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博士論文題目	Automatic construction of image feature extraction programs by using linear genetic programming	

This thesis involves an evolutionary approach for constructing image feature extraction programs. Linear genetic programming (GP), i.e., a variant of the GP technique, is adopted to search for optimal or sub-optimal feature extraction programs. Such evolutionary approaches can automatically construct feature extraction programs without domain-specific knowledge. In particular, users only need to input training images and ground truths, and define objective function(s) that will be used for program evaluation.

First, this thesis considers redundancy in program representation (chromosome) and investigates their causes. Redundant representation causes inefficiency in evolutionary construction. This thesis proposes a canonical transformation for linear GP. The canonical transformation converts a linear representation, which contains a lot of redundancies, into a canonical form, in which redundancies are removed. This transformation is very fast, compared with the execution time of an individual (feature extraction program).

The canonical transformation enables us to adopt three techniques to improve efficiency and effectiveness of the evolutionary construction system. The first is *fitness retrieval*, the second is *intermediate-result caching*, and the third is *prohibition of redundant individuals*. Fitness retrieval technique helps evolutionary construction system avoid execution of programs that are already discovered in the search. We call such programs redundant programs. Based on this technique, we can reduce overall computation time of the constructing feature extraction program by around 80%. With the intermediate-result caching technique, we can avoid the execution of program-parts that have been recently executed, resulting in further reduction of computation time by around 25%. GP, with prohibition of redundant individuals, verifies whether the generated offspring represents a program that has already been discovered. If so, a mutation operation is applied to that offspring until it becomes a new individual that has not been discovered. This forces GP to explore new areas at every generation, leading to an improvement in search performance.

Next, this thesis proposes a novel approach to accelerate GP by using a hierarchical structured learning process, named *hierarchical structure GP* (HSGP). HSGP performs evolutionary process by using multiple learning nodes (LNs) connected in a hierarchy structure, e.g., binary tree. The evolutionary process starts from the bottom-level LNs through to the top-level LN. Each LN executes conventional GP and sends the learned population to the connected higher-level LN to learn further. Lower-level LNs learn with smaller data subsets, whereas the top-level LN learns with the entire dataset. By doing that, we can reduce wasteful executions of unreasonable programs, which frequently occurred in the beginning of evolutionary process, resulting in a great reduction of computation time (60-70%).

In addition, this thesis attempts to introduce multi-objective optimization into the evolutionary construction system. A new multi-objective GP (MOGP), which was modified from a well-known evolutionary multi-objective optimization (EMO), i.e. non-dominated sorting genetic algorithm 2 (NSGA-II), is proposed. The key modification is that redundancy-regulation mechanisms are introduced into three main steps of non-dominated sorting MOGP, i.e., population truncation, sampling, and offspring generation. The redundancy-regulations can improve not only population diversity, but also the convergence

rate. The proposed MOGP is significantly better than two conventional EMOs, i.e., NSGA-II and strength-Pareto evolutionary algorithm 2 (SPEA2).

Finally, this thesis shows some results of constructed feature extraction programs, compared with human-designed programs. This was in two real-world problems: lawn weed detection and iris segmentation. Experimental results show that the programs that are automatically constructed by the proposed evolutionary construction system are comparable with human-designed programs.