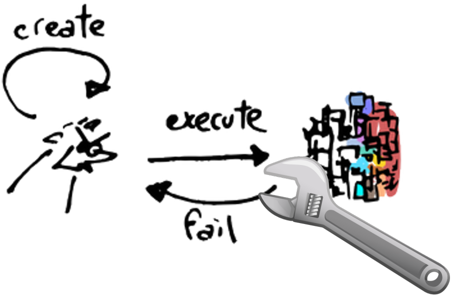
THE COST OF REPAIRS



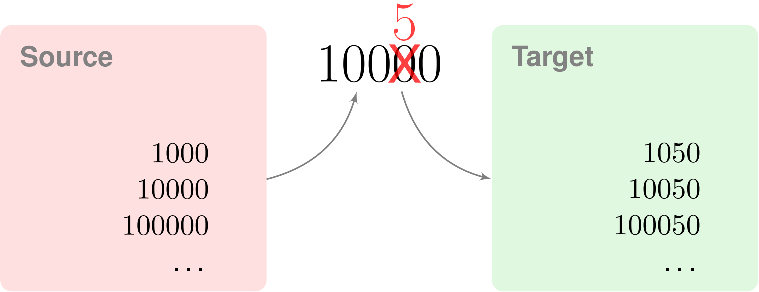
Gabriele Puppis

LaBRI / CNRS

based on joint works with

Michael Benedikt,
Pierre Bourhis,
Cristian Riveros,
Slawek Staworko

What do you do when a computational object fails a specification?



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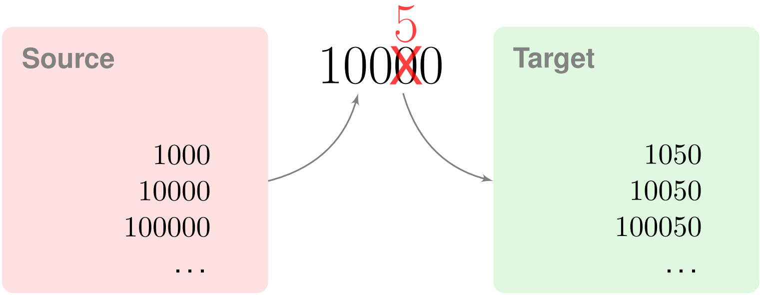

Worst-case cost of repairing source into target:

$$\max_{s \in S} \min_{t \in T} \mathsf{dist}(s, t)$$

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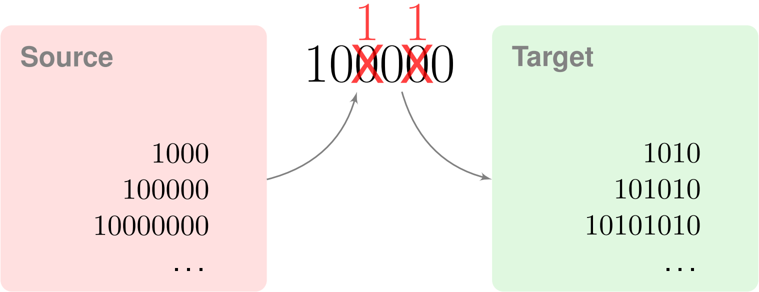

Worst-case cost of repairing source into target:

$$\max_{s \in S} \min_{t \in T} \mathsf{dist}(s, t)$$

Can be **finite** or **infinite**, depending on source and target
...can we decide this?

Plan

A. **Bounded repairability of regular word languages**

1) characterization
2) streaming setting
3) complexity

B. **Bounded repairability of regular tree languages**

1) curry encodings, stepwise automata, contexts
2) characterization
3) complexity

Part A. Problem setting:

- Given two languages $S \subseteq \Sigma^*$ and $T \subseteq \Delta^*$
  (represented by finite state automata)

- Decide whether $\max_{s \in S} \min_{t \in T} \text{dist}(s, t)$ is finite.

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  (represented by finite state automata)

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Examples

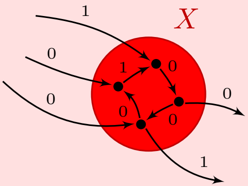
10^* is <u>bounded repairable</u> into 10^*50

10^* is <u>not</u> bounded repairable into $(10)^*$

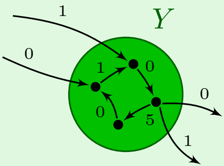
$(1+0)^*$ is <u>not</u> bounded repairable into $(1+0^*5)^*$

Rule of thumb: *“If you need to edit, you’d better do it outside a loop!”*

Source automaton



Target automaton



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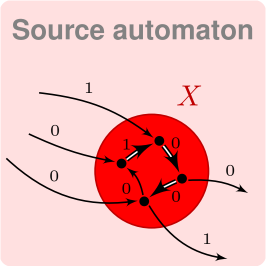

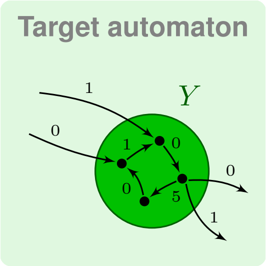

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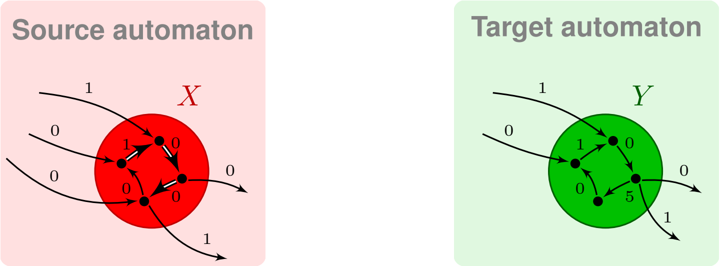


For any strategy that repairs traces of X into traces of Y:

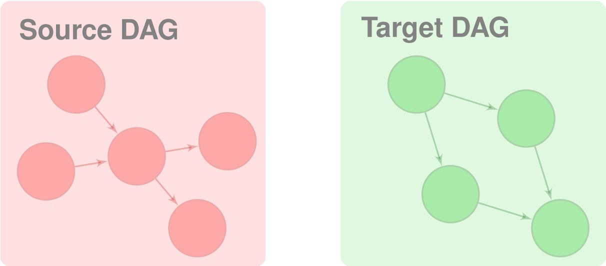
1. either $\mathsf{traces}(X) \subseteq \mathsf{traces}(Y)$
2. or the strategy has unbounded cost.

