Computation with Absolutely No Space Overhead

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Outline

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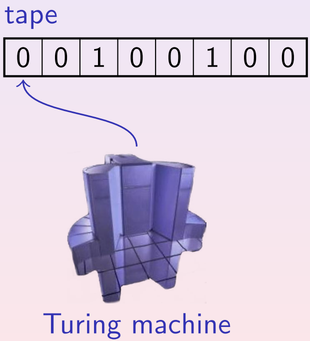
The Standard Model of Linear Space



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

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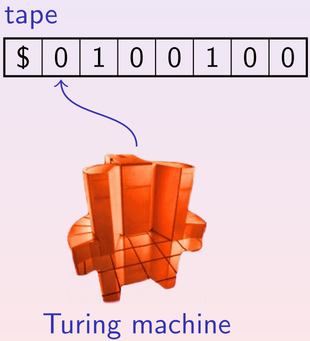

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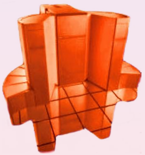

Turing machine

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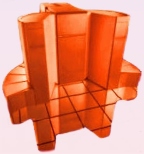

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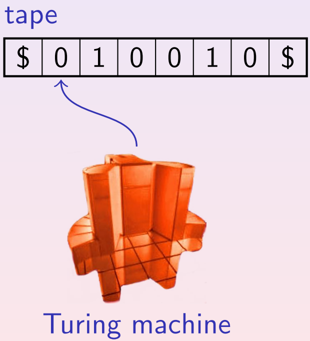

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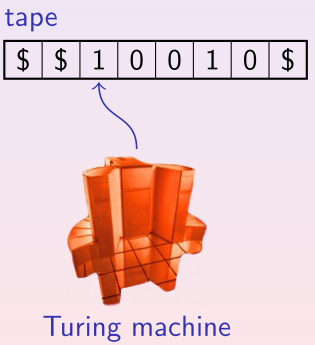

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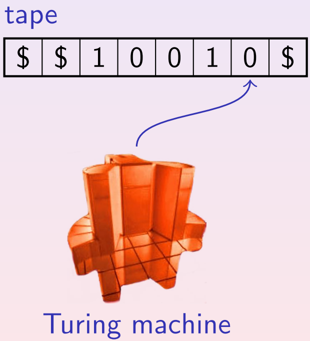

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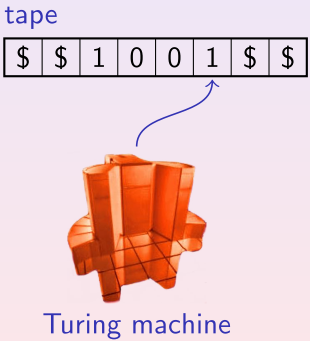

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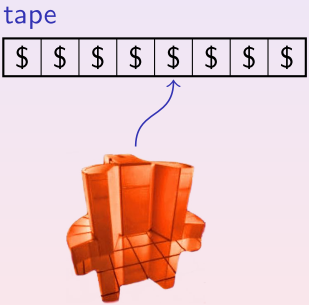

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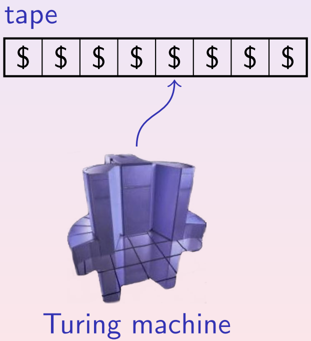

