CNT-PUFs: Highly Robust Physical Unclonable Functions Based on Carbon Nanotubes

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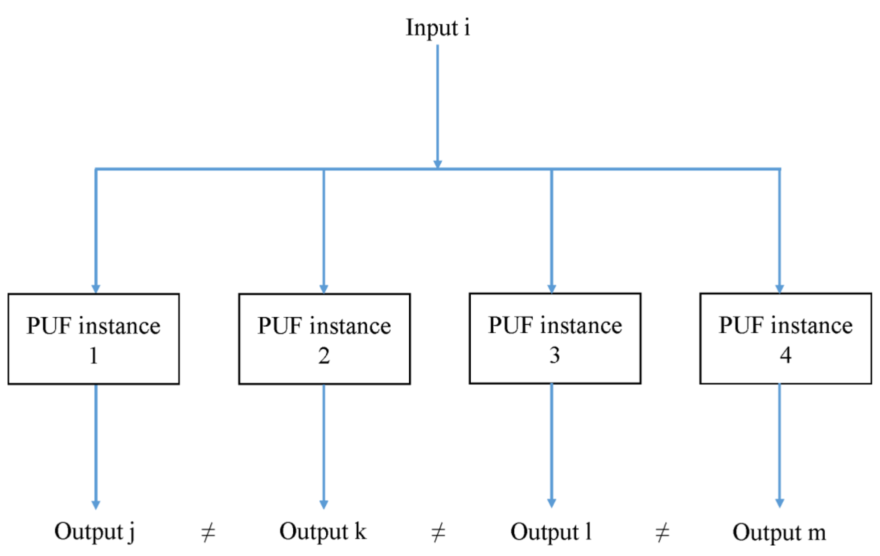
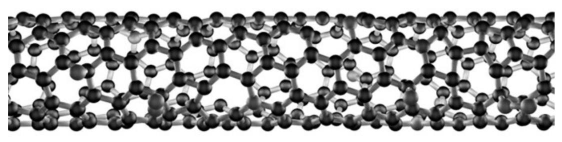
Introduction and Motivation

Physical Unclonable Functions (PUFs) are physical objects with highly distinguishable physical properties that do not affect their normal operation or use, but which can be utilised for the production of unique and unpredictable security tokens, such as keys.

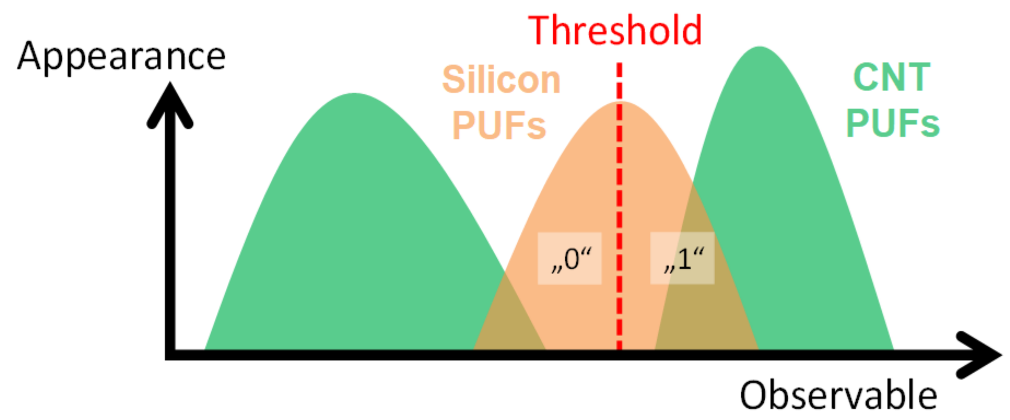
PUFs have been proposed as low-cost security anchors in embedded systems and have successfully been applied to the problems of device identification, key storage, and software protection.



