Chapter 8

Conclusion and Future Directions

This chapter summarizes the key findings from the contributions of this thesis. Furthermore, it suggests promising future research directions in the field of EC for large-scale optimization and ML.

8.1 Conclusion

The recent trend demonstrates a paradigm shift from ML to Evolutionary ML (EML) and, more broadly, AI evolution. Despite the remarkable performance of EC methods and their enormous application growth, premature convergence, local optima stagnation, scalability, and poor solution diversity in large-scale optimization problems are still open issues in EC. Many EC methods are not adaptive and stable and limit their ability to modern applications. Thus, the primary objective of this thesis aimed to design efficient optimization techniques that overcome the aforementioned limitations of ECs so that they can be adaptive and suitable for both engineering problems and real-world applications of AI. The present study addresses several bottlenecks in the EC approaches and ML applications. The main concerns addressed and the major contributions of the present study can be summarized as follows:

1. **GDWCN-PSO:** To address the premature convergence and local optima stag-

nation DWCN-PSO, we proposed a GDWCN-PSO by incorporating the operators of GA just after the update process. It increased the convergence ability without losing the diversity of particles and thus improved the performance of DWCN-PSO. It retains the diversity of the particles by the mutating capabilities and the divide and conquer nature of the algorithm. GDWCN-PSO performs better than DWCN-PSO and PSO because of the aforesaid reasons. Further, we have also introduced MGDWCN-PSO to address multi-objective problems. Premature convergence and local optima stagnation have been found to be somewhat resolved by combining the core abilities of two optimizers. The importance of data privacy in smart healthcare services leads us to address this problem as an optimization. So, GDWCN-PSO was used to generate an optimal key by utilizing a specific objective function, and this key was then used to encrypt the medical images. Due to randomization, it is hard to access the key by an adversary or malicious server.

The dynamic formation of a network of particles in GDWCN-PSO may significantly raise the computation in the context of large-scale optimization problems such as feature selection and parameter optimization, necessitating a more adaptable, robust, and effective approach for such real-world problems. SSA is proven to be more effective than PSO. Also, it has characteristics that can be investigated and modified to make modern hybrids while utilizing its strength with other concepts.

2. **QL-SSA:** Local optima stagnation and lack of adaptive, reliable, and stable methods are another major concern in EC, which were addressed by proposing a novel QL-SSA algorithm in this study. In contrast to basic QL, we attempted to identify effective solutions employing cooperative agents (squirrels) in a multi-agent context. Since QL is insensitive to exploration points but not efficient in the exploitation phase, we used QL to enhance the diversity of solutions and exploit the

previous solution's evaluation to achieve superior results in QL-SSA. By modifying the local search of SSA using QL, we tried to overcome local optima stagnation limitations and enhance the stability, adaptiveness, and diversity of solutions. It is validated against crucial combinatorial problems (feature selection) in Big data analysis using ML. QL-SSA is more stable, adaptive, and suitable for solving problems in multi-agent environments. Although it offers a reliable and stable optimizer, computation time has been noted to be high.

3. **CSSA and QCSSA:** Efficient search space representation is one of the avenues which is still unexplored and huge possibilities to address the expensive computation in EC. Multidisciplinary research is also protruding. Quantum computing has exceptional search space representation ability and provides good diversity and making the optimizer suitable for large-scale problems. Another concept, chaos theory, has random, dynamic, non-dynamic, and ergodic properties. Due to its dynamic property, it ensures the different solutions given by algorithms even in the complex multimodal landscape. Three chaotic maps have been investigated in the original SSA, which produced three versions of CSSA. Additionally, we have used quantum computing's qubit representation and gates to maintain effective search capabilities with population diversity, leading to QSSA and QCSSA. Their applicability and effectiveness have been verified on large-scale genomic datasets for optimal feature subset selection and achieved excellent results.

