Computation with Absolutely No Space Overhead

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Developments in Language Theory Conference, 2003

Outline

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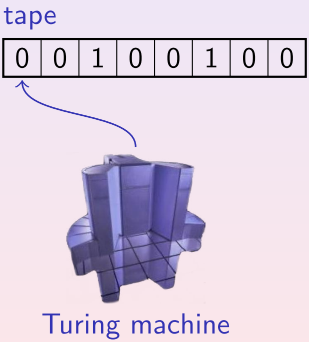
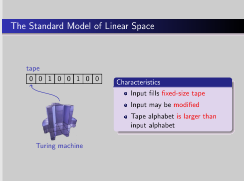
The Standard Model of Linear Space



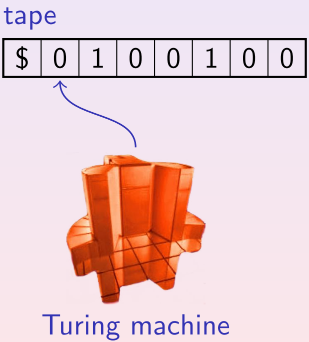
Characteristics

- Input fills fixed-size tape
- Input may be modified
- Tape alphabet is larger than input alphabet



1. Point out that \$ is a marker symbol.
2. Stress the larger tape alphabet.

The Standard Model of Linear Space



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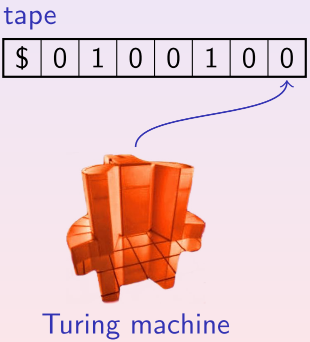

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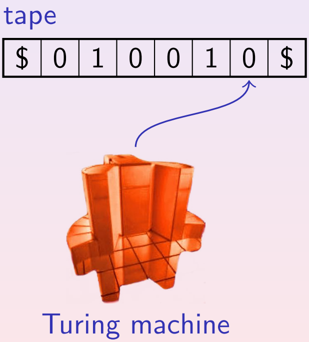

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The Standard Model of Linear Space

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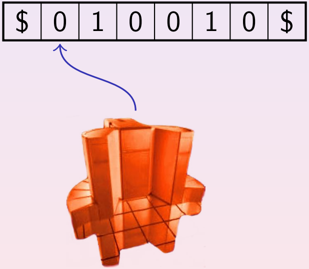

Turing machine

Characteristics

- Input fills fixed-size tape
- Input may be modified
- Tape alphabet is larger than input alphabet

The Standard Model of Linear Space

tape

$	$	1	0	0	1	0	$

Turing machine

Characteristics

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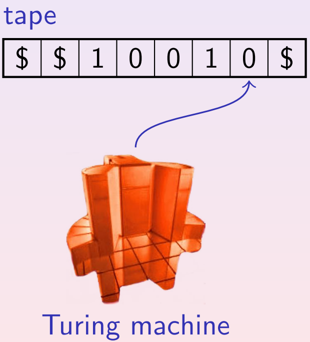
The Standard Model of Linear Space



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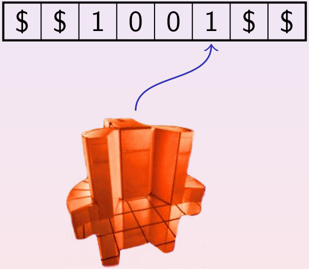

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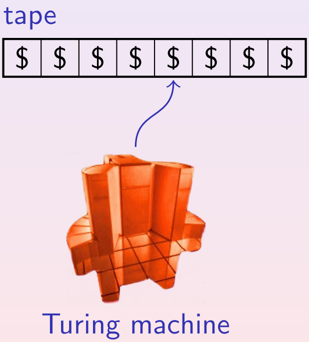

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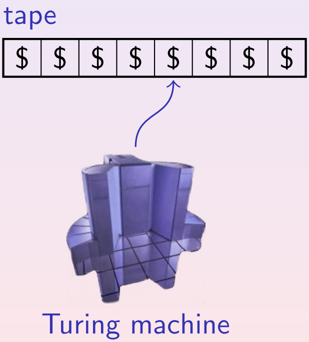