Characterization of bounded repairability of word languages

S is repairable into T with uniformly bounded cost

$$\Updownarrow$$

Given some (trimmed) automata for S and T
and the DAGs of strongly connected components...



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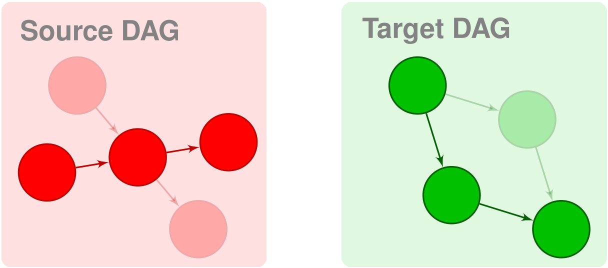

...every chain of components in the source is
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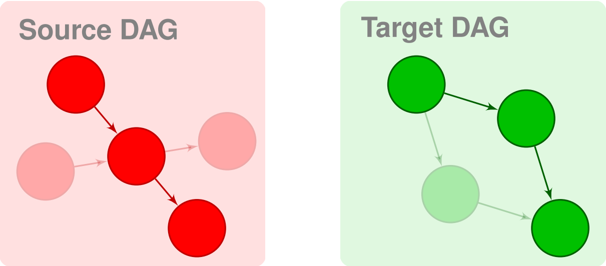

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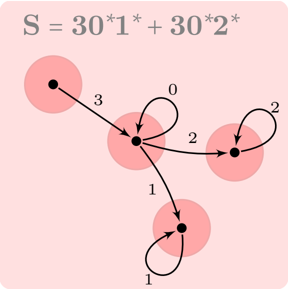
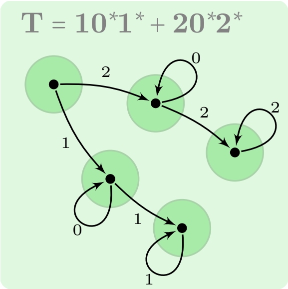
An example

All chains of source DAG are covered by chains of target DAG

$\Rightarrow$ S is repairable into T with uniformly bounded cost.





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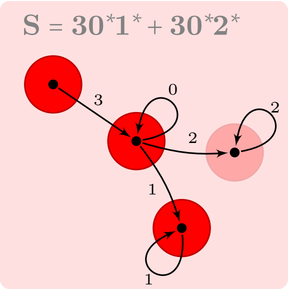

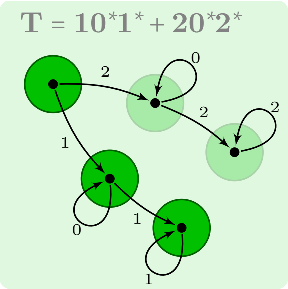

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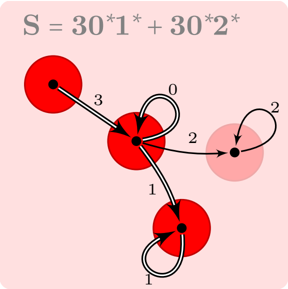

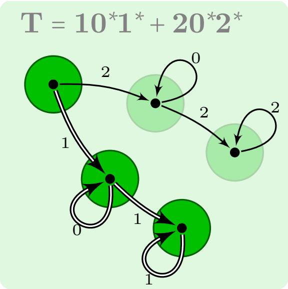

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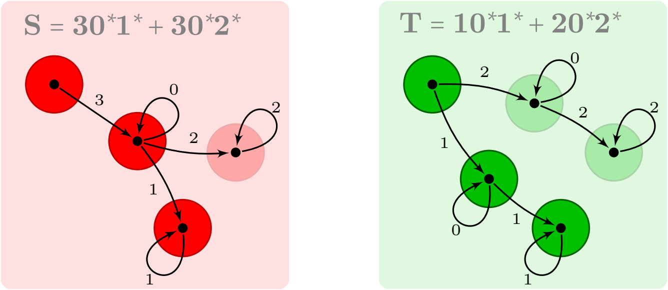

There is no covering relation **compatible with prefixes**
⇒ the repair strategy is not **streaming**
(i.e. implementable by a sequential transducer)

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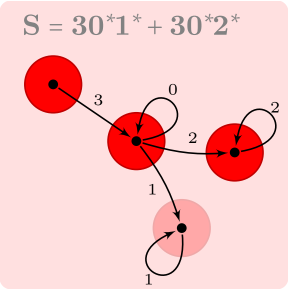

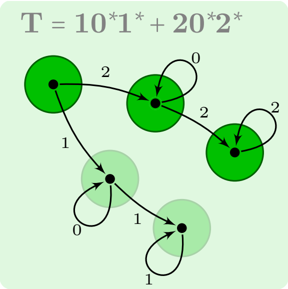

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Complexity of **non-streaming** bounded repairability problem:

	fixed	DFA	NFA
fixed	**CONST**	**P**	**PSPACE**
DFA	**P**	**coNP**	**PSPACE**
NFA	**PTIME**	**coNP**	**PSPACE**

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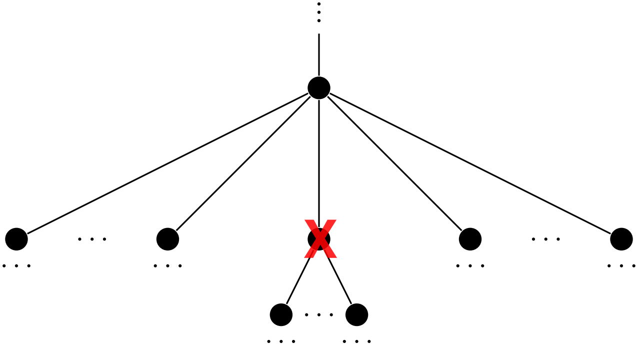
Complexity of **streaming** bounded repairability problem:

	fixed	DFA	NFA
fixed	**CONST**	**P**	**PSPACE**
DFA	**P**	**P**	**PSPACE**
NFA	$\leq$ **PSPACE** $\geq$ **P**	$\leq$ **PSPACE** $\geq$ **P**	$\leq$ **EXP** $\geq$ **PSPACE**

Part B. New tools for a more general setting...

