hole's tidal force would disrupt a small cloud, and their results seem to be consistent with their observation of a progressive elongation of the blob, and perhaps with a gaseous tail following the blob in its orbit. But it will be necessary to add numerical hydrodynamic calculations of this phenomenon in order to assess whether the tiny cloud that the authors have found could survive the violent plunge long enough to deposit a significant amount of matter near the black hole. If not, one might consider the possibility that a much larger mass than the cloud — a relatively faint star or a stellar-mass black hole — binds the dusty gas that Gillessen *et al.* have observed in the form of a circumstellar disk as the ensemble orbits towards Sgr A*. Even then, the black hole's tidal force near closest approach may be able to wrench some of the gas from the disk, and fuel an accretion-induced brightening of the Galactic black hole. Many telescopes are likely to be watching. ■

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SYNTHETIC BIOLOGY

Bacteria collaborate to sense arsenic

A method developed to allow rapid communication between bacterial cells across long distances enables the cells to detect arsenic collectively, and to report it as an oscillatory output. **SEE ARTICLE P.39**

CHRISTOPHER A. VOIGT

Living cells can be exploited to sense and process environmental stimuli, including poorly defined microenvironments, biological markers of disease, defects in materials and complex small molecules. But obtaining a reliable signal from individual cells has proved a challenge. On page 39 of this issue, Prindle *et al.*[1] report a solution to this problem: a sensor composed of millions of bacterial cells that communicate with each other over long distances (up to 2.4 centimetres). The cells respond to the presence of arsenic by altering the rate at which they produce synchronized pulses of fluorescence.

Cells have been engineered to sense many environmental signals, including light, chemicals, touch, metal ions and pH. For example, sensors have been made in which human olfactory receptors are expressed in yeast cells[2]. Most cellular sensors are based on a protein or messenger RNA that responds to a signal by causing the expression of a gene. Such genetic sensors often suffer from low dynamic range (that is, there is little change in output between the absence and presence of a signal) and nonspecificity (they are activated by multiple signals). Furthermore, because cells are living systems, individual responses may vary because of stochastic effects or differences in growth states.

Prindle *et al.*[1] have addressed the problem of dynamic range by applying the principles of signal processing to a biosensor based on genetic circuits. Such circuits use biochemical interactions to produce functions analogous to their electronic counterparts. Previously, the same group built a robust genetic oscillator[3] — a network of genes and proteins that produced regular pulses of molecules — and used this as a time-keeping mechanism to control cell–cell communication between bacteria. This yielded populations of bacteria that expressed a fluorescent protein in unison, and so produced synchronized pulses of light.

Theoretically, such an oscillator would enable a sensor to use the frequency of oscillations as signals, making the sensor less sensitive to environmental noise and exposure time than systems based on steady-state signals. A problem with the previous oscillator[3], however, was that cell–cell coupling relied on the diffusion of a small molecule through cellular media, a process that is too slow to allow rapid, long-range coupling of millions of cells. Molecular diffusion in the gas phase is much faster, so Prindle *et al.*[1] used this mechanism to accelerate the coupling between separate colonies of bacteria.

In this way, the authors were able to couple 2.5 million cells of the bacterium *Escherichia coli*, which were arranged as an array of colonies across a distance of 5 millimetres. As in the previously reported oscillator[3], the output of the system[1] was the coordinated, oscillating expression of a fluorescent protein, which the authors detected using a microscope. The period of the oscillations was quite long (more than an hour), but the degree of synchronization was high — the colonies produced light pulses within 2 minutes of each other.

To demonstrate a potential application of their system, Prindle *et al.* 'rewired' their network to incorporate elements that respond to arsenic. The resulting system acted as an arsenic sensor: once the concentration of arsenic reached a threshold value, the amplitude and period of the oscillations increased significantly. This produced a device with a large dynamic range. What's more, because the device averaged the outputs of a population of cells, noise was reduced and the sensor's response was decoupled from the growth state of individual cells. The authors scaled up their device so that it included more than 12,000 communicating bacterial colonies, covering an area of 2.4 × 1.2 centimetres.

Several advances, yet to be achieved, would improve the ability to connect this living sensor to an electronic system. One problem is that the minimum response time of the sensor to an input signal is slow, because gene expression — which takes about 20 minutes to occur — is required. Another issue is that the output involves fluorescence, which is awkward for electronic devices to use; the ideal output would be a direct electrical signal. To this end, cells have been metabolically engineered so that they can be induced to release electrons, which can then be read by an electronic sensor[4]. The electron-transport system found in bacterial nanowires (extracellular appendages that conduct electricity[5]) has also been harnessed[6] to link cells to an electronic system. Nevertheless, these strategies still require the expression of a gene that triggers electron flux, so the resulting sensors are relatively slow to respond to signals.

More broadly, there are several collaborative research efforts aiming to develop better toolboxes for building interfaces between cellular and electronic components. One such project is to build a millimetre-scale robot that swims like a lamprey, using a combination of human muscle cells, yeast-based sensors, an electronic brain and flexible materials (nicknamed 'cyberplasm')[7]. Another project is to develop genetic sensors, along with genetic circuits to apply signal processing within the cell[8] and new approaches to link cellular outputs to an electronic system, with the ultimate objective of controlling robots[9]. As the integration of cellular and electronic systems matures, it will be interesting to see how circuitry in future devices is divided between biological and electronic components. ■

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OPTICAL PHYSICS

How to hide in time

As if the idea of a device that makes an object seem invisible was not mind-boggling enough, researchers have now demonstrated a system that can conceal an event in time. SEE LETTER P.62

ROBERT W. BOYD & ZHIMIN SHI

An exciting development in optical physics has been the proposal[1,2] and subsequent demonstration[3–6] of a spatial cloak, a structure that can render invisible any object placed in a specific region of space. Writing in this issue, Fridman *et al.*[7] (page 62) extend this concept by demonstrating a temporal cloak — a device that hides events occurring during a specific time window.

