Lower Bounds for Levin–Kolmogorov Complexity

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Preliminaries

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- **Kolmogorov complexity** $\mathsf{K}(x) := \min_{\Pi}\{|\Pi| \mid \Pi(\varepsilon) = x\}$

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- **Levin's notion** [Lev84]
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- **Kolmogorov complexity** $\mathsf{K}(x) := \min_{\Pi}\{|\Pi| \mid \Pi(\varepsilon) = x\}$
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  $\mathsf{Kt}(x) := \min_{\Pi}(|\Pi| + \lceil \log_2(t) \rceil \mid \Pi(\varepsilon) = x \text{ in } t \text{ steps})$
- **Decisional problem** $\mathsf{MKtP} := \{(x, k) \mid \mathsf{Kt}(x) \leq k\}$

Hardness of Kt

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Results about the hardness of Kt [Hirahara; LiuPass]

Hardness of MKtP

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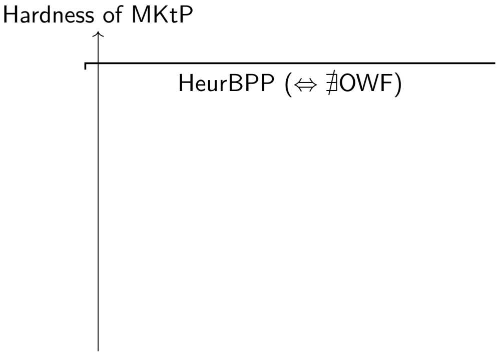

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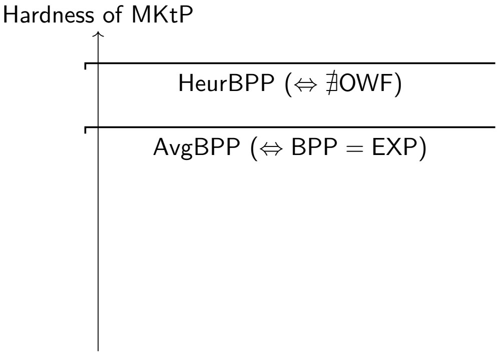

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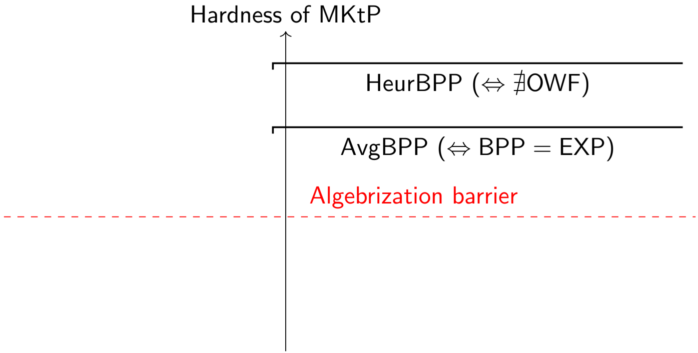

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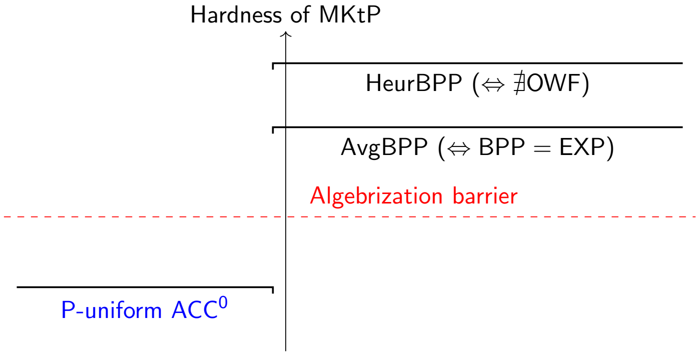

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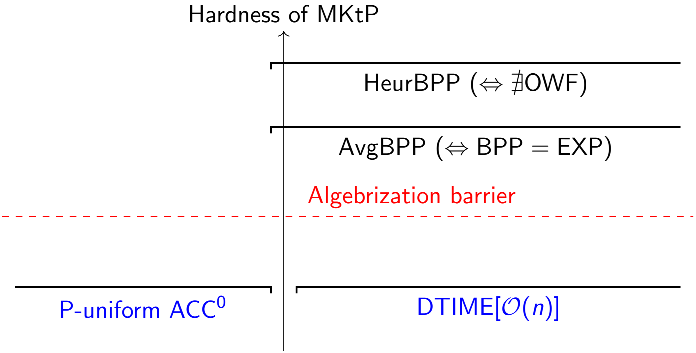

