inactivated after fertilization in the absence of prior MSCI clearly shows that key aspects of imprinted X inactivation can take place without it.

One interesting outcome of these studies[2,6,7] is that the pre-inactivation and the *de novo* inactivation hypotheses can both be correct, as summarized in Fig. 1. X-linked genes in the sperm could arrive in the egg in an epigenetically inactive form. The egg cytoplasm could then exert an immediate response to reverse this state — perhaps as part of the genome-wide reprogramming events that affect the paternal genome in the newly fertilized egg[11]. It is likely, given the results of Okamoto *et al.*, that most genes on the paternal X, including the *Xist* gene, are activated at the two-cell stage. But it seems that over the next few cell divisions they become inactivated again through the action of *Xist*, without necessarily requiring prior MSCI.

The latest work illustrates the amazing plasticity and dynamic nature of epigenetic programming and reprogramming in germ cells and early embryos. Insight into these events will give us clues about how the genome functions in normal development and in disease. It may also eventually provide tools for treating diseases of genome malfunction. ■

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COMMUNICATIONS TECHNOLOGY

Chaos down the line

Rajarshi Roy

Chaos, goes conventional wisdom, can only be a malign influence in telecommunications. But a technique that uses chaotically varying signals to transmit information more privately may help it shed that bad-boy image.

Synchronization leads to communication — even when the signals used are chaotic. That is the lesson of a study by Argyris and colleagues on page 343 of this issue[1]. It reports the successful transfer of digital information at gigabit rates by chaotically fluctuating laser light travelling through more than 100 kilometres of a commercial fibre-optic link around Athens, Greece (Fig. 1). The transmitter and receiver become harmonized in chaotic synchrony, allowing information to be reliably extracted at the other end — a result that brings us closer to exploiting the inherent advantages of chaos, rather than trying to eliminate it whenever it appears.

The phenomenon of synchronization in periodic systems has been known since at least 1665, when Christiaan Huygens observed that pendulum clocks become synchronized when placed close to each other on a common support. Asian fireflies flashing together, flocks of geese flying in remarkable formations and pedestrians in lock-step on London's Millennium Bridge are illustrations of synchronization when large numbers of living creatures get together[2]. But synchrony also arises in inert matter: lasers and masers both exploit the ability of large ensembles of atoms and molecules to harmonize their oscillations and emit light in coherence. The key to synchrony in such systems is that the individual elements

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Figure 1 | Attic experiment. Argyris and colleagues[1] successfully used chaotic waveforms to transmit information over a distance of more than 100 kilometres in the telecommunications network of Athens (seen here from the Acropolis).

50 & 100 YEARS AGO

50 YEARS AGO

An Outline of the Cancer Problem. — It is almost as difficult to review a popular book on cancer as to write one, and for similar reasons. The subject ranges over such a vast canvas that one is always acutely aware of numerous important omissions and of the minor distortions which inevitably appear... One is compelled to stress those aspects most dominant in one's own experience, and Dr. I. Hieger naturally stresses the important role of the chemical carcinogens in etiology. He was in the team which first isolated from coal tar a pure chemical carcinogen, and he gives us the most interesting story of this pioneer discovery. Moreover, we have seen lately the firm linkage of exposure to tobacco and industrial smoke to the tremendously rising incidence of lung cancer... If it is shown that lung cancer is in fact due to exposure to chemical carcinogens in smoke, their practical significance in human cancer will become of greatly enhanced importance.
From *Nature* 19 November 1955.

100 YEARS AGO

American palaeontologists are becoming more and more strongly convinced of the decisive character of the evidence afforded by extinct faunas of a comparatively recent connection between South America, South Africa, and Australia. A short time ago, Dr. W. B. Scott...announced his opinion that the fossil Santa Cruz insectivore Necrolestes is closely allied to the South African Chrysochloris, and that this relationship indicated a connection between South Africa and South America. Now Mr. W. J. Sinclair... states unequivocally that Prothylacinus and the other marsupial-like carnivores of the Santa Cruz beds are true marsupials closely related to the Australian thylacine... Mr. Sinclair considers himself justified in stating that..."a land connection between Patagonia and the Australian region existed not later than the close of the Cretaceous or the beginning of the Tertiary".
From *Nature* 16 November 1905.

are in some way coupled to each other, leading to the formation of — sometimes beautiful — patterns in space and time.

So can synchrony be observed in systems that behave chaotically? One of the hallmarks of chaotic systems that are isolated from one another is that their evolution diverges exponentially fast, even when their initial conditions are very similar. This is why predicting the weather more than a few days in advance is so hard. Therefore, the finding a couple of decades ago that suitably coupled chaotic systems could (under certain conditions) do exactly the opposite, and converge from distant initial conditions to synchronize their chaotic motions, came as a huge surprise[3,4].

