Trajectory Optimization for Robotic Manipulators Using Multigrid CHOMP

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CHOMP [1]

Covariant Hamiltonian Optimization and Motion Planning (CHOMP) is a trajectory optimizer based on covariant gradient descent. Optimize a trajectory ξ subject to the objective function $f(\xi)$.

$$f(\xi) = f_{prior}(\xi) + f_{obs}(\xi)$$

- The prior term f_{prior} measures the cost of dynamical qualities, such as smoothness or acceleration.
- The obstacle term f_{obs} measures the cost of being near or in collision with objects.

$$\xi_{k+1} = \xi_k - \alpha M^{-1} \nabla f(\xi_k)$$

- Trajectory updates descend the gradient of $f(\xi)$ with a step size α, subject to a smoothing operator M.
- The smoothing operator smoothes the update, resulting in smooth trajectories.

Constrained CHOMP [2]

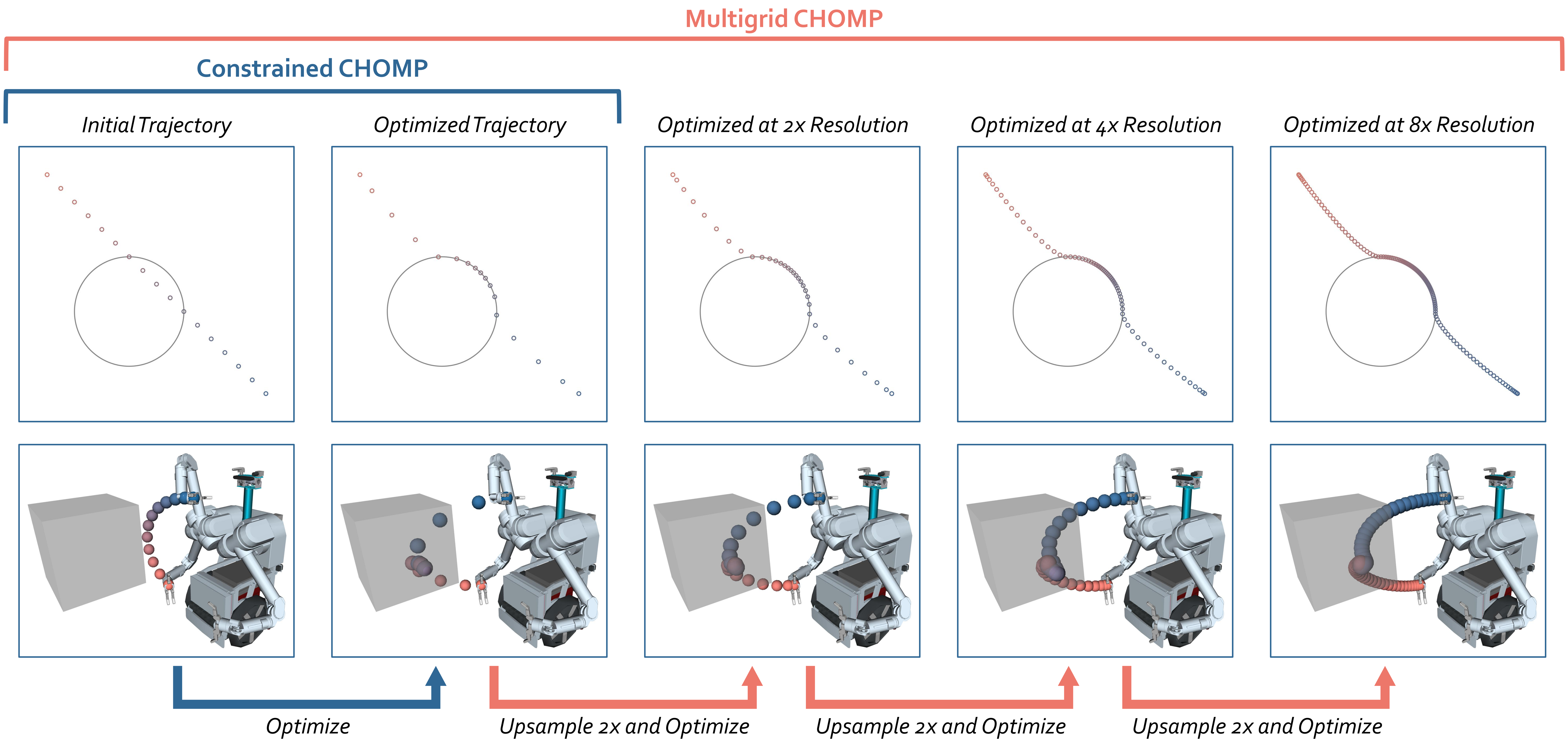
Constrained CHOMP uses Lagrange Multiplier based gradient descent. Given a constraint $h(\xi)$, evaluating to zero when satisfied, and a mapping H, mapping changes in the trajectory to changes in the constraint, the constrained update rule is:

