Editing and Constraining Kinematic Approximations of Dynamic Motion

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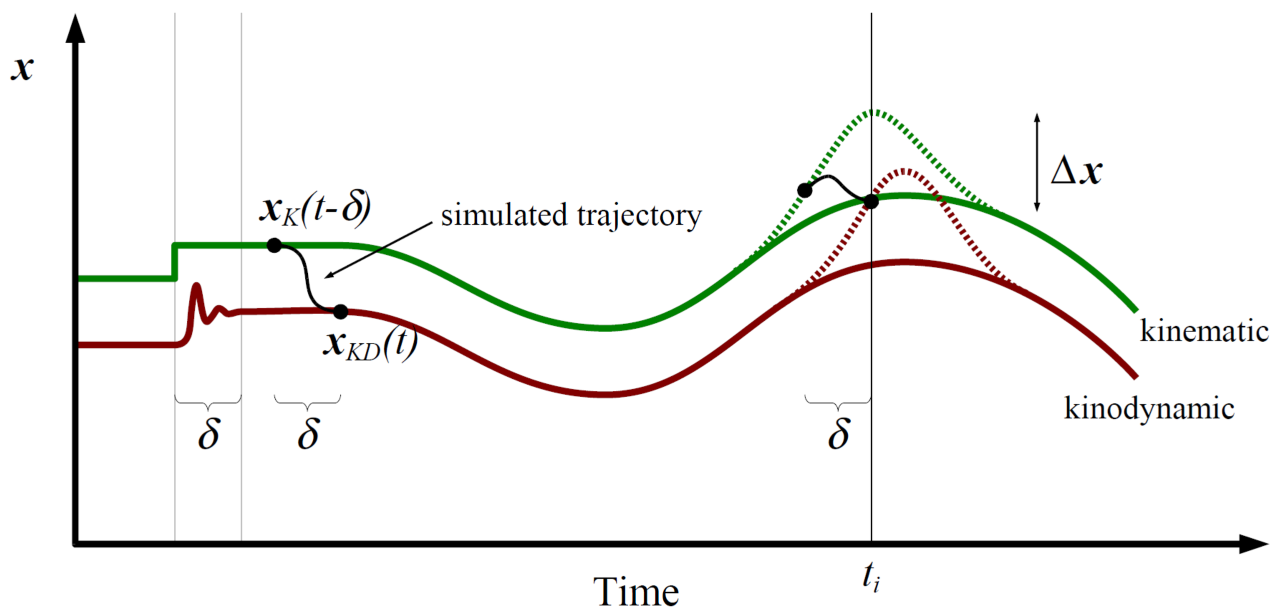
Summary

We present inverse kinodynamics (IKD), a technique that allows a kinodynamic system to precisely attain a set of animator constraints or targeted states at specified times.

What is Kinodynamics?

Kinodynamics (KD) provides a kinematic approximation to systems with short-lived dynamics, where the system state at a given time is the result of a past kinematic state, physically simulated forward over a finite temporal window up to the given time [AS07]. KD can be used in applications where:

- animator interaction with the time-line is WYSIWYG (what-you-see-is-what-you-get)
- secondary dynamics of skeletal animation are mixed with relaxation and tension [NE02].
- animator wants to reach key poses or "money shots".