The subsequent discovery that lasers can emit light in patterns that are chaotic in time and space clearly implied that remote lasers should be able to synchronize if they receive light from one another, whether through space or through an optical fibre. Experiments soon confirmed this, and with the exchange of only small amounts of light, too[5,6]. The synchronization is sufficiently robust for information to be exchanged: if one of the chaotic laser systems, the transmitter, is perturbed by a message source, it can 'fold' that information into its own chaotic waveform, which it transmits to the input of the second laser system, the receiver. Meanwhile, the receiver's output is a synchronized replica of the transmitter's original, unperturbed chaotic waveform — so the receiver recovers the message as the difference between its input and output waveforms. (Analogously, a radio receiver that is tuned to a carrier frequency recovers information from perturbations of the amplitude or frequency of a periodic waveform.)

Argyris and colleagues[1] take a large stride towards showing that the method of transmitting and receiving information using chaotic waveforms can also work in the real world, without the stable conditions of the laboratory. Applying chaotic systems in real-world communications is a beguiling prospect, because a third party intercepting the signal would have difficulty extracting the information sent. Such security aspects of chaos-based communications admittedly need much further analysis. But as the authors point out, chaotic carrier waveforms offer privacy in a manner that could be complementary to and compatible with conventional software-based and quantum-cryptographic systems.

The remarkable features of the authors' work are the simplicity of their set-up — they use chaotic diode laser systems and instrumentation that are widely available off the peg — and their demonstration that information can be recovered with quite reasonable bit-error rates over a commercial fibre-optic link. The optical fibre used for the experiments in Athens was temporarily free of network traffic, but was still installed and connected to the switches of the network nodes. The authors measured the characteristics of the fibre, such as its attenuation and chromatic dispersion, before the experiment. This allowed them, for example, to exactly counter the effects of dispersion by inserting an appropriate length of dispersion-compensating fibre at the beginning of the link. Three amplifiers were used, one at the transmitter, one 50 kilometres from the transmitter, and one at the receiver, followed by optical filters with bandwidths of around 1 nanometre — this respectively compensated for optical losses and removed spontaneous noise.

The scheme used by Argyris *et al.* exploited time-delayed feedback to generate high-dimensional, high-capacity chaotic waveforms at high bandwidths. This has turned out to be a most fruitful approach: the bit-rate limit of several gigabits in these experiments is set by the electronic and optical components used, and could become much higher with suitably designed systems. For instance, the authors' strategy is compatible with a technique known as wavelength multiplexing; this allows much higher bit rates to pass through a single fibre by transmitting light of many different wavelengths simultaneously.

The exciting possibilities revealed by these experiments[1] may be pursued in other directions that more fully exploit the possibilities available for communication using electromagnetic waves. The vector properties of light waves (their polarization) could be used to encode data[7]. Optical patterns that are chaotic in time and space might also be used to communicate holographic information[8] by generalized synchronization. Here, transmitter and receiver do not share identical synchronized dynamics; instead, the relationship between the two is given by a mathematical function, supplying an additional element of privacy.

The success of such developments will ultimately depend on our willingness to implement new ways of transporting optical signals, as well as on novel transmitters and receivers. The rewards could be considerable, not only in understanding the communication of information using chaotic physical systems. Such work could in the long term also help us to elucidate the workings of that most private of communication networks — the human brain. ■

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CELL BIOLOGY

Two pores better than one?

Arnold J. M. Driessen

The movement of proteins through a cell's membrane requires a dedicated molecular machine. A glimpse of this apparatus in action shows that it has two channels, and hints at how these pores might be regulated.

A cell's membrane bristles with proteins that sense and communicate with its environment, and the cell secretes other proteins to send messages farther afield. To reach their destination, these proteins must travel from the aqueous environment of the cytoplasm where they are synthesized, through the seemingly impenetrable boundary of the lipid membrane. To ease the proteins' emigration, cells use a specialized protein complex called a translocase to direct proteins across or into the membrane. On page 318 of this issue, Mitra *et al.*[1] report the structure of this remarkable complex caught in the act of inserting a newly synthesized protein into the membrane.

Proteins that must be secreted or inserted in the cell membrane are synthesized (translated) by membrane-bound organelles called ribosomes; they have a short sequence at one end (the amino terminus) that acts as an address label to signal their final destination. The translocase consists of a protein-conducting channel (PCC) in the membrane that binds to the ribosome and passes newly synthesized proteins bearing the appropriate address label across or into the cell membrane. The translocase must provide an aqueous path across the membrane for hydrophilic protein segments, as well as a side opening to the membrane lipid phase to release hydrophobic protein segments into the membrane. The aqueous path must be tightly controlled, or valuable ions and molecules will leak out of the cell.

Mitra *et al.*[1] have used cryo-electron microscopy to determine the structure of the Sec translocase, from the bacterium *Escherichia coli*[2], that is associated with a ribosome in the process of synthesizing a protein called FtsQ. They reveal a unique strategy by which a translating ribosome assembles a PCC