

Unambiguous languages exhaust the index hierarchy

Michał Skrzypczak

Highlights 2018

Berlin 19.09.2018



Foundation for
Polish Science



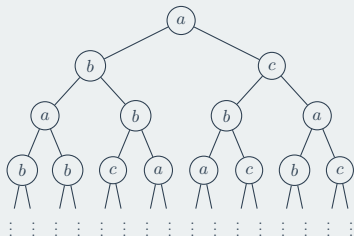
UNIVERSITY
OF WARSAW



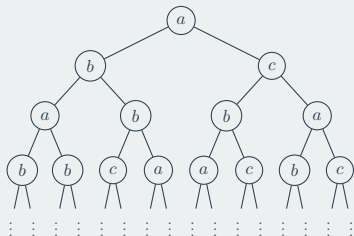
NATIONAL SCIENCE CENTRE
POLAND

Regular languages of infinite trees

Regular languages of infinite trees

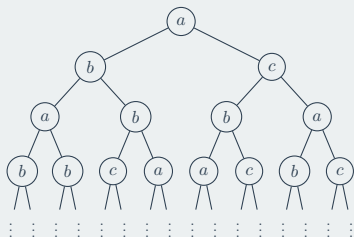


Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$

Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$

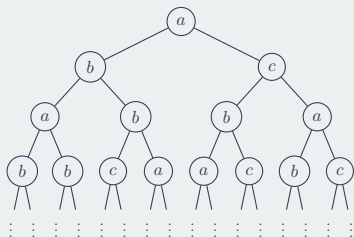
Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.

Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$



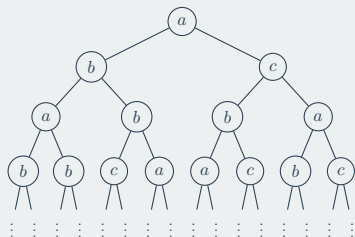
Theorem (Rabin)

Monadic Second-Order logic

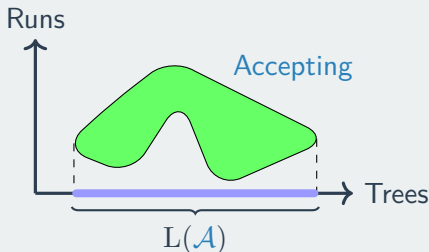


Non-deterministic parity tree aut.

Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$



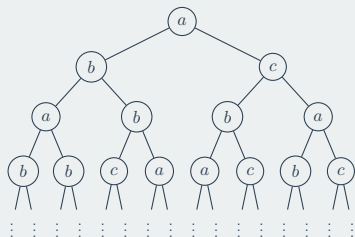
Theorem (Rabin)

Monadic Second-Order logic

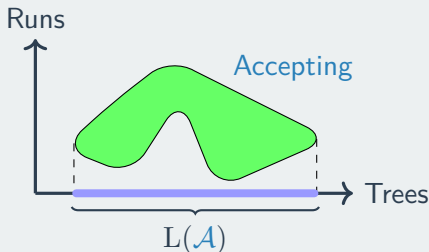


Non-deterministic parity tree aut.

Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

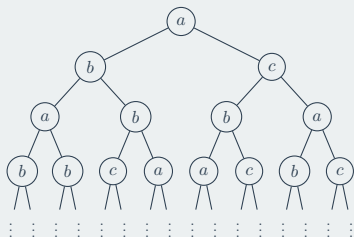
Theorem (Rabin)

Monadic Second-Order logic

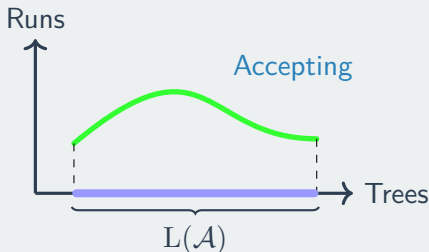


Non-deterministic parity tree aut.

Regular languages of infinite trees



$$t: \{L, R\}^* \rightarrow A$$



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

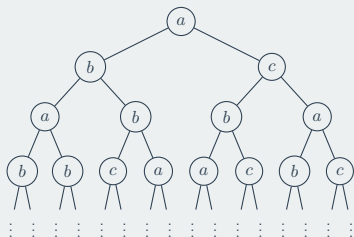
Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.