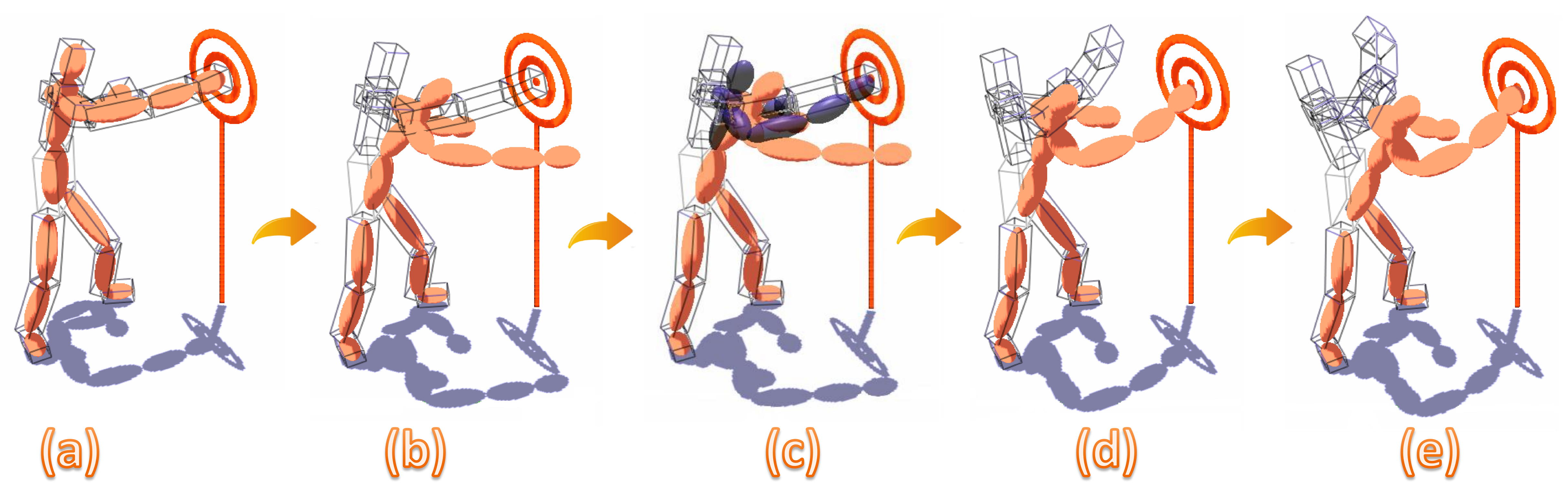


This plot illustrates how we modify a kinematic trajectory to create a kinodynamic trajectory satisfying the constraint that the original kinematic state be produced at time t_i.

Our Approach

Given a constraint, we first compute the IKD error in meeting the target, and from this we form bell shaped correction curves to add to the kinematic trajectory. The bell shaped curve has a shape that provides a local correction, has its peak value of 1 at t_i. The curve is defined as a low degree polynomial or Gaussian, and has a limited temporal width selected by the artist. We modify this estimated correction to take into account the dynamics of the system, by boosting the correction, assuming that the system dynamics are approximately locally linear. Using this correction, the process is repeated, until the system state converges to within a numerical threshold.

