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研究課題名（和文）簡潔な・利用しやすい構造を有する学習ネットワークの構成と応用に関する研究

研究課題名（英文）Study on Succint Learning Networks and its Applications

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研究成果の概要（和文）：本研究では簡潔な構造を持つ学習ネットワークとその応用を行った。一方では、最先端の効率を達成する有向ネットワーク、無向ネットワーク、モジュラーネットワークおよび可変サイズネットワークの簡潔な構造が可能になった。そして経路計画とCAD問題における応用は提案したアルゴリズムの優れた性能、効率とスケーラビリティを示すことを明らかにした。

研究成果の学術的意義や社会的意義
Succinct learning networks bring the unique benefits of representational economy, algorithmic versatility and conceptual clarity when encoding richer and complex knowledge structures through graphs, rendering improved approaches when tackling complex problems in control and design.

研究成果の概要（英文）：In this research, learning networks with succinct structures and their applications were conducted. In one hand, succinct structures for directed networks, undirected networks, modular networks and variable-size networks achieving the state of the art efficiency were made possible. And the applications in path planning and CAD problems have shown the excellent performance, efficiency and scalability of the proposed algorithms.

研究分野：工学

キーワード：learning　networks　graph representation　optimization　network design　product design　path planning　evolutionary computing

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９、ＣＫ－１９（共通）

１．研究開始当初の背景

(1) Representations enabling the efficient and scalable computation and modelling with learning networks in complex problems are relevant to formulate effective solutions to control and design. The study of network representations using concurrency and synchrony is potential to allow succinct encodings allowing new and improved sampling, storage, transmission, design, and (machine) learning using network representations.

(2) Large scale problems involving the control, the planning and the design of machines suffer from limited scalability and performance due to the conventional modelling approaches. The study of synchrony and concurrency in network-based control and computer-aided design problems is potential to expand the performance and scalability frontiers of control, planning and design.

２．研究の目的

This research aims at constructing algorithms to compute and learn with succinct networks using concurrency and synchrony, and let evolve their structures for applications in robot control and computer-aided design problems.

３．研究の方法

(1) Structure of Succinct Networks

The succinct representations using concurrency and synchrony of network structures were developed. In particular, the state-of-the-art succinct representations of directed networks, undirected networks, modular networks and variable-size networks were proposed.

(2) Applications

The applications underlying succinct learning networks using synchrony and concurrency in directed, undirected, modular and variable-size learning networks for robot control and computer-aided design problems were proposed. In particular, the applications in path planning, aesthetic design, network design, and the data-driven parametric design of vehicle layouts were proposed.

４．研究成果

The algorithms and applications underlying succinct learning networks for computer-aided design and path planning were developed:

(1) Succinct representation of graph structures. New algorithms for computing the succinct, canonical and efficient representation of directed graphs, undirected graphs, graphs with self-loops, modular graphs and large/distributed graphs were developed. The newly developed algorithms enable, for the first time, graph encoding using integer numbers, achieving the encoding/decoding efficiency with space being equivalent to the theoretical tight bounds. Also, the decoding efficiency outperforms the state-of-the-art graph representation techniques both using a single processor and multiple processors in parallel. The above enables the utmost efficiency in involving network sampling, storage, transmission, design, and (machine) learning. For instance, in some scenarios, it becomes possible to encode large graphs with 1 bit. The achievements in this line of work also enables using number theory into network-based learning algorithms, rendering a new and improved approach to “learning” of graphical models in control problems.

(2) Aesthetic Design. The foundations and the application on computer-aided design on aesthetic surfaces were stablished. We designed and evaluated novel curvature metric which performs faster (124x improvement compared to the state of art) and producing significantly smoother surfaces compared to the conventional metrics.

(3) Parametric Design. The algorithmic framework for parametric design of new and high-performing product layouts, and its application of vehicle design schemes, under historic real-world data were stablished and rigorously evaluated. This work streamlined the use of past data to evaluate novelty and performance in parametric conceptual designs, avoiding the use of inaccurate simulations or expensive real-world experiments, e.g. in vehicle design problem.

