization can be extended to three-dimensional rotations
- it is not able to synthesize some movements that are at the periphery of performance, such as certain ballet moves that require an enormous amount of precision

Thank you for your attention

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