particular, the work is consistent with the ideas of Anderson that quasiparticles with fractional quantum numbers must combine into composite quasiparticles with integer quantum numbers to survive in a system of higher dimension.

Future studies could focus more on the connection between spin liquids and superconductivity. In this regard, the most promising potential material is an organic molecular crystal, κ-$(\mathrm{BEDT\text{-}TTF})_2\mathrm{Cu}_2(\mathrm{CN})_3$, which seems to have a spin-liquid ground state at ambient pressure but becomes superconducting at high pressures. Interestingly, the relevant model hamiltonian is closely related to that for $\mathrm{Cs_2CuCl_4}$ (ref. 8). Solving this problem will require extending the current technique for Heisenberg models to Hubbard models that can describe holons and spinons in sets of chains with frustrated interchain coupling. Also, experimentalists should search for the predicted anti-triplon mode and do polarized neutron scattering to see if all three triplons have the same dispersion relation.

More broadly, the approach of Kohno, Starykh and Balents illustrates how properties of the ground state (vacuum) and low-energy excited states (quasiparticles) of quantum many-body systems are emergent. That fractional quantum numbers are emergent phenomena leads some condensed-matter theorists to make radical claims that in elementary particle physics the 'vacuum' state, fundamental symmetries and even fermion statistics are also emergent phenomena[9,10]. If so, what are the truly 'elementary' particles of nature?

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SOCIAL DYNAMICS

Emergence of language

Our social behaviour has evolved primarily through contact with a limited number of other individuals. Yet as a species we exhibit uniformities on a global scale. This kind of emergent behaviour is familiar territory for statistical physicists.

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On the eve of statistical mechanics, Maxwell and Boltzmann were guided by social statistics in the development of the kinetic theory of gases. Even earlier, data from births, deaths, marriages and crimes had been crucial in the development of statistics in the seventeenth century. Such social numbers triggered passionate debates among philosophers and scientists. So the idea that human societies can be studied using the tools and methods of physics is not new, but only in the past few years have physicists shown renewed interested in understanding and, to some extent, explaining phenomena occurring in social contexts. Is a new discipline about to be born?

What is the meaning of terms like agreement, order, globalization, assimilation or coordination? And what do we mean by disorder, disagreement, polarization, fragmentation? Each individual interacts socially with a limited number of peers. Yet human societies are characterized by stunning global regularities. How do they arise? How are global opinions formed? How does a population manage to speak the same language? These kinds of questions brought scholars from physics, mathematics, computer science, linguistics, anthropology, archaeology, sociology and economics together to a summer school in Erice, Italy[1]. The school was also a satellite of STATPHYS 23, the largest triennial meeting of statistical physicists in the world. Discussions focused particularly on language as the prime example of a collective phenomenon arising out of local social interactions. But what has statistical physics to do with language?

As the final speaker William Wang pointed out, the linguistic study of language is typically focused on 'the system' underlying a particular language at a particular point in time: its sound structure, vocabulary and grammar. This structuralist point of view was initiated by the Swiss linguist Ferdinand de Saussure near the beginning of the twentieth century as a counter-reaction to the emphasis on historical and philological investigations in the nineteenth century, and it was given a more formal foundation by the American linguist Noam Chomsky, who developed generative grammar, managing to make it the dominant linguistic paradigm for almost half a century. Within this conception of language, there is no place for statistical physics.

But as linguists begin to gain access to more and more data from systematic recordings and the massive volume of text appearing on the World Wide Web, and as they look at new language-like communication systems that have emerged recently — such as text messaging protocols for use with mobile phones or social tagging of resources available on the web — doubt has arisen as to whether human communication systems can be captured in a clean formal calculus. The static picture of language is giving way to the view that language is undergoing constant change as speakers and listeners use all their available resources in creative ways to achieve their communicative goals.

Once you adopt the view that language is a complex adaptive system, statistical physics suddenly becomes very relevant for building a theoretical foundation for the study of language. Linguists have largely focused on compiling a catalogue of the language constructs that we encounter today in specific languages or across languages, and this empirical work will of course remain the core of the discipline. But a full theory of language must (1) circumscribe the problem-solving strategies and mental resources that speakers may bring to bear to the communicative task, including the creative moves they make while extending existing conventions, and (2) show how the systematic application of these strategies gives rise to global emergent properties, such as the same word being used by all members of the population to express the same concept. Whereas linguists and psychologists work on the first question, deconstructing the cognitive strategies needed for participation in a language community, statistical physicists can help with the second question, as they have tremendous experience with the emergence of macroscopic effects from microscopic structure and interactions.