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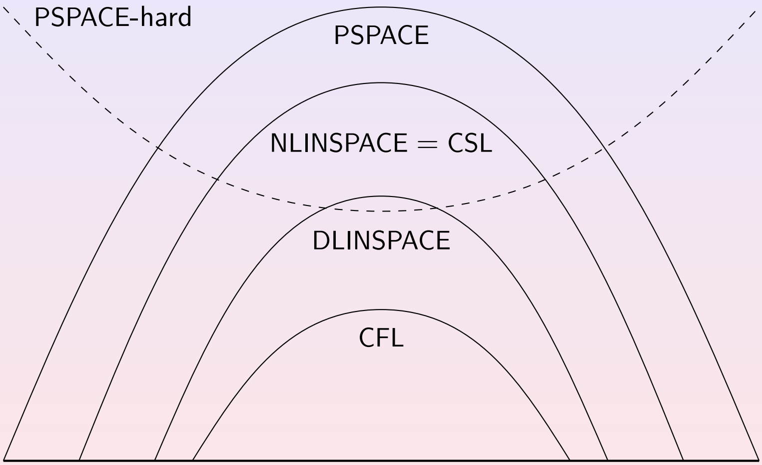
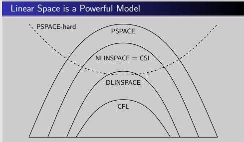
Linear Space is a Powerful Model

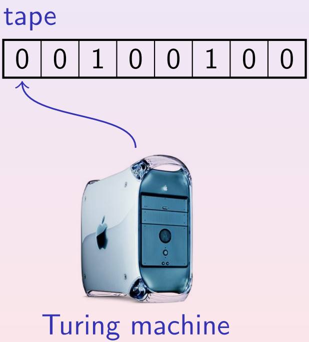




1. Explain CSL.
2. Point out the connections to formal language theory.

Outline

Our Model of “Absolutely No Space Overhead”



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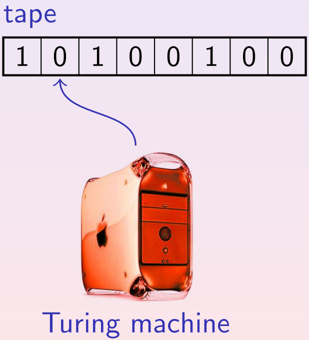

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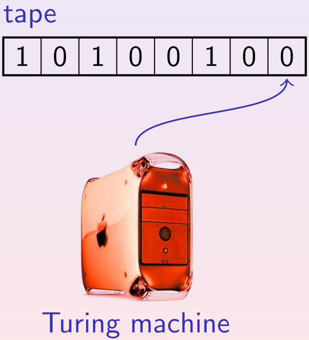

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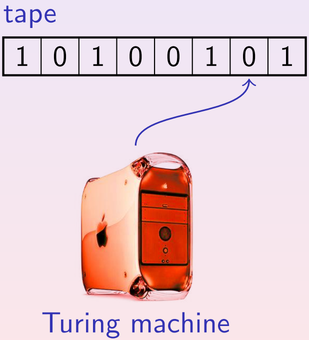

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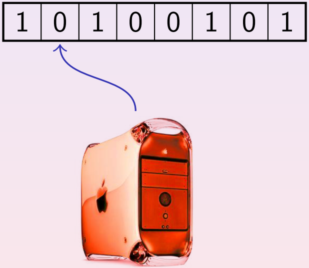

Turing machine

Characteristics

- Input fills fixed-size tape
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Our Model of "Absolutely No Space Overhead"

tape

1	1	1	0	0	1	0	1

Turing machine

Characteristics

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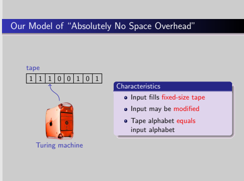
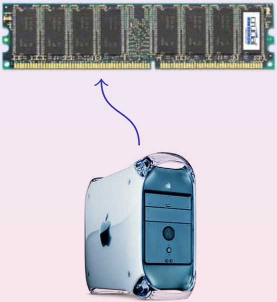


1. Point out that no markers are used.

Our Model of “Absolutely No Space Overhead”



Turing machine

Intuition

- Tape is used like a RAM module.