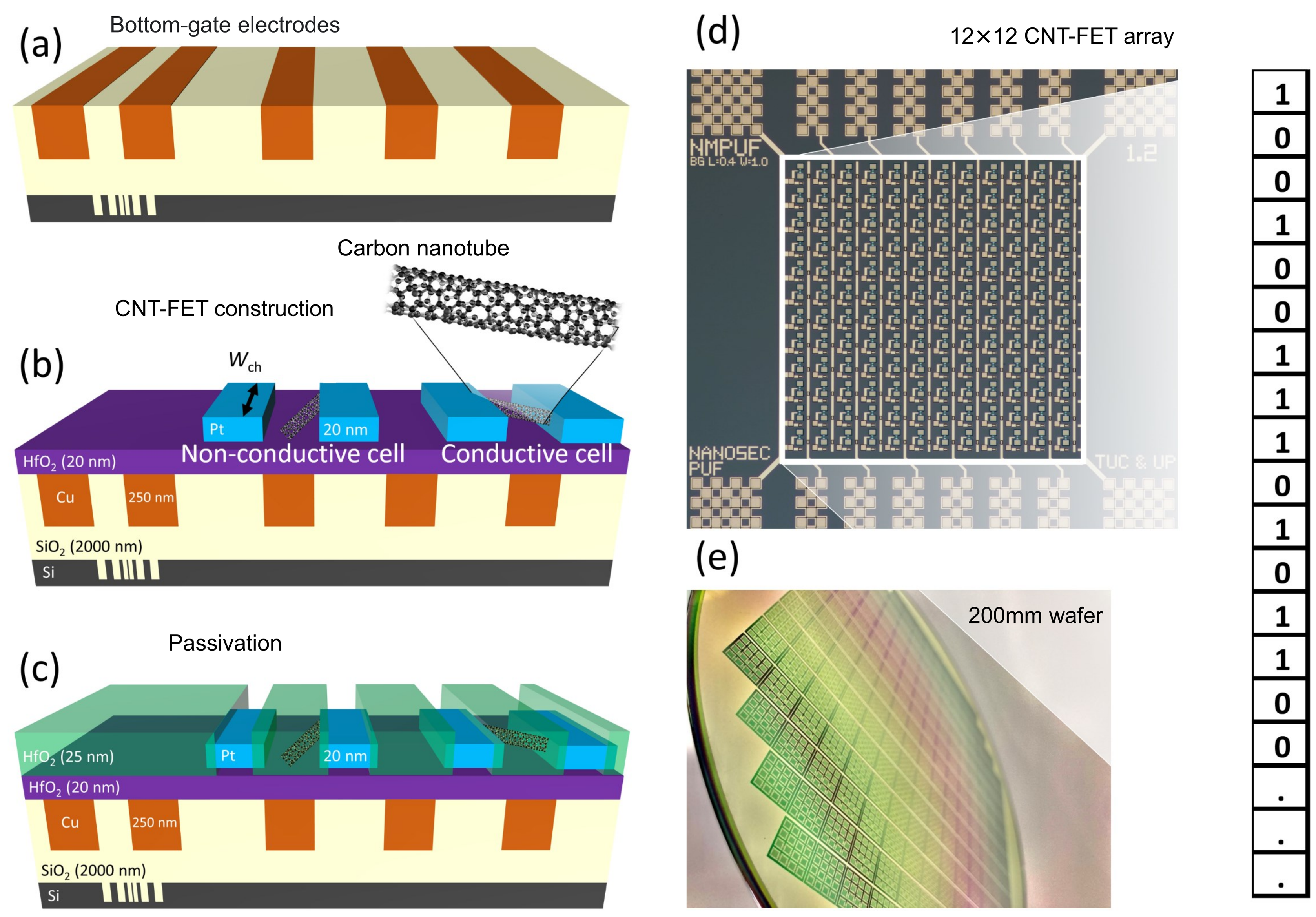


Semiconducting single-walled Carbon NanoTubes (CNTs) have already proven their capabilities for post-silicon electronics as well as for gas, chemical, or bio-sensors enabled by their high intrinsic charge-carrier mobility, high current-carrying capacity and their mono-atomic surface. Moreover, the use of CNT-FETs for the creation of miniaturized PUFs has already been examined. Additionally, major achievements in technology integration have led to the ability to manufacture CNTs in scalable and CMOS-compatible procedures, allowing for hybrid features combining conventional applications of CNTs with security on the same technological basis.

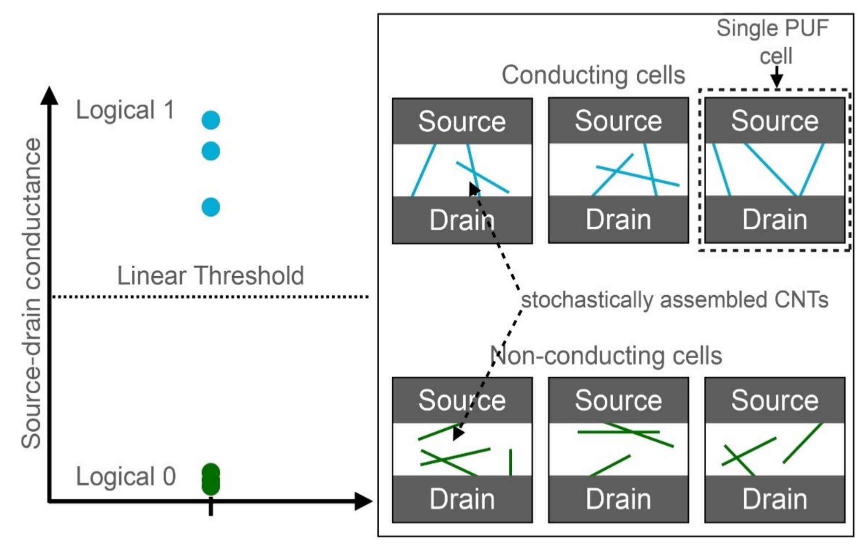
Due to their inherent characteristics, CNT-PUFs may offer high uniqueness, uniformity and robustness, but no comprehensive evaluation of the quality of their responses has so far been provided. Here, we consider 28 measurements of CNT-PUFs formed from encapsulated 144-CNT-FET arrays produced on CMOS-compatible 200mm wafers to evaluate these PUFs.



