Sampling-based Contact-rich Motion Control

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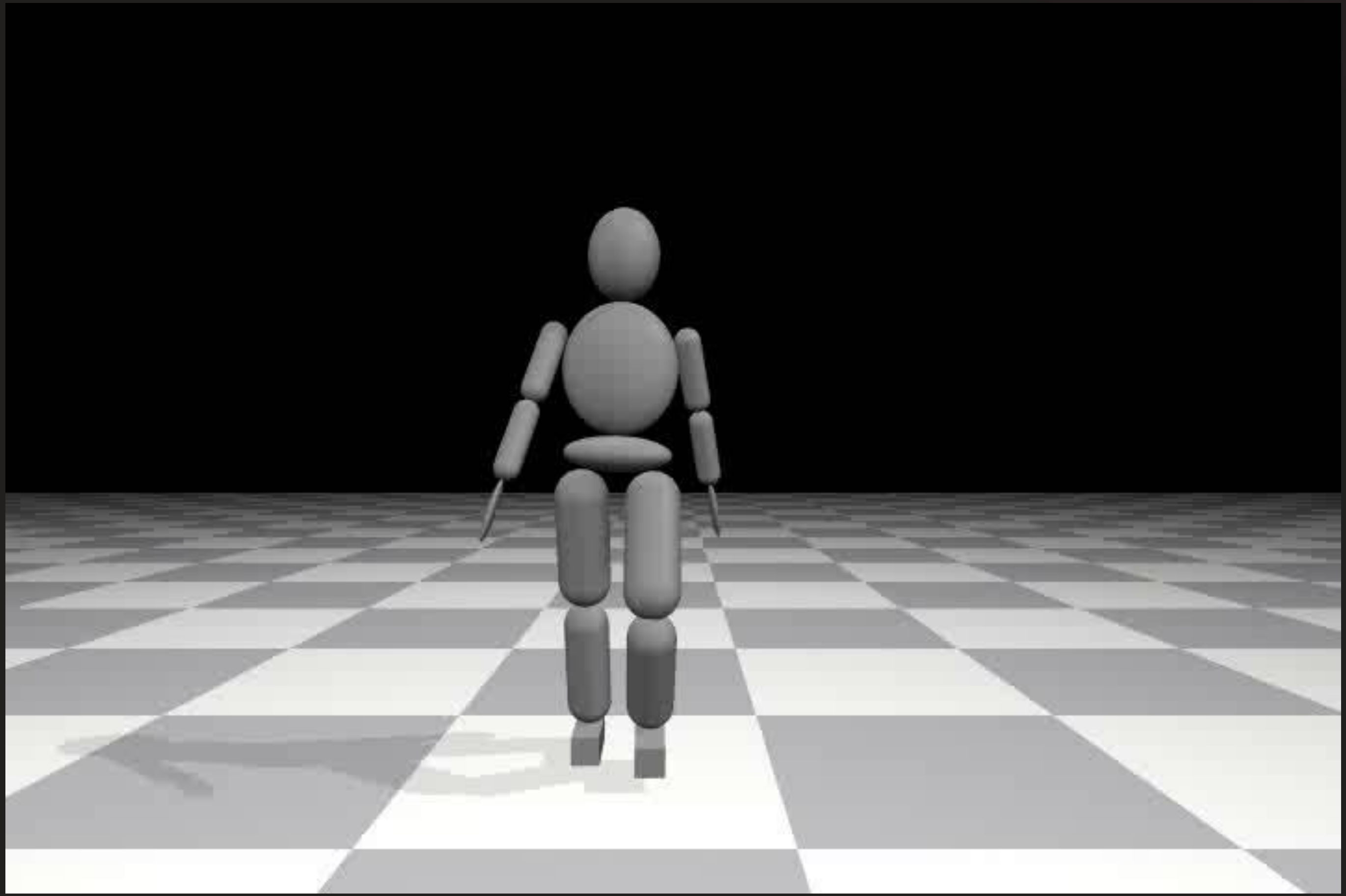
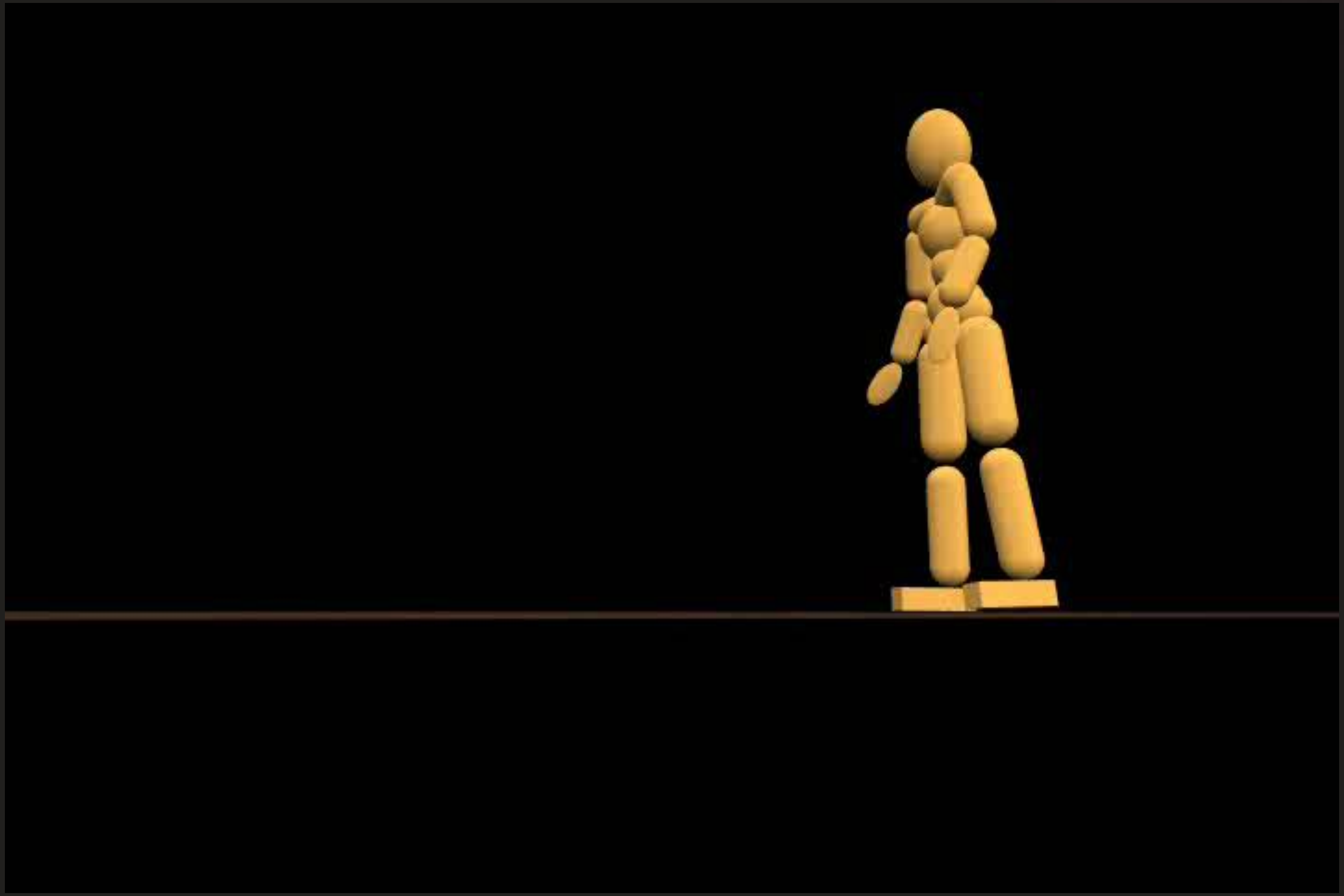
Motivation