Regular languages of infinite trees



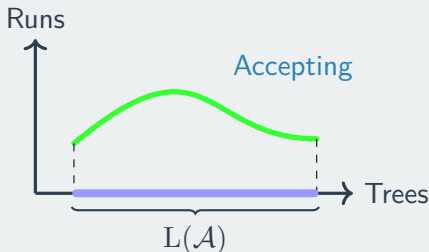
$$t: \{L, R\}^* \rightarrow A$$

Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

non-deterministic

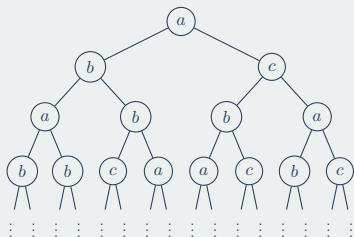
$\neq \cup$

unambiguous

$\neq \cup$

deterministic

Regular languages of infinite trees



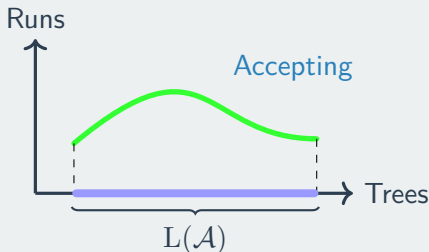
$$t: \{L, R\}^* \rightarrow A$$

Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

non-deterministic

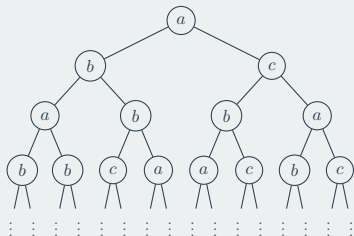


unambiguous



deterministic

Regular languages of infinite trees



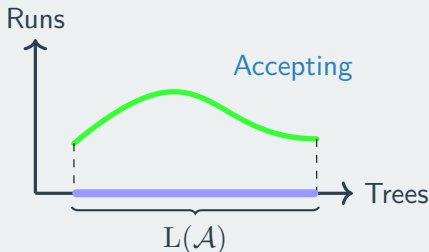
$$t: \{L, R\}^* \rightarrow A$$

Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

non-deterministic

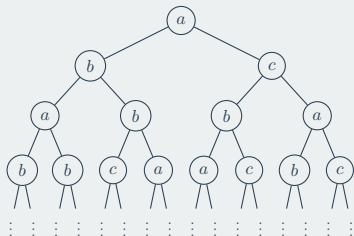


unambiguous



deterministic

Regular languages of infinite trees



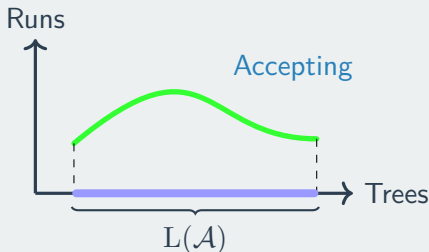
$$t: \{L, R\}^* \rightarrow A$$

Theorem (Rabin)

Monadic Second-Order logic



Non-deterministic parity tree aut.



\mathcal{A} is unambiguous
iff

$\forall t \in L(\mathcal{A}). \exists! \rho. \rho$ is accepting over t

non-deterministic

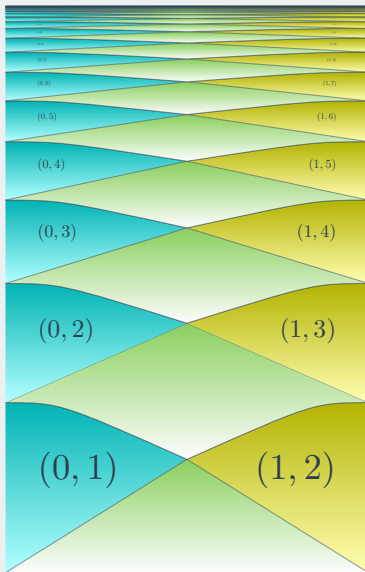
? ~~U~~ ?