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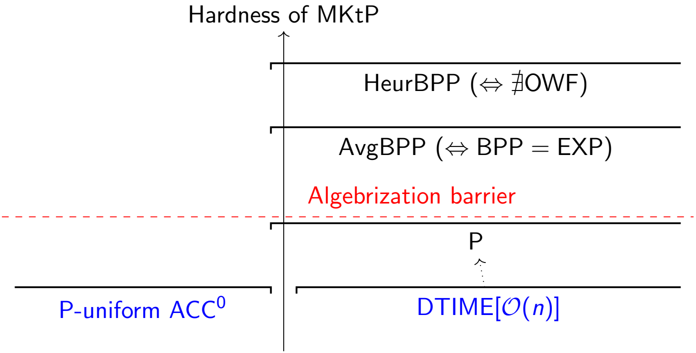

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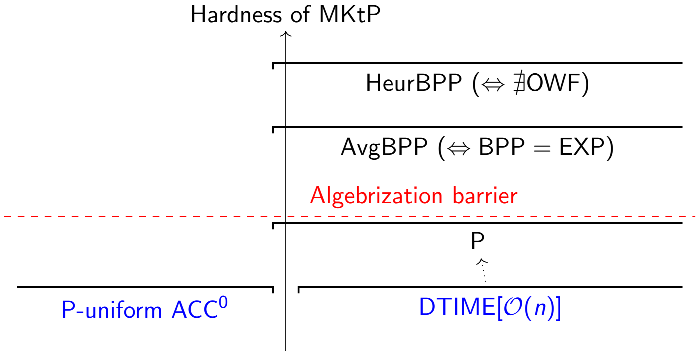

[RenSanthanam] oracle: approx. to with $(1+\epsilon)$ and BPP = EXP

Diagonalization Approach

Simple Diagonalization for K

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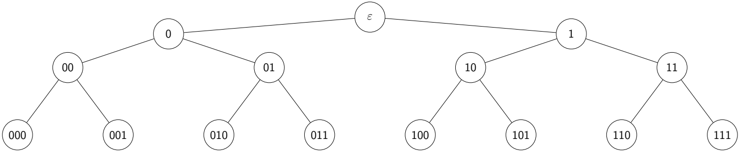

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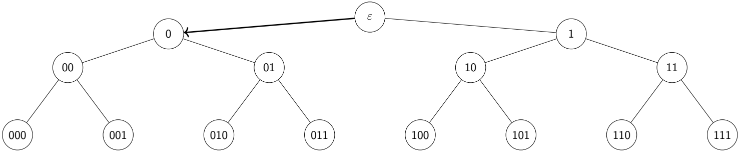

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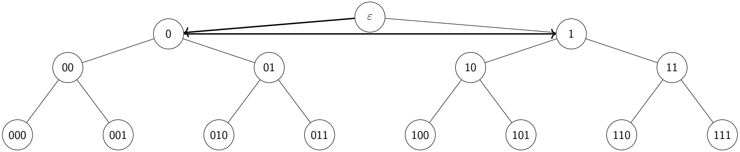

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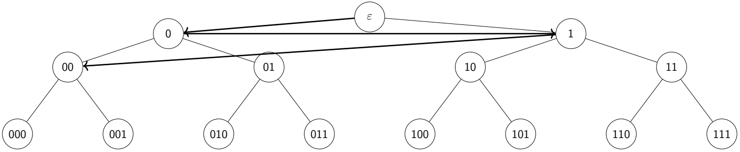

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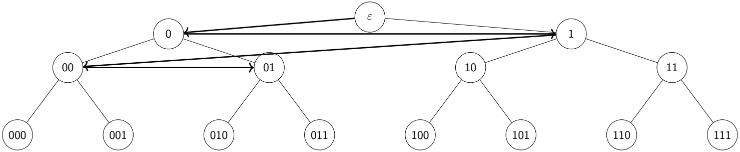

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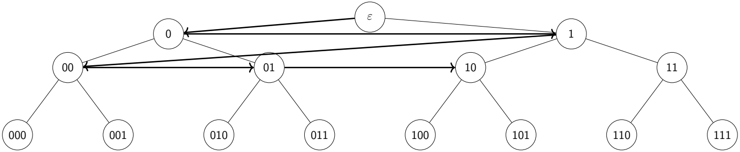