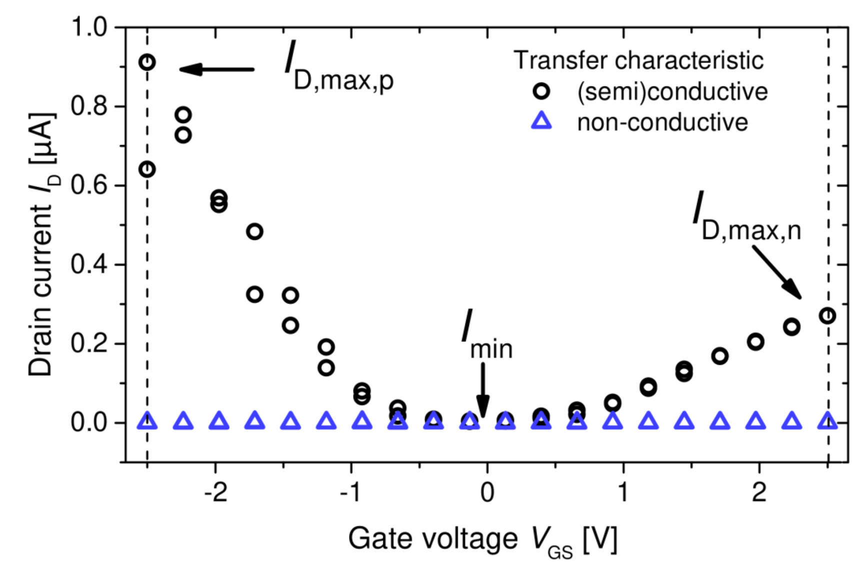
CNT-FET Fabrication



PUF Implementation



Conducting and semiconducting CNT-FETs are conducting for V_{GS} = –2.5 V and V_{DS} = –1 V, while non-conducting do not. This is based on whether the CNTs bridge the source and the drain, or not.



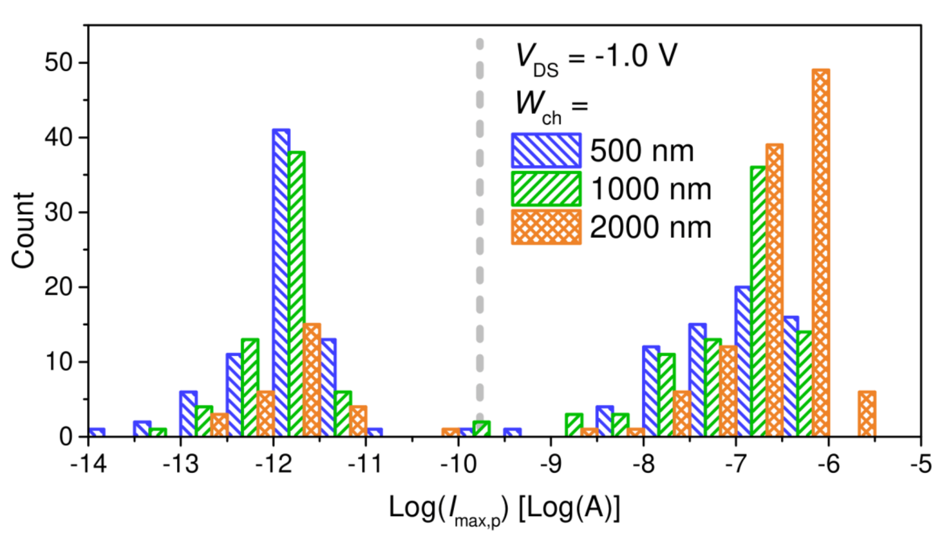
Transfer I-V characteristics for a semiconducting and a non-conducting CNT-FET