Languages of words:	Languages of unranked trees:
insersions / deletions	**insertions / deletions**
finite state automata	**stepwise tree automata**
components & traces	**components & contexts**
coverability of chains	**coverability of synopsis trees**

Edit operations on unranked trees: **deletions**



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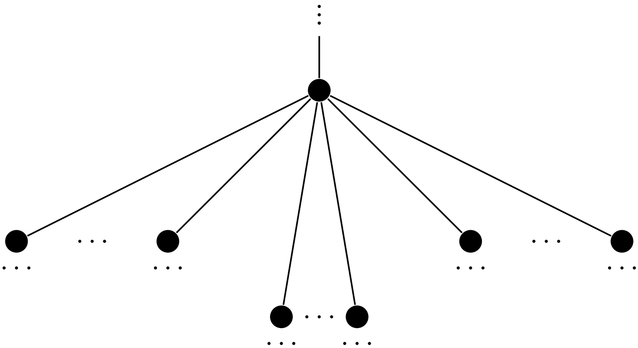

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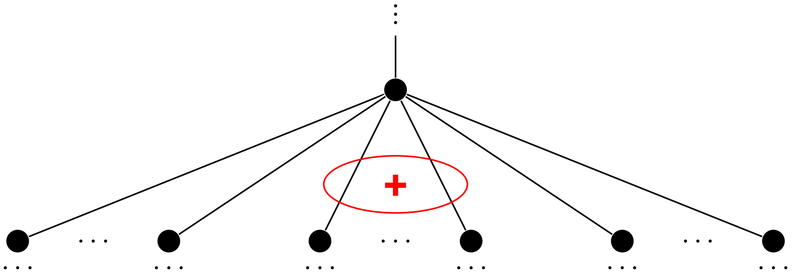

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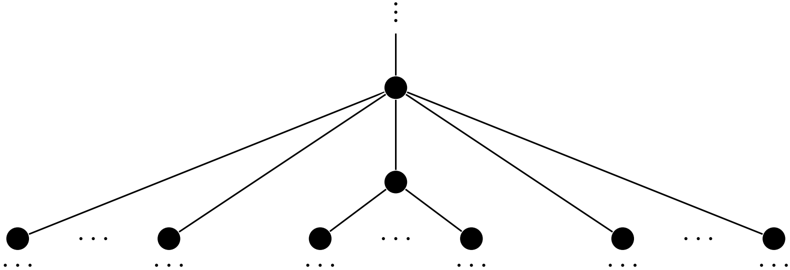
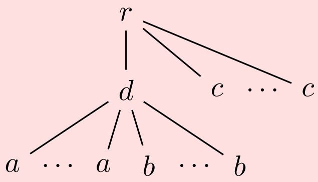
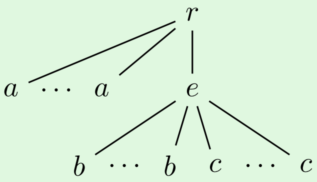


An example

Source



Target



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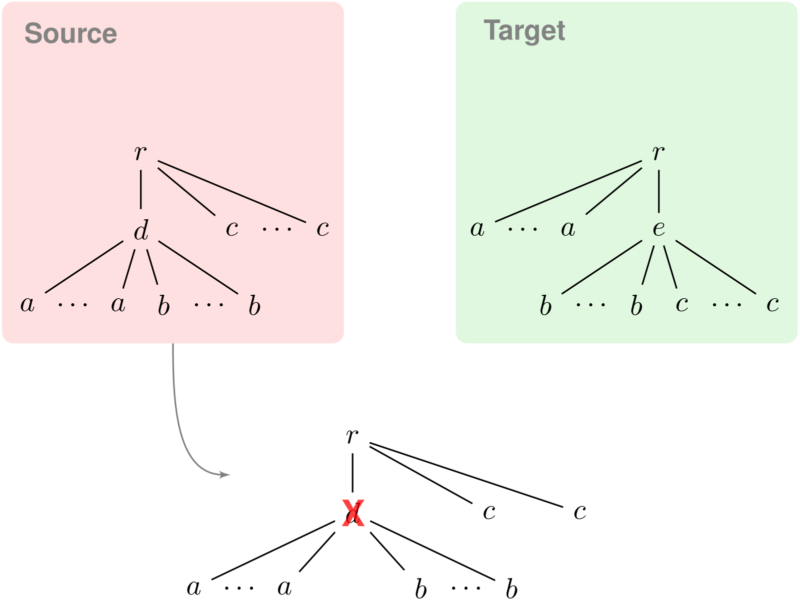

