and are establishing a laboratory to study the reprogramming and differentiation of stem cells.

Solter said that Biopolis is a mixed expat society with scientists from many nationalities including British, French, Russian, Portuguese, Spanish, Italian Scandinavian and American. "People came for different reasons. But a major reason is the funding is secure. You don't have to write grants. Everybody agrees that working conditions are very good because Singapore is really committed to establishing a major scientific place," Solter explained. "There are probably between 500 and 1,000 independent senior scientists. In scientific terms, it's an excellent place." Indeed, Solter plans to finish his career in Singapore. "There are people who work and work and then one day they drop dead in the middle of the lab and that's it," he said. "I would rather not do that. But Singapore is definitely my last place."

It was the promise of a better climate that drove cancer geneticists Neal Copeland and Nancy Jenkins—a husband and wife team—to become two of the top 50 most-cited biomedical scientists to join A*STAR in 2006. It was not just the weather in Singapore that appealed to them, however. "The heat and humidity in the summer in Washington is much worse than in Singapore. In Singapore, the average high is 90–91 °F. And the average low at night is around 76–77 °F, 78 °F maybe. To me, that's perfect," Copeland said. Rather, it was the funding climate in the USA.

"Under the eight years of Bush, the money going into research went down in real dollars. All our friends were losing grants, even friends who were Nobel laureates"

Copeland, who is now the executive director of A*STAR's Institute of Molecular and Cell Biology (IMCB), explained that to make the move, they had to leave behind their long-time research base at the National Cancer Institute–Frederick (MD, USA). Both of them had held senior positions at the institute, but, as they approached retirement age, they became increasingly frustrated with the reduced levels of funding available for science during the Bush era. "I was 59 when we left and Nancy was 56," Copeland

said. "We were tenured at [the National Institutes of Health (NIH)]; we directed a big program. Things were good, but every year it got more depressing in the United States [...] Under the eight years of Bush, the money going into research went down in real dollars. All our friends were losing grants, even friends who were Nobel laureates. [...] When people left, we couldn't replace them."

Jenkins added that when they announced that they were looking to leave the NIH, they fielded offers from Stanford University (CA, USA) and Memorial Sloan–Kettering Cancer Center (New York, NY, USA). Despite this, the paucity of grants in the USA gave them pause for thought. Copeland explained that they would have faced a hard slog to raise the money needed to run a laboratory with thousands of cages of mice. "We were at NIH, and all the money came from the federal government. And the reason we stayed at NIH for so long was that we had huge amounts of money," he said. "If we went to Stanford, we were going to have to write ten grants to support our mice. We were going to spend our whole life writing grants." As such, the affluent research climate of Singapore beckoned.

Their long-time collaborator, cancer researcher Yoshi Ito, had joined the IMCB

when he was forced to retire in Japan at the age of 62. "He invited us to Singapore to give seminars," Copeland said. "One thing led to another and [the IMCB] made us offers. The attraction for us was [that all] the money to fund the research comes directly from the government. There are no grants [...] we could move here and still support our research [...] and [we could] get out of the NIH system and the American system into a place that seems to appreciate research and is investing heavily in research [...]"

Copeland and Jenkins relocated themselves and 100 strains of mice to Singapore and now plan to stay there. Copeland said that they visit the USA regularly and are concerned about the future of science there. "The system is broken, but President Obama is great. I think he's a good president and they're lucky to have him because he wants to put more money in science. But where is it going to come from?"

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How smart is smart?

Is human intelligence still evolving?

The development of higher cognitive functions in *Homo sapiens*—commonly and perhaps wrongly described as intelligence—preceded and enabled the rise of human civilization. Yet, although it has been an important factor for our social, cultural and technological evolution, intelligence itself remains an elusive concept. Molecular biologists, neurologists, psychologists and anthropologists have long-pursued the questions of how, why and when intelligence evolved, and have also been debating whether human intelligence will continue to evolve and, if so, where it could lead.

The challenge of investigating intelligence and understanding how it works begins with its definition and measurement.

Bob Sternberg, for instance, a psychologist from Tufts University (Medford, MA, USA) and a pioneer of human intelligence research, believes that intelligence is an adaptive trait, but not a quantity that can be measured by standard intelligence quotient (IQ) tests. Instead, he has defined human intelligence as "a mental activity directed toward purposive adaptation to, selection, and shaping of real-world environments relevant to one's life" (Sternberg, 1985). However, there is a caveat to this so-called 'triarchic' theory: its human devisers are not objective bystanders. "Higher levels of intelligence as we conceive of it can be and [have] been adaptive," Sternberg said. "I say 'as we conceive of it' because the concept [of intelligence] is in large part a human

invention of successful people to explain their own success."