Let us first describe the operation of a spatial cloak. One example of such a device consists of a shell that surrounds the object to be hidden[2]. Using a method known as transformation optics, the way in which the refractive index changes across the material that constitutes the shell is set such that any light ray incident on the shell is deflected so as to miss the object to be hidden. The ray is redirected so that, when it leaves the shell, it is travelling in the same direction as if both the shell and the object hidden inside had not been present at all.

The experimental realization of spatial cloaking is intimately related to the development of optical metamaterials[8]. These are artificial materials with highly controllable optical properties that can be very different from those of naturally occurring materials. A prime example is a metamaterial designed to have a negative refractive index so that it bends light rays in the opposite direction to that in which conventional materials do. So far, spatial cloaking has been realized in, for example, a cylindrical geometry at radio frequency[3] and 'carpet' geometries at infrared[4,5] and visible[6] wavelengths.

The concept of cloaking has been extended to cloaking in time by a recent theoretical treatment[9]. This work showed that a time gap can be opened in an optical wave by locally manipulating the speed of light such that the front and rear parts of the wave get accelerated and slowed down, respectively. Any event that occurs within the resulting time gap — in which no light is present — would be rendered invisible to someone monitoring the transmitted light wave. However, the presence of this time gap in the light intensity would be a clear indication that someone had tampered with the time history of the system. The gap can be closed by subsequently reversing the modification of the light's speed as it leaves the 'interrogation region' that is to be cloaked. In this way, the previously accelerated light gets slowed down and the previously slowed-down light gets accelerated. When the restored light reaches an observer, a continuous, uniform light field is observed, and there is no indication that some event has occurred.

In their experimental study of temporal cloaking, Fridman *et al.*[7] made use of time-lenses and dispersive media[10]. To understand the principle of a time-lens, we should recall that a conventional optical lens is a device that can cause an incident light beam to converge or diverge spatially. From a mathematical perspective, the spatial and temporal evolution of light are quite similar, and therefore the principle of a lens can be extended to a time-lens.

A time-lens modifies a light field's temporal, rather than spatial, distribution. An ideal time-lens changes the colour of the light field at different moments in time. This modified light field is then passed through a dispersive medium in which different colours of light travel at different velocities and therefore emerge from the medium with different time delays. When the system is properly designed, all the colours can be made to arrive at a given spatial point at the same time, or, by analogy with a conventional lens, they can all be 'focused' to the same point in time.

In their work, Fridman and colleagues used a split time-lens, which is a slight modification of a time-lens. This lens is composed of two half time-lenses, which are connected at their tips. The light passing through the first half of the split time-lens experiences a colour change in the opposite direction to that passing through the second half: the first half makes the light bluer and the second half makes it redder. Then, after passing through a dispersive medium — an optical fibre in the

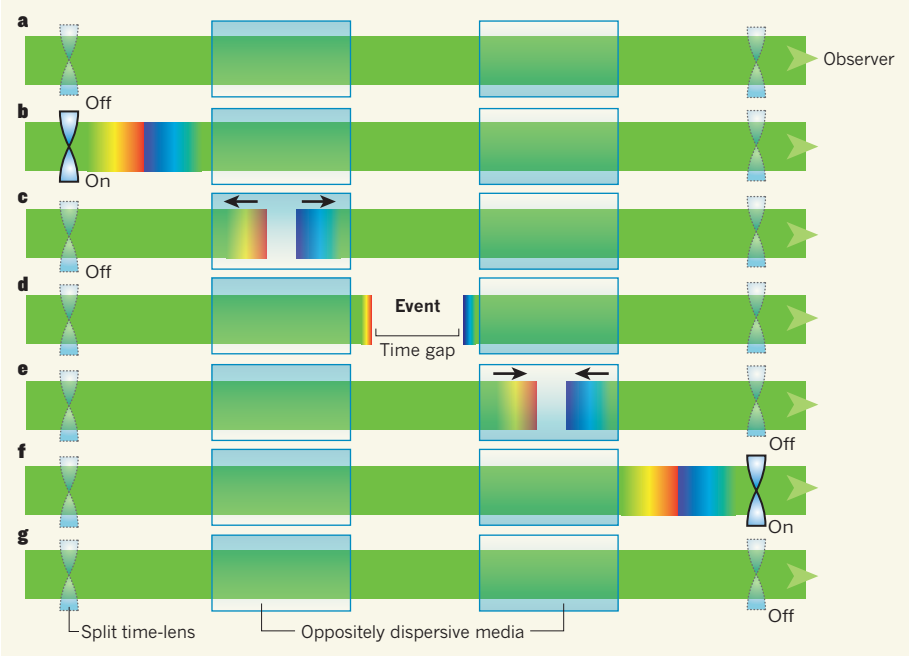

Figure 1 | Schematics of the temporal cloaking system of Fridman and colleagues[7] at different times. **a**, A continuous stream of green light passes through the system from left to right. **b**, The first time-lens is turned on and the light's colour changes as a function of time. **c**, The modified light travels through a dispersive medium. Because in this medium the blue-shifted light travels faster than the green, and the red-shifted light slower, a time-gap gradually opens up. **d**, The time gap is maximally open, and in its centre an event occurs in the form of a light pulse (not shown). **e**, The time gap gradually closes as the light passes through an oppositely dispersive medium from the first one. **f**, After the time gap is completely closed, a second time-lens is turned on such that all the colours are changed back to green. **g**, All the observer sees is basically a continuous green light as if the event in **d** never occurred.