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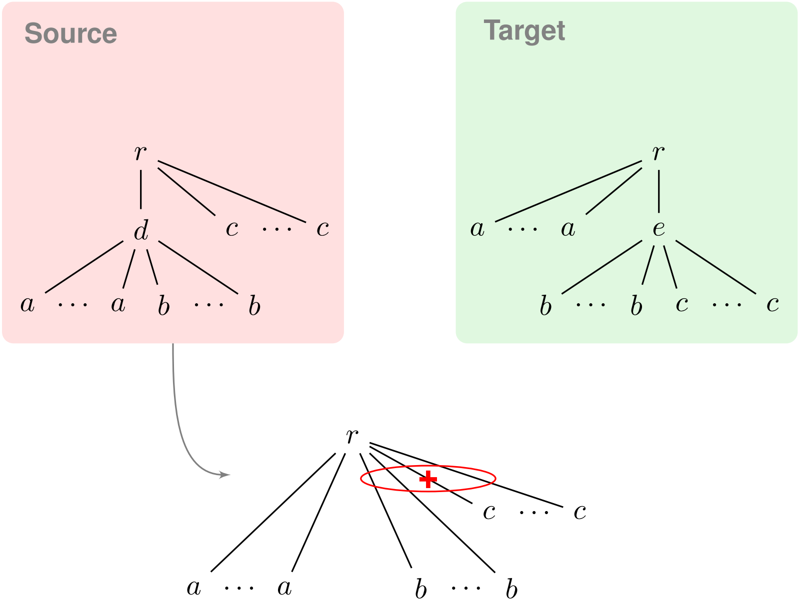

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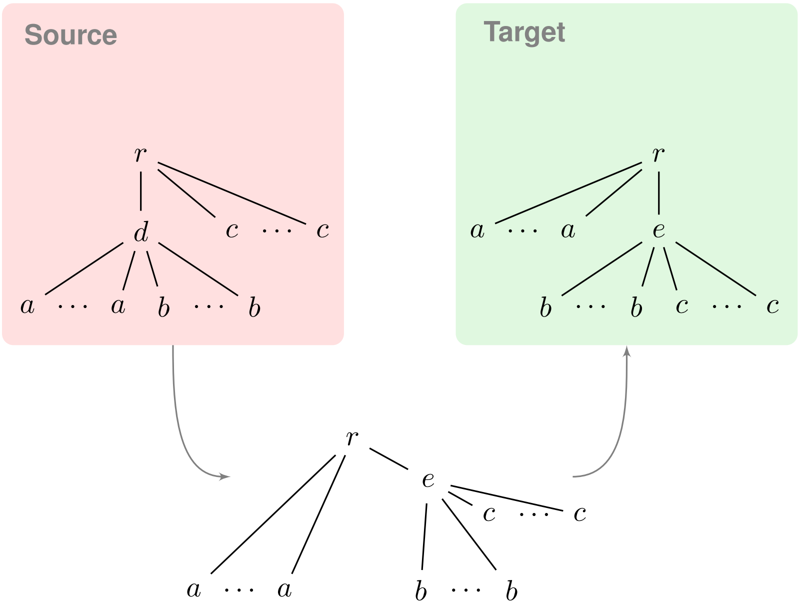
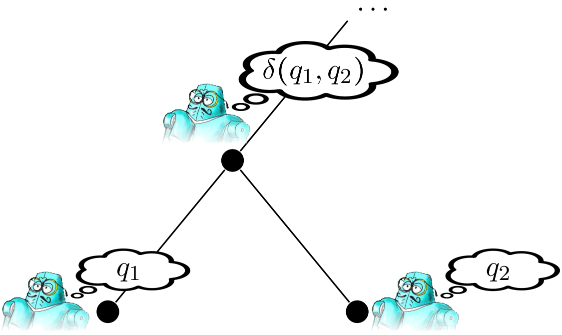


Bottom-up automata on ranked (binary) trees:



How to parse unranked trees?

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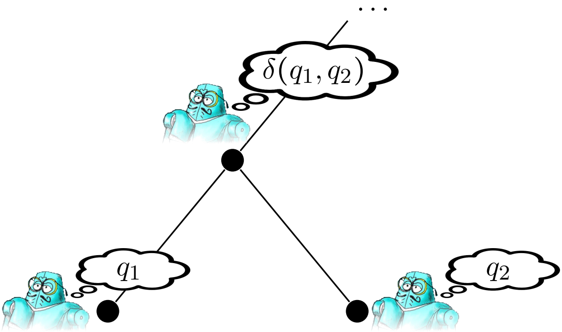
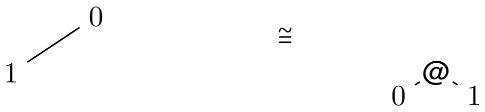


How to parse unranked trees?

☞ Encode them using binary trees!

The curry encoding



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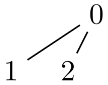
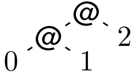


$\cong$



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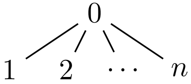

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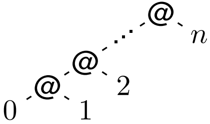

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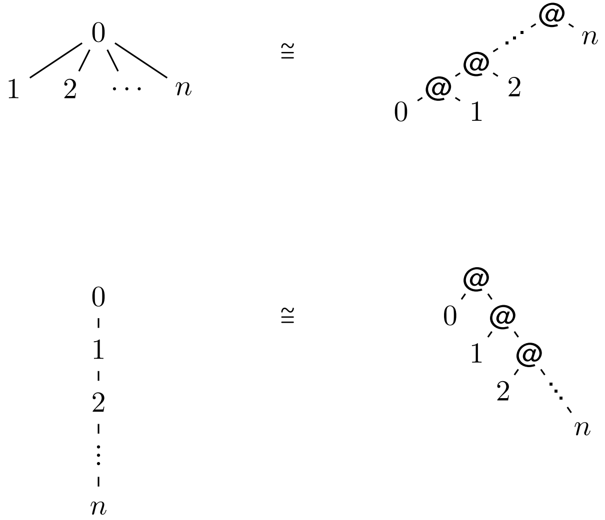