   However, Quantum proposals may seem conceptually hard to understand for applied researchers of the Non-EC domain. This opens new avenues for designing efficient, simple optimization methods for low-cost devices and Non-EC researchers.

4. **MDO and MDO-M:** : A novel MDO was proposed by utilizing the concepts of natural phenomena, namely starling murmuration, the V-shaped flight of migrating birds, and the dispersive migration followed by certain species of birds. In

order to design better search capabilities from the initial point of local search, this study also introduced a population initialization approach rather than considering a random population. It was observed that the proposed algorithm attains significantly accurate results and is sufficiently efficient in terms of search space exploration when compared to the other pre-existing algorithms. The performance of the proposed algorithm was also found to be either better than or on par with nine other optimizers it was compared with. After validating the proposed MDO against benchmarks, we used it for medical data security by using an innovative optimum cryptographic key generation approach that utilized two different objective functions.

Further, MDO-M was proposed for multi-objective optimization problems and tested against test suites on different performance metrics. Both proposals have been applied for optimal feature selection and classification problems. It was observed that MDO attains significantly accurate results and is sufficiently efficient in terms of search space exploration when compared to the other pre-existing algorithms. According to the analysis of benchmarks and feature selection problem, we overcame the constraint of expensive computation by using simple concepts to achieve effectiveness. Compared to the pre-existing optimizers, the proposal drastically reduced computation time while sacrificing minor datasets' accuracy. It appears to be a strong contender and advantageous for low-end devices for making initial assessments for critical tasks.

5. **EMOCGAN:** The major bottleneck with Cyclic-GAN training is training instability, vanishing gradient, and mode collapse. To address these issues, we have introduced a new approach for model training by combining EC, multi-objective optimization, and Cyclic-GAN along with different selection mechanisms, resulting in EMOCGAN. ECs in training help to deal with mode collapse and training instability, while a metropolis acceptance mechanism with Pareto selection over

two objective functions helps to overcome local optima stagnation. It has been validated for unpaired image translation.

6. **QEMCGAN:** The previous model was further extended by introducing an intelligent gradient-aware selection scheme along with three well-known evaluation metrics for Pareto-based selection to generate more realistic and consistent images. QEMCGAN was capable of performing the majority of I2I translation tasks with a single training run. It demonstrated its reliability in reproducing the results shown in this study due to the several randomizations we added to the model training framework. Quantization has been incorporated to make it suitable for future IoT applications. QEMCGAN is quite effective in retaining salient objects, texture, background, and color, leading to more realistic image translation for unpaired images and being capable of generalization in other tasks.

7. **Parallel Corner sort:** Non-dominated sorting is a more computationally expensive step in multi and many-objective optimization. With theoretical analysis, a parallel implementation of Corner Sort has been proposed. Large sequential processes were distributed on multiple threads using CUDA to achieve a lower time complexity.

Overall, the approaches proposed in this thesis are validated on mathematical benchmarks and real-world datasets from various application domains, demonstrating the efficacy of EC techniques on a broader scale.

8.2 Future Directions

It is worth mentioning that the revolution of Industry 4.0 has created a plethora of opportunities in EC. Specifically, Figure 8.1, shows the five potential future directions from three levels in EC. There is still more work to be done on EC and ML. The following are promising future directions that can be explored based on the research work presented in this thesis.