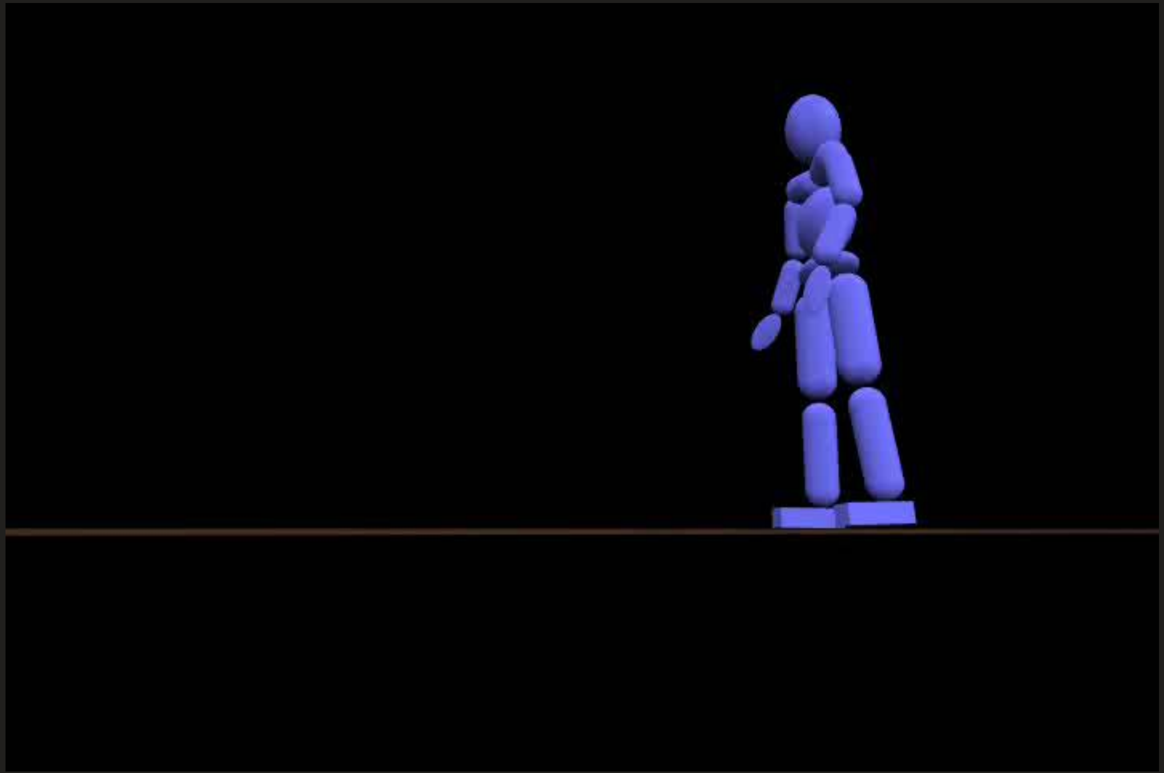
Motivation



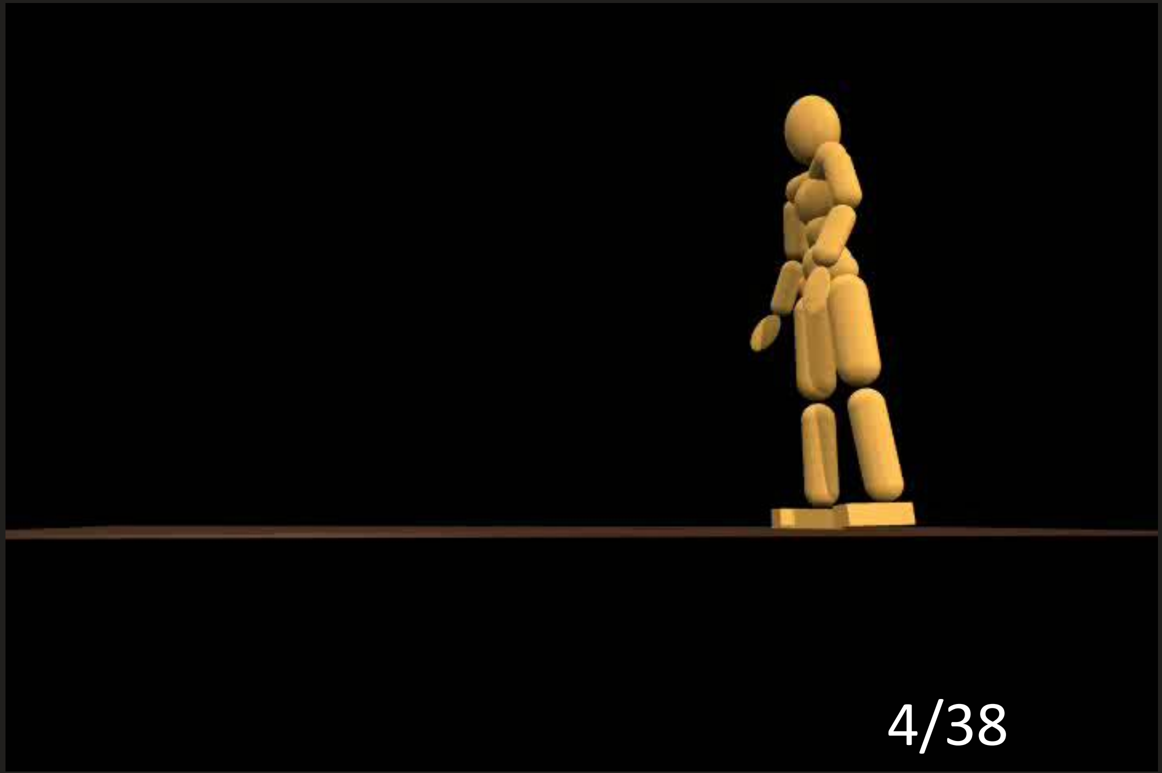
Motivation

Physically-plausible motion reconstruction

Input

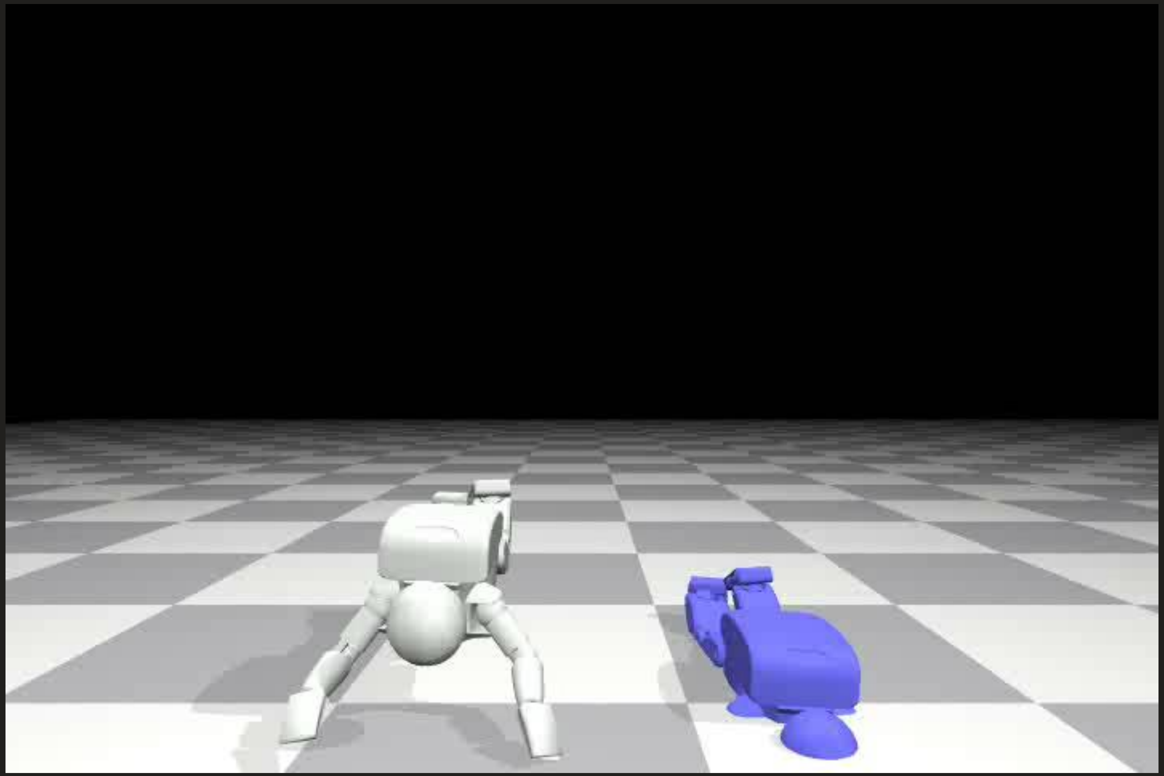


Output

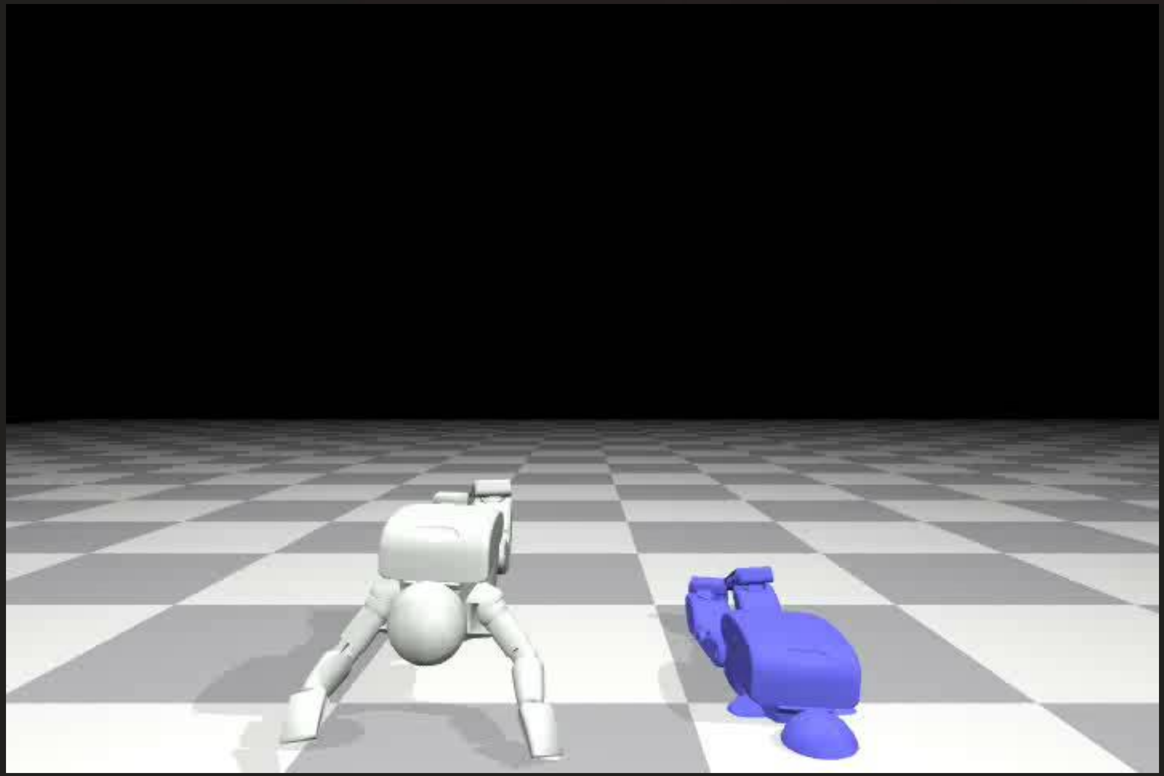


Motivation

Retargeting to new characters



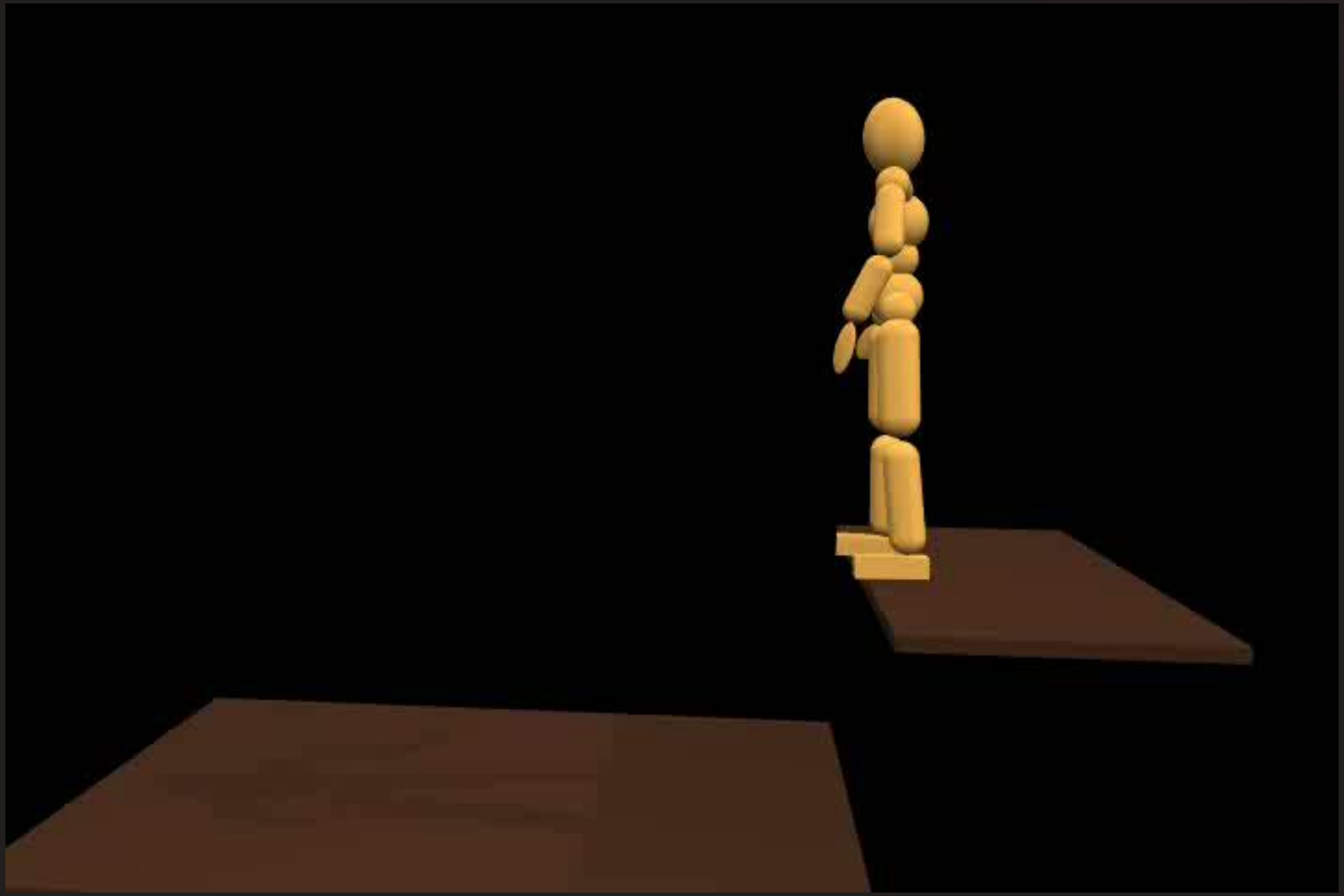
Direct tracking



Our open-loop control

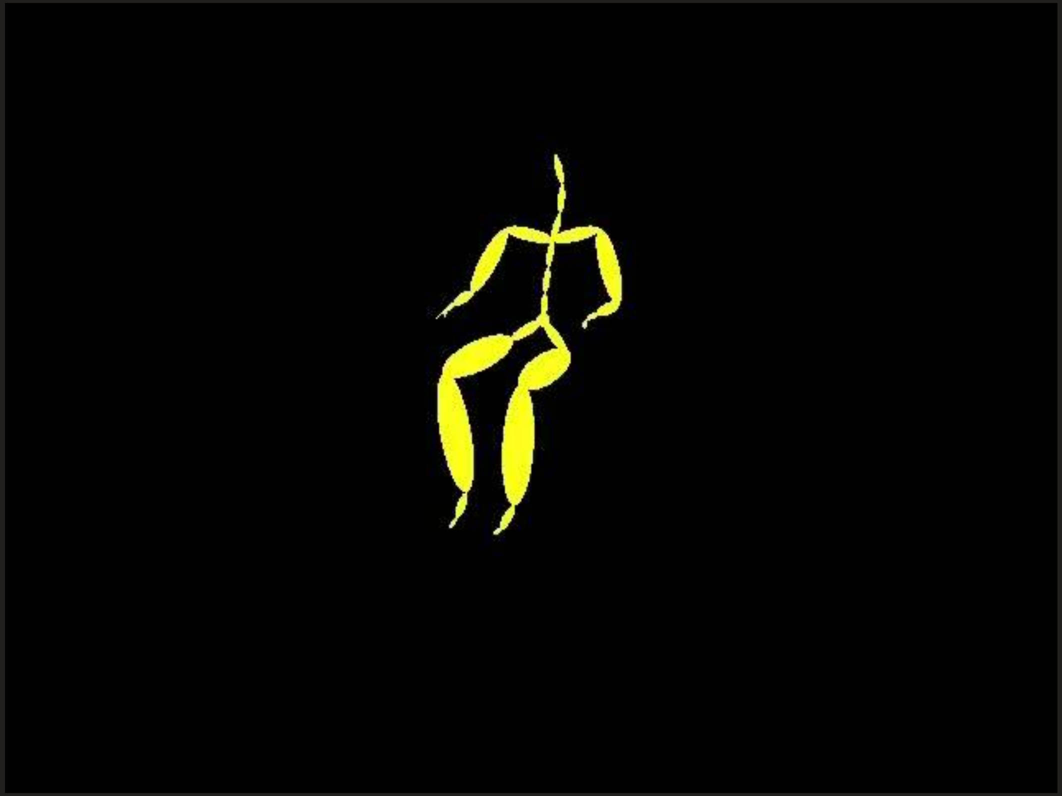
Motivation

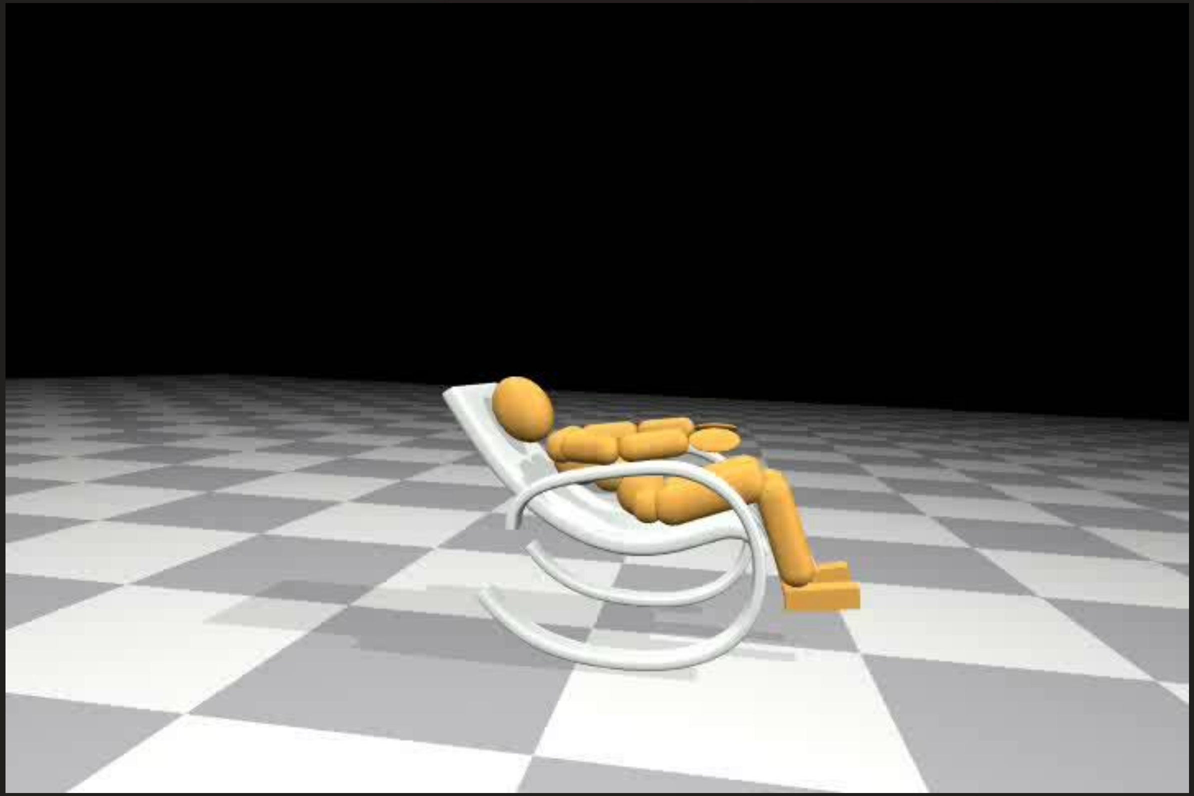
Retargeting to new environments



