nature portfolio

https://doi.org/10.1038/s41586-021-03623-y

Supplementary information

Mechanical computing

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Supplementary Discussion: "*n*-ary Abstractions"

In this Perspective, especially Section II, we have discussed the abstraction of binary information based on the static/dynamic response of a mechanical computing unit. Although binary representations have been widely used in both conventional and unconventional computers, mechanical computing systems can also offer n-ary abstractions (n > 2) of information, which may enhance the efficiency of information storage. For example, a mechanical unit with tristable behavior (i.e., there exists three stable configurations) can represent discrete values of {'0', '1', '2'} or {'−1', '0', '+1'} (see also Ref.[S1] for a ternary calculating machine designed in 1840).

To examine the efficiency, we explore a case study in which we express a positive integer k by using various n-digit systems (see Fig. S1a for the change of the required number of digits for different n-ary digit systems). Here, we define the efficiency (f) as $f = an + \log_n k$ where a is a weight coefficient, and we plot this efficiency as a function of n. If $k = 10^5$ is selected, the minimum efficiency can be obtained by choosing other n-ary systems, instead of binary storage (see Fig. S1b). By extending this calculation to different k values, we find that to express smaller k values (e.g., 10^3), $n = 3, 4$ can be advantageous, compared with binary or decimal digits as shown in Fig. S1c (see also Ref. [S2] for a discussion of why "ternary digit" can be optimal for storage efficiency compared with binary digit (bit) systems). Recently, multistable mechanical structures have been reported, e.g., tristable rotating squares Ref. [S3] and quadstable origami Ref. [S4] (see Fig. S1d-e), and such multistable elements have potential for developing n = 3, 4 digit information storage.

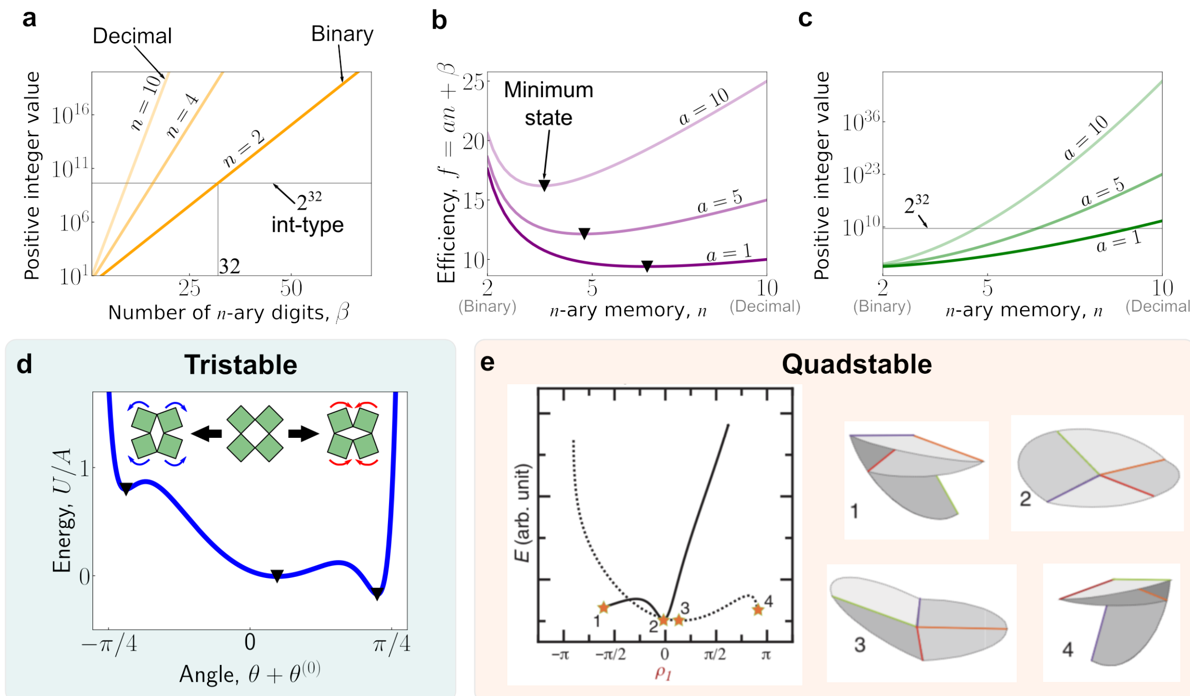

FIG. S1. Analysis of Information Storage in Systems with Non-binary Abstractions (**a**) The number (β) of n-ary digits required to express a positive integer (k) can be calculated as $\beta = \log_n k$. The grey horizontal line indicates 2^{32}, which corresponds to the maximum value of a 4-byte integer representation. (**b**) To express a large integer number efficiently, we assume that the efficiency of information storage is proportional to n and define the efficiency (f) as $f = an + \log_n k$ where a is a weight coefficient. We consider the case of $k = 10^5$, and plot the result for a = 1, 5, and 10. The black triangle markers represent the local minimum state, which means the most efficient storage, i.e., smaller n and smaller number of digits. (**c**) We calculate and plot various positive integer numbers as a function of the efficient n-ary storage. Based on this calculation, to express smaller numbers (e.g., 10^3), $n = 3, 4$ can be advantageous, compare to binary or decimal digits. Please note that this calculation is a rough estimation without considering fabrication challenges, operation speed, or robustness. Example multistable mechanical structures include (**d**) ternary memory based on rotating squares (reprinted with permission from Reference [S3], © 2020 American Physical Society) and (**e**) quaternary memory based on origami (reproduced with permission from Reference [S4], © 2015 American Physical Society). See also Ref. [S2] for a discussion of why base $n = 3$ (i.e., ternary digit) can be optimal for storage efficiency.

References:

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