Definition of Overhead-Free Computations

Definition

A Turing machine is overhead-free if

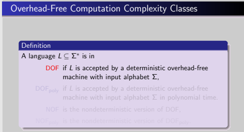
1. it has only a single tape,
2. writes only on input cells,
3. writes only symbols drawn from the input alphabet.

Overhead-Free Computation Complexity Classes

Definition

A language $L \subseteq \Sigma^*$ is in

- DOF if L is accepted by a deterministic overhead-free machine with input alphabet Σ,
- $\mathrm{DOF}_{\mathrm{poly}}$ if L is accepted by a deterministic overhead-free machine with input alphabet Σ in polynomial time.
- NOF is the nondeterministic version of DOF,
- $\mathrm{NOF}_{\mathrm{poly}}$ is the nondeterministic version of $\mathrm{DOF}_{\mathrm{poly}}$.



1. Joke about German pronunciation

Overhead-Free Computation Complexity Classes

Definition

A language $L \subseteq \Sigma^*$ is in

- **DOF** if L is accepted by a deterministic overhead-free machine with input alphabet Σ,
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- **NOF** is the nondeterministic version of DOF,
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Overhead-Free Computation Complexity Classes

Definition

A language $L \subseteq \Sigma^*$ is in

- DOF if L is accepted by a deterministic overhead-free machine with input alphabet Σ,
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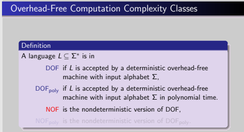

1. Stress meaning of D and N.

Overhead-Free Computation Complexity Classes

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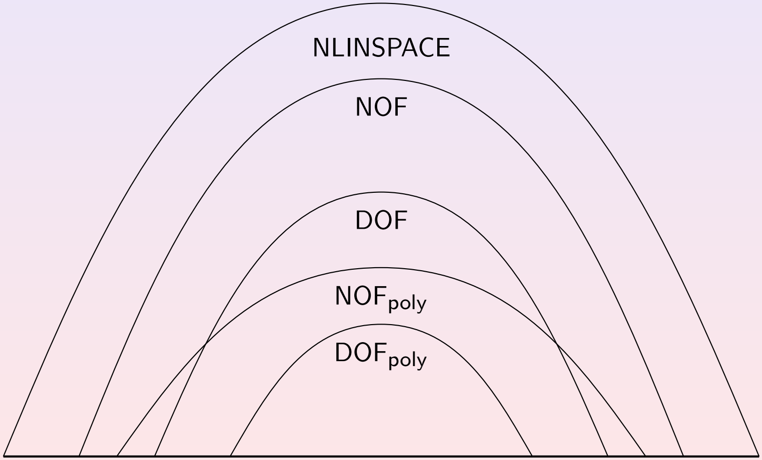
Simple Relationships among Overhead-Free Computation Classes

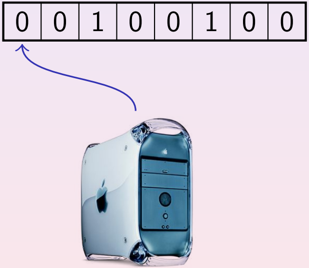


Outline

1. The Model of Overhead-Free Computation
   - The Standard Model of Linear Space
   - Our Model of Absolutely No Space Overhead
2. The Power of Overhead-Free Computation
   - Palindromes
   - Linear Languages
   - Context-Free Languages with a Forbidden Subword
   - Languages Complete for Polynomial Space
3. Limitations of Overhead-Free Computation
   - Linear Space is Strictly More Powerful

Palindromes Can be Accepted in an Overhead-Free Way

tape

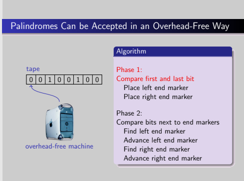


overhead-free machine

Algorithm

Phase 1:
Compare first and last bit
- Place left end marker
- Place right end marker

Phase 2:
Compare bits next to end markers
- Find left end marker
- Advance left end marker
- Find right end marker
- Advance right end marker



Use 3 minutes.