Motivation

Synthesis of difficult-to-capture motions





Outline

- Motivation
- Related Work
- Control Construction
  - Trajectory-based sampling
  - Practical implementations
  - Trajectory-free sampling
- Results
- Discussion

Related Work

- Motor Control and Contact Dynamics

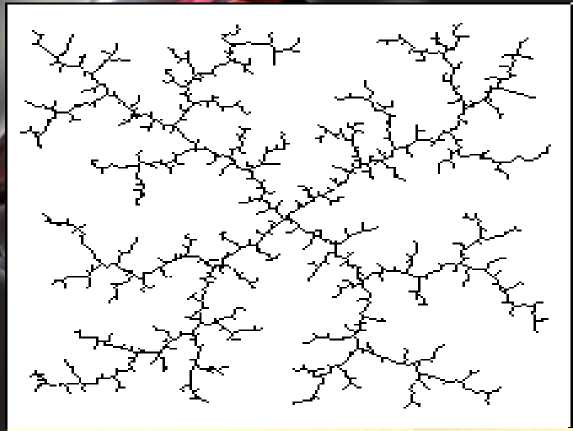
  [Kawato 99, Jordan and Wolpert 99, Brubaker et al. 09]

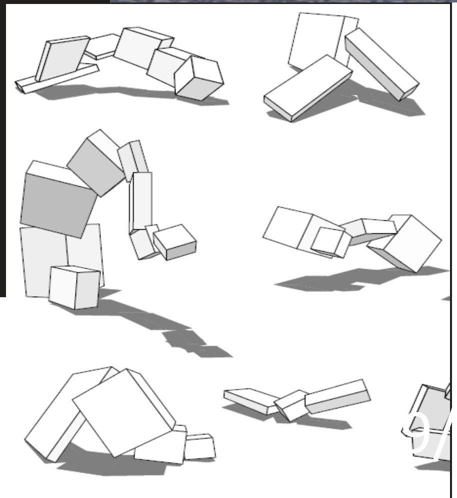
- Motion Planning

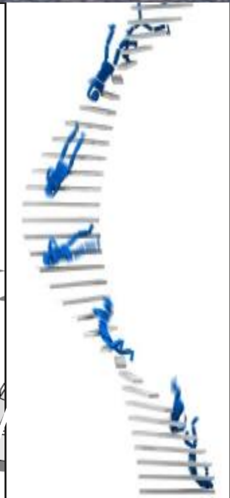