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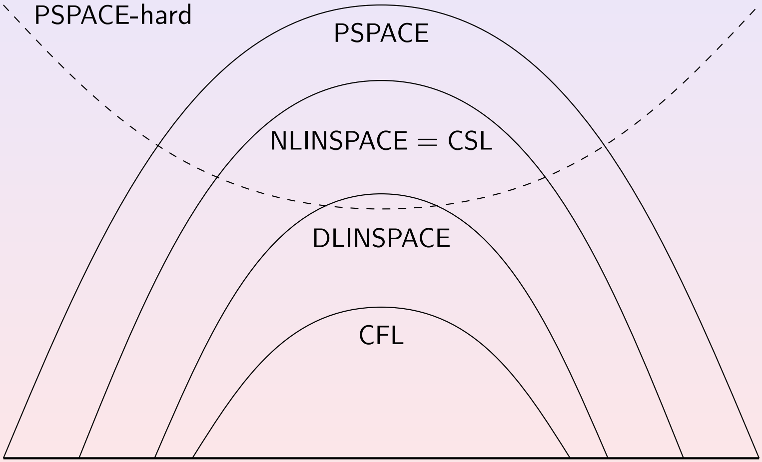
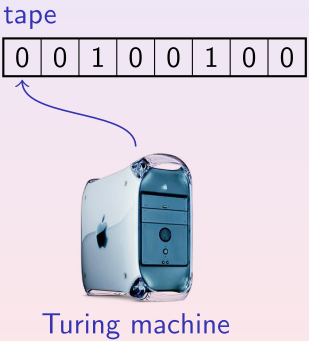
Linear Space is a Powerful Model



Our Model of “Absolutely No Space Overhead”



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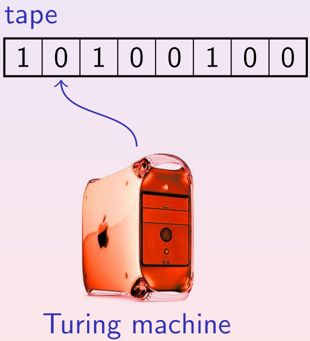

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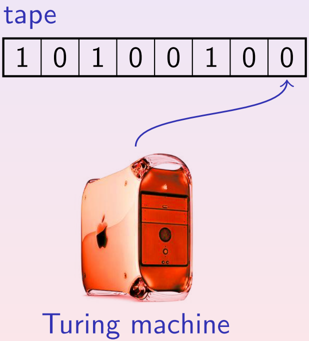

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Turing machine

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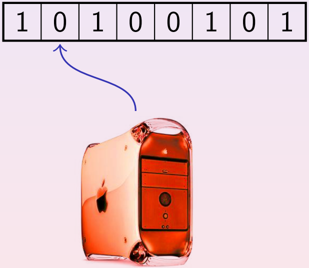

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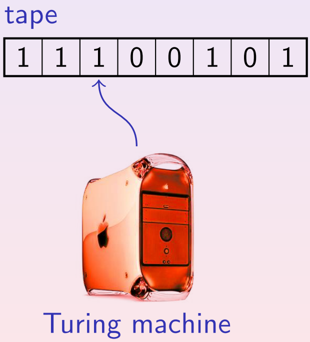

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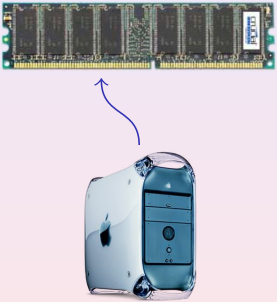

Turing machine

Intuition

- Tape is used like a RAM module.

Definition of Overhead-Free Computations

Definition

A Turing machine is overhead-free if

- it has only a single tape,
- writes only on input cells,
- 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 $\mathrm{DOF}_{\mathrm{poly}}$.

Overhead-Free Computation Complexity Classes

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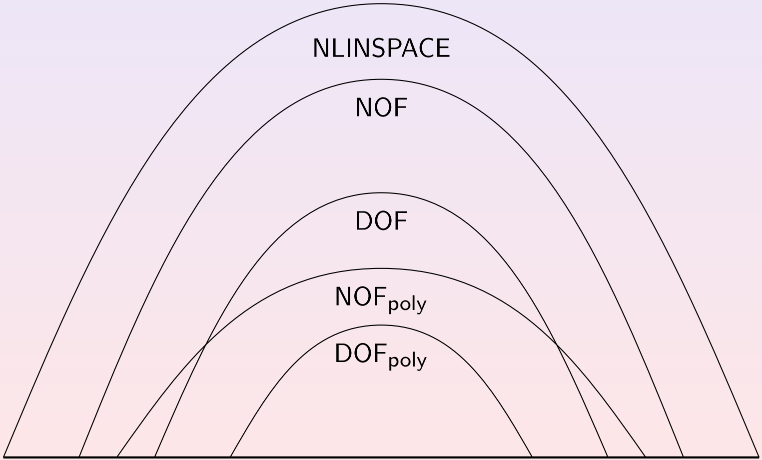
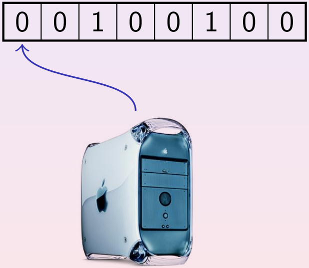
Simple Relationships among Overhead-Free Computation Classes