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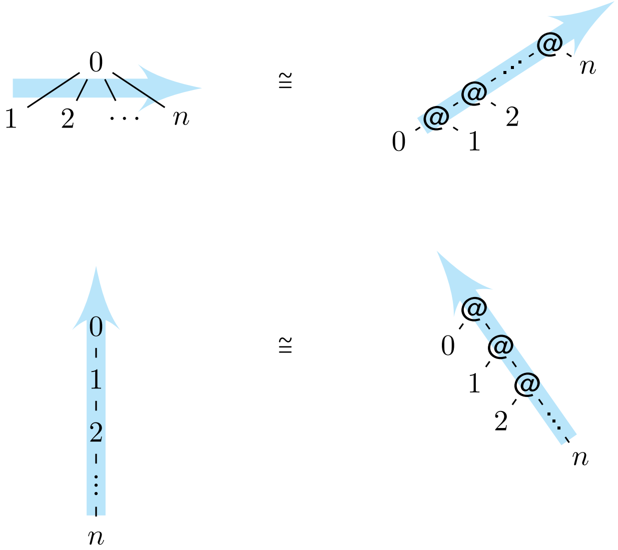
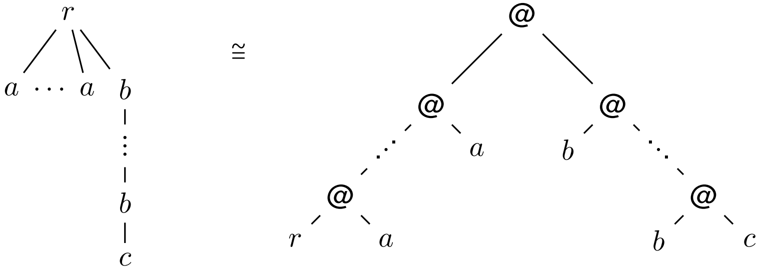


Stepwise automata = bottom-up on curry encodings

An example



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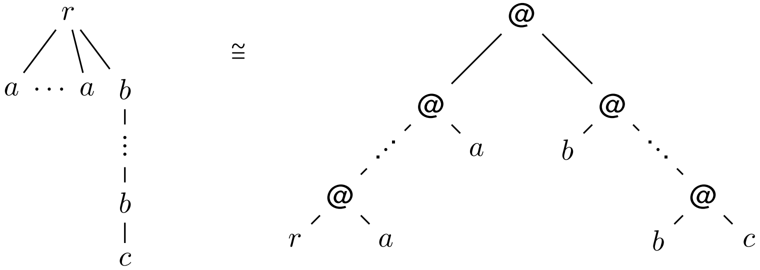
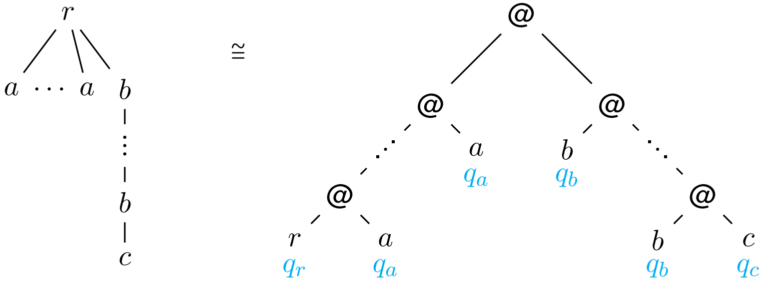


$$
\begin{aligned}
r &\mapsto q_r \\
a &\mapsto q_a \\
b &\mapsto q_b \\
c &\mapsto q_c
\end{aligned}
$$

$$
\begin{aligned}
q_r \,@\, q_a &\mapsto q_r \\
q_b \,@\, q_c &\mapsto q_c \\
q_r \,@\, q_c &\mapsto q_{\mathsf{final}}
\end{aligned}
$$

An example



$r \mapsto q_r$

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$q_r \; @ \; q_a \mapsto q_r$

$q_b \; @ \; q_c \mapsto q_c$

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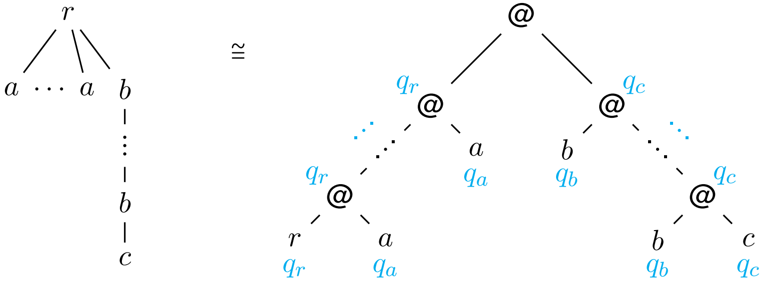

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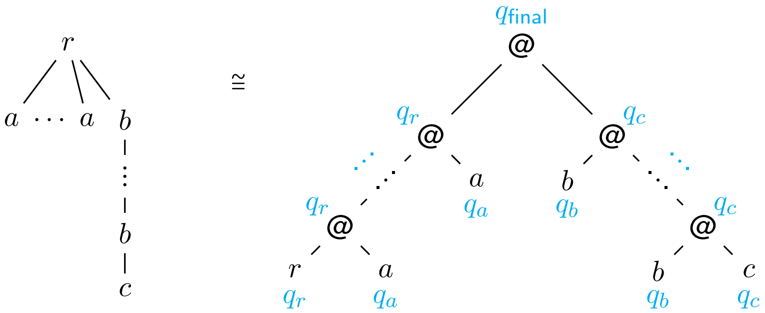
An example



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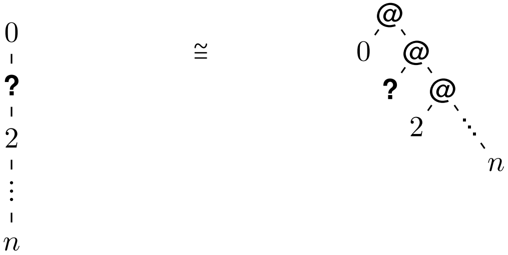
Contexts = trees with holes