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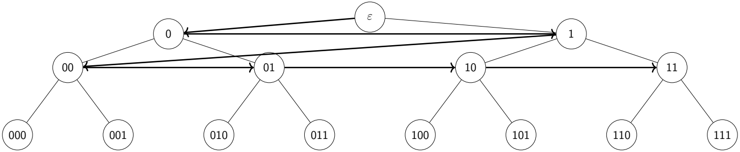

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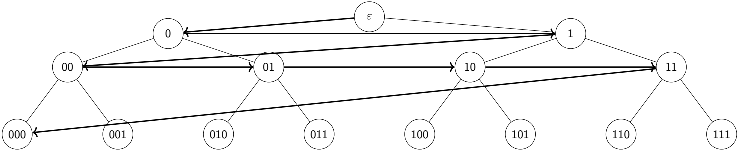

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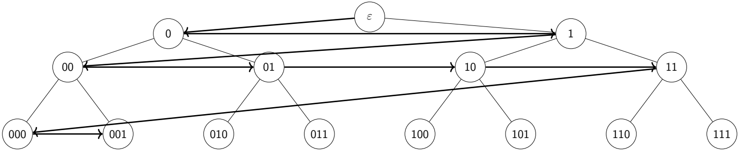

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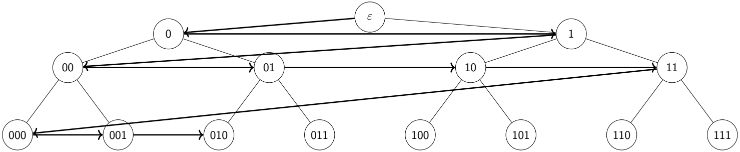

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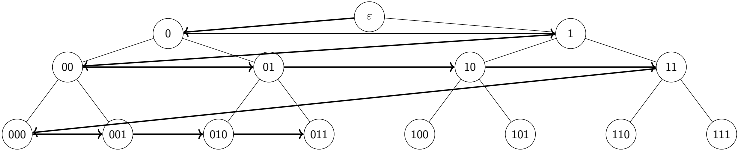

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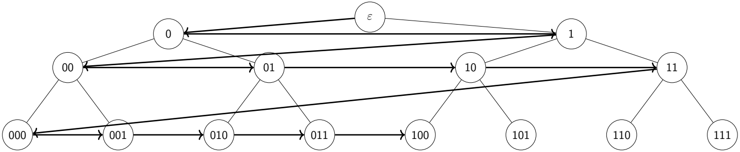

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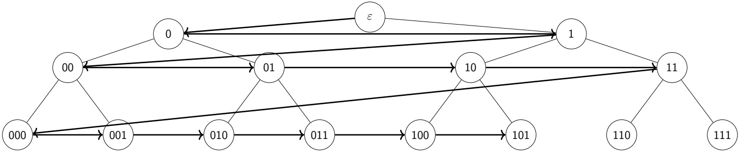

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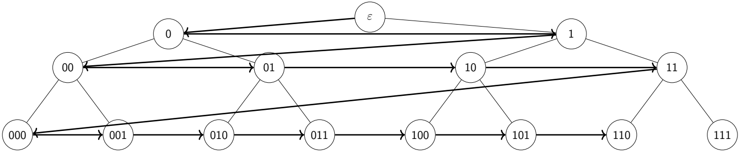

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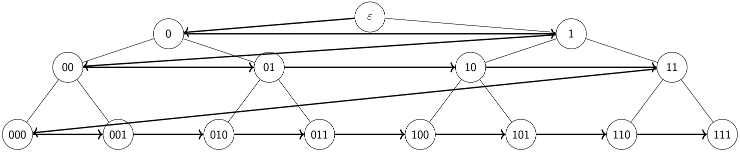

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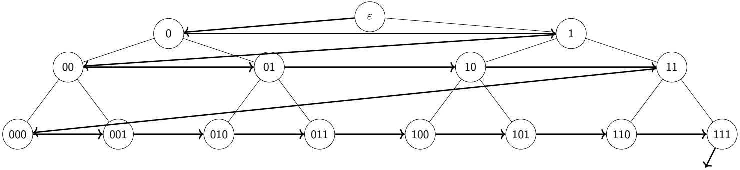