Outline

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
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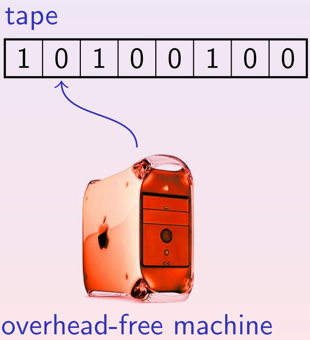
Palindromes Can be Accepted in an Overhead-Free Way



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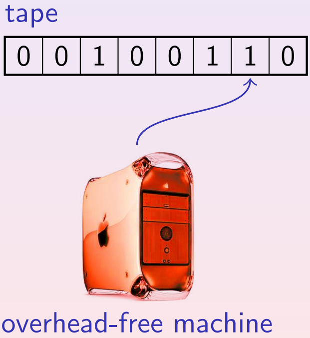

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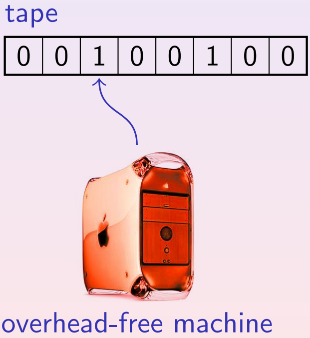

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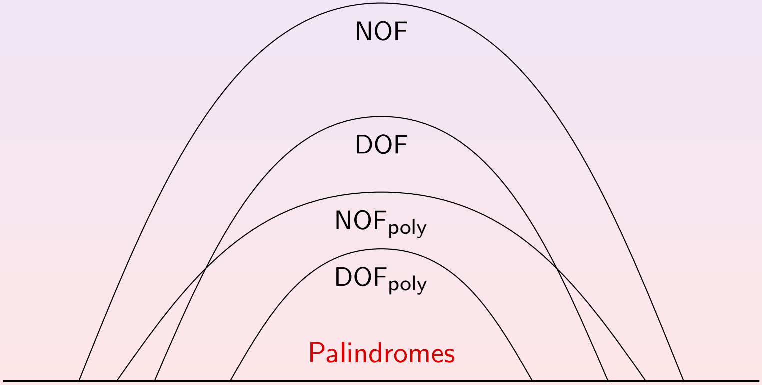
Relationships among Overhead-Free Computation Classes



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

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

Definition

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

Example

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

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Example

$G_1 : S \to 00S0 \mid 1$ is deterministic.
$G_2 : S \to 0S10 \mid 0$ is not deterministic.

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

$\textsc{triple-palindrome} = \{uvw \mid u, v, \text{ and } w \text{ are palindromes}\}$.

Theorem

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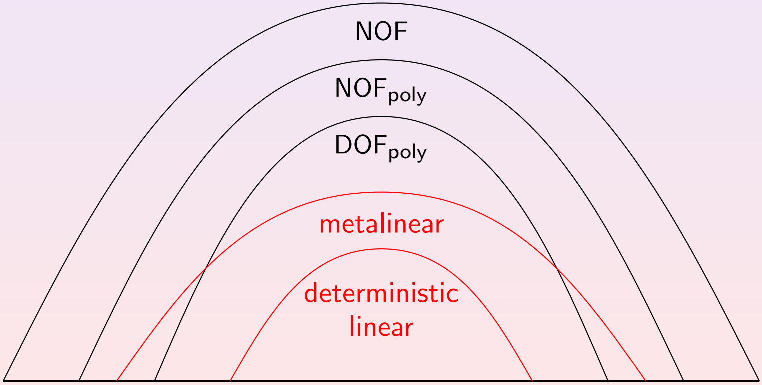