Social dynamics models usually postulate a population of agents and an interaction protocol between two agents, called a game. The game could concern a decision to buy a certain item, to adopt an opinion expressed by somebody else, to vote for a certain political candidate, and so forth. Different strategies for playing a game lead to different measurable outcomes. For example, we are interested in understanding whether and how, starting from each agent having a different opinion, consensus emerges or instead fragmentation occurs. Which mechanisms favour, or hinder, the agreement? At the meeting, Sidney Redner, Gérard Weisbuch and Katarzyna Sznajd–Weron surveyed the most important models for opinion formation, Claudio Castellano discussed the well-known Axelrod model for cultural dynamics[2] and Santo Fortunato made an introduction to voting phenomena. Society is typically modelled as a graph, with agents placed on nodes with links representing their interactions, and particular attention should be paid to the role of the underlying topology. In this respect, Matteo Marsili and Damian Zanette introduced models where a co-evolution of the dynamics and of the underlying topology is taking place.

The step from these various social dynamics models to those of language dynamics is small. Language dynamics models assume again a population of agents that have only local interactions. Instead of voting or buying goods, the agents carry out some communicative task, such as drawing the attention of another agent to an object in their surroundings by using a name. Typically, agents do not start with a given communication system but must build one up from scratch. They may invent new forms of conceptualization and expression as part of a game and adjust their knowledge about the frequency, utility or social prestige of language conventions based on the outcome of a game.

ANNABELLA BLUESKY/SPL

Out of the crowd: statistical physics aids understanding of linguistic complexity.

A basic language game of this sort is the Naming Game[3]. It is used to study the emergence of coherence (sharing of inventories across members of the population). In the Naming Game, speakers and listeners are only allowed to use names (not words for categories or more complex constructions) to draw attention to an object and they must then each develop a vocabulary of object–name pairs. Computer simulations of the Naming Game have led to the discovery of a number of successful strategies — some of them have even been shown to work in experiments in which physical robots build up and negotiate a vocabulary for objects in their world without human intervention. Various analytic models exist as well, explaining why coherence arises and why we see power-law behaviour.

Alain Barrat reviewed these analytic models of the Naming Game and, in particular, how network structure (mean field, lattice, small-world) impacts the speed and level of coherence as well as the memory requirements of the agents. Maxi San Miguel and Dietrich Stauffer presented models of language competition showing how social value and darwinian competition dynamics may produce a winner-takes-all situation with only one language surviving. Using empirical data gleaned from social tagging sites, Ciro Cattuto showed how the power-law distributions observed in co-occurrence of tags can be explained by models of preferential attachment, similar to the Yule–Simon process[4]. Les Gasser and Samarth Swarup showed that this process has the same underlying structure as the replicator dynamics that is also commonly used as an analytic model of language dynamics.

Besides helping us understand how universal dynamical processes discovered in natural systems are also at work in cultural systems, the microscopic and macroscopic models of language dynamics that were discussed at this summer school are important for two reasons. First they could help us address one of the greatest unresolved puzzles of science: the origins and evolution of human languages. The archeologist Francesco D'Errico surveyed in his opening lecture the evidence for symbolic culture, which goes much further back than most observers would have thought, and has propagated and evolved as a complex adaptive system in a very similar way as captured by the models of social and language dynamics discussed at the meeting. The linguists Jean-Marie Hombert and William Wang retraced the renewed interest in linguistics for the reconstruction and genealogy of human languages despite an obvious lack of empirical data on the earliest languages. Language dynamics models cannot address the physiological or social issues, but they do show how an 'invisible hand' pushes populations towards a coherent language.

Second, semiotic dynamics, the processes whereby individuals invent and share signs and meanings, is not something from the past but an ongoing phenomenon. Existing human languages do not change so quickly, except in their vocabularies, but there are other new human communication systems that are undergoing rapid development, such as the 'folksonomies' that emerged in the course of a few years on the World Wide Web[5,6]. In his contribution, Les Gasser pointed out that the insights obtained from the analytical models and computer simulations discussed at the summer school can help to design and understand new collective communication systems and therefore further revolutionize human communication and knowledge sharing through information technology.

The study of semiotic dynamics is still in its infancy and many basic problems have hardly been touched upon, but, as this summer school showed, the momentum is clearly there and the powerful results already obtained after only a few years of investigation bode well for the future of the field.