  [Kavraki et al. 96, LaValle and Kuffner 00, Choi et al. 03, Yamane et al. 04]

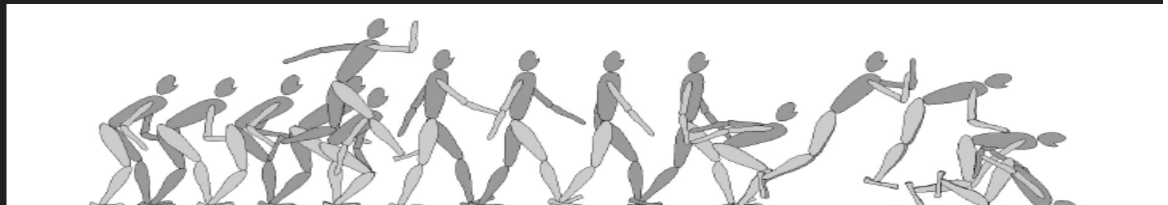
- Sampling in Animation

  [Sims 94, Hodgins and Pollard 97, Twigg and James 07, Sok et al. 07, Wang et al. 09, Wampler and Popović 09]









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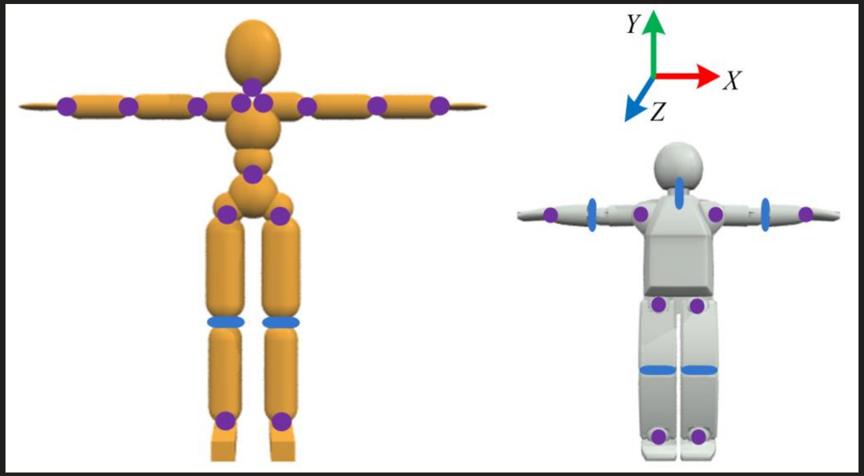
Simulation Basics

- PD servo

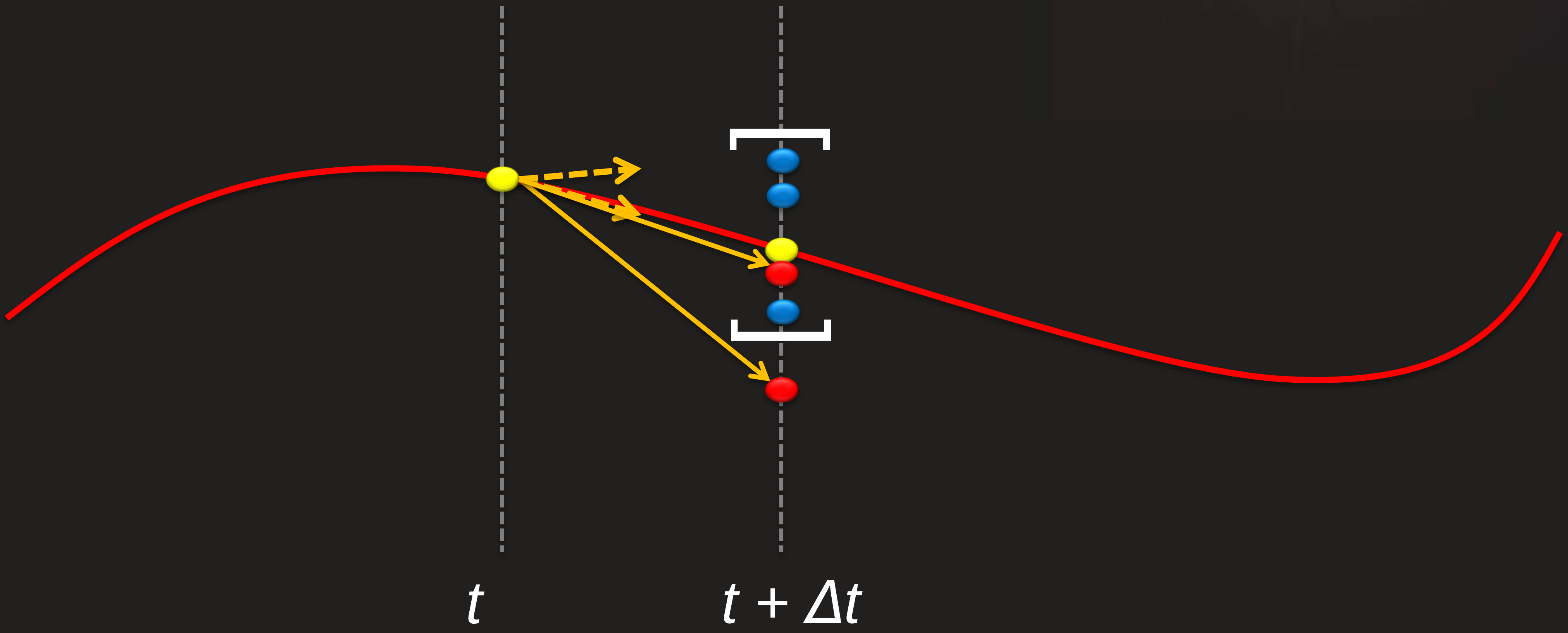
$$\tau = k_p\left(\tilde{\theta} - \theta\right) - k_d\left(\dot{\theta}\right)$$