unambiguous

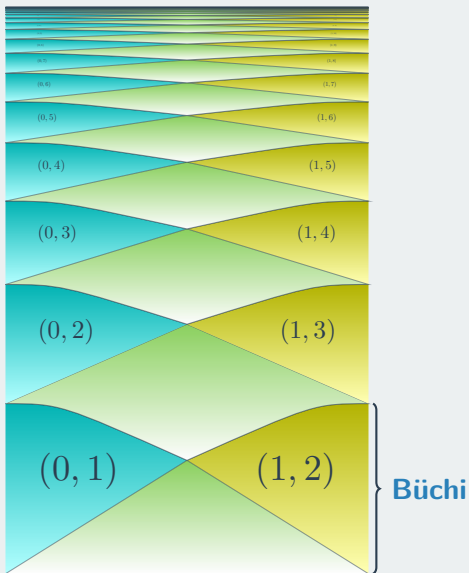
U

deterministic

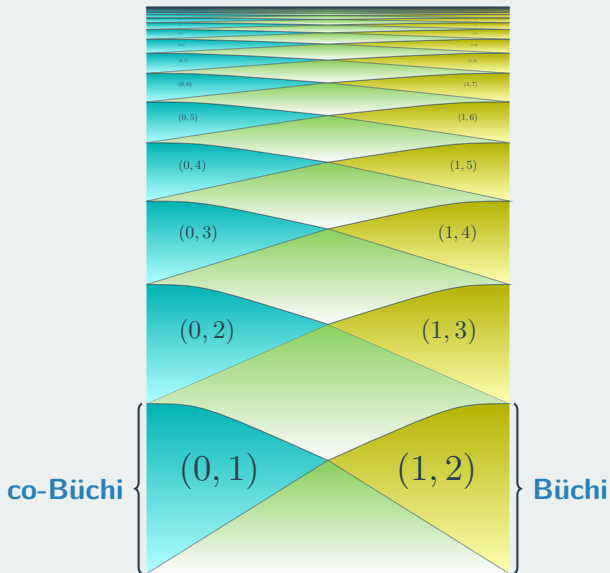
Alternating index hierarchy & unambiguous languages



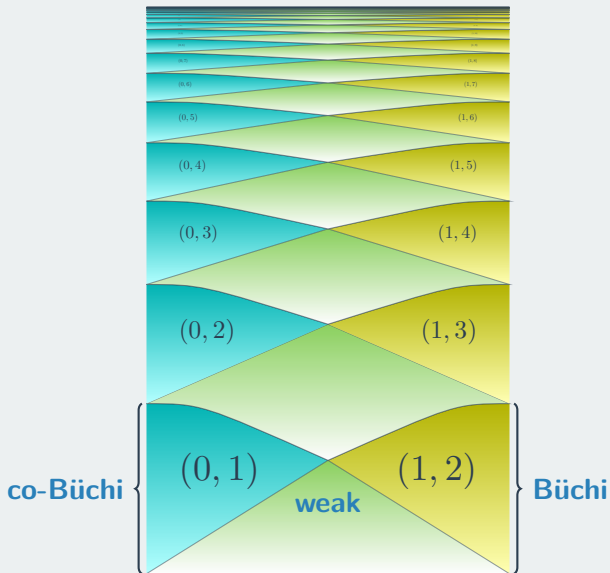
Alternating index hierarchy & unambiguous languages



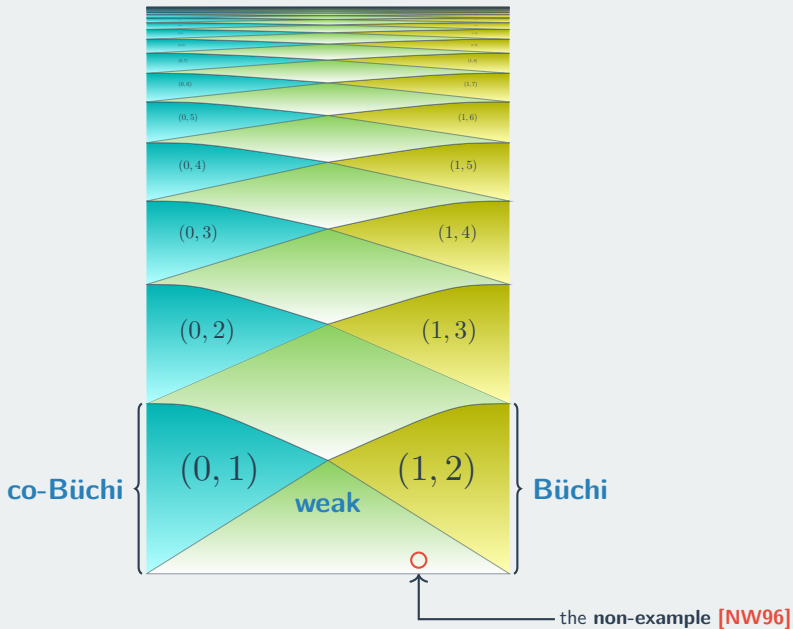
Alternating index hierarchy & unambiguous languages