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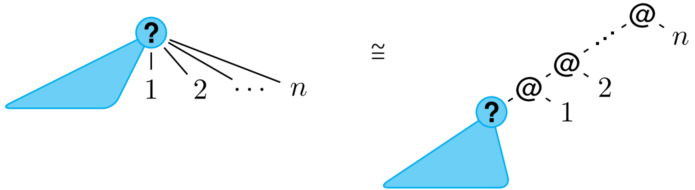

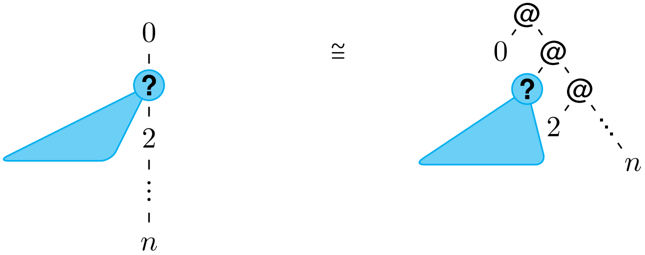

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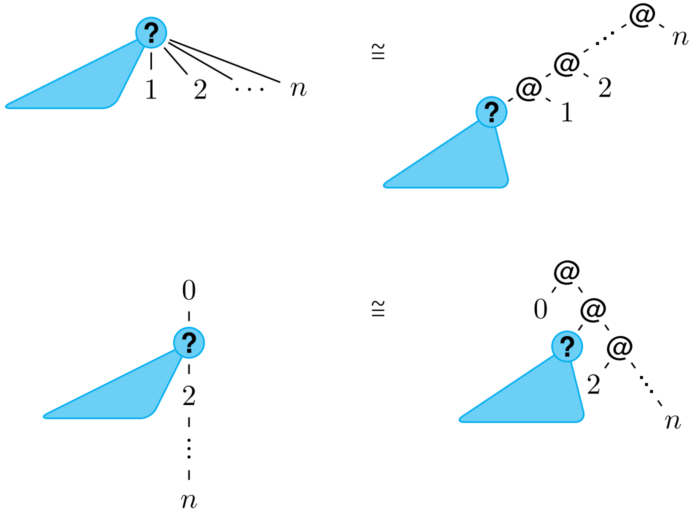

Contexts can be parsed between two states: $p \xrightarrow{C} q$

(accessibility of states and components are defined accordingly)

Recall: a run of a finite state automaton induces a **chain of components**...

Likewise, a run of a stepwise automaton induces a tree of components, called **synopsis tree**.

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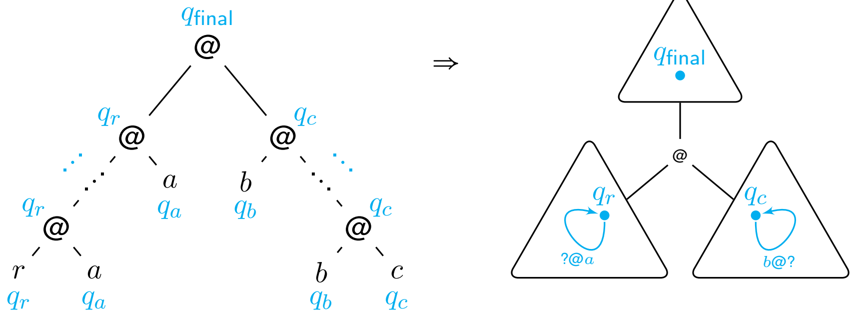
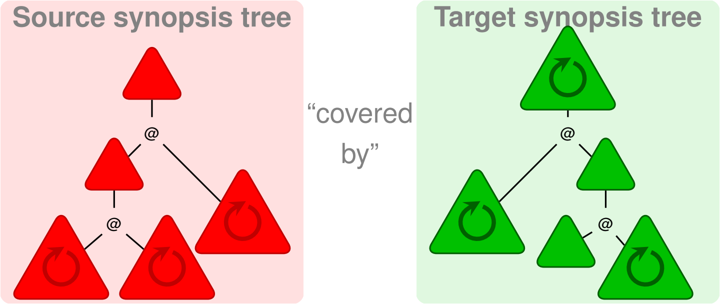


Characterization of bounded repairability of tree languages

S is repairable into T with uniformly bounded cost

$$\Updownarrow$$

Given some (trimmed) stepwise automata for S and T,
all synopsis trees of S are covered by synopsis trees of T



i.e. ...

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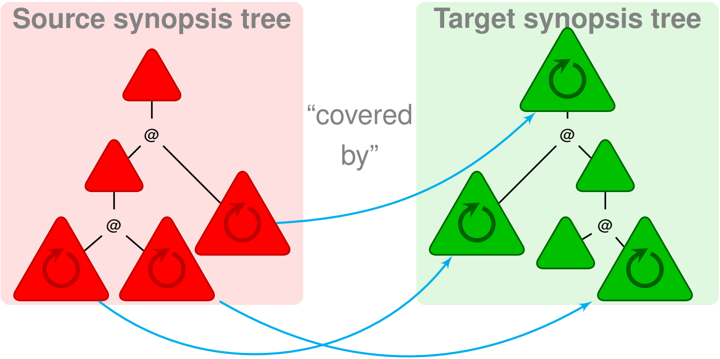

i.e. $\exists\ \lambda$: cyclic components $\longrightarrow$ cyclic components

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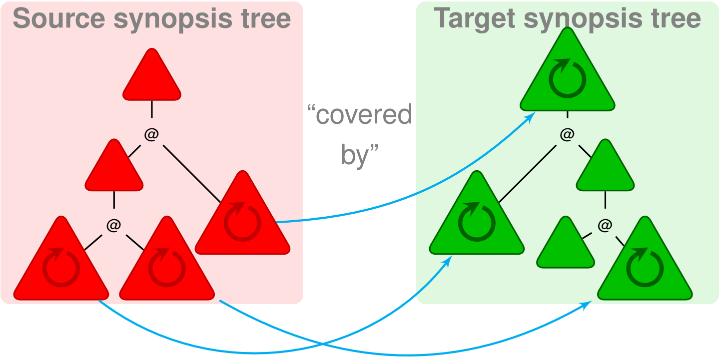