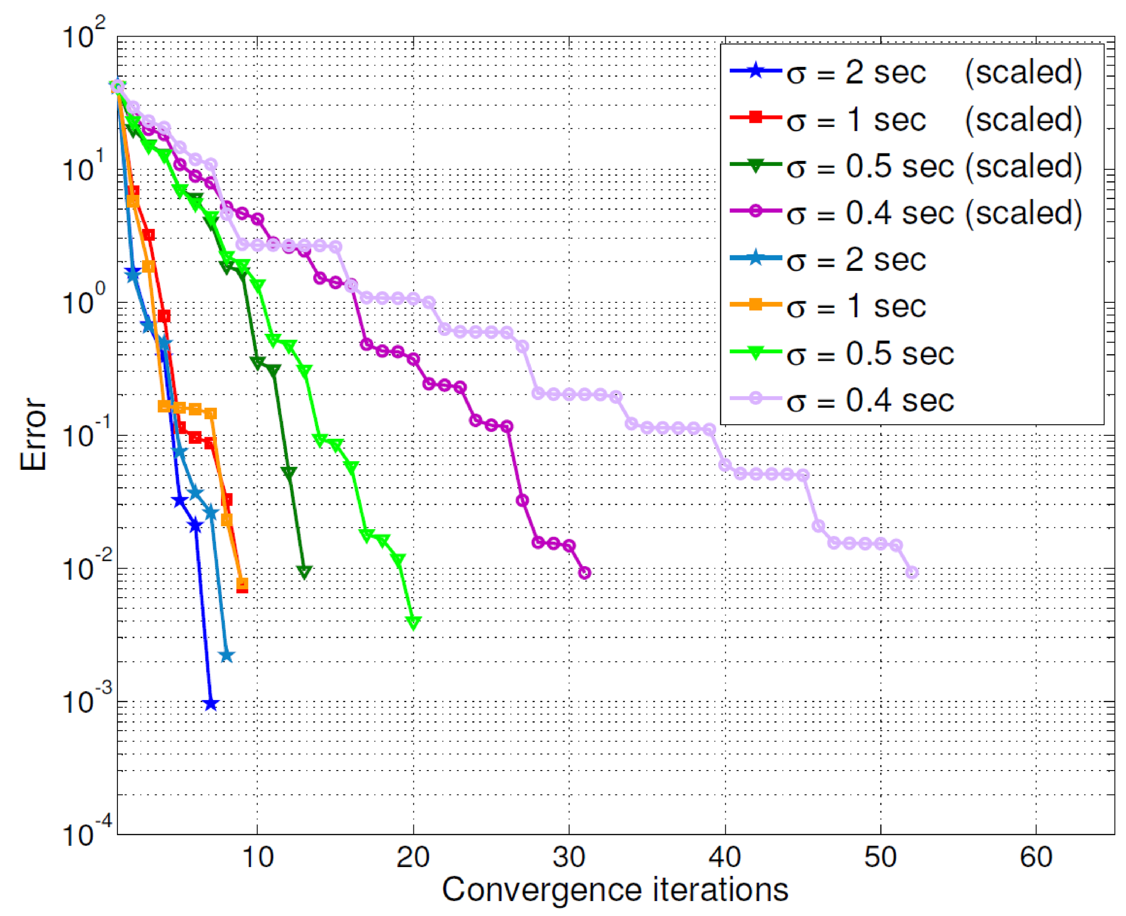
Inverse Kinodynamics



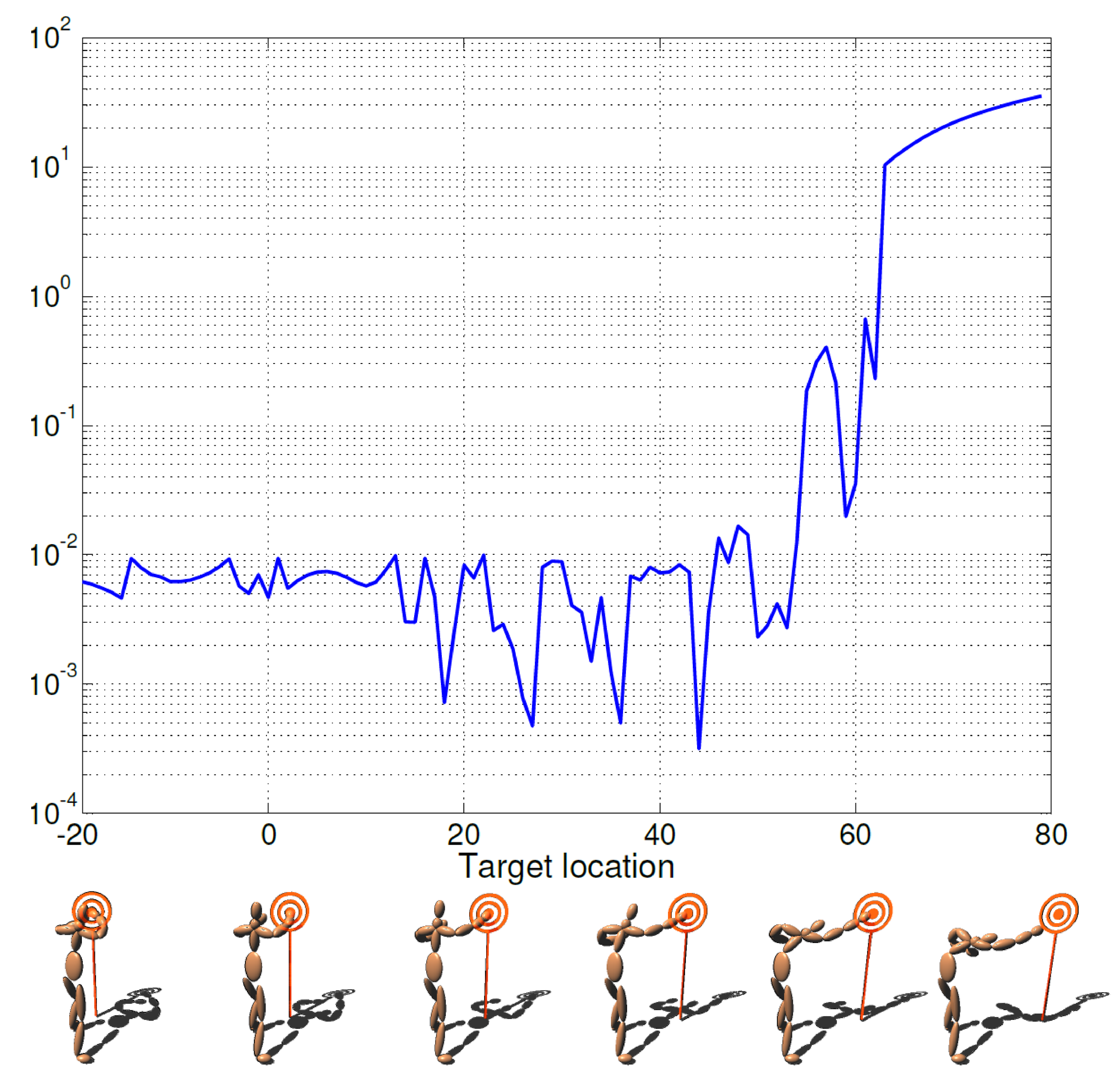
The poses above illustrate how IKD is used to produce an animation of a relaxed character that punches a target.