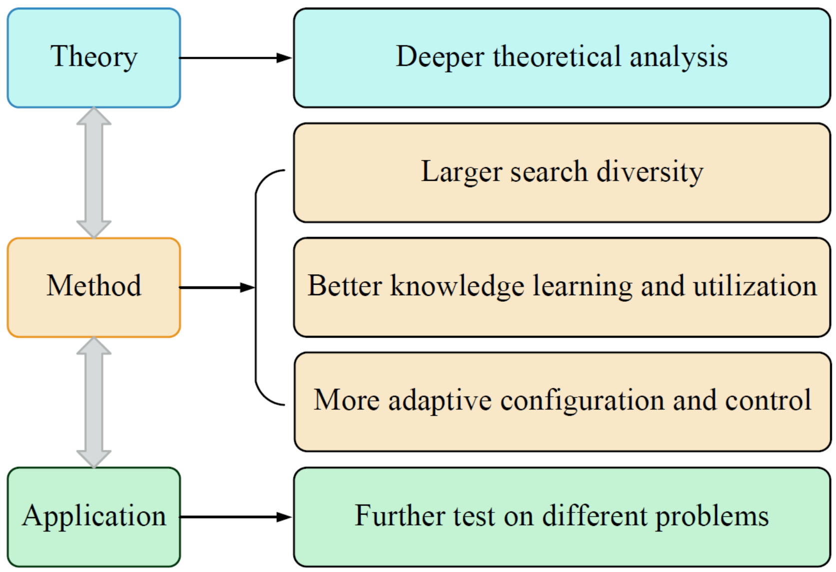

Figure 8.1: Prospective future research directions

1. This study initially focused on designing and developing efficient optimization approaches by addressing the major concerns of EC methods and adapting them to modern complex real-world problems and ML applications. A number of different single-objective optimization techniques are put forth in this study, including GDWCN-PSO, QL-SSA, CSSA, QSSA, QCSSA, and MDO. It will be interesting to investigate these optimizers in the near future in various problems such as resource optimization in wireless sensor networks, traveling salesman problems, link prediction in dynamic networks, optimal route finding for parcel delivery applications, routing problems, and so on.

2. Future studies may focus on how to adapt the proposals made in this thesis to solve image thresholding, steganography, and watermarking in cloud-based applications. Applying these techniques for clustering in high-dimensional data can be another direction that we will be investigating with our proposed algorithm.

3. Investigating CSSA, QCSSA, MDO, and MDO-M for optimal structure learning in deep networks will be worthwhile in the context of advanced ML applications in the near future.

4. QL-SSA is a stable, reliable, and adaptable method. It is well-suited for multi-agent environments, so it is worth investigating its applicability in emotion learning by robots. In this thesis, we have applied the original QL method to modify the local search, which can be improved by experimenting with advanced QL.

5. Using our proposals, we can explore feature selection in large-scale data as a multi-task optimization problem. Besides that, feature selection is a type of multi-modal optimization problem, which means that more than one feature subset can provide comparable performance. It is quite interesting to investigate MDO, MDO-M, QCSSA, CSSA, and other approaches for solving feature selection as a multi-modal multi-task optimization problem.

6. We aim to broaden our research by experimenting with and observing the performance of various hybrid optimization approaches with other different classifiers. We intend to apply and compare the proposals with deep features of the critical disease in order to assess their efficacy in a broader context.

7. Advanced computing, such as parallel computing, can be another possible direction to investigate with QL-SSA, CSSA, and multi-objective proposals MGDWCN-PSO and MDO-M. A parallel version of non-dominated sorting can be experimented with multi-objective proposals.

8. To address scalability issues on large-scale problems, parallel or distributed EML methods can be explored utilizing GPU/CPU architectures that are currently in the early stages of development.

9. Evolutionary transfer learning is another potential research area where EC can

be applied to transfer learning in the near future. The four primary transfer learning approaches, instances transfer, feature representation transfer, parameter transfer, and rational-knowledge transfer, have received little attention in EC. Furthermore, rather than applying transfer learning in EC, the applications of EC to transfer learning are likely to be explored in the future.

10. The proposed models EMOCGAN and QEMCGAN are generalized enough so they can be tested for other potential applications such as image segmentation, inpainting, and other image restoration tasks. Further, achieving many-to-many mapping using our proposals would be another potential future direction. From the perspective of secure modeling, generated images can be used for knowledge distillation with federated learning for designing secure classification models.

11. Surrogate-assisted modeling, ensemble in optimization, large-scale global optimization, and evolutionary federated learning will be interesting areas to investigate with our proposed proposals or other EC approaches.