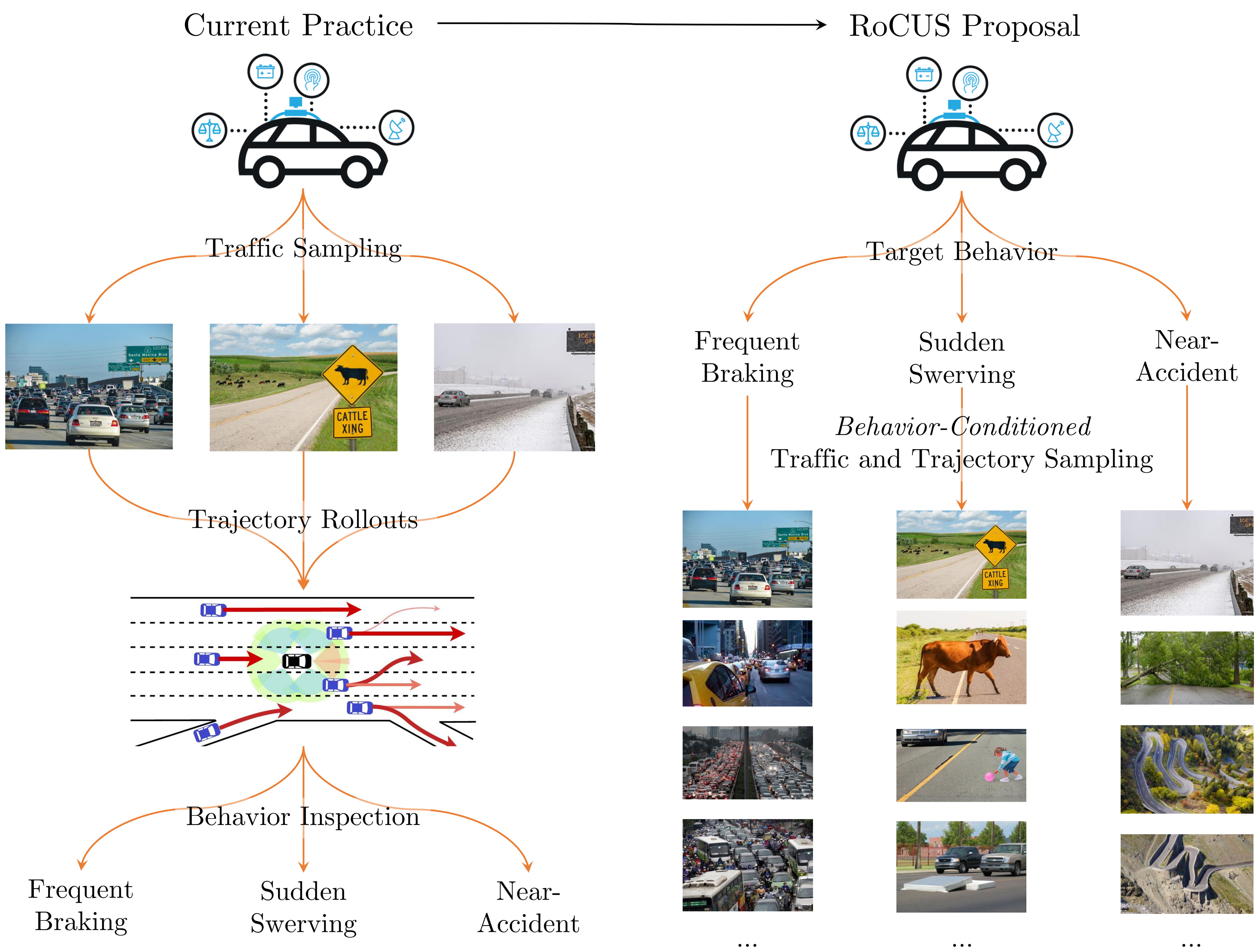
RoCUS: Robot Controller Understanding via Sampling

Yilun Zhou, Serena Booth, Nadia Figueroa, Julie Shah

MIT CSAIL

Project Page

Why?



Inferring behaviors from random samples	Finding samples for target behaviors
Scenario-driven	Behavior-driven
No prior expectation on discovery	Strong expectation on samples
Independent samples	Samples naturally grouped by behavior
No targeted debugging	Explicit targeted debugging

How?

