Toward a mechanistic account for imitation learning: an analysis of pendulum swing-up

Takuma Torii and Shohei Hidaka

Japan Advanced Institute of Science and Technology

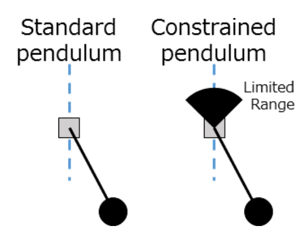
Social agents learn action repertoires from others' behaviors. This is not just a mere replication of movements, but it requires inference on intention behind actions. Empirically, past studies have reported that young children could infer the action to be completed by observing a partial and incomplete action of the demonstrator (Warneken & Tomasello 2006).

In the present study, we seek for a theoretical account for the inferential process of "successful" or "intended" actions discriminated from "unsuccessful" or "unintended" ones. Toward this goal, we ask the two basic questions:

1. How can we identify multiple seemingly different actions generated by the same motor control scheme?
2. How can we differentiate multiple seemingly similar actions generated by two different motor control schemes?

Here, we suppose that the motor control scheme or the plan of actions reflects the intention behind the actions.

To address these questions, we resorted a computer simulations of the simplest possible physical body and action repertoires — the classical pendulum swing-up task of one degree-of-freedom. We analyzed two agents controlling the pendulum movements in different control schemes given the identical pendulum with the same condition. Due to the given identical physical condition, the two pendulums' movements seem quite similar (see the top panel of Fig. 1), but their underlying control scheme are substantially different. Each of control schemes was constructed by minimizing the error function, that is minimized at the inverted position for this task. In constructing the two different control schemes, however, two different physical conditions on the pendulum were imposed: (a) a standard single pendulum without any constraint (the left in the side figure) and (b) a single pendulum with a physical constraint (the right) that prevents it from taking a certain range of posture including the inverted (the state with minimal error). We call the one with the control scheme of (a) *standard* pendulum, and the other (b) *constrained* pendulum.



To reveal latent differences in two different dynamical systems, we analyzed dimensions of the two systems by treating the generated pendulum movements as attractors. In this analysis, we employed the method proposed by Hidaka & Kashyap (2013), which numerically estimates pointwise dimension for each data point in a dataset. The estimated pointwise dimension for each time point of the standard (green) and constrained (blue) pendulum is shown in different colors in the bottom panel of Fig. 1. The result shows that both the standard and constrained pendulum show drastic changes around 5000 time steps. After 5000 time steps, the dimension of the standard one increases on average, but that of the constrained one decreases on average. As a follow-up analysis, we generated a set of multiple movements with different initial conditions for each of the two pendulums, and found that the movements of the same pendulum with different initial conditions tend to show similar patterns in pointwise dimensions. To questions (1) and (2), it suggests that this analysis on the pointwise dimension can differentiate two seemingly similar movements generated by the two different control schemes, and identify multiple seemingly different movements generated by the same control scheme.

In the past literature on the computational mechanism of motor control, the problem of interest in this paper is treated as an ill-posed inverse problem, that is by identifying the control scheme from movements, to its forward problem. The standard solution for this class of ill-posed problem is to model the constraints given by the nature of the system, namely physical laws and body structures in this case, as the prior knowledge in the estimation process (Marr 1982; Kawato 1990). In contrast to this approach, we suppose that our approach taken here is another class of approaches, that do not explicitly model the given physical constraints. Our approach assumes that the movements reflect a generic dynamical system. Then the present study demonstrated that this assumption served a sufficient basis for identification/differentiation of the systems — at least in the case concerning the simplest physical model such as a single pendulum.

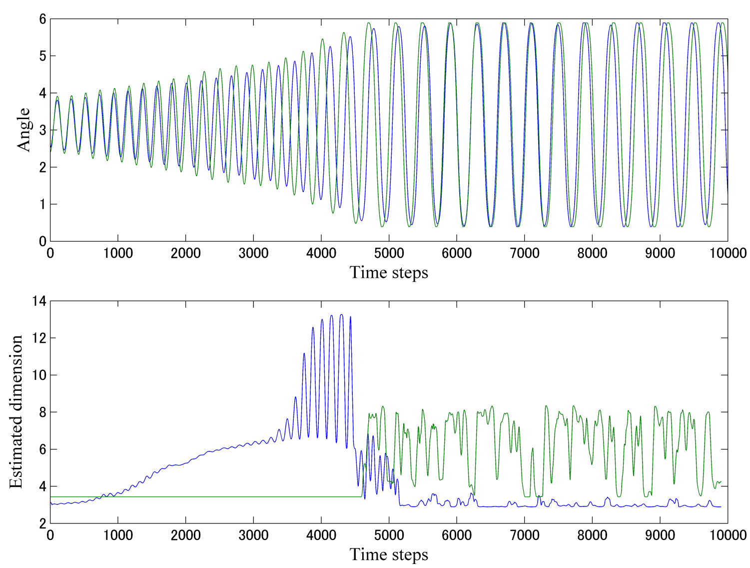


Fig. 1: Pointwise dimensions of pendulum movements