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contexts(X) $\subseteq$ contexts$(\lambda(X))$

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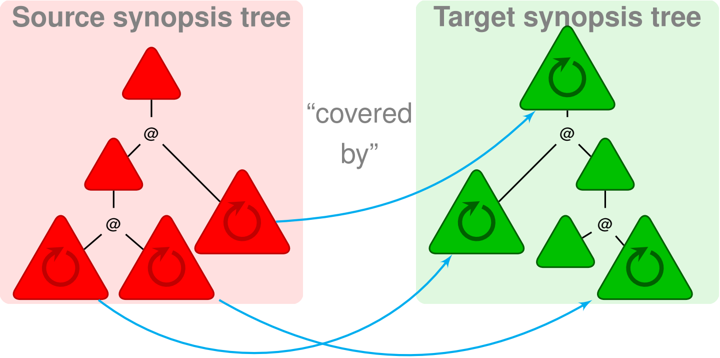
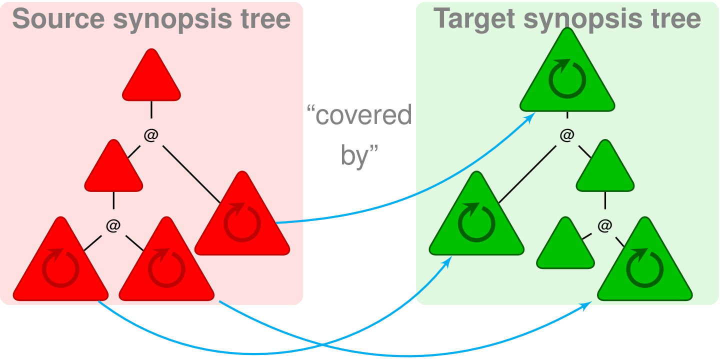


i.e. $\exists\ \lambda$: cyclic components $\longrightarrow$ cyclic components

1. λ preserves contexts:
   contexts(X) $\subseteq$ contexts$(\lambda(X))$

2. λ respects post-order of components:
   $X \leq_{\text{postorder}} Y \ \leftrightarrow\ \lambda(X) \leq_{\text{postorder}} \lambda(Y)$

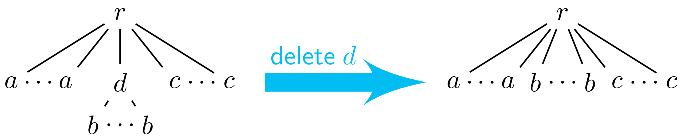


i.e. $\exists\ \lambda$: cyclic components $\longrightarrow$ cyclic components

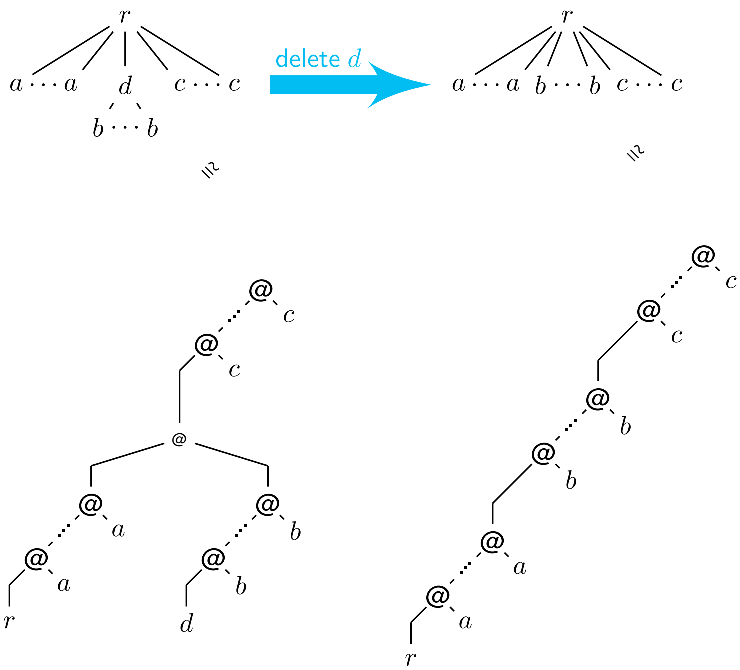
1. λ preserves contexts:
   $\text{contexts}(X) \subseteq \text{contexts}(\lambda(X))$

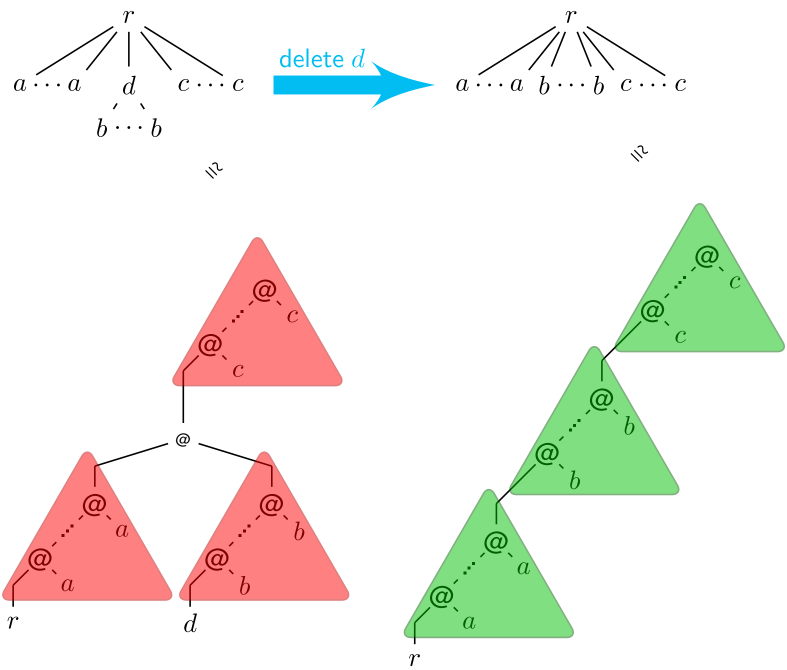
2. λ respects post-order of components:
   $X \leq_{\text{postorder}} Y \leftrightarrow \lambda(X) \leq_{\text{postorder}} \lambda(Y)$