Indeed, the psychometric testing of intelligence that Sternberg rejects often correlates with success, whether measured financially or in terms of career advancement. This is particularly true of IQ tests, which, despite being derided as merely measuring a narrow kind of technical intelligence, have consistently proven to be a reliable marker of success in the workplace, particularly in scientific, academic and managerial positions (Coward & Sackett, 1990). To address some of this criticism, the concept of IQ has been expanded to the notion of general intelligence, which correlates strongly with an individual's performance across a wider range of cognitive tasks.

This broader measure of intelligence has enabled researchers to look beyond humans and to measure intelligence in other species, so as to address the questions of how, when and why intelligence emerged. Most recently, a study at Harvard University (Cambridge, MA, USA) measured the general intelligence, or 'g', in 'cotton-top' tamarin monkeys (Banerjee *et al*, 2009). "We believe ours to be the first systematic demonstration of g in a nonhuman primate, and perhaps in any nonhuman species," commented Fritz Tsao—a professor of psychology at Hillsdale College (MI, USA) and co-author of the study—noting that previous studies of rats and mice had not used an approach directly comparable with assessing g in humans.

...although it has been an important factor for our social, cultural and technological evolution, intelligence itself remains an elusive concept

Tsao's study was conducted using 22 tamarins, which were given 11 unique tasks that had been designed to assess different cognitive functions. Monkeys with higher g scores tended to outperform monkeys with lower scores across most of the

tasks. The study also found that variation between individual g scores correlated with differences in performance among the monkeys—but to a lesser extent than among humans. This suggests that if g is a phenotype that has evolved, which many neuroscientists dispute, it only became a significant factor for selection in primates, or in higher mammals at least.

However, similar observations of differences in g and of performance in cognitive tasks have been made by using animals with less advanced brains than tamarins, but only in species that live in social groups, such as dogs (Keagy *et al*, 2009; Topál *et al*, 2009). "It is highly likely that most social animals, not only mammals but birds as well, will show the kind of individual variation observed in our study," commented Konika Banerjee, a research assistant at Harvard University's Department of Psychology and the study's primary author.

Such findings have given credence to the idea that, as humans formed societies, the increasing competition for mates and status in the group drove the evolution of intelligence. Indeed, some evolutionary biologists, such as Robin Dunbar, who specializes in primate behaviour at the University of

Oxford in the UK, believe that all adaptive human intelligence is essentially social. "Technical intelligence, which we usually refer to as IQ, is, in my opinion, a by-product of social intelligence and the factors that select for this," he said.

Although Dunbar's assertion might not sound terribly controversial, it has led to the idea that some human groups or subpopulations are more intelligent than others because cultural and political factors have exerted a selective pressure for higher intelligence on them. The case of Ashkenazi Jews is the most widely studied, and there is a general agreement that this human subpopulation, which is defined by a common ancestry in central Europe over the past 1,200 years, has an average IQ that is significantly higher than any other ethnic group for which there is reliable data: in the range of 112–115 (Cochran *et al*, 2006).

The explanation for this, however, is controversial. Henry Harpending and Gregory Cochran from the University of Utah (Salt Lake City, UT, USA) have argued that the Ashkenazi intelligence boost results from natural selection favouring white-collar workers during the middle ages, and that the intelligence gap continued to widen until the last century (Harpending & Cochran, 2006). Their argument is rooted in the historical fact that European Jews were prohibited from working in many common jobs—especially agriculture—in the approximate period of 800–1,700 AD. The result was that they worked in emerging professions, such as finance and trade, some of which were forbidden to Christians by the church. According to Harpending, those who performed better at these jobs are known to have successfully raised more children to adulthood, thus passing on their genes to more offspring.

Harpending commented that other human subpopulations have also undergone selection for intelligence, as they were also forced to take up certain occupations due to discrimination. He cited the case of the Parsees as a possible example—Persians who emigrated to India more than 1,000 years ago to escape religious oppression by the

Muslims, and who have since made considerable contributions to the history and development of India, despite their small number.

The hypothesis has attracted attention from several prominent evolutionary psychologists, including Steven Pinker, a Canadian-American cognitive scientist working at Harvard University, who is best known for popularizing the idea that language developed as an instinct shaped by natural selection. Pinker commented that it will take some time to settle the argument, although he believes that the core of Harpending's hypothesis could be assessed beyond reasonable doubt by a suitable study.

...as humans formed societies, the increasing competition for mates and status in the group drove the evolution of intelligence among humans

Yet, there is still a substantial body of opinion disputing the idea that human intelligence has undergone selection in the modern era. Steven Rose, a neurobiologist at the Open University and the University of London in the UK, is a prominent opponent of the idea that human social behaviour has an evolutionary explanation at all. "No evidence that I know of suggests that Ashkenazis in general have higher 'intelligence'," he said. "But for historic reasons, there has been a strong cultural tradition encouraging certain forms of specialization among Ashkenazis—from tailoring and joinery to medicine, science and law." Rose argues that any apparent increase in IQ among the Ashkenazis occurred for cultural reasons rather than through natural selection. Such factors are taken to include education, along with intellectual stimulation both at home and in the professional occupations they were forced to take.

