Learning Sensorimotor Maps with Dynamic Neural Fields

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When you look around at your immediate environment, you perceive a coherent arrangement of objects, available for acting upon them: e.g., a table in the middle of the room, a computer on the table, a key near a coffee cup. You can easily stretch you arm and grasp the key, hardly even looking at it – your body seems to know what commands to send to your arm and fingers to touch the key, which was barely detected by the cells in your retina. If you think about the processes involved in such a simple action, their complexity is immense. Indeed, the temporal and spatial smoothness of our perception is an illusion, created by the neural processing of visual information in a sequence of brief fixations, interrupted by saccades. Saccades are fast and precise eye movements, which bring interesting objects into the highly sensitive area of the retina – the fovea – so that the visual features of the fixated objects may be analysed and fused in a stable representation of the world around us. The visual representation of the target object on the eye's retina has to be transformed into an allocentric, or body-centered, representation in order to inform arm movement generation circuitry about the movement parameters even if the eye is already looking at something else. In order to generate behaviour in the physical world, the neural controller has to initially learn the sensorimotor mappings that transform the perceptions of potential targets to actions. Obviously, constant calibration of the sensorimotor mappings, involved in saccade generation and reaching, is needed, since the motor plant of biological systems changes due to fatigue, development, and ageing. Learning the sensorimotor mapping, which enables precise saccadic eye movements, is critical for development of other object-directed behaviours, since it allows to align the reference systems of the agent's body with the outer world: looking at objects precedes other object-directed actions, such as reaching, pointing, or grasping, in development, but also in new spatial arrangements.

We have recently investigated adaptation in the saccade generation system and have developed an embodied architecture, based on Dynamic Neural Fields (DNFs) [1], which autonomously generates precise and fast eye (or camera) movements and adapts the amplitude of these movements to changes in the sensorimotor system of the behaving agent [2]. Dynamic Neural Fields are mathematical formalisations of dynamics of neuronal populations, which implement attractor dynamics in continuous behavioural spaces. Because of their attractor properties, DNFs are particularly well-suited to implement cognitive architectures, which may be coupled to real-world sensors and motors. Our neural-dynamic architecture for adaptive looking has been extended to reaching and integrates DNF networks for saliency calculation, attentional region selection, habituation and scene exploration, motor command generation, and adaptive sensorimotor gains and mappings. Critically, the system for behaviour organisation [3] "orchestrates" the neural-dynamical modules of the architecture. The system creates an allocentric representation of the observed visual scene by storing the motor state of the visual system during object fixations. A predictive mechanism allows to anticipate this motor state without actually executing the saccade and to use this representation to store memories in allocentric reference frame to enable double-step (memory) saccades, as well as arm movements directed at visually perceived objects. When the ability to form an allocentric representation of visually perceived target develops in the architecture, a mapping may be learned from this representation to the motor parameters of reaching arm movements.

The model respects principles of neuronal processing and models well-known effects in eye-movements generation (e.g., saccadic adaptation, velocity profiles, developmental trajectory in double-step saccade paradigm). Systems for memory formation, habituation, scene exploration, fixation, and smooth pursuit, as well as biologically plausible arm-movement generation are all integrated in a single neural-dynamic architecture. The architecture was implemented on a simulated robot CAREN and on a physical humanoid robot NAO and allowed the robots to learn to produce precise saccades after a few trials and improve their performance gradually with experience. In our robotic experiments, we demonstrate that the richness of the environment and complexity of the available visual scenes are crucial for the exploration process, learning, and the quality of the resulting sensorimotor maps.

References

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