3. λ preserves ancestorship of vertical components:
   $X \leq_{\text{ancestor}} Y \leftrightarrow \lambda(X) \leq_{\text{ancestor}} \lambda(Y)$
   whenever $\text{vertical-contexts}(X) \neq \emptyset$



r
a ⋯ a
d
b ⋯ b
c ⋯ c
delete d
r
a ⋯ a
b ⋯ b
c ⋯ c


delete d



r
a ⋯ a
d
b ⋯ b
c ⋯ c
delete d
r
a ⋯ a
b ⋯ b
c ⋯ c
≅
≅
@
c
@
c
@
@
a
@
a
r
@
b
@
b
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c
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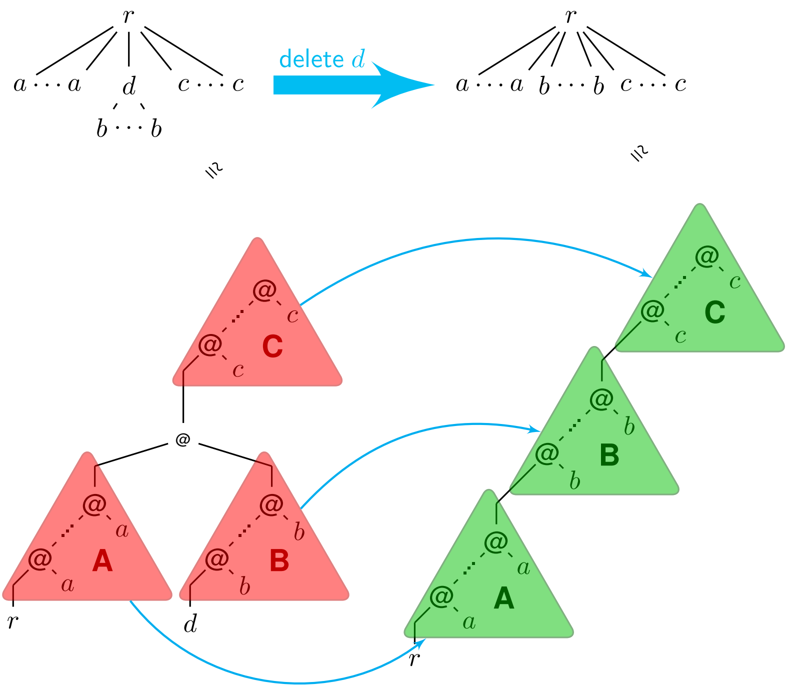
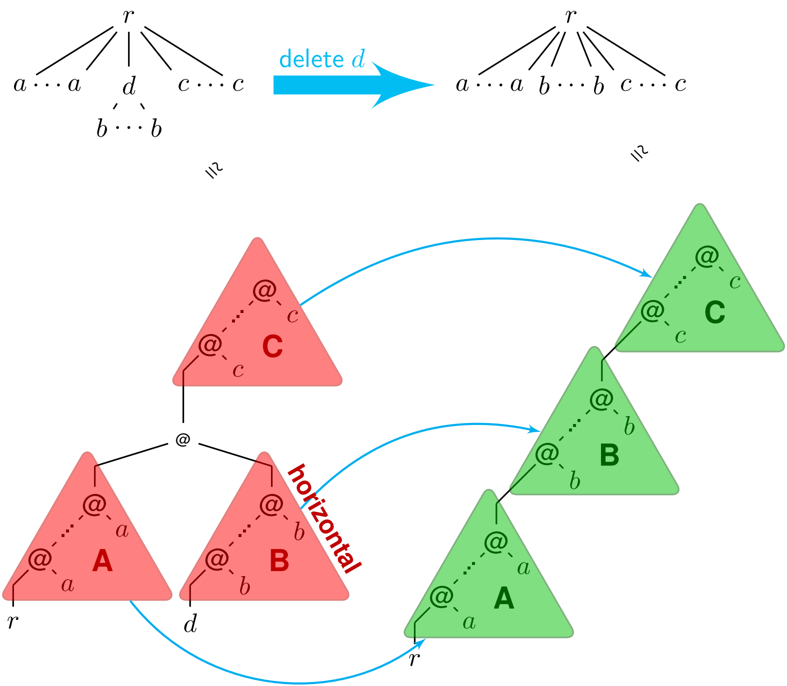
@
a
@
a
r



delete d
A
B
C
A
B
C



r
a ⋯ a
d
b ⋯ b
c ⋯ c
delete d
r
a ⋯ a b ⋯ b c ⋯ c
≅
≅
C
A
B
horizontal
r
d
C
B
A
r

Complexity of **non-streaming** bounded repairability problem:

	det. DTD	DTD	stepwise
universal	**P**	**PSPACE**	**EXP**
fixed alphabet det. DTD	**coNP**	**PSPACE**	**PSPACE**
non recursive det. DTD	**coNEXP**	**coNEXP**	**coNEXP**
stepwise	**coNEXP**	**coNEXP**	**coNEXP**

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Complexity of **streaming** bounded repairability problem:

	det. DTD	DTD
universal	**P**	**PSPACE**
DTD	**EXP**	**EXP**

Some references...

- **Regular Repair of Specifications**
  Benedikt, Riveros, P. – LICS 2011
- **The cost of traveling between languages**
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- **Bounded repairability for regular tree languages**
  Riveros, Staworko, P. – ICDT 2012
- **Which DTDs are streaming bounded repairable?**
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...and other related topics

- normalized edit cost $\sup_{s \in S} \min_{t \in T} \frac{\text{dist}(s,t)}{|s|}$
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- energy games with perfect/imperfect information

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