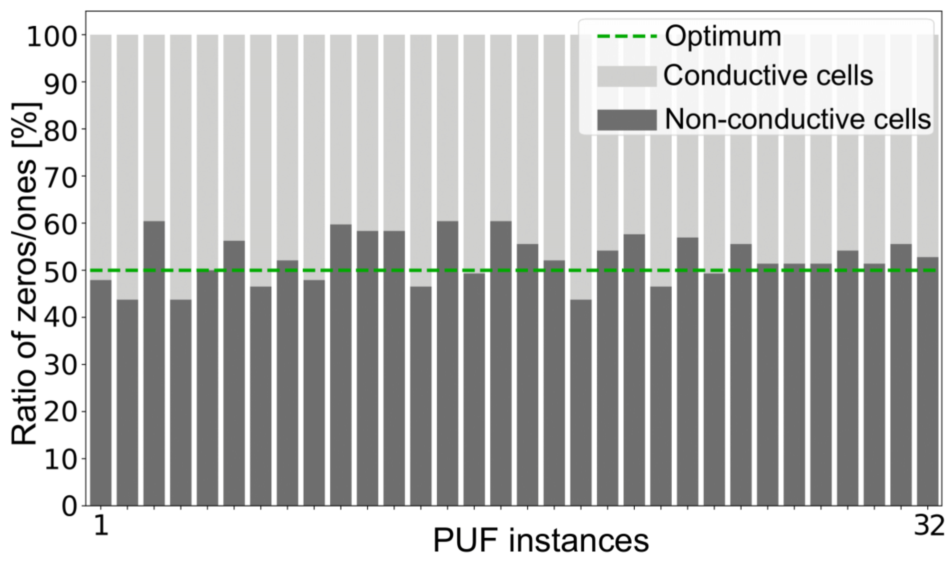
Conducting and semiconducting CNT-FETs contain CNTs which bridge the source and drain electrodes, resulting in high source-drain conductance for a gate-source voltage of –2.5 V or 2.5V, corresponding to the logical value of 1. In contrast, non-conducting CNT-FETs exhibit very low source-drain conductance, corresponding to the logical value of 0.