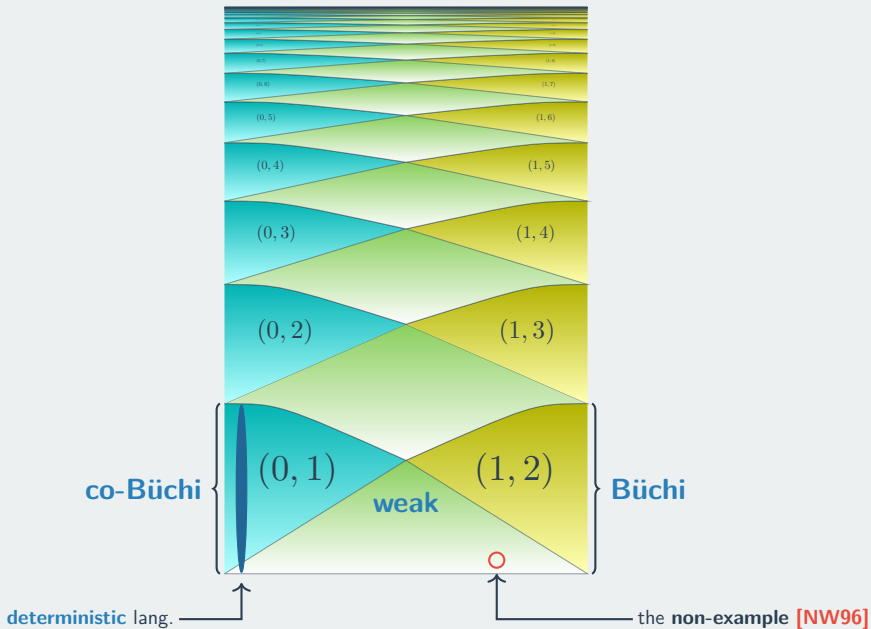
Alternating index hierarchy & unambiguous languages



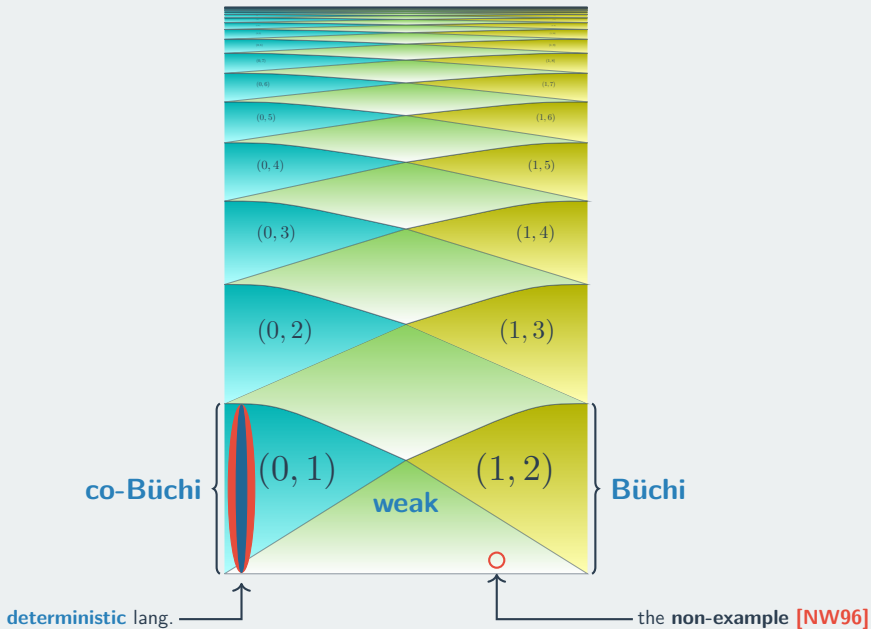
Alternating index hierarchy & unambiguous languages