Definition of Almost-Overhead-Free Computations

Definition

A Turing machine is almost-overhead-free if

- it has only a single tape,
- writes only on input cells,
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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

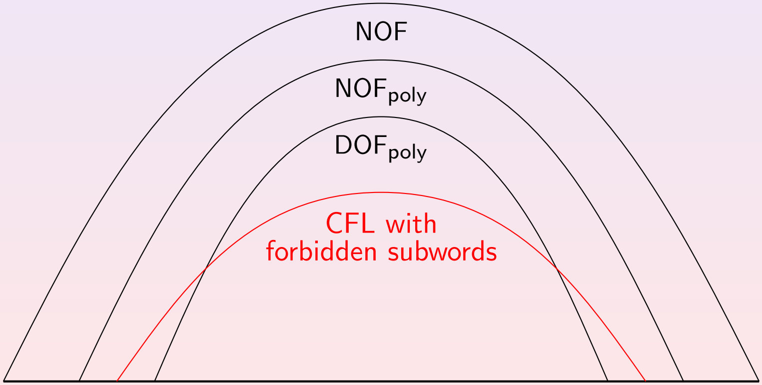
Theorem

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



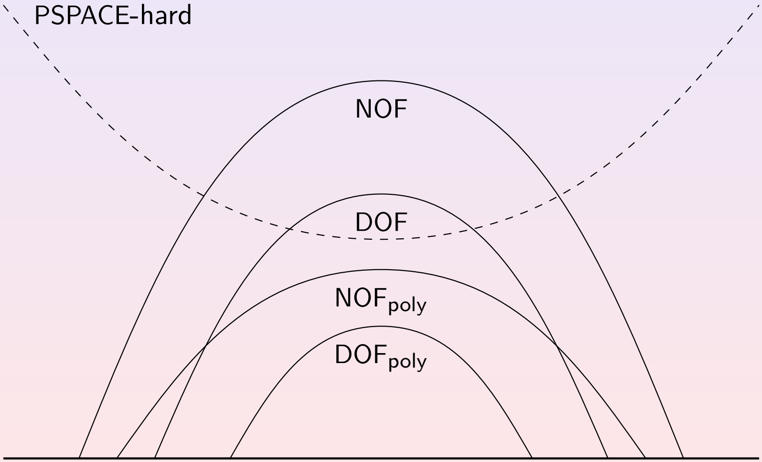
Some PSPACE-complete Languages Can Be Accepted in an Overhead-Free Way

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

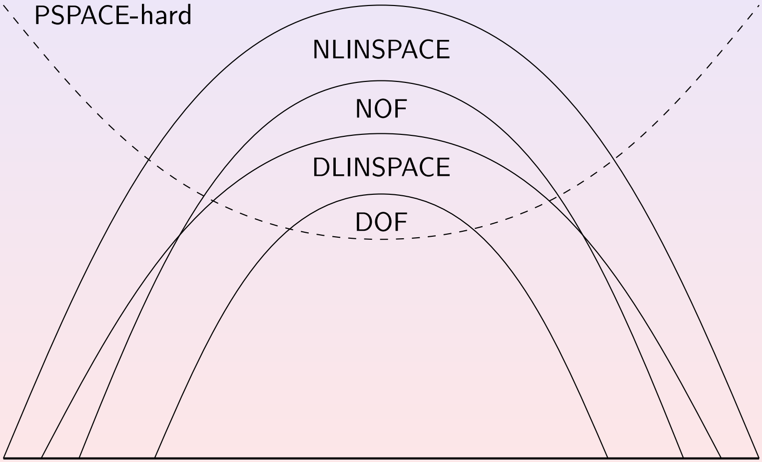
$\mathrm{DOF} \subsetneq \mathrm{DLINSPACE}$.

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

$\textsc{double-palindromes} \notin \mathsf{DOF}$.

Conjecture

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

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

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.

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.
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Appendix Outline

Overhead-Free Languages can be PSPACE-Complete

Theorem

DOF contains languages that are complete for PSPACE.

Proof.

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

◂ Return

Improvements

Theorem

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