$$\xi_{k+1} = \xi_k - \alpha[M^{-1} - M^{-1}H^T(HM^{-1}H^T)^{-1}HM^{-1}]\nabla f(\xi_k)$$
$$-M^{-1}H^T(HM^{-1}H^T)^{-1}h(\xi_k)$$

- The first term of the update rule is a constrained step down the gradient.
- The second term projects the trajectory onto the constraint manifold.

Multigrid CHOMP [3]

"A multiresolution approach to speeding up the constrained CHOMP algorithm while preserving its strengths in trajectory optimization."
Start with a coarse resolution trajectory, optimize and upsample it, repeating until the desired resolution has been reached.



The diagram above visualizes trajectories from various stages of Multigrid Chomp in 2 dimensions (planar displacement) and 7 dimensions (the arm of the Personal Robotics Lab's HERB). In the 2D example, the colored circles are the waypoints of a trajectory, constrained to lie on the large gray circle for the middle half of the trajectory (from time 0.25 to 0.75). In the 7D example, the colored spheres are the positions of the end-effector for each waypoint, and the end-effector is constrained to be within the grey box for the middle half of the trajectory.

Results

I worked under Professor Srinivasa to integrate Matt Zucker's Multigrid CHOMP with the PR Lab's robotic planning environment. This consisted of integrating Multigrid CHOMP with collision detection and constraint handling, and extending the implementation of Multigrid CHOMP to include several modifications explored in the literature, including: Hamiltonian Monte Carlo method and momentum updates [4], goal set chomp [2], task space region constraints [5], and joint limit constraints [4]. Lastly, I integrated CHOMP with NLopt [6], a nonlinear-optimization library, hoping to improve upon CHOMP's current optimization method of gradient descent. For non-constrained cases, my CHOMP module reduces planning time by 30% on average over the current module, and for constrained cases the speedup is even greater.

References

[1] Nathan Ratliff, et al. "CHOMP: Gradient optimization techniques for efficient motion planning." *Robotics and Automation, 2009. ICRA'09. IEEE International Conference on. IEEE, 2009.*

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[3] Keliang He, Elizabeth Martin, Matt Zucker. "Multigrid CHOMP with Local Smoothing". *Humanoids*. 2013.

[4] Matt Zucker, et al. "Chomp: Covariant hamiltonian optimization for motion planning." *The International Journal of Robotics Research* 32.9-10 (2013): 1164-1193.

[5] Dimitry Berenson, Siddhartha Srinivasa, James Kuffner. "Task Space Regions: A Framework for Pose-Constrained Manipulation Planning," *International Journal of Robotics Research (IJRR)*, Vol. 30, No. 12, October, 2011, pp. 1435 - 1460.

[6] Steven Johnson. "The NLopt Nonlinear-Optimization Package". <http://ab-initio.mit.edu/nlopt>.