- Open Dynamics Engine v0.11



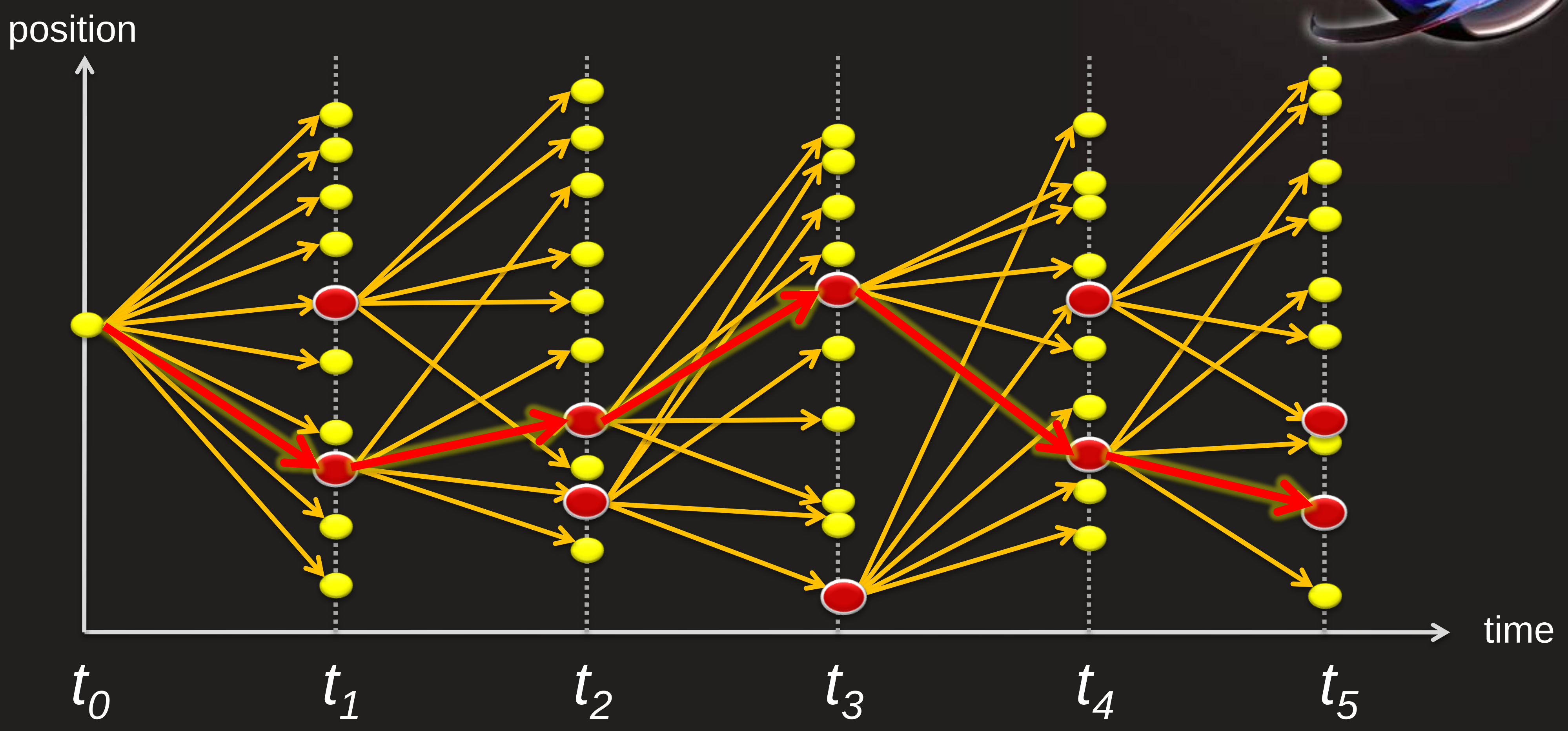
Trajectory-based sampling

Sampling



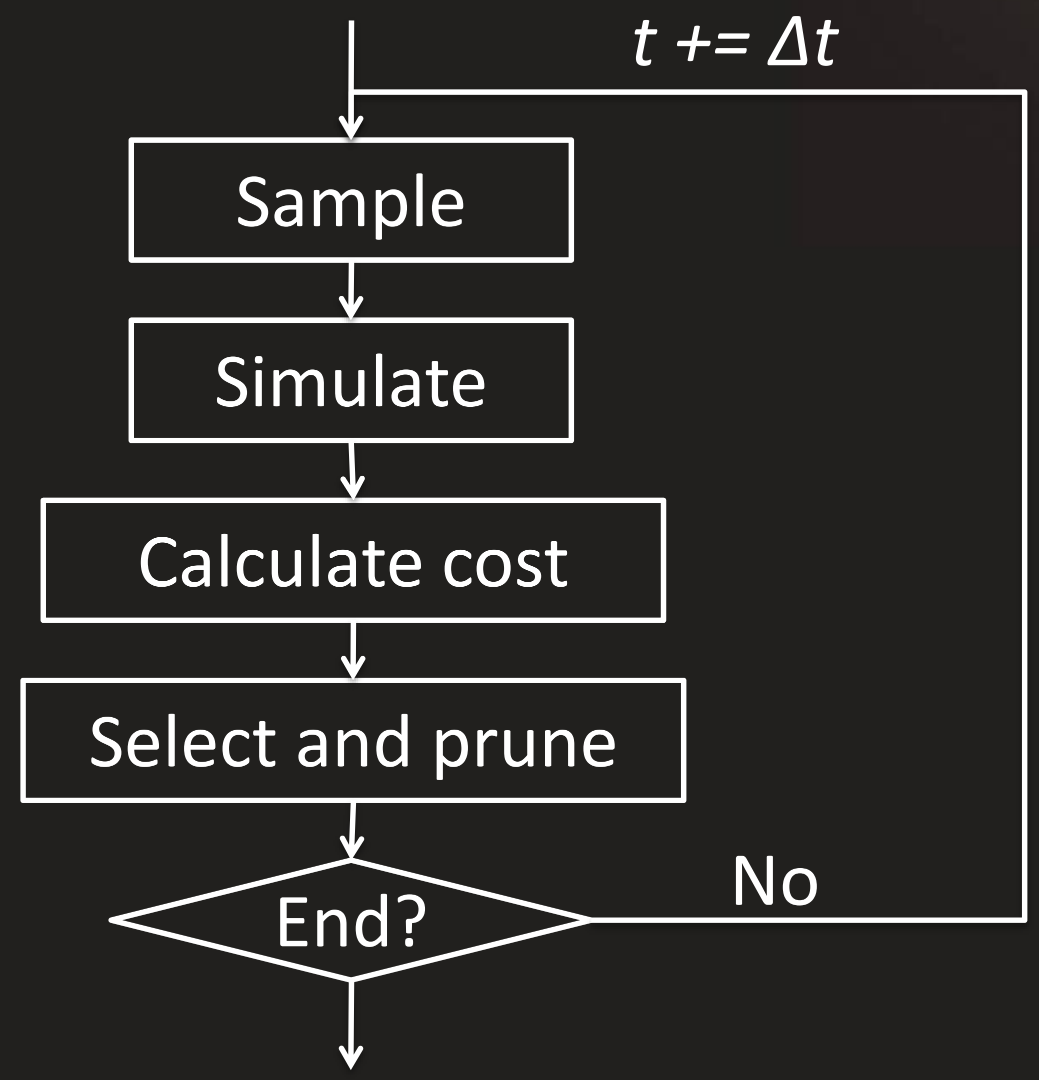
Trajectory-based sampling

Steps



Trajectory-based sampling

Steps



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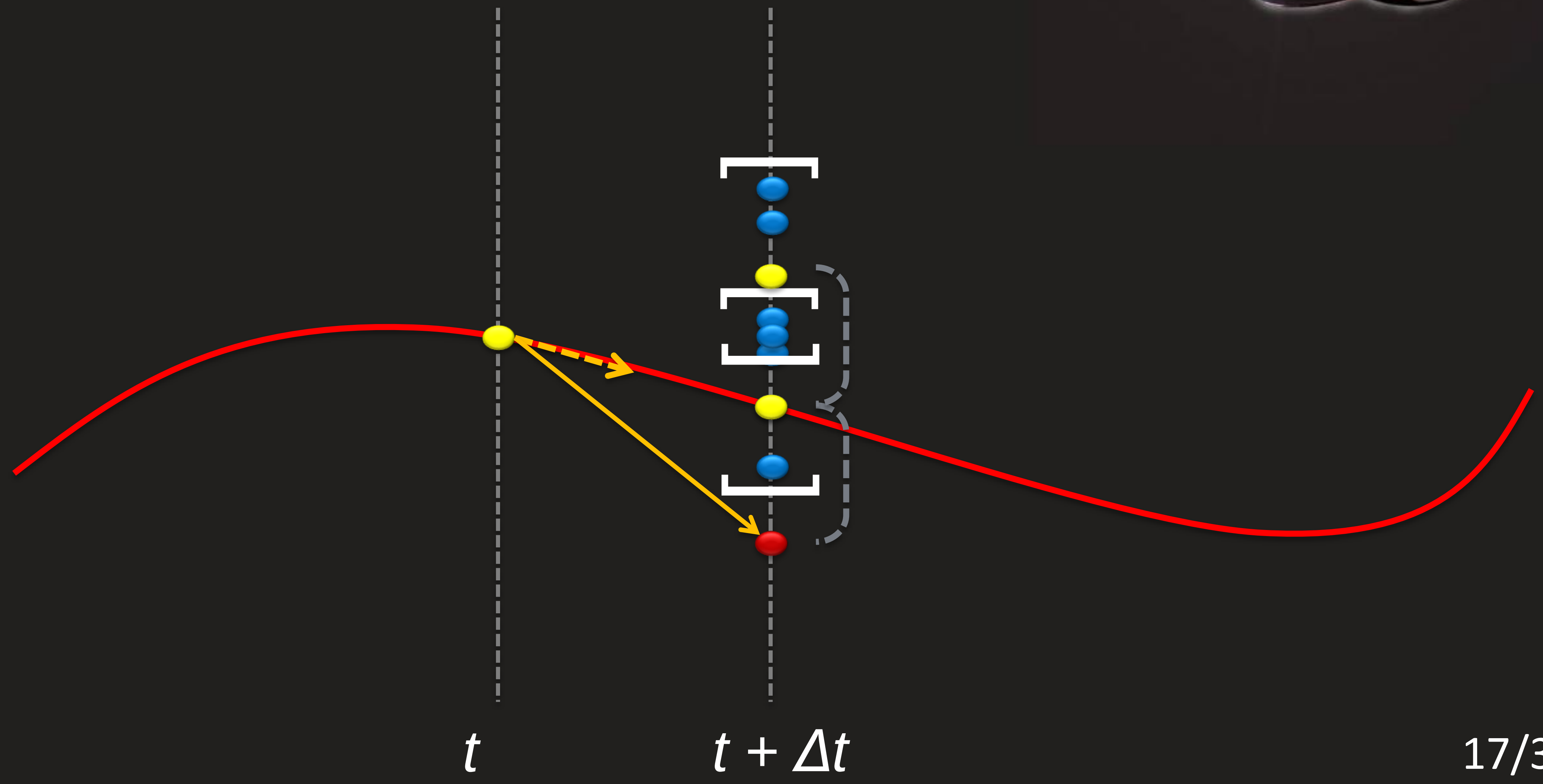
Sample generation

- Sampling window size
  - Noise level
  - Joint activeness
  - Stability of motion dynamics

Feedforward torques



Sampling time step

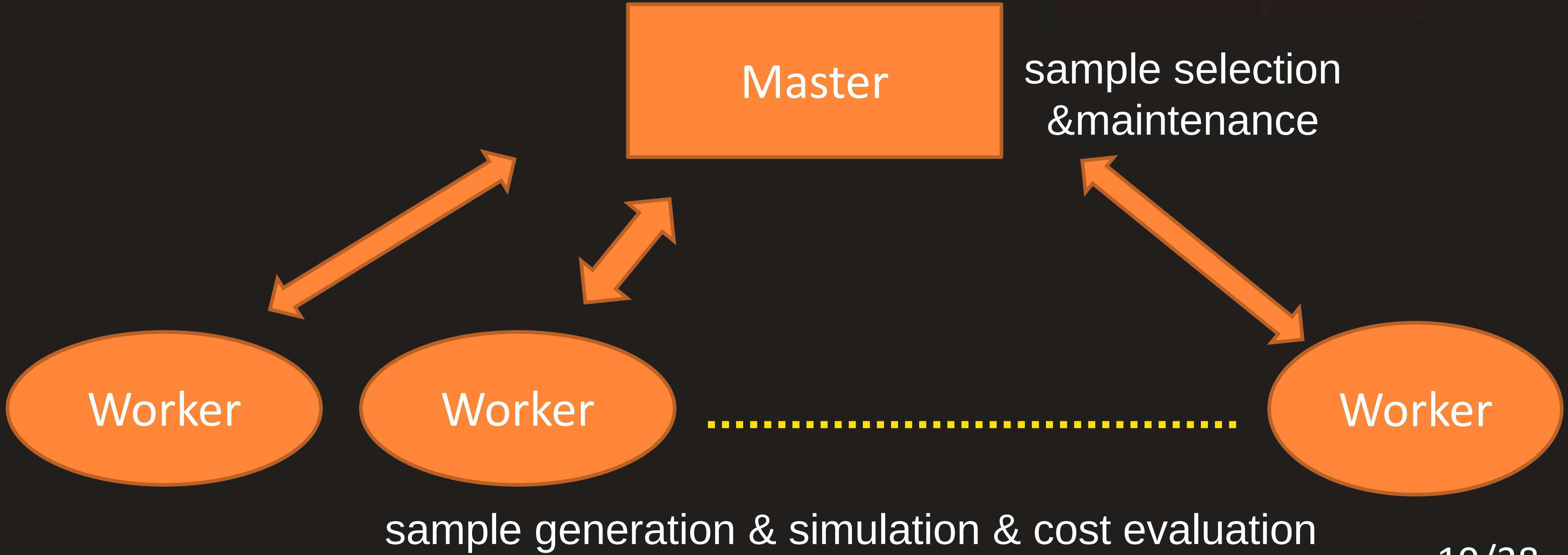
- Small vs. Large

- Uniform vs. Semantic

Practical Implementations

Simulations in Parallel

- Master-worker model