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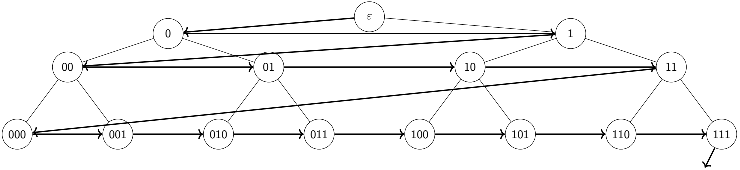

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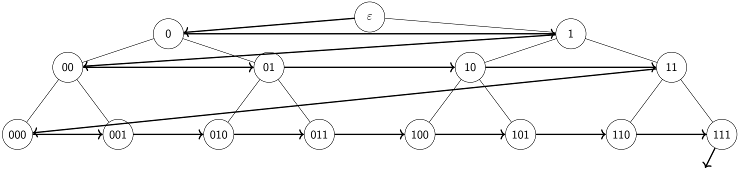

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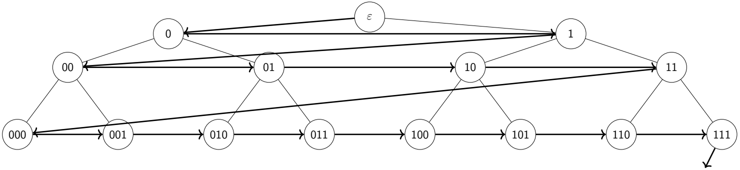

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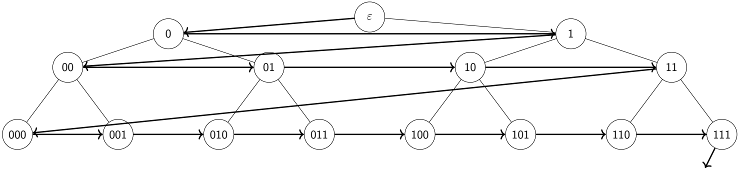

- Contradiction: $|x| \leq \mathsf{K}(x) \leq c \lneq |x|$.
- Need structure of R_{K}: infinitely many K-random strings exist.

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Simple Diagonalization fails for Kt

- Suppose linear-time TM (of size $c \geq 2$) decides $R_{\mathsf{Kt}} = \{x \mid \mathsf{Kt}(x) \geq |x| + \lceil \log |x| \rceil\}$.

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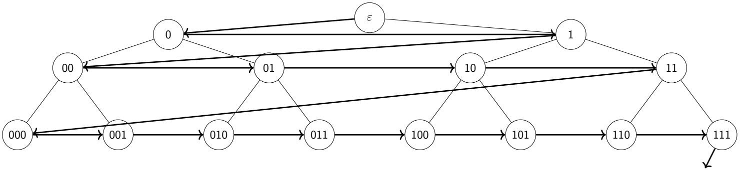

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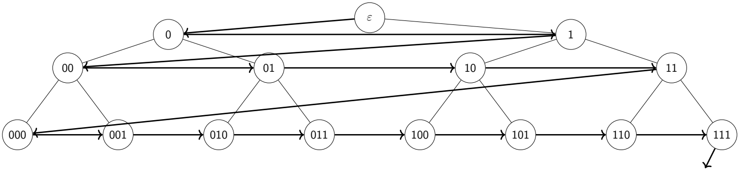

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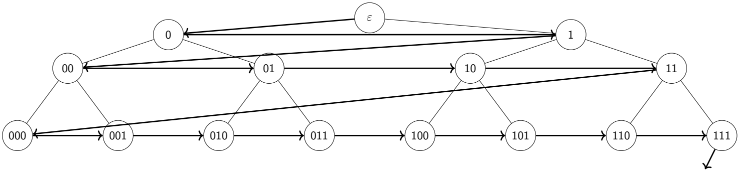

- Level ℓ costs $t \geq 2^\ell \ell$ time. Never output any string $x \in \{0,1\}^{\ell+1}$ because $|x| + \lceil \log |x| \rceil \leq c + \lceil \ell + \log(\ell) \rceil \leq c + \lceil \log(t) \rceil$.