More generally, Rose argues that natural selection can only operate across the whole spectrum of social functions, rather than on isolated components of cognitive function. In his view, IQ as measured in standard tests is one such isolated component: "For a neuroscientist, any aspect of 'intelligent behaviour' involves many different processes—attention, motivation, arousal, motor skills, perception, memory. To lump all these together into one 'crystallized intelligence' makes no biological sense, whether for humans or any other species,"

he said. "The second issue is whether individual differences provide the materials of variation on which natural selection can work and, in a strict neo-Darwinian sense, this can only be the case if the variation results in differential survival of offspring, and for that one would need evidence not speculation."

In parallel to these psychological and anthropological studies, molecular biologists are looking at the genetic and molecular factors that underpin the evolution of mental capacities. A 2006 study from the University of Chicago (IL, USA) suggested that two genes, *microcephalin* and *ASPM* (abnormal spindle-like microcephaly-associated), which are thought to regulate brain size, have been under strong selective pressure since humans left Africa (Evans *et al*, 2005). However, the team, led by Bruce Lahn, do not claim that these genes are associated with cognitive functions, and others have suggested that they might have undergone selection to cope with the decreasing amounts of good daylight as humans migrated northwards through Europe, Asia and possibly North America. "There is now nice evidence of selection over recent time for genes that promote large brains at high latitudes, such as Bruce Lahn's work," Dunbar agreed. "But this is almost certainly due to the need for a larger visual area at high latitudes [where light levels are lower], not for greater intelligence, although this is as yet unpublished data."

"[In the past], [b]eing brilliant likely made a real difference in terms of one's ability to acquire social influence and access to material resources [...] but it is not so important now."

An actual link between brain size and intelligence is subject to dispute. As primate intelligence has increased, so has average brain size: the brains of hominids have increased in volume by a factor of three since the Pliocene period 5–2.5 million years ago (Henneberg, 1998). However, human brains have actually decreased by about 10% in volume during the past 30,000 years; the rapid evolution of new cognitive functions—language in particular—might therefore have resulted from structural rather than volume changes.

"We should be more concerned with what is likely a distinctively human quality—wisdom—the skill in how to use our intelligence in a way that promotes a common good..."

One explanation for this reverse trend in human brain size is that brains come with metabolic costs attached—the brain consumes about 20% of the basal calories used by our bodies each day—and human evolution might have reached a point where increased metabolic demand outweighed the benefits of greater brain volume. Instead, selective pressures might have begun to favour genes that conferred greater processing efficiency and improved coordination between functional units. But for selection to take place there had to have been an underlying source of variability in cognitive function. According to Marc Hauser, a professor of psychology at Harvard University and a co-author on the tamarin monkey study, this variability could have resulted from individual differences in global factors, including neural conductivity, or central faculties such as working memory or cognitive control. Of those global factors, things such as neural efficiency, plasticity and the volume of white matter—the brain's 'communications network'—are important. Taken together, white matter and neuronal efficiency define the speed limit and capacity of the brain's communications.

Of the other source of variation, the central working memory and coordination shared by all processes almost certainly have a role. "Working memory and cognitive control may be two central neural processes that are recruited in the vast majority of problem-solving contexts," Hauser commented. "Consequently, variation in the available amount and efficiency of these neural processes may account for variation in performance across diverse cognitive tasks."

However intelligence is explained and defined, there is some evidence that the selective forces operating on human intelligence are changing, according to David Geary, a professor of psychological sciences at the University of Missouri (Columbia, MO, USA). "[In the past], [b]eing brilliant likely made a real difference in terms of one's ability to

acquire social influence and access to material resources [...] but it is not so important now," Geary said. "It is important for career success and advancement but is not as strongly related to mortality or differential reproduction as it once was. In short, selection pressures for cognitive ability are weaker now than before the demographic transition [sharp decline in mortality]." Geary's argument is that however we measure intelligence, it is no longer so strongly correlated with lifespan or reproductive success; at least not in the wealthier nations (Geary, 2005).

Indeed, it is possible that human civilization has reached a point at which the selective advantage of cognitive attributes has disappeared, or even been reversed in some societies. "In particular circumstances, intelligence could be disadvantageous for [the] survival of genes, such as when the genocidal government in Cambodia [...] decided to slaughter those whom [it] deemed as more intelligent and hence a threat to the repressive society [it] sought to create," Sternberg explained by way of example.

Sternberg also believes that 'raw intelligence' without consideration of long-term and global implications is no longer a valuable asset for the human species. "Much of the economic mess that our society is in results from policies created by some of the most 'intelligent' minds our society has to offer, people who received first-rate educations at the nation's top schools. The nuclear hazard facing the world similarly is the result of the work of people with sky-high IQs," he said. "We should be more concerned with what is likely a distinctively human quality—wisdom—the skill in how to use our intelligence in a way that promotes a common good, over the long term as well as the short term, through the infusion of positive ethical values."

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