Representing the Denotations of Bodily Action Verbs Based on the Propagation of Movements

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In an attempt to denote the meanings of action verbs by modal-logic, we use the kinematic tree retrieved from the motion planning of the actions simulated by a humanoid robot. Real human joints, highly complex, are subcategorized into five groups or more by their modes of rotation (Zatsiorsky 1997, Köpf-Maier 1997). Based on movement causation, we simplified these real rotations into three kinds: *rotation*, *turn* and *turn'* (Nishina 2009). The humanoid robot KHR-1, equipped only with one manner of rotation, *rotation*, has a series of simple rotations replace a human complex rotation (Kondo Kagaku 2007).

By using the actions of a humanoid robot to capture the denotations of their relevant verbs, we have proposed to express the humanoid's skeleton into a rooted tree presupposing a support structure, (Nishina 2012). The tree represents each joint's possible causation of another or an endpoint to "move", as was defined in the "causative analysis" by Lakoff (1970) and Jackendoff (1992, 1992, 1993), in terms of dominance, and it can include each joint's degree of rotation in its terminal string. The motion planning set for each action shows a sequence of datum (rotation degrees for each servomotor) at each time point, for each channel (joint). As a sample, we chose the motion planning for "push-up", with relevant 17 channels and 20 data, and reformulated the planning matrix into a differential matrix showing a sequence of degree differentials at intervals for each channel. A tree shows the support structure of a humanoid skeleton with the degree differentials for each joint while it takes part in performing an action at each interval. The support structure as a rooted tree, on which the propagations of movement causations can be traced by dominance relations, contains moving and staying events (M/S), each of which has its respective predicate "move"/"stay", a joints as subject argument and its degree of rotation it dominates, and another such event as object argument. Each event embeds itself repeatedly until we reach the bottom one that has an endpoint in place of another event.

We constructed a PSG generating the tree structures for the motion planning for the actions the humanoid robot can perform (Nishina 2012). Each motion (action), consists of a sequence of around 20 positions. Each position, i.e. the robot's posture at each time point in its specific motion, consists of the combination of the joints' values at that time point. Thus, a motion planning is a sequence of positions. The motion planning for push-up is expressed in terms of a sequence of sets of specific degree values for the joints at each time point. We modified this into a sequence of sets of degree differentials for the joints at each interval. Based on the relation of a joint's "causing" another or an endpoint to "move", we were enabled to reconstruct each position of the human skeleton simulated by a robot, into a "kinematic tree", which is generated by the following PSG:

R → S S S S S; M → m J EN; M → m J; M/S S → s J EN; S → s J S/M;
J → j, where j ∈{R, N, Sh, Sh, Sho' Sho', E, E', I , I', H, H', K, K' A, A', An, An};
j → θ, where $-90 \leq \theta \leq +270$, EN → en, where en ∈{He, M, M', F, F'}; en → *e*.

When observing a human's (a humanoid's) actions, the relevant portions in charge of sub-actions, supporting joints cause supported joints, generally propagating from the center of the body to its periphery. In order to capture the multiple movements of the body parts in action so that the kinematic features of the relevant action may be highlighted, while suppressing the specific degree values, we resort to modal logic, as was shown in Gamut II (1991) and Hughs & Cresswell (1996).

In our model, each joint of robot skeleton is located in a separate world. If a joint rotates as an axis by some positive/negative degree, let us suppose that in that world, there is a positive/negative movement (at w:□x [j(x) э +/-MOVE(x)] , which is shortened as +/-P). A world is accessible to another if and only if and only if the joint in the latter world directly or indirectly causes the joint in the former world. Given the kinetic tree, shown in the above, we are enabled to valuate the formula with respect to the relevant sub-tree of the kinematic tree at each interval for Pushup. We cite the first several examples.

Table 1: Movement Causation Formulas at the First Four Intervals for Push-Up

At interval 1, at w(H'): P, ◇P, ◇□P, ◇◇□P; at w(K'): □P, ◇□P; at w(A'): P; □P, at w(An') P; at w(Sh'): P, at w(Sh): P, w(H): -P, ◇−P.
At interval 2, at w(H'): -P, ◇−P, ◇P, ◇□P; at w(K'): -P, □P, ◇□P; at w(A'): P; □P; at w(An'): P; at w(Sh'): -P; at w(Sh): P; at w(H): P, ◇P, ◇−P; at w(K): P, at w(A): -P.
At interval 3, at w(H'): -P, □−P, ◇□−P, ◇◇□−P; at w(K'): -P, □−P, ◇□−P; at w(A'): -P; □−P; at w(An') -P; at w(Sh'): P, ◇P; at w(Sh): -P, ◇-P; at w(Sho): -P; w(H): P, ◇−P, ◇P, ◇◇P; w(K): -P, ◇P; w(A): P.
At interval 4, at w(A'): P, □−P; at w(An'): -P; at w(A):-P, □-P; at w(An): -P.

As the world H' at interval 3 shows, H' causes K' to move, K' causes A' to move, and A' causes An' to move, which is modal-logically expressed as a (((possible), possible), necessary) formula. We will discuss how to characterize actions in terms of modal logic.