Trajectory-based sampling

Sample Cost Evaluation

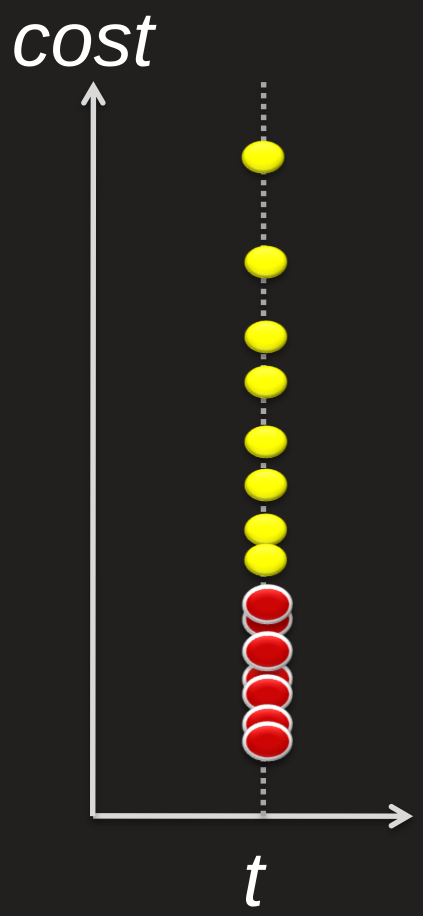
$$E = w_p E_p + w_r E_r + w_e E_e + w_b E_b$$

- Pose Control : $E_p = \frac{1}{n}\sum_{i=1}^{n} w_i(d_q(\mathbf{q}_i, \tilde{\mathbf{q}}_i) + 0.1 * d_v(\omega_i, \tilde{\omega}_i))$
- Root Control: $E_r = d_q(\mathbf{q}_{root}, \tilde{\mathbf{q}}_{root}) + 0.1 * d_v(\omega_{root}, \tilde{\omega}_{root})$
- End-effector Control: $E_e = \frac{1}{k}\sum_{i=1}^{k} d_s(\mathbf{p}_{iy}, \tilde{\mathbf{p}}_{iy})$
- Balance Control: $E_b = \frac{1}{hk}\sum_{i=1}^{k}(d_v(\mathbf{r}_{ci} - \tilde{\mathbf{r}}_{ci})) + 0.1 * d_v(\mathbf{v}_{CoM}, \tilde{\mathbf{v}}_{CoM})$