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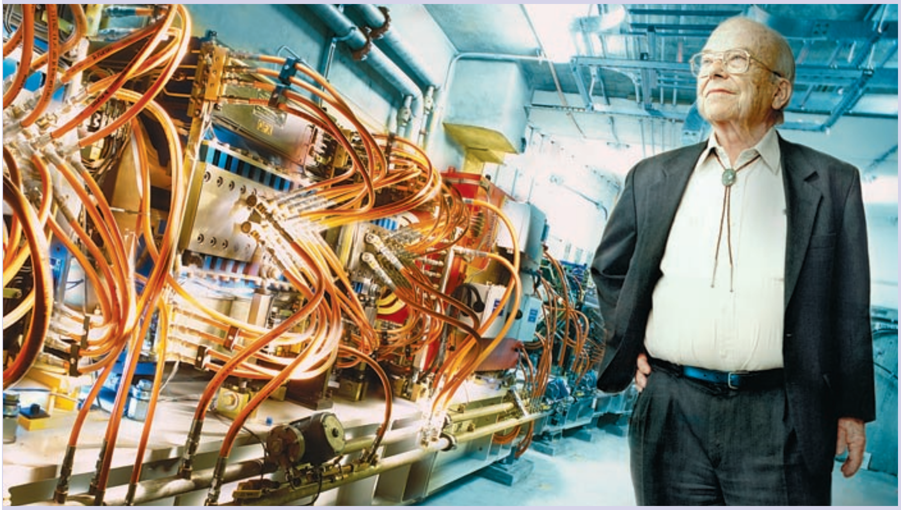
WOLFGANG PANOFSKY

Man and machine



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If ever a career exemplified the stunningly rapid development of high-energy physics since the Second World War, it was that of Wolfgang Panofsky. In 1950, working at the pioneering 184-inch cyclotron in Berkeley, California, he was one of the first to produce a particle in an accelerator, confirming the existence of the neutral pion. His undoubtedly greatest achievement was the building in the 1960s of the 3.2-km-long accelerator at the Stanford Linear Accelerator Center, SLAC. On his retirement from SLAC in 1984, after 23 years as the facility's director, what had become the standard model of particle physics was largely complete — in no small measure through discoveries made under his aegis.

Of Jewish stock, Panofsky was born in Berlin in 1919 and raised in Hamburg, where his father was a professor of art history. Fleeing Germany with his family in 1934, he reached Berkeley via Princeton University, Caltech and the wartime Manhattan project, where he designed a device for measuring the pressure wave from the first nuclear bombs detonated over the Nevada desert.

His production of the neutral pion at Berkeley after the war, in collaboration with Jack Steinberger, was a masterwork of experiment. Cecil Powell, César Lattes and Giuseppe Occhialini of the University of Bristol had just discovered pions in cosmic rays, and the Berkeley cyclotron had produced the first charged pions in 1948. But the neutral pion's lack of charge made it impossible to spot directly in the photographic emulsions then used for tracking particles. Its existence had instead to be inferred from the energy and angular distributions of electrons produced following the pion's initial decay into photons.

In 1951, Panofsky left Berkeley for Stanford in protest at the insistence that he sign the McCarthyite anticommunist oath. He worked on upgrading Stanford's existing electron accelerator, while lobbying hard for a more powerful machine. The green light for SLAC — at $114 million, then the most expensive physics facility ever built — came from the US Congress in 1961, and Panofsky became the centre's founding director. Shares of three Nobel prizes were awarded for work during his tenure: to Burton Richter (1976) for the discovery of the J/Ψ charmed meson; to Richard Taylor (1990) for fleshing out the quark model through studies of electron–proton scattering; and to Martin Perl (1995) for the discovery of the heaviest lepton, the tau.

Wolfgang Panofsky's history and wartime experience gave him great moral authority in the sabre-rattling of the cold war. He was an advisor to US administrations from Eisenhower to Carter on nuclear proliferation, and was instrumental in securing both the atmospheric test-ban treaty (1963) and the anti-ballistic-missile treaty (1972). At SLAC, he fostered scientific exchange with the Soviet Union and China as a direct contribution to *détente*. Such issues continued to move him in retirement: he excoriated current US nuclear policy as an "overly broad and obsolete relic of the cold war" at a public colloquium at SLAC in March this year. He died on 24 September, aged 88.

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