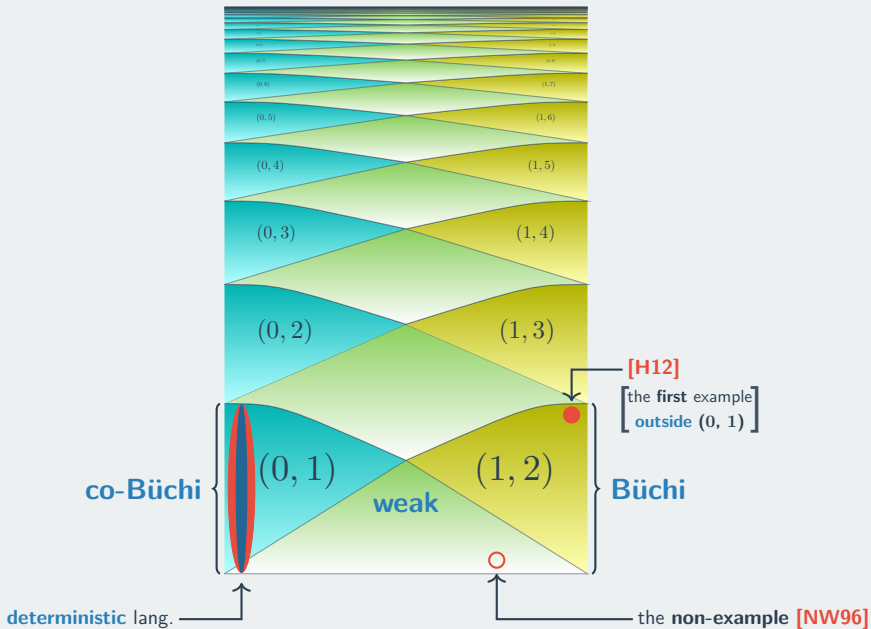
Alternating index hierarchy & unambiguous languages



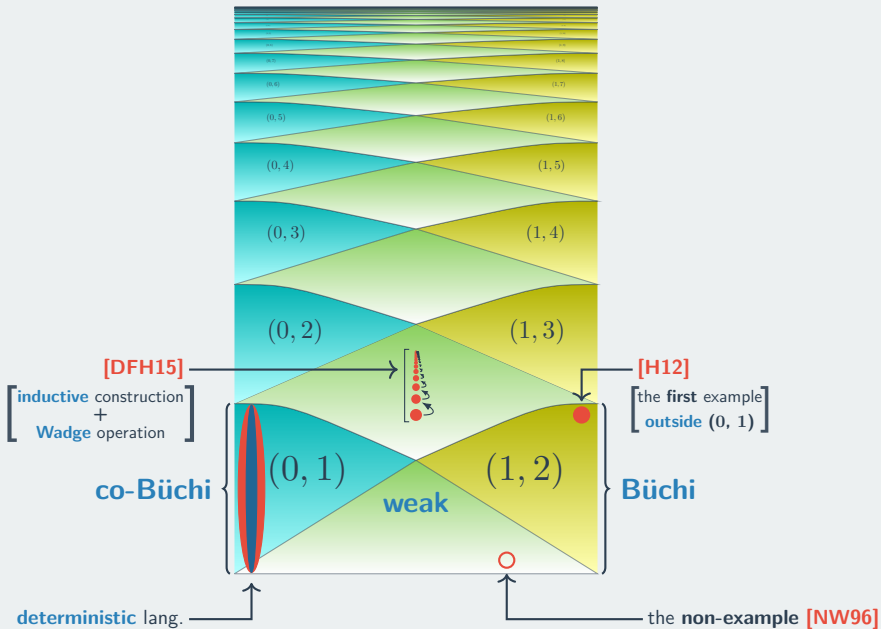
Alternating index hierarchy & unambiguous languages



