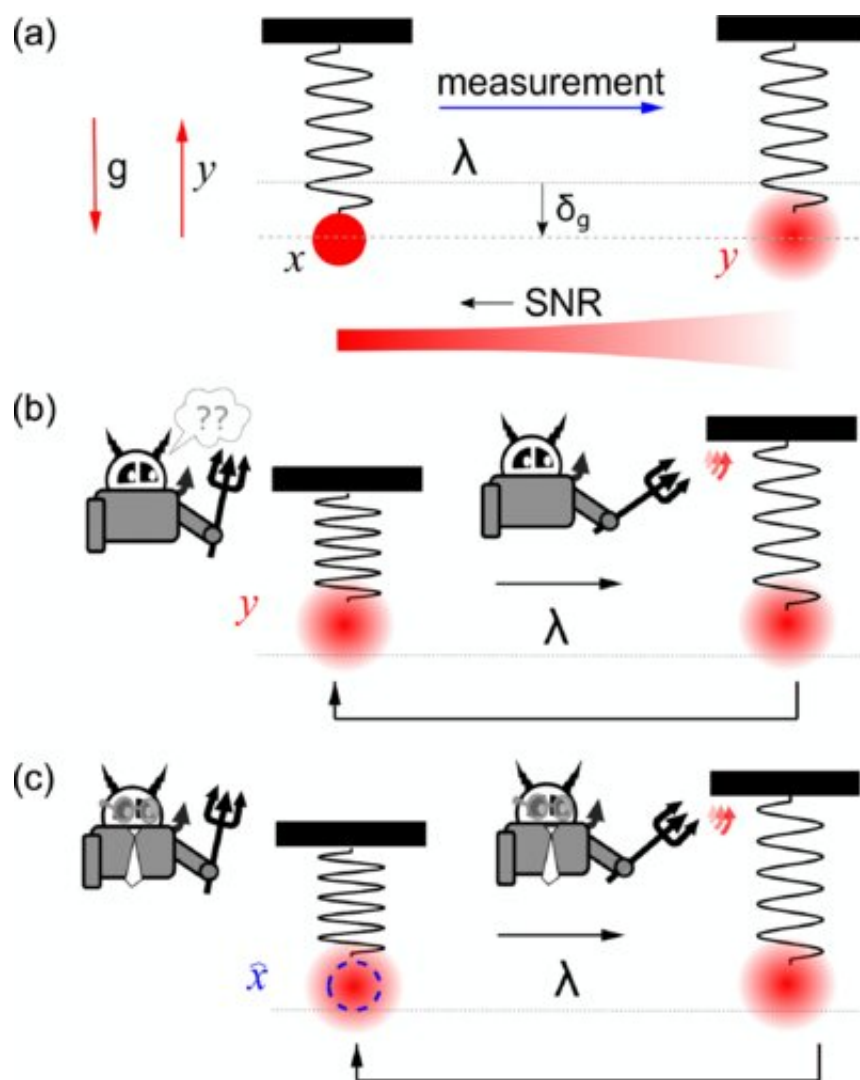


Mini-engine exploits noise to convert information into fuel

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Schematic information engine. (a) Noisy detector measures position y of the bead, actually located at x . Ratchet based on either (b) noisy position measurement y or (c) Bayesian position estimate \hat{x} (blue dashed circle). Credit: *Physical Review Letters* (2022). DOI: 10.1103/PhysRevLett.129.130601

Too much background noise is usually guaranteed to disrupt work. But physicists have developed a micro-scale engine—made from a glass bead—that can not only withstand the distracting influence of noise, but can harness it to run efficiently. Their experiment is reported in the journal *Physical Review Letters* and was selected by the journal as a research highlight.

In [everyday life](#), we're familiar with engines and motors that consume fuel to move in a directed way and thus perform useful work. But things are more complicated in the microscopic world, where noise in the form of heat can easily scupper things.

"Heat makes the components of small machines jiggle back and forth all the time," explains senior author John Bechhoefer, a [quantum physicist](#) at Simon Fraser University in Burnaby, British Columbia, and member of the Foundational Questions Institute, FQXi, a physics think tank. So usually the effect of such thermal noise from heat in the environment is to reduce the amount of useful work a tiny [engine](#) can produce.