Palindromes Can be Accepted in an Overhead-Free Way

tape

1	0	1	0	0	1	0	0

overhead-free machine

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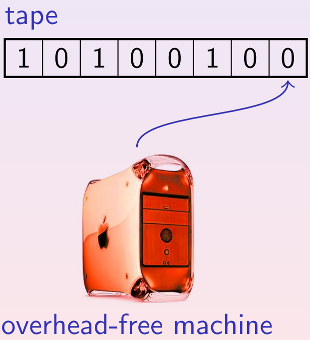

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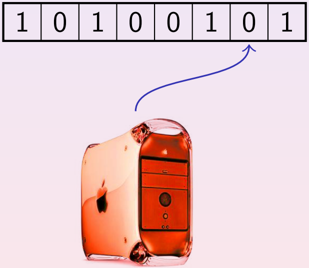

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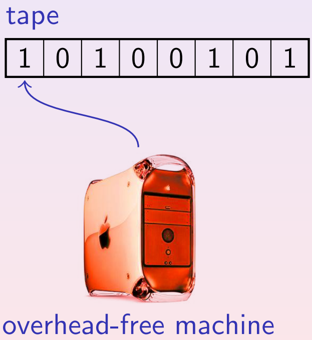

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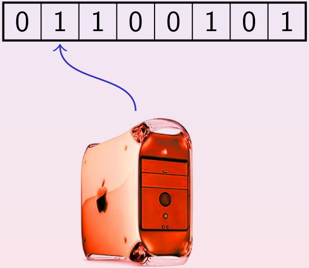

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Palindromes Can be Accepted in an Overhead-Free Way

tape

0	1	1	0	0	1	0	1

overhead-free machine

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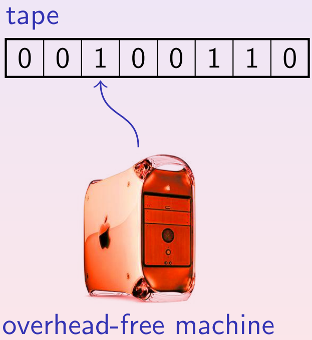

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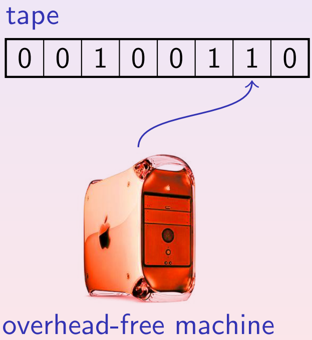

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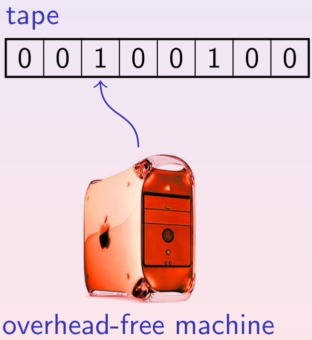

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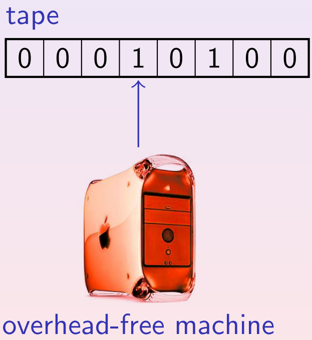

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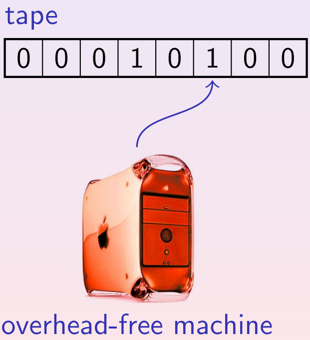