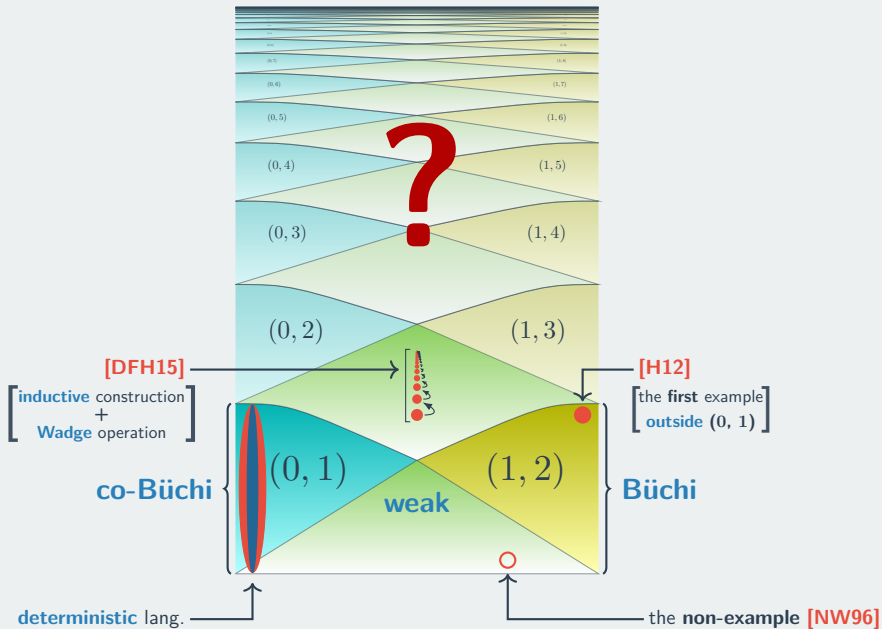
Alternating index hierarchy & unambiguous languages



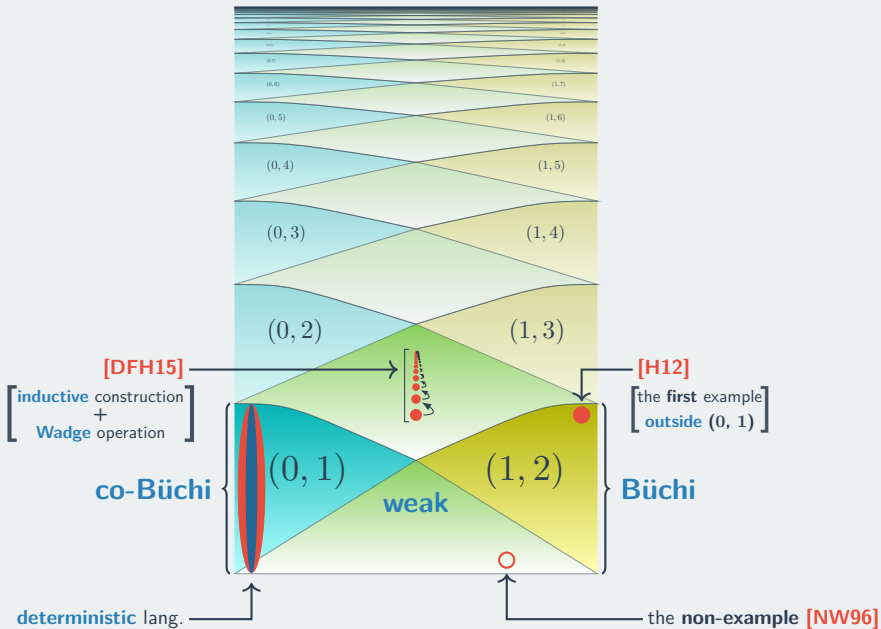
Alternating index hierarchy & unambiguous languages



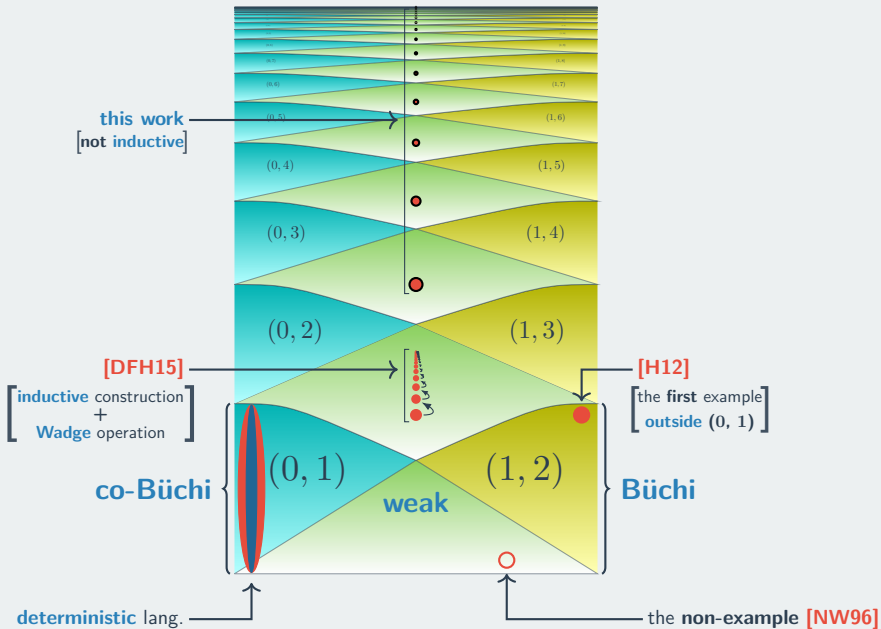
Alternating index hierarchy & unambiguous languages