(4) An efficient algorithm for the optimization of ZigBee network topologies was proposed for the first time. This achievement enables the efficient construction of low-cost networks for the Internet of Things. This work also stablished the foundation for developing network-based learning algorithms with optimal / efficient communication topologies.

(5) The concept of concurrency and parallelism were streamlined into the design of a small-scale,

low-cost sensor that detects the inclination of the arm accurately, and into the learning networks for (prosthetic) hand robotic interfaces and human activity recognition. The achieved result makes possible the construction of affordable sensor interfaces for amputees and enables the highest accuracy in challenging testing environments for state recognition of (prosthetic) robotic hand, and human activity recognition.

(6) The new self-adaptive algorithms for bundling multiple routes in a polygonal map were proposed. This work enables faster and efficient composition of multiple paths into a single compounded route by finding optimal anchoring points at intermediate joints, which serve as coordinating locus for resource-efficient transport of information/goods/people under obstacle-constrained environments. This work has potential applications to enable adaptive and energy-efficient logistics, communication and distributed control.

(7) The new algorithms for path planning using log-aesthetic curves were proposed. This work enables path planning for autonomous mobile navigation systems with safety/efficiency considerations, minimizing the (variation) of curvature along the curved paths in environments consisting of convex and non-convex polygonal maps. The achieved results demonstrated the feasibility and the computational efficiency compared to the conventional energy-based methods.

(8) The k-subset sum problem was formulated and tackled for the first time as a search (optimization) problem based on enumerative encoding. This work realizes the practical/efficient algorithms for combinatorial and planning problems involving modularity, resource allocation and management, cooperative work and reliability planning.

(9) The new algorithms that enable the construction of robot trajectories that pass through (data-driven) anchoring points were proposed. This work enables to generate feasible trajectories by compounding paths which minimize curvature and fitting to fair curves given inputs of trajectories of real-world robotic hardware. This work enables the construction of computationally efficient robot controllers, avoiding the need of expensive trajectory tracking.

(10) The new algorithmic frameworks computing minimal-length tree layouts given n nodes in a polygonal map were proposed. This work enables to construct minimal-length network layouts while preserving a hierarchical topology by using nature-inspired concepts for the first time. The rigorous computational experiments using a diverse set of polygonal maps and configuration of nodes shows the feasibility and efficiency of our approach, achieving a quasi-linear time complexity. The achieved results have potential applications towards the realization of efficient and adaptive routing of resources in networked systems. Also, the proposed algorithms are useful to compute topologically compact, and clutter-free network layouts, which has potential applications to enable efficient coordination of multi-agent systems in cluttered environments.

(11) The new algorithms using modularity concepts to bias the formation of ensembles in network design and path planning problems were proposed. In computer-aided design, the achievements allow to construct modular network ensembles which enable the identification of granular design layouts effectively. In path planning, this work realizes the network-based and non-overlapped distributed control of multi-robot systems. Furthermore, the newly developed algorithms enhanced the scalability, achieving quasi-linear computational efficiency as a function of number of nodes in the system.

(12) The frameworks to enable the representation of general combination objects succinctly, realizing the utmost performance in time and space complexity were proposed. This work is useful to allow sampling and handling of combinatorial objects with utmost efficiency, in which for combinations of n elements taken m at the time, the decoding and the encoding shows performance depending on m only. Also, this achievement has potential to enable the representation and sampling of large-scale combinatorial where n is very large compared to m. Furthermore, the achieved results bring useful applications to allow canonical sampling in combinatorial optimization, being potential to construct efficient gradient-free optimization algorithms for NP-hard combinatorial problems.

(13) The algorithms using learning networks with variable size in the data-driven design of vehicle layouts were proposed, enabling the new vehicle models outperforming the frontiers of mileage consumption. The achieved results allows to identify modules in vehicle clusters, enabling the finer personalization and analysis of novelty and performance. This work is useful to allow the market and data-driven design of unique and high-performing product layouts with utmost efficacy.

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〔**その他**〕

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６．研究組織

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