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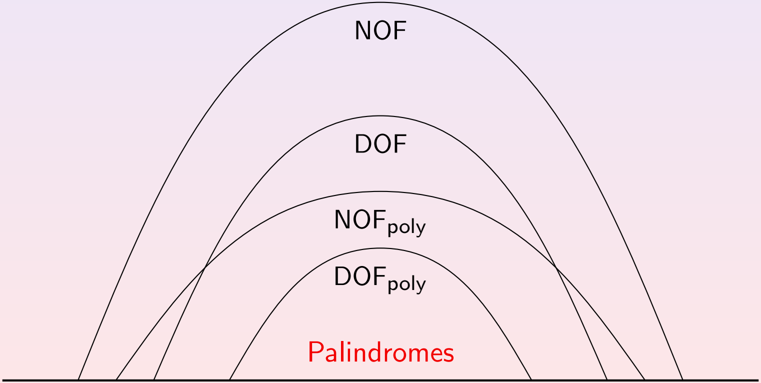
Relationships among Overhead-Free Computation Classes



Outline

A Review of Linear Grammars

Definition

A grammar is linear if it is context-free and
there is only one nonterminal per right-hand side.

Example

$G_1 \colon S \rightarrow 00S0 \mid 1$ and $G_2 \colon S \rightarrow 0S10 \mid 0$.

Definition

A grammar is deterministic if
"there is always only one rule that can be applied."

Example

$G_1 \colon S \rightarrow 00S0 \mid 1$ is deterministic.
$G_2 \colon S \rightarrow 0S10 \mid 0$ is not deterministic.

A Review of Linear Grammars

Definition

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$G_1 : S \rightarrow 00S0 \mid 1$ and $G_2 : S \rightarrow 0S10 \mid 0$.

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Just explain intution.

Deterministic Linear Languages Can Be Accepted in an Overhead-Free Way

Theorem

Every deterministic linear language is in $\mathrm{DOF}_{\mathrm{poly}}$.

Metalinear Languages Can Be Accepted in an Overhead-Free Way

Definition

A language is metalinear if it is the concatenation of linear languages.

Example

$\text{TRIPLE-PALINDROME} = \{uvw \mid u, v, \text{ and } w \text{ are palindromes}\}$.

Theorem

Every metalinear language is in $\mathrm{NOF}_{\mathrm{poly}}$.

Metalinear Languages Can Be Accepted in an Overhead-Free Way

Definition

A language is metalinear if it is the concatenation of linear languages.

Example

$\text{TRIPLE-PALINDROME} = \{uvw \mid u, v, \text{ and } w \text{ are palindromes}\}$.

Theorem

Every metalinear language is in NOF_{poly}.

Metalinear Languages Can Be Accepted in an Overhead-Free Way

Definition

A language is metalinear if it is the concatenation of linear languages.

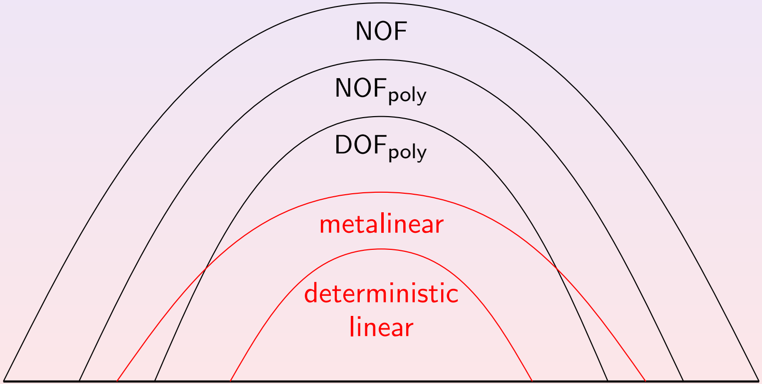
Example

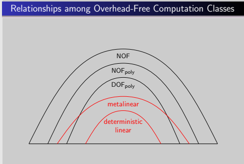
$\text{TRIPLE-PALINDROME} = \{uvw \mid u, v, \text{ and } w \text{ are palindromes}\}.$

Theorem

Every metalinear language is in $\mathrm{NOF}_{\mathrm{poly}}$.

Relationships among Overhead-Free Computation Classes





1. Skip next subsection if more than 18 minutes have passed.

Outline

Definition of Almost-Overhead-Free Computations

Definition

A Turing machine is almost-overhead-free if

1. it has only a single tape,
2. writes only on input cells,
3. writes only symbols drawn from the input alphabet plus one special symbol.