Alternating index hierarchy & unambiguous languages



Alternating index hierarchy & unambiguous languages



Starting point

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously:

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Technical core

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Technical core

$$c: (t_1, t_2) \mapsto t$$

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Technical core

$$c: (t_1, t_2) \mapsto t \\ \text{[continuous]}$$

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Technical core

$$c: (t_1, t_2) \mapsto t$$

[continuous]

$$\sigma(t_1) \leq \sigma(t_2)$$

Starting point

$W_{i,j}$ — the language of parity games of index (i, j) won by \exists

Aim

Recognise a variant of $W_{i,j}$ unambiguously: $L_{i,j} \cong W_{i,j} \oplus \text{advice}$

Problem

How to choose a unique winning strategy of \exists ?

Solution

Choose the subtree of smaller signature $\sigma(t)$!

Technical core

$$c: (t_1, t_2) \mapsto t$$

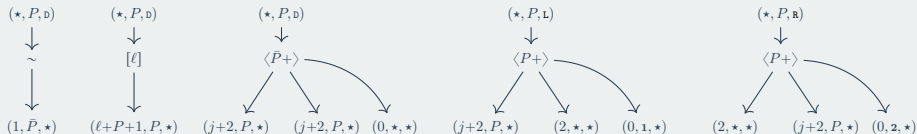
[continuous]

$$\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$$

Summary

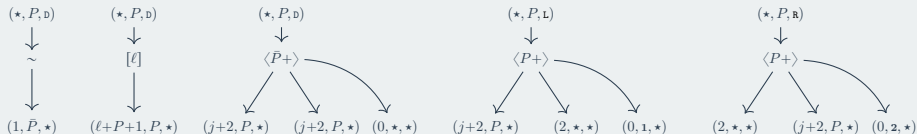
Summary

1. Simple automata $\mathcal{A}_{i,j}$



Summary

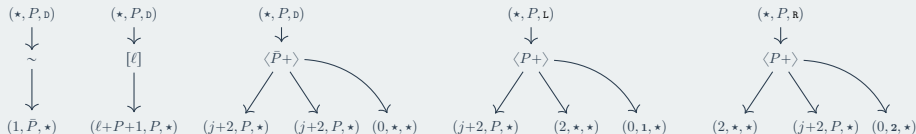
1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

Summary

1. Simple automata $\mathcal{A}_{i,j}$

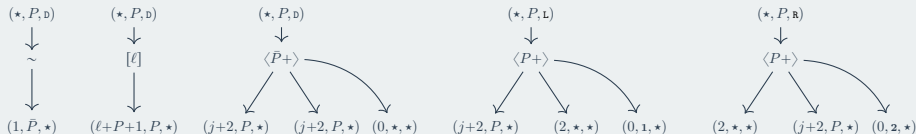


2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

Summary

1. Simple automata $\mathcal{A}_{i,j}$



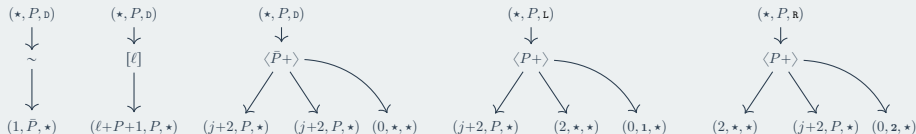
2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