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Our Diagonalization

- Suppose linear-time TM (of size c) decides $R_{\mathrm{Kt}} = \{x \mid \mathrm{Kt}(x) \geq |x| + \lceil \log |x| \rceil\}$.
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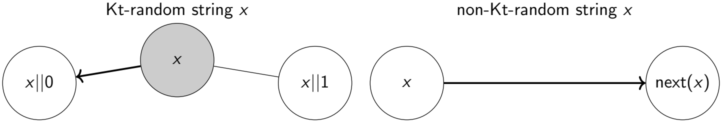

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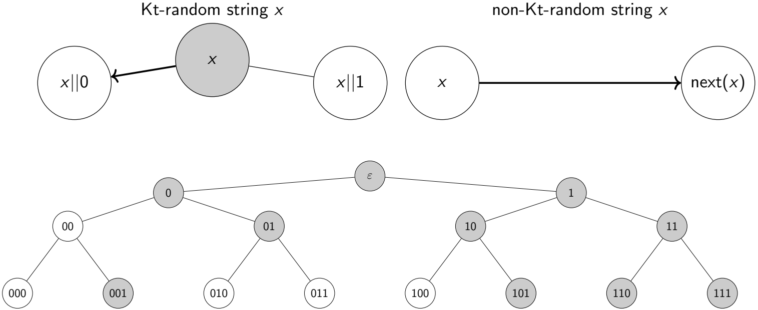

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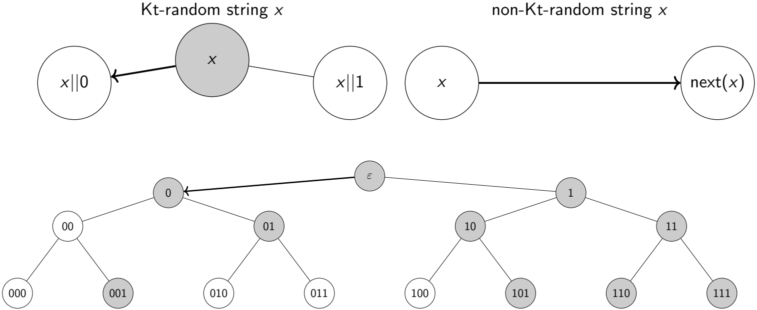

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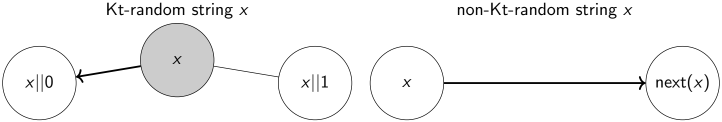

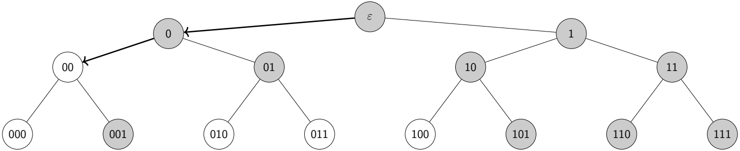

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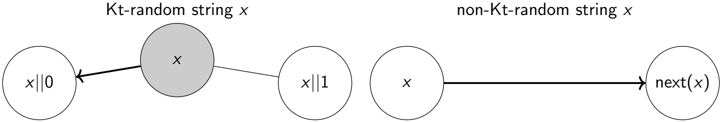

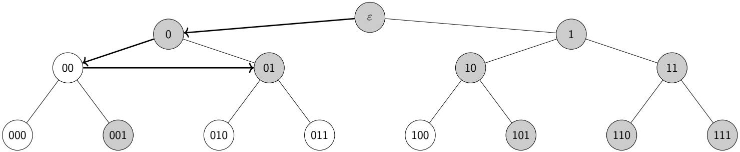

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- Suppose linear-time TM (of size c) decides $R_{\mathsf{Kt}} = \{x \mid \mathsf{Kt}(x) \geq |x| + \lceil \log |x| \rceil\}$.
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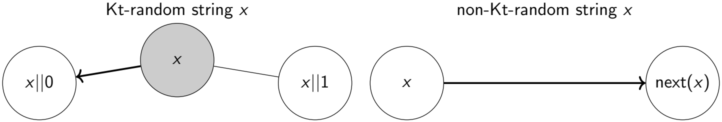