But there is a special family of microscopic machines, called "information engines" that can actually exploit the noise to move in a directed way. An information engine acts by measuring small movements caused by heat and using that information to selectively reinforce those movements that go the "right" way, in the direction the machine requires.

"An information engine is a machine that converts information into work," says Bechhoefer.

Physicists and engineers are excited about building such tiny information-harnessing motors to design novel microscopic machines for

nanotechnology applications. "There is great interest in taking inspiration from the biomolecular machines that nature has evolved," says co-author David Sivak, a physicist also at SFU. "Our work advances our understanding of how information may be utilized in such machines, pointing to possible uses for sustainable energy-harvesting or more efficient computer storage and computation."

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Bechhoefer, Sivak and their SFU colleagues Tushar Saha, Joseph Lucero and Jannik Ehrich have built an information engine using a microscopic glass bead—about the size of a bacterium—suspended in water. The bead is loosely held in place by a laser beam that acts like a support under the beam. The molecules in the water jostle the bead gently, due to natural thermal fluctuations in the liquid, and every so often the bead will be buffeted up.

Here comes the trick: When the team measures that the bead has moved up against gravity, due to thermal fluctuations, they raise the laser support. In this higher position the bead now has more stored energy, or gravitational potential energy, like a ball that is held up, ready to drop.

The team has not had to expend work to lift the particle up; that motion happened naturally thanks to the jiggles of the water molecules. So the engine converts the thermal heat from the water into stored gravitational potential energy using feedback about the motion of the bead to adjust the laser trap. "The decision on whether the trap should be raised, and if so by how much, depends on the information we collect about the bead's position, which acts as the 'fuel' for the engine," says lead author Saha.

That's how it works in principle, but correctly implementing the strategy is tough if there is too much measurement noise, generated in the system

from the brightness of the laser beam used to locate the bead. In such cases, the uncertainty in the bead's position for each measurement can be greater than the bead's movements produced by the jiggling water molecules. "Measurement noise leads to misguided feedback and thereby degrades performance," says Saha.

'Bayesian' information engine

Typical information engines use feedback algorithms that base decisions on the last measurement of the bead's position, but these decisions can be wrong when the measurement errors are large. In their recent paper, the team wanted to investigate if there was a way to get around this disruptive issue.

They developed a feedback algorithm that did not simply rely on a direct measurement of the bead's last position—since this measurement could be inaccurate—but instead on a more accurate measurement of the bead's last position that was based on all previous measurements. This filtering algorithm was thus able to allow for measurement errors in making its estimate—called a "Bayesian estimate."

"By combining many noisy measurements in a smart way involving a model of the bead's dynamics, one can recover a more accurate estimate of the true bead position, significantly mitigating the performance losses," says Lucero.

In their new experiment, reported in *Physical Review Letters*, the team demonstrated that an information engine that applies feedback based on these Bayesian estimates performs significantly better than typical information engines, when measurement errors are large. In fact, most typical information engines will stop, if the measurement errors are too large.

"We were surprised to find that when measurement errors exceed a critical threshold, the naive engine can no longer operate as a pure information engine: the best strategy is simply to throw up your hands and do nothing," says Ehrich. "By contrast, the Bayesian information engine is able to eke out some small positive work whatever the amount of measurement error."

There is a price to pay for the Bayesian information engine's ability to extract energy even with large measurement errors. Since the Bayesian engine uses information from all previous measurements, it needs more storage capacity and involves more information processing.

"A trade-off arises because reducing measurement error increases the work extractable from fluctuations, but also increases the information-processing costs," says Ehrich. The team thus found maximum efficiency at an intermediate level of measurement error, where they could achieve a good level of energy extraction, without requiring too much processing.

"There is great interest in taking inspiration from the biomolecular machines that nature has evolved," says David Sivak.

The team is now investigating how things might change if the noise that "fuels" the engine arises from something other than heat. "We are preparing a paper that studies how the optimal feedback strategy and performance change when the fluctuations are no longer simply thermal," says Saha, "but also arise due to active energy consumption in the surrounding environment, as is the case in living cells."

More information: Tushar K. Saha et al, Bayesian Information Engine that Optimally Exploits Noisy Measurements, *Physical Review Letters* (2022). [DOI: 10.1103/PhysRevLett.129.130601](https://doi.org/10.1103/PhysRevLett.129.130601)

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