$$\begin{tikzcd} t \arrow[r] \arrow[rr, bend left] & \tau \arrow[r] & b \arrow[r] & \hat{b} \end{tikzcd}$$

t: task (i.e., scenario) τ: trajectory

b: behavior value $\hat{b}$: relaxation

Target behavior value $= b^*$:

$$\hat{b} \mid b \sim \mathcal{N}(b, \sigma^2)$$

$$t, \tau \sim p(t, \tau \mid \hat{b} = b^*)$$

$$\propto p(\hat{b} = b^* \mid t, \tau)\, p(\tau \mid t)\, \pi(t)$$

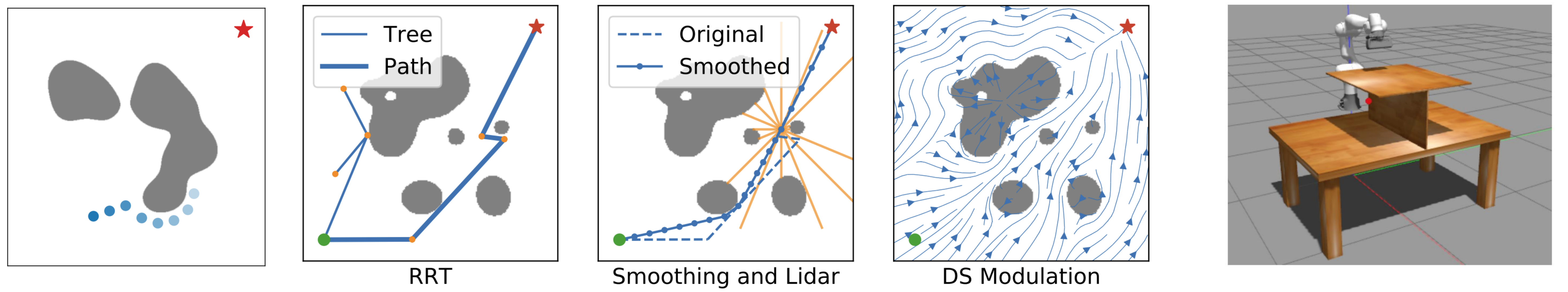
Target behavior value = "$+\infty$":

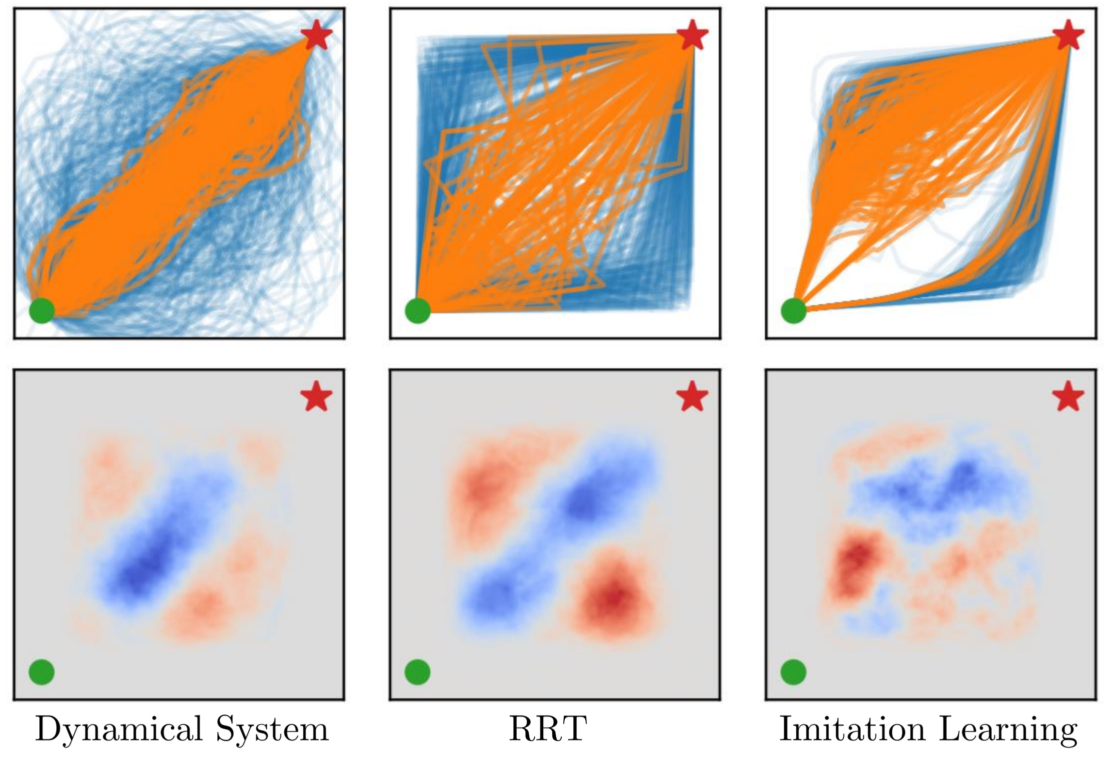
$$\beta(b) = \left(1 + e^{-(b - \mathbb{E}[b])/\mathbb{V}[b]}\right)^{-1}$$