3.1 use signatures

Summary

1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

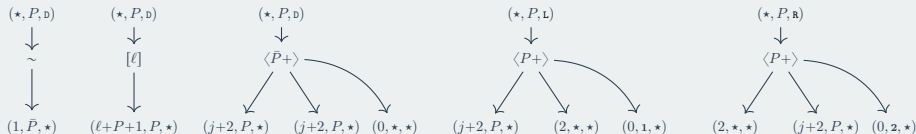
3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$

Summary

1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

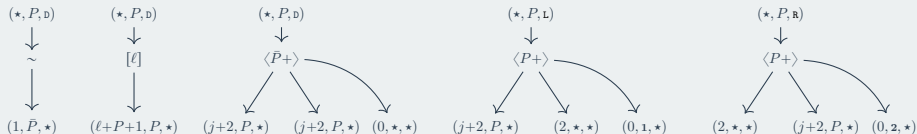
3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$



Summary

1. Simple automata $\mathcal{A}_{i,j}$

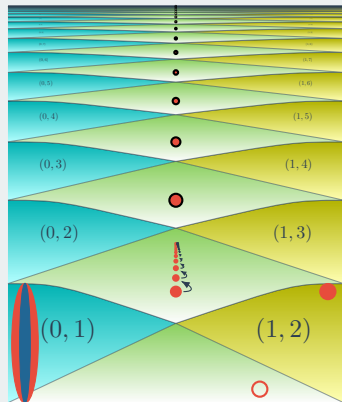


2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

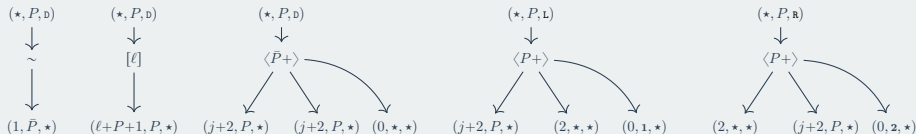
3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$



Summary

1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

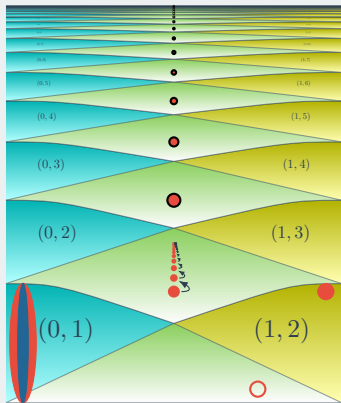
3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$

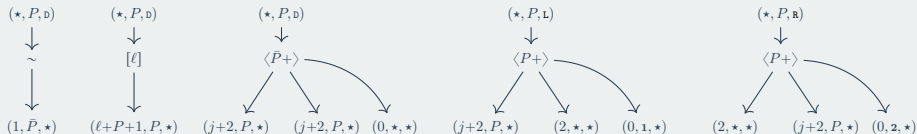


~> some unambiguous languages are complex



Summary

1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

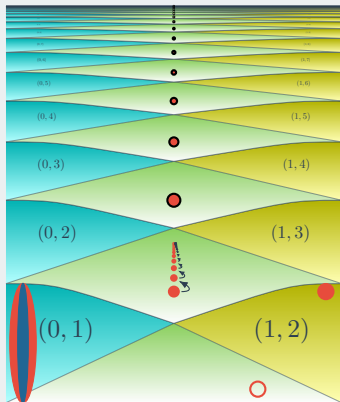
3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$



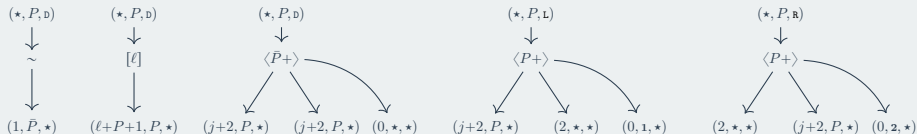
~> some **unambiguous** languages are **complex**

~> possible insights into **parity games**



Summary

1. Simple automata $\mathcal{A}_{i,j}$



2. Unambiguous by the definition

3. Claim: $L(\mathcal{A}_{i,j}) \cong W_{i,j} \oplus \text{advice}$

3.1 use signatures

3.2 $\sigma(t_1) \leq \sigma(t_2) \iff c(t_1, t_2) \in W_{i,j}$



~> some **unambiguous** languages are **complex**

~> possible insights into **parity games**

~> relations with **stage comparison theorems**