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Context-Free Languages with a Forbidden Subword Can Be Accepted in an Overhead-Free Way

Theorem

Let L be a context-free language with a forbidden word. Then $L \in \mathrm{NOF}_{\mathrm{poly}}$.

Skip proof

Context-Free Languages with a Forbidden Subword Can Be Accepted in an Overhead-Free Way

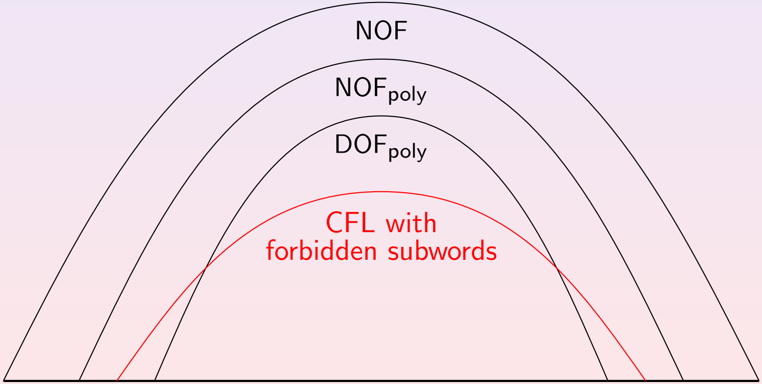
Theorem

Let L be a context-free language with a forbidden word. Then $L \in \mathrm{NOF}_{\mathrm{poly}}$.

Proof.

Every context-free language can be accepted by a nondeterministic almost-overhead-free machine in polynomial time. ∎

Relationships among Overhead-Free Computation Classes



Outline

1. The Model of Overhead-Free Computation
   - The Standard Model of Linear Space
   - Our Model of Absolutely No Space Overhead
2. The Power of Overhead-Free Computation
   - Palindromes
   - Linear Languages
   - Context-Free Languages with a Forbidden Subword
   - Languages Complete for Polynomial Space
3. Limitations of Overhead-Free Computation
   - Linear Space is Strictly More Powerful

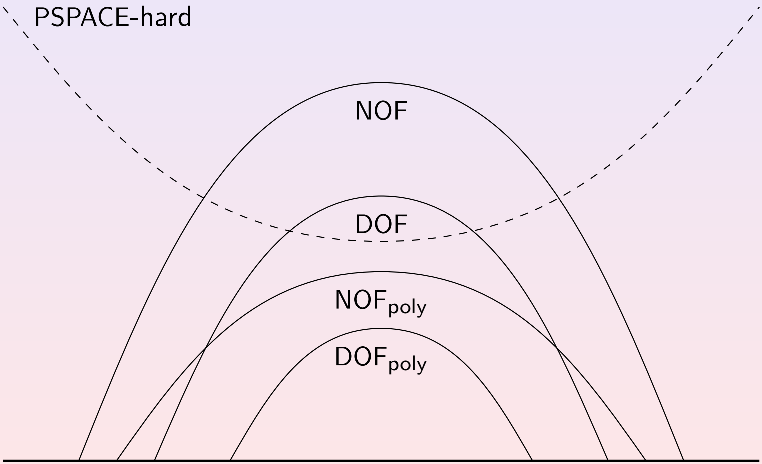
Overhead-Free Languages can be PSPACE-Complete

Theorem

DOF *contains languages that are complete for* PSPACE.

