Advanced Topics in Theoretical Computer Science

Other Models of Computability

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Other computation models

- Variations of register machines (one register; two registers)
- Variations of TM; links with register machines
- Reversible computations: e.g. chemical reversibility or reversibility as in physics
- DNA Computing and Splicing
  Computing machines consisting from enzymes and molecules
- Quantum Computing

Other computation models

- Variations of register machines (one register; two registers)

One-register register machines with WHILE/GOTO programs compute the same functions as normal register machines.

Similar results for two-register register machines.

Proofs: Erk & Priese Theoretische Informatik pages 327-336.

Other computation models

- Variations of TM; links with register machines

- TM with restricted alphabet (2 Letters)
- TM over an alphabet $\{\#, 1\}$, such that every configuration contains 1 exactly 3 times
- Wang machines (empty fields can be written; written fields cannot be changed)

Equally powerful as TM

Proofs: Erk & Priese, Theoretische Informatik pages 336ff.

Other computation models

- Reversible computations: chemical and psysical reversibility

Each computation step: possible in both directions.

- **Chemical reversibility:** Analogous to chemical reactions;
  Model – very nondeterministic:
  A state can have many successors and many predecessors.
  Every step has to be executable also in the reversed direction.
- **Physical reversibility:** Analogous to physical phenomena;
  Model – deterministic:
  Actual state determines not only the future development but also the past.
  $\mapsto$ Important for understanding quantum computing.

Abstract computability models:

- Chemically reversible asynchroneous automata/nets
  - Chemically reversible Rödding Nets: as strong as TMs
    (Definition and Proofs: Erk, Priese, Pages 351-378; 393-404)
  - Chemically reversible grammars; link with Thue Systems (Erk,Priese: 405-411) -

Physically reversible TMs: as strong as TMs (Remark & Trick: Erk,Priese, Page 390)

Other computation models

- DNA Computing and Splicing
  Computing machines consisting from enzymes and molecules

Exploring the computational power of biological molecules, in particular DNA.

A DNA computer represents information as a pattern of molecules in a strand of DNA. That information is manipulated by subjecting it to "precisely designed chemical reactions that may mark the strand, lengthen it, or even destroy it" (Kierman).

$\mapsto$ can simulate TM

Other computation models

- Quantum Computing

Quantum computing is the exploitation of collective properties of quantum states, such as superposition and entanglement, to perform computation.

Various models, including quantum TM (a variation on probabilistic TMs)

(In a probabilistic Turing machine (PTM) we characterise the computer's choices by associating a particular probability with each of its possible transitions)

$\mapsto$ as powerful as TMs

For more informations: `https://plato.stanford.edu/entries/qt-quantcomp/`

Other computation models

- Quantum Computing

While quantum computers provide no additional advantages over TMs in terms of computability, quantum algorithms for certain problems have significantly lower time complexities than corresponding known classical algorithms.

$\mapsto$ The study of the computational complexity of problems with respect to quantum computers is known as quantum complexity theory.

For more informations: `https://plato.stanford.edu/entries/qt-quantcomp/`

Other computation models

- Quantum Computing

Do physical processes exist which contradict the (physical) Church-Turing thesis?

- Examples purporting to show that the notion of recursion, or Turing-computability, is not a natural physical property:
  (Pour-El and Richards 1981), (Pitowsky 1990), (Hogarth 1994)
- Hypercomputability $\mapsto$ computing non-TM-computable functions

  Attempt to use a "quantum adiabatic algorithm" to solve Hilbert's Tenth Problem [Kieu 2002, 2004] (TM-undecidable, equivalent to the halting problem).
- Criticism: unphysical character of the alleged quantum adiabatic hypercomputer (see [Hodges 2005]; [Hagar and Korolev 2007]).

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Variants of automata

- Tree automata
- Automata over infinite words

Variants of automata

Tree automata

Like automata, but deal with tree structures, rather than the strings.

Tree automata are an important tool in computer science:

- compiler construction
- automatic verification of cryptographic protocols.
- processing of XML documents.

Variants of automata

Automata on infinite words (or more generally: infinite objects)

ω-Automata (Büchi automata, Rabin automata, Streett automata, parity automata and Muller automata)

- run on infinite, rather than finite, strings as input.
- Since ω-automata do not stop, they have a variety of acceptance conditions rather than simply a set of accepting states.

Applications: Verification, temporal logic

Look forward

Next semesters:

SoSe 2022:

- Seminar: Decision procedures and applications $\mapsto$ emphasis on decidability and complexity results for various application areas.

WiSe 2022/23:

- Lecture: Decision procedures for verification
- Lecture: Non-classical logics

Various possibilities for BSc/MSc thesis and Forschungspraktika.