$$\hat{b} \mid b \sim \mathcal{N}(\beta(b), \sigma^2)$$

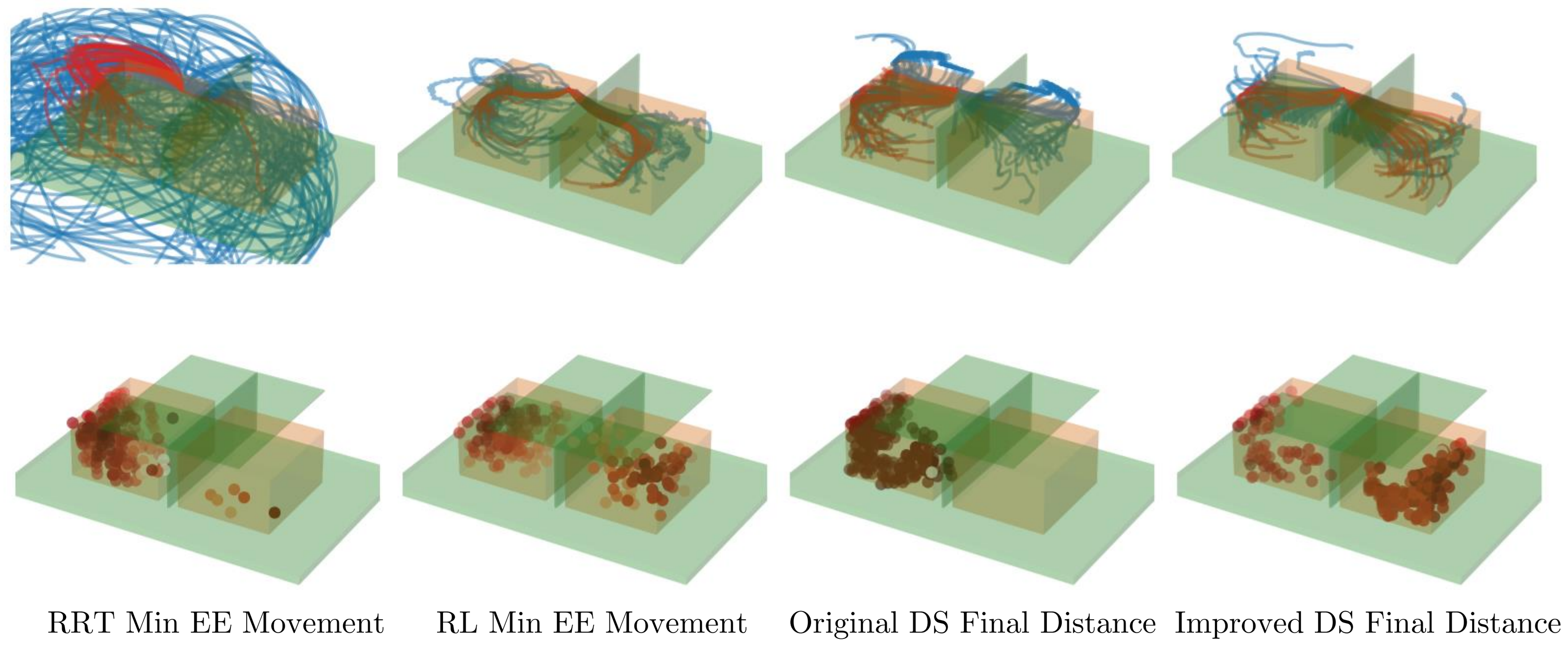
$$t, \tau \sim p(t, \tau \mid \hat{b} = 1)$$

Name	Definition	Name	Definition
Trajectory Length	$b = \int_\tau 1\, ds$	Straight-Line Deviation	$b = \frac{1}{\lVert\tau\rVert}\int_\tau \left\lVert \mathbf{x} - \mathrm{proj}_{\mathbf{x}_f - \mathbf{x}_i}\mathbf{x} \right\rVert ds$
Average Velocity	$b = \frac{1}{\lVert\tau\rVert}\int_\tau \lVert\dot{\mathbf{x}}\rVert\, ds$	Obstacle Clearance	$b = \frac{1}{\lVert\tau\rVert}\int_\tau \min_{\mathbf{x}_o \in \mathcal{O}} \lVert\mathbf{x} - \mathbf{x}_o\rVert\, ds$
Average Acceleration	$b = \frac{1}{\lVert\tau\rVert}\int_\tau \lVert\ddot{\mathbf{x}}\rVert\, ds$	Near-Obstacle Velocity	$b = \frac{\int_\tau \lVert\dot{\mathbf{x}}\rVert / \min_{\mathbf{x}_o \in \mathcal{O}} \lVert\mathbf{x} - \mathbf{x}_o\rVert\, ds}{\int_\tau 1 / \min_{\mathbf{x}_o \in \mathcal{O}} \lVert\mathbf{x} - \mathbf{x}_o\rVert\, ds}$
Average Jerk	$b = \frac{1}{\lVert\tau\rVert}\int_\tau \lVert\dddot{\mathbf{x}}\rVert\, ds$	Motion Legibility	$b = \frac{1}{\lVert\tau\rVert}\int_\tau p(g \mid \mathbf{x})\, ds$





Minimal straight-sine deviation on 2D navigation



Various behaviors on 7DoF arm reaching