Proof details

Relationships among Overhead-Free Computation Classes



Outline

Some Context-Sensitive Languages Cannot be Accepted in an Overhead-Free Way

Theorem

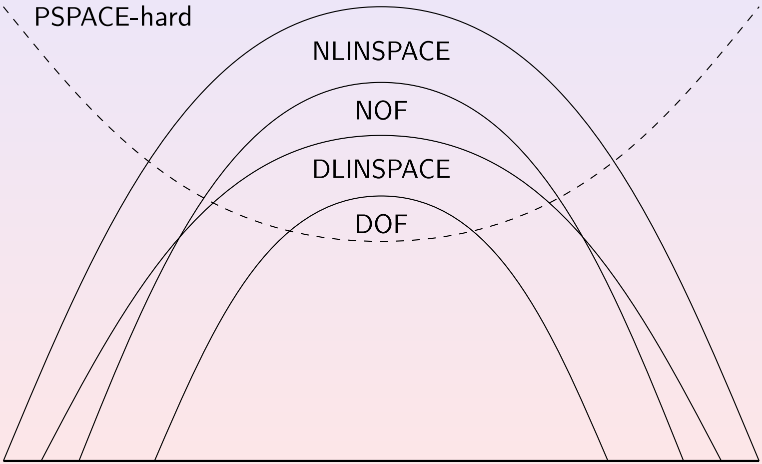
$\mathrm{DOF} \subsetneq \mathrm{DLINSPACE}$.

Theorem

$\mathrm{NOF} \subsetneq \mathrm{NLINSPACE}$.

The proofs are based on old diagonalisations due to Feldman, Owings, and Seiferas.

Relationships among Overhead-Free Computation Classes



Candidates for Languages that Cannot be Accepted in an Overhead-Free Way

Conjecture

DOUBLE-PALINDROMES $\notin$ DOF.

Conjecture

$\{ww \mid w \in \{0,1\}^*\} \notin$ NOF.

Proving the first conjecture would show DOF $\subsetneq$ NOF.

Candidates for Languages that Cannot be Accepted in an Overhead-Free Way

Theorem

DOUBLE-PALINDROMES $\in$ DOF.

Conjecture

$\{ww \mid w \in \{0,1\}^*\} \notin$ NOF.

Proving the first conjecture would show DOF $\subsetneq$ NOF.

Summary

- Overhead-free computation is a more faithful model of fixed-size memory.
- Overhead-free computation is less powerful than linear space.
- Many context-free languages can be accepted by overhead-free machines.
- We conjecture that all context-free languages are in $\mathrm{NOF}_{\mathrm{poly}}$.
- Our results can be seen as new results on the power of linear bounded automata with fixed alphabet size.

- Overhead-free computation is a more faithful model of fixed-size memory.
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- We conjecture that all context-free languages are in $\mathrm{NOF}_{\mathrm{poly}}$.
- Our results can be seen as new results on the power of linear bounded automata with fixed alphabet size.

1. Point out result concerning all context-free languages.
2. Relationship to restart automata.

For Further Reading

A. Salomaa.
Formal Languages.
Academic Press, 1973.

E. Dijkstra.
Smoothsort, an alternative for sorting in situ.
Science of Computer Programming, 1(3):223–233, 1982.

E. Feldman and J. Owings, Jr.
A class of universal linear bounded automata.
Information Sciences, 6:187–190, 1973.

P. Jančar, F. Mráz, M. Plátek, and J. Vogel.
Restarting automata.
FCT Conference 1995, LNCS 985, pages 282–292, 1995.

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Appendix Outline

4. Appendix
   - Complete Languages
   - Improvements for Context-Free Languages
   - Abbreviations

Overhead-Free Languages can be PSPACE-Complete

Theorem

DOF *contains languages that are complete for* PSPACE.

Proof.

1. Let $A \in$ DLINSPACE be PSPACE-complete.
   Such languages are known to exist.
2. Let M be a linear space machine that accepts $A \subseteq \{0,1\}^*$ with tape alphabet Γ.
3. Let $h\colon \Gamma \to \{0,1\}^*$ be an isometric, injective homomorphism.
4. Then $h(L)$ is in DOF and it is PSPACE-complete. ∎

Return

Improvements

Theorem

1. $\mathrm{DCFL} \subseteq \mathrm{DOF}_{\mathrm{poly}}$.
2. $\mathrm{CFL} \subseteq \mathrm{NOF}_{\mathrm{poly}}$.

Explanation of Different Abbreviations

DOF	Deterministic Overhead-Free.
NOF	Nondeterministic Overhead-Free.
$\mathrm{DOF}_{\mathrm{poly}}$	Deterministic Overhead-Free, polynomial time.
$\mathrm{DOF}_{\mathrm{poly}}$	Nondeterministic Overhead-Free, polynomial time.

Table: Explanation of what different abbreviations mean.