Nominativo dell’assegnista di ricerca: Luca Prigioniero

Titolo dell’assegno di ricerca: Automata and Formal Languages meet Reversibility: Understanding Theory to Improve Computations

Specificare se si tratta di assegno di ricerca di tipo A o di tipo B: Tipo A

Docente referente: Prof. Giovanni Pighizzini

Durata del contratto: dal 1/3/2020 al 28/2/2024

Periodo di riferimento della relazione: dal 1/3/2022 al 28/2/2023

Obiettivi della ricerca:
- Investigation of reversibility in computations and devices.
- Study of formal systems from the descriptional complexity point of view.

Risultati della ricerca:

Reversibility
Reversibility allows computations to proceed not only in the standard, forward direction, but also backward, recovering past configurations. While reversible computations have attracted interest for their multiple applications, covering different areas as low-power computing, simulation, robotics, and debugging, such applications need to be supported by a clear understanding of the foundations of reversible computation.

In this regard, we relaxed the definition of reversibility, by considering finite automata whose computations can be reversed, at any point, by accessing the last k symbols read from the input, for a fixed k. These devices are said to be “weakly irreversible”. We characterized the languages accepted by weakly irreversible automata and languages not having any weakly irreversible automaton (“strongly irreversible” languages).

Descriptional complexity and computation devices
We pursued the investigation on descriptional complexity of devices characterizing the class of regular languages.

In particular, we deepened the study on 1-limited automata: linear bounded automata allowed to rewrite the contents of each tape cell only during the first visit. These machines characterize the class of regular languages. However, 1-limited automata can be significantly more succinct than equivalent finite automata. We presented and discussed some languages which can be used as witnesses of the exponential gaps between different kinds of 1-limited automata and finite automata.

Moreover, we investigated the descriptional complexity of basic language operations using 1-limited automata. When simulating operations on deterministic finite automata with deterministic 1-limited automata, the sizes of the resulting devices are polynomial in the sizes of the simulated machines. The situation is different when the operations are applied on deterministic 1-limited automata: while for boolean operations the simulations remain polynomial, for product, star, and reversal they cost exponential in size. These bounds are tight.

Furthermore, we studied the costs of the conversions of nondeterministic finite automata into some variants of one-tape deterministic Turing machines working in linear time. All these variants are known to
share the same computational power: They characterize the class of regular languages. However, we showed that these machines can simulate nondeterministic finite automata, even in the two-way variant, paying only a polynomial increase of size. This study contributes to the longstanding Sakoda and Sipser question, about the cost, in terms of size of representations, of the transformation of two-way and one-way nondeterministic automata into equivalent two-way deterministic automata. In fact, we presented a new approach in which nondeterministic automata are simulated by deterministic models extending two-way deterministic automata.

We also focused on classical pushdown automata (in which there is no fixed bound on the size of the store), and we studied their space complexity, that is the relationships between the input length and amount of space used along their computations. In particular, we proved that it cannot be decided whether a pushdown automaton accepts using a pushdown height which does not depend on the input length, i.e., when it accepts using constant pushdown height. Furthermore, when a pushdown automaton accepts in constant height, the height of the pushdown can be arbitrarily large with respect to the size of the description of the machine. In contrast, in the unary case, acceptance in constant height is decidable and, if an automaton accepts using constant pushdown height, the height is at most exponential with respect to the size of the description of the pushdown automaton. Finally, we extended this study to one-counter automata.

Obiettivi che si intendono raggiungere nel prossimo futuro:

In the literature are present some computational devices that have not been studied from the descriptional complexity point of view. We conjecture that, using the techniques we developed for studying models describing the class of regular languages, we will be able to extend our results to such devices. Moreover, we plan to study the time and space complexity of computational devices more powerful than finite automata.

Attività da svolgere nel prossimo futuro:

- Study of descriptional complexity of extensions and restrictions of models considered in the first part of the project
- Investigation of decidability properties of extensions and restrictions of models considered in the first part of the project
- Study of time and space complexity of extensions and restrictions of models considered in the first part of the project

Some of the devices that we plan to study are counter automata, queue automata, real-time machines, etc.

Attività svolte:

Peer reviewer for the conferences
- Developments in Language Theory 2022,
- Descriptive Complexity of Formal Systems 2022,
- Conference on Implementation and Application of Automata 2022,

and for the journals
- Theoretical Computer Science and
Prodotti della ricerca conseguiti:


Descrizione dell’attività di ricerca svolta all’estero (eventuale; specificare: periodo, luogo, affiliazione):

- **January 2023 – University of Liège, Department of Mathematics**
  
  During this visit, we studied the magic numbers problem applied to periodic sequences. In formal languages and automata theory, the magic number problem can be formulated as follows: for a given integer n, is it possible to find a number d in the range \([n, 2^n]\) such that there is no minimal deterministic finite automaton with d states that can be simulated by an optimal nondeterministic finite automaton with exactly n states? If such a number d exists, it is called magic. We considered the magic number problem in the framework of deterministic automata with output, which are known to characterize automatic sequences. More precisely, we characterized magic numbers for periodic sequences viewed as either automatic, regular, or constant-recursive.

- **February-March 2023 – Carnegie Mellon University Qatar, School of Computer Science**
  
  During this scientific stay, we deepened topics in descriptional complexity, including open questions about the size and the time complexity of limited one-tape Turing machines (limited automata, two-way finite automata, etc.) in various modes of operation (deterministic, alternating, etc.).

Data 14/3/2023

Il Responsabile Scientifico

(Firmato digitalmente)

L’ Assegnista di Ricerca

(Firmato digitalmente)

La presente relazione, non contiene dati sensibili e dati giudiziari di cui all’art. 4, comma 1, lettere d) ed e) del D.Lgs. 30.6.2003 n. 196.

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