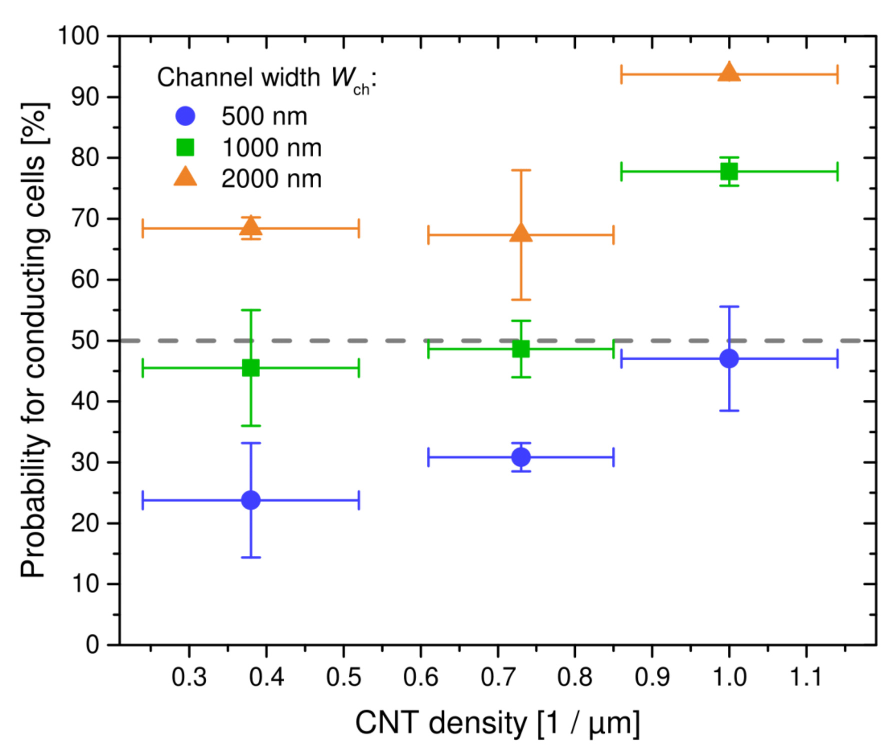
Results and Discussion

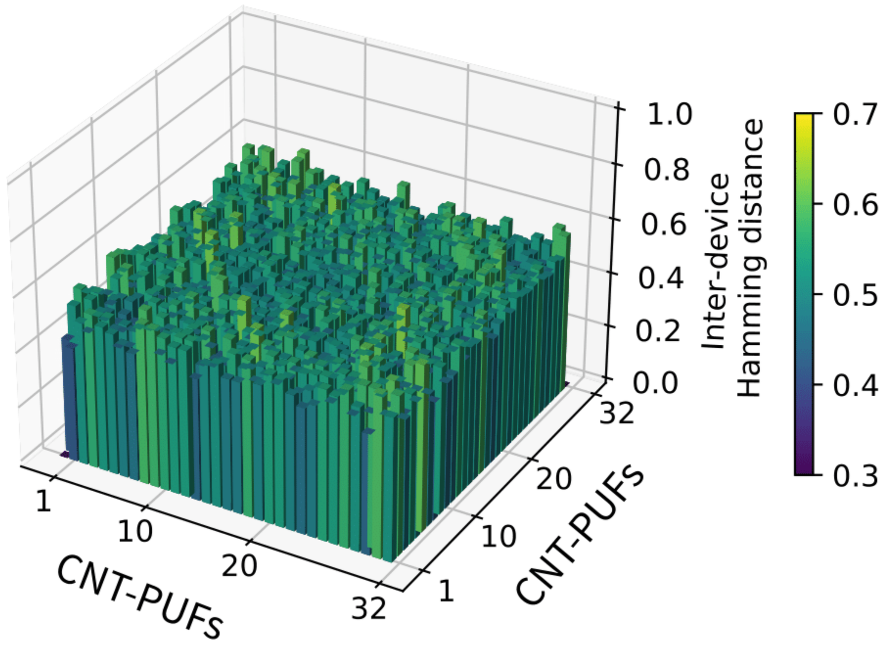
Influence of the channel width and the CNT density

- The distribution of non-conducting (logical 0s) and conducting (logical 1s) CNT-FETs strongly depends on the channel width and the CNT density.
- A larger channel width leads to more conducting CNT-FETs (logical 1s).
- A higher CNT density also leads to more conducting CNT-FETs (logical 1s).









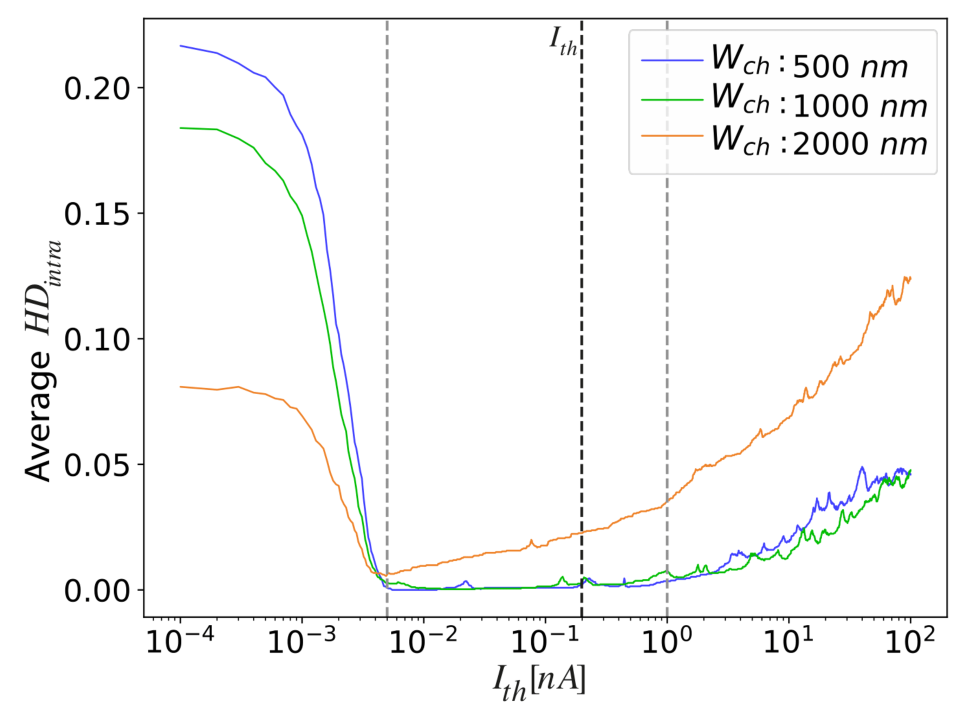
Quality of the CNT-PUF responses

Uniformity: Average HW: 53.8%

Uniqueness: Average HD_{inter}: 51% (39% to 64%)

Robustness: (within I_{th} window) Average HD_{intra}: 1% (I_{th}=0.2 nA, W_{ch}=1000 nm – black dashed line)

Highest HD_{intra}: 3% (I_{th}=1 nA, W_{ch}=2000 nm – left grey dashed line)



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