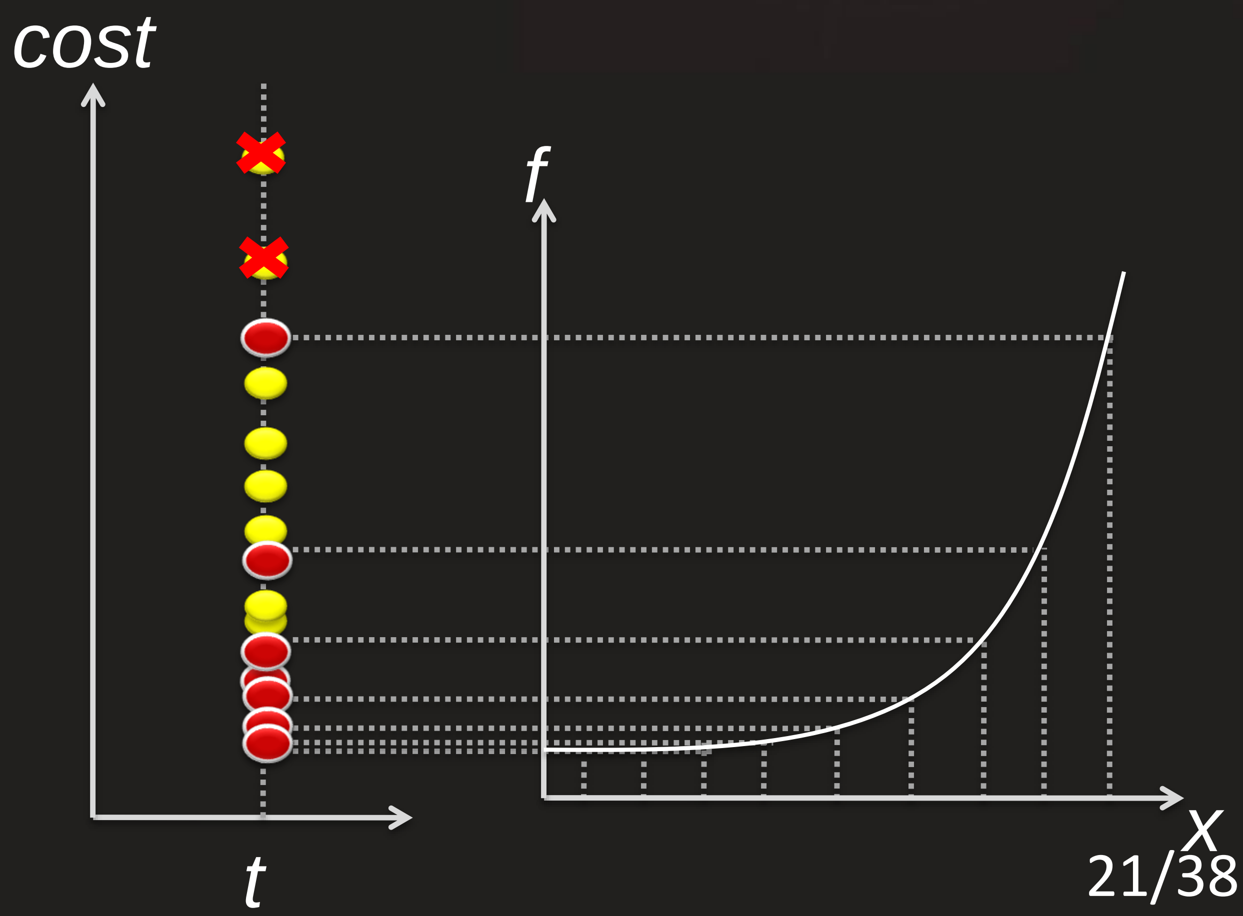
Practical Implementations

Sample Pruning

greedy



diversified



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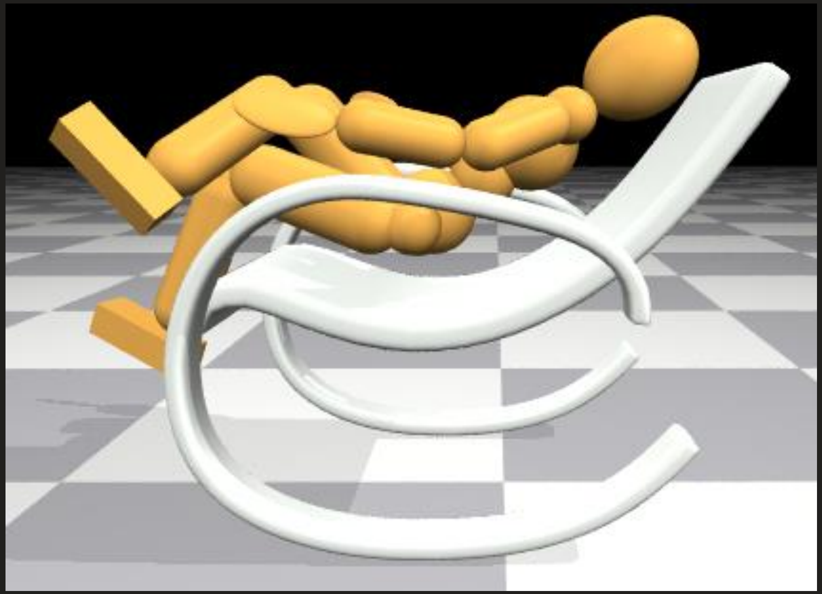
Idling