- **(a)** shows the kinematic motion at the time of contact in both wire-frame and solid orange.
- **(b)** orange character shows the KD state of the relaxed character, which fails to reach the target at contact time.
- **(c)** a naive application of inverse kinematics generates the pose of the character in dark blue.
- **(d)** iteratively computing the error and modifying the kinematic trajectory produces a KD state which hits the target (orange). Here the modified kinematic trajectory pose is shown in wire-frame.
- **(e)** shows the result of using a smaller temporal width for the bell shaped correction curve, which results in more of an upper cut and follow through.

IKD Performance



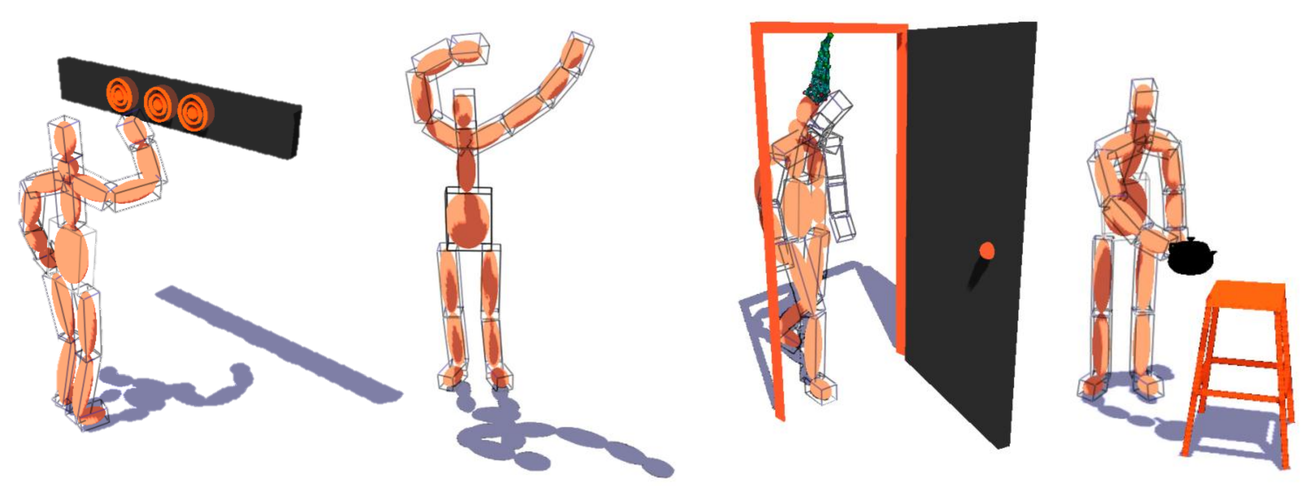
IKD convergence rates for the punch scenario using a bell shaped correction function with different temporal widths, with end effector error measured in cm, and error threshold 10^{-2} cm. The IKD convergence can be slower when a small temporal width is used, but is improved by damping the correction adjustment by 0.8, as shown by the trajectories denoted (scaled).



IKD error in cm after 6 iterations for varying target locations in the punch scenario. The error consistently falls to less than 0.1 mm after 6 iterations, except when the target is out of reach.

IKD Examples

Our approach solves the IKD problem iteratively, and is able to handle full pose or end effector constraints at both position and velocity level, as well as multiple constraints in close temporal proximity. Our approach can also be used to solve position and velocity constraints on passive systems attached to kinematically driven bodies. We show IKD to be a compelling approach to the direct kinematic control of character, with secondary dynamics via examples of skeletal dynamics and facial animation. Below, examples can be seen of multiple position constraints in a control panel, the YMCA dance "C" pose, a passive deformable hat, and a position constraint for grasp. See the videos at http://www.cs.mcgill.ca/~crahgo/i3d/.



Conclusion

The contribution of our approach is the development of a usable kinodynamic framework for interactive character animation with real-time performance. In summary we have proposed the concept of inverse kinodynamics, and we have presented a first algorithm that opens up the possibility of straightforward control and superposition of secondary dynamics for traditionally dogmatic key frame animators. In future work we would like to address:

- coupling of kinodynamic trajectories with fully dynamic environments via adaptive kinodynamic window sizes.
- collision events awareness and other discontinuities in a full physical simulation.

References

[AS07] Angelidis A., Singh K., Kinodynamic skinning using volume-preserving deformations. In Proceedings of the 2007 ACM SIGGRAPH / Eurographics Symposium on Computer Animation (2007).

[NE02] Neff M., Fiume E., Modeling tension and relaxation for computer animation. In Proceedings of the 2002 ACM SIGGRAPH / Eurographics Symposium on Computer Animation (2002).