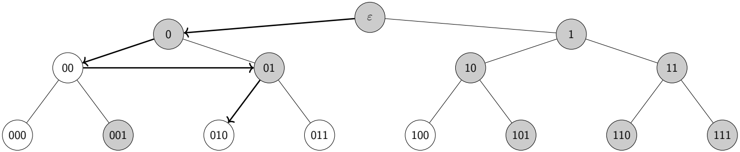

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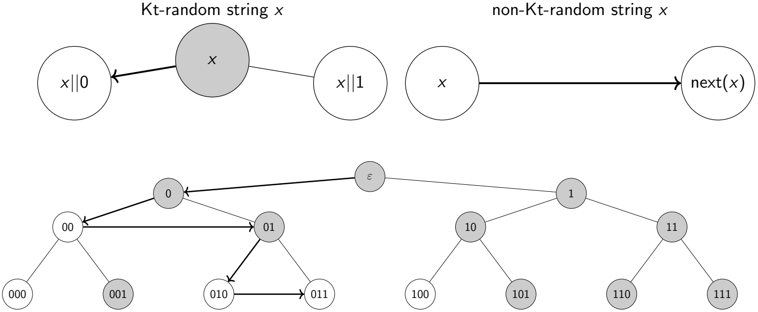

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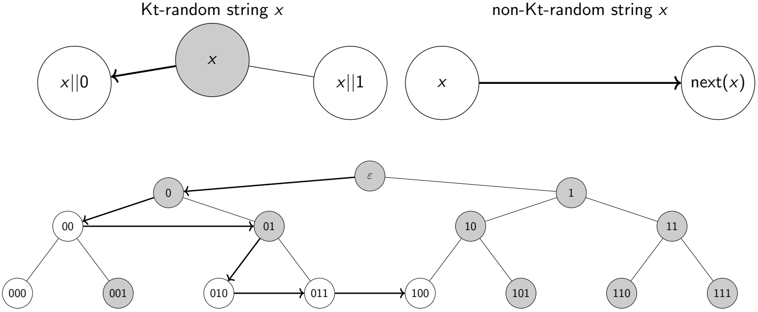

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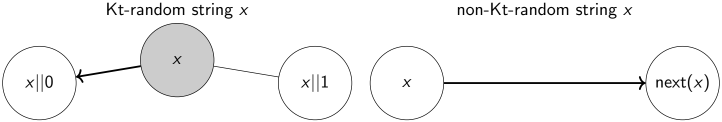

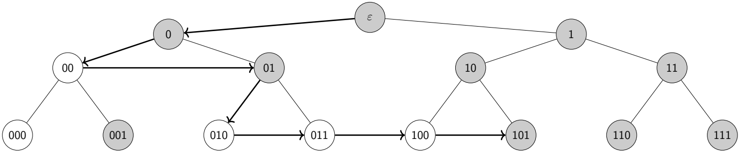

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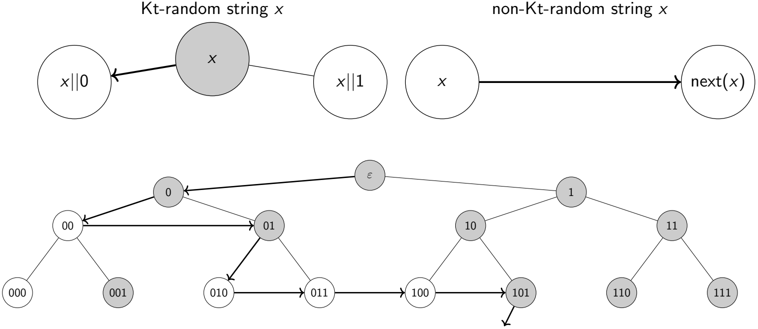

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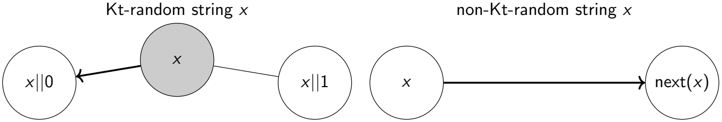

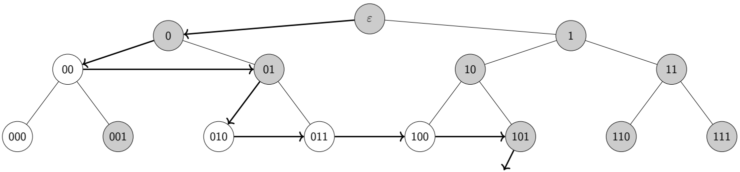

- Need structure of R_{Kt}: a 1-Kt-random string (Chaitin's constant Ω [Cha75]); here 101...

Results

1

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Unconditional Results

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Thus, MKtP $\in$ P $\implies$ MKtP $\notin$ DTIME$[\mathcal{O}(n)]$ with $1/\text{poly}_{\exists}(n)$ two-sided error which implies a very weak[1] form of OWF against *deterministic* inverters.

[1] OWF is computable in poly-time, and linear-time inversion is correct or $\perp$.

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