Trajectory-free Sampling



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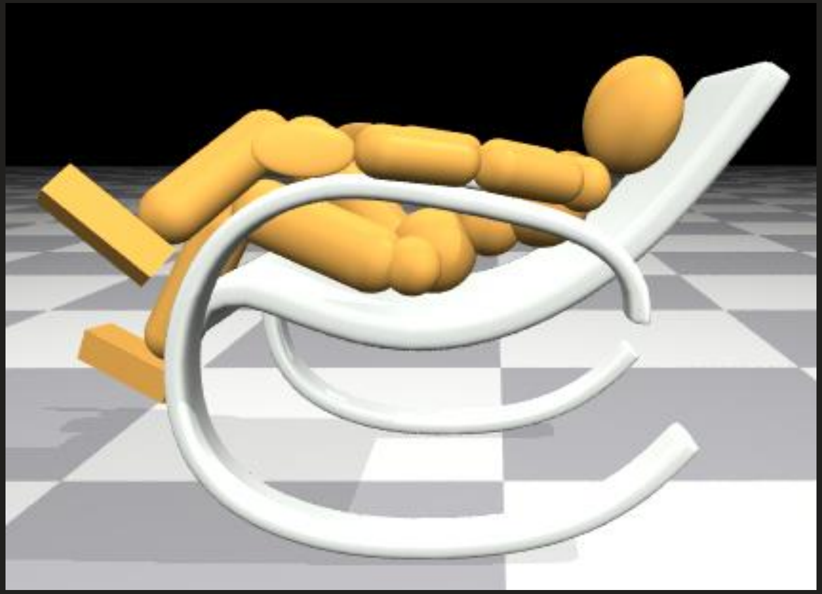
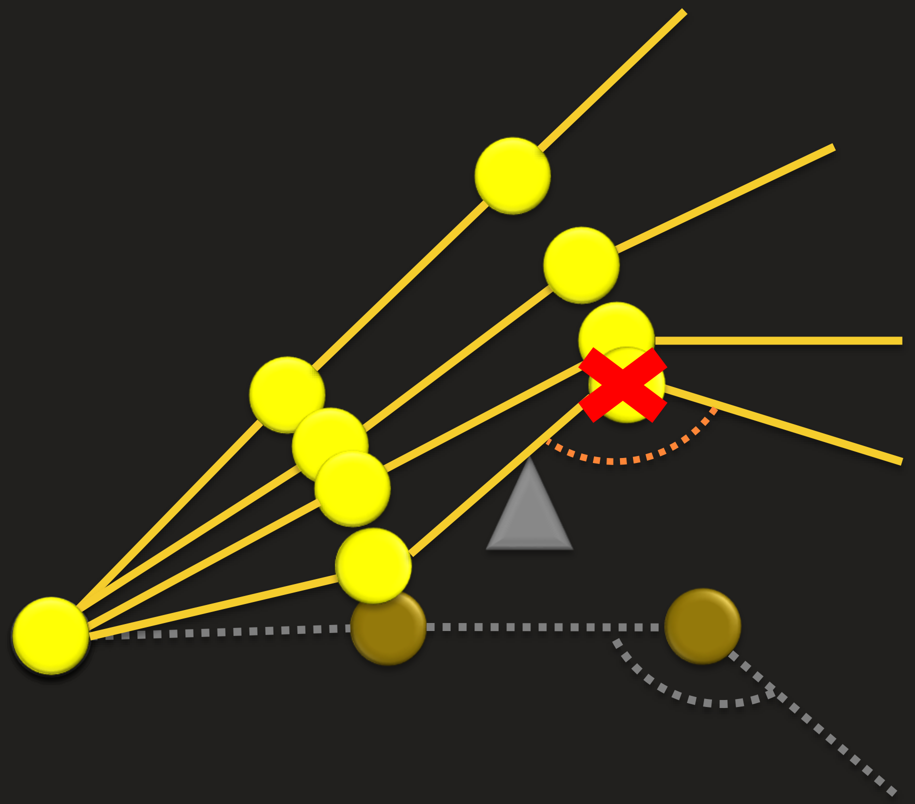
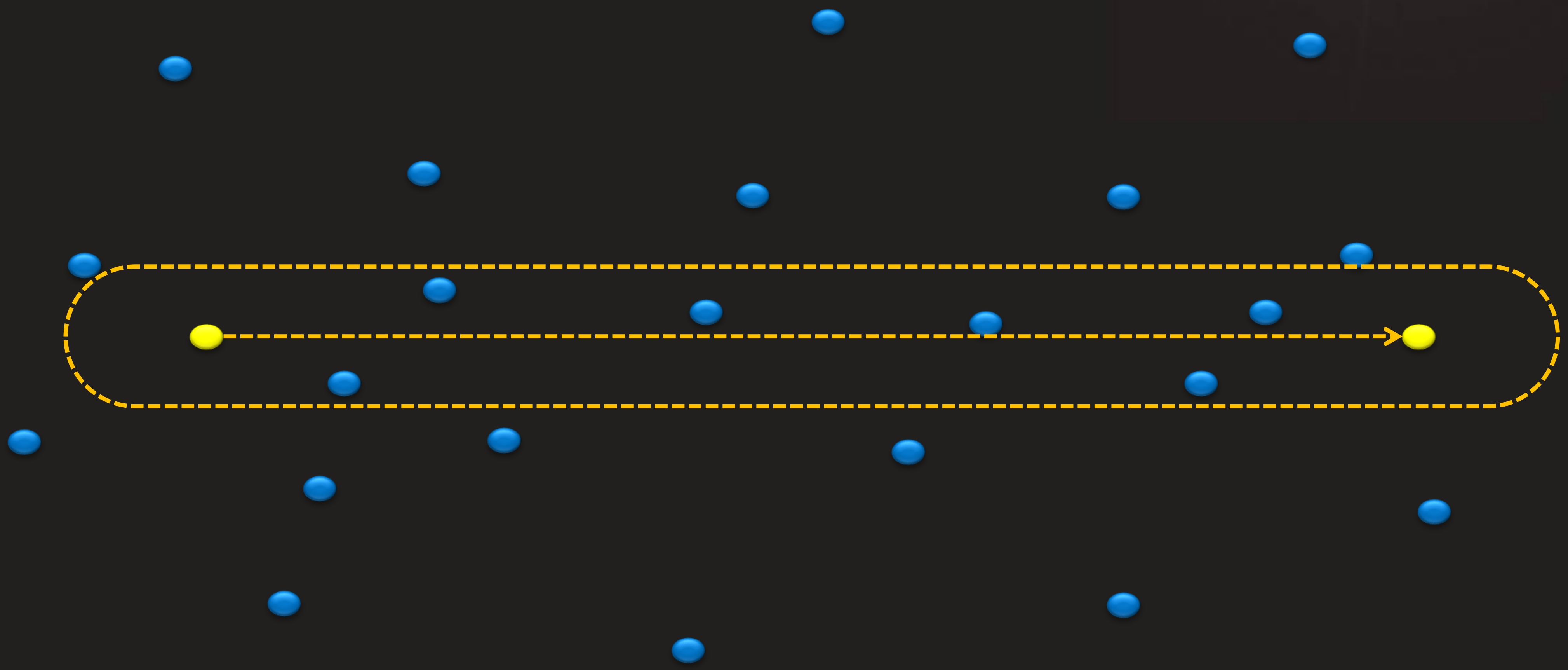


Idling

Dynamic RRT: DoF pruning



Dynamic RRT: Space Pruning



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Results

Performance

Trial	Duration (s)	Reconstruction time (s)
walk	5.2	143
run	2	51
sideways roll	3	78
forward roll	3	78
backward roll	2.1	57
get-up	3.5	93
kip-up	6.6	184

1400 samples for each iteration with success rate > 80%

~25 times slower than real time on cluster of 80 cores

Results

Control Reconstruction

Motion Transformation

Results:

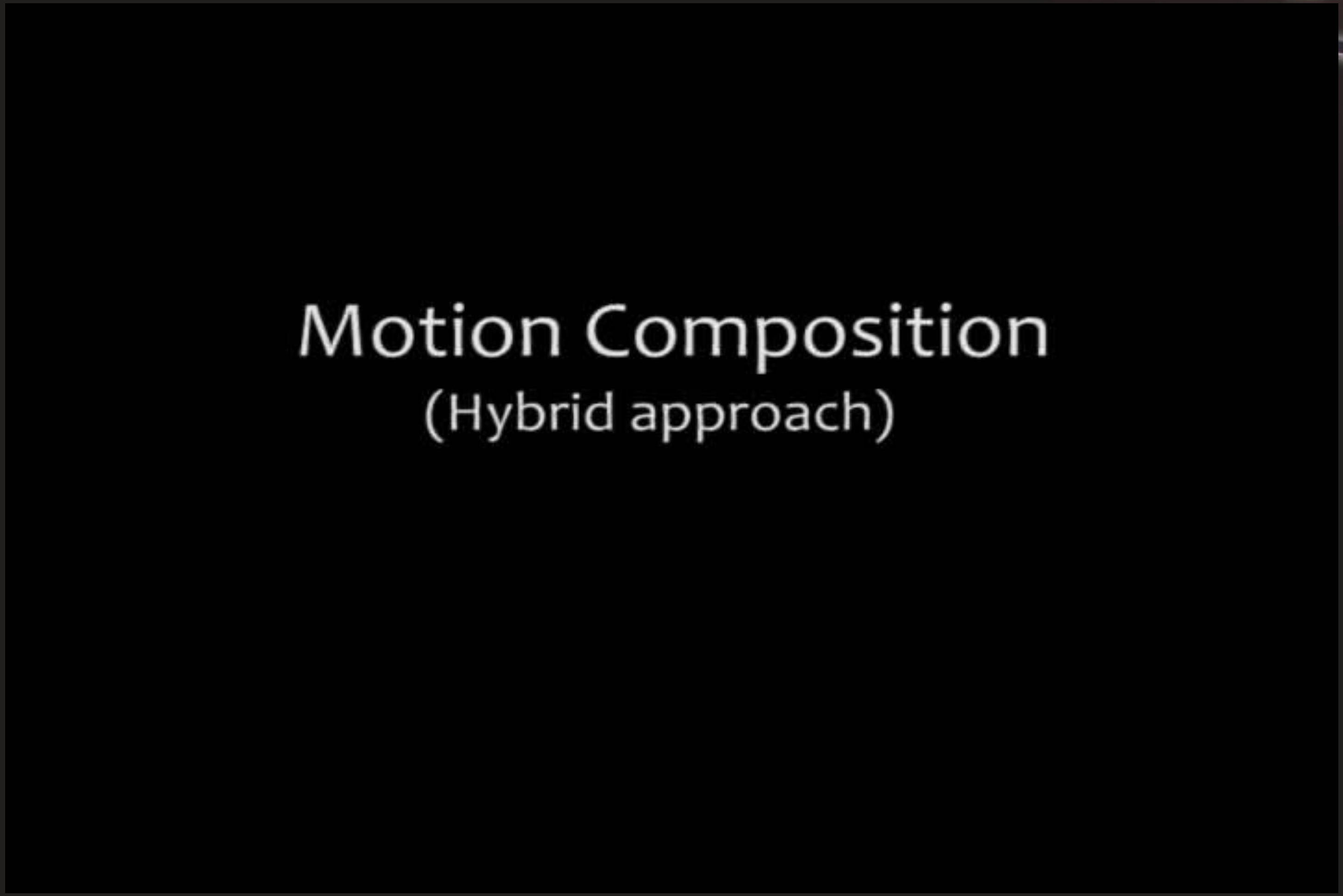
Motion Retargeting

Results

Trajectory-free Control Construction

Results

Motion Composition



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Advantages of Sampling

- Derivative-free
- General
- Robust wrt. local minima
- Easy to parallelize

Limitations

- Robustness of Reconstruction: <100%
- Robustness of Control: open-loop
- Generalization: trajectory-tracking nature
- Smoothness: can be jerky

Conclusions

- Sampling-based reconstruction method
  - general, robust, parallelizable
- Contact-rich tasks
  - get-up, rolling, idling
- Unified framework
  - inverse dynamics, motion transformation and retargeting

Acknowledgement

- Our mocap subjects
- Organizations and authors who generously shared their mocap data
- Xiao Liang, Teng Gao, Kevin Loken

Thank you