In general, there are two clear trends in the development of modern science and technology, says Jingyuan Yu, a Chinese systems scientist and mathematician. The first is that scientific disciplines such as physics and biology, for example, have become increasingly subdivided, giving birth to new disciplines, such as thermodynamics and cell biology. “Under the first trend, research is guided by a method of thinking called reductionism. We have gradually come to see its limitations. For example, the study of the structure of matter has reached the quark level, but knowledge about the quark still cannot explain macro structures,” Yu observes. “We have already conducted life science research at the gene level, but just as with our knowledge of the quark, this research cannot answer the larger question of what life really is,” he says. The second trend is that different disciplines have begun to integrate with each other, such as information technology (IT) and biochemistry.

This second trend appeared later and is guided by systematology. Throughout the 20th century, systems science evolved from simple theories about operational methods into a highly sophisticated discipline. In contrast to the approach of most modern scientists, who break down the world into its basic building blocks to understand how it works, systems theorists are concerned with how the blocks fit together, and why.

Yu recognizes the limits of modern science and is keen for young scholars to observe how systems theories can explain the world in a way that traditional science cannot.

A think tank for systems engineering

Since its origins in the mid-1980s, the Hsue-Shen Tsien Think Tank has focused on how some of the world’s most complex systems—including comprehensive policy systems, engineering systems, and social systems—can be improved to serve humanity. Inspired by the theories of Hsue-Shen Tsien (also known as Xuesen Qian), founder of the Chinese school of systems engineering and one of China’s most revered systems scientists, the Think Tank’s academic team analyzes the challenges facing society using multiple approaches—including industrial and economic development forecasting—and develops theories that can spur systems innovation.

Yonggang Qian, the son of Tsien, is the chair of the Hsue-Shen Tsien Decision-Making Advisory Committee and curator of the Hsue-Shen Tsien Library at Shanghai Jiaotong University. He explains that the application of Tsien’s theories to social systems engineering can solve problems that are inherent to the formation of a modern society. “We want to provide a scientific basis for changing people’s pattern of thinking about problems,” he explains. “We want to facilitate scientific and wise judgment, and provide the theoretical support to solve social problems.”
The development of systems and aerospace engineering in China

According to Huifeng Xue, an academician of the International Academy of Astronautics and director of the Think Tank, systems science emerged as a modern discipline in the first half of the 20th century, when “theories like operational research, information theory, and cybernetics were developing rapidly,” he says.

During the second half of the 20th century, systems engineering methods were thrown into the spotlight, as they were successfully applied and practiced in science and technology on a large scale, Xue explains. “The success of the American Apollo program, which succeeded in landing the first humans on the Moon in 1969, was its peak, and subsequently these methods began to be widely used in European defense-related science and technology fields,” he adds.

Tsien began his research in systems engineering when he was in the United States, studying at the California Institute of Technology. Specifically, he put forward the concept that a highly reliable system can be composed of components that are not completely predictable. This was far beyond the research scope of automatic control theory at that time and ushered in the field of systems science. Tsien had already been working independently on systems theories for many years when he returned to China from the United States in 1955, and began his career as a rocket scientist.

In 1956, the year the Chinese aerospace industry began in earnest, Tsien was appointed to guide China's aerospace and defense engineering program, eventually overseeing such achievements as the country's first aerodynamics research institute as well as its first satellite and nuclear-powered submarine. While leading China's aerospace program, Tsien established a set of systems engineering management methods and technologies. At their core is a management mode called “one overall design department, two command lines.” The overall design department integrates the work of all staff from different fields and oversees the design, coordination, and planning of the entire project. It strategically allocates resources to create a reliable, high-quality engineering system that works quickly and economically.

As his work and research evolved, Tsien refined his experience into a comprehensive theory of general systems engineering that would eventually prove useful in many different settings. “In theory, systems engineering techniques are organizational management tools that could be applied to social systems as well,” says Xue. “However, humans are highly complex. So if they are participating in a system, you need more advanced theories, such as Tsien's Open Complex Giant System methodology [see next page], to study them.”
A change in thinking

According to Yu, who worked closely with Tsien, there have been two important breakthroughs in systems thought in China. The first was in 1978, when Tsien, Xu Guozhi, and Shouyun Wang jointly published the article “Technology for Organization and Management: Systems Engineering” in the Chinese newspaper Wenhui Daily. “Through this article, systems engineering was introduced to the academic world in China for the first time. More importantly, it explained what systems engineering is and how it can be applied,” says Yu. Readers learned that systems engineering is a tool that can help us reconstruct the objective world.

The second occurred in 1990, with the publication of “A New Discipline of Science—The Study of the Open Complex Giant System and its Methodology” in the Chinese Journal of Nature, which dealt with both social and engineering systems. “Social systems are systems that include human beings. They are open complex giant systems that are much more complicated than engineering systems. Can systems engineering technology be applied in such systems? Certainly yes. But the limitations of the original method for dealing with engineering systems have now been exposed,” Yu adds.

Yu believes that social systems engineering techniques can be used to improve the governance of society. In his theories, Tsien advocated the importance of having an Overall Design Department (see previous page) at the heart of any systems process. This department would be a headquarters for the management of large-scale projects that would take a prototype from conception to reality—an innovative approach not only to organization and management but also from the perspective of systems engineering. “For social governance, a holistic view is required,” says Yu. “The application of the Overall Design Department can greatly improve the governance effect. It can be used to help design, coordinate, and plan more holistically. The macro level could be countries, for example. The mid-level consists of local units, and the micro level comprises schools, hospitals, and enterprises.”

Given that social systems have complex hierarchical structures, they need to be governed from the perspective of the whole of society, rather than in parts, according to Yu.

The work of the Think Tank

At present, the Think Tank is working in key industrial areas in China that require reform, including IT. The revolution in IT will come from a major transformation in space exploration, say Think Tank experts. They believe that civilization must necessarily transcend its physical boundaries. Huifeng Xue has proposed a concept that would integrate space, air, and ground systems, called the “Satellite Metasynthesized Network.” “To comply with the inevitable trend of human space exploration, we must create a ubiquitous, interconnected network that bridges Earth and space,” he says. All countries should work together, Xue believes, to establish a governance framework, promoting network development at the international level. They should merge all levels of space–air–ground network resources to achieve integrated treatment and maximum utilization of complex time–space networks; bring together a multitude of military–civil–commercial resources to realize unified, efficient management of space resources; and consolidate communication–navigation–remote sensing constellation resources to develop efficient, coordinated satellite service capability, he says.

“For the purposes of social governance, it is important to monitor how the environment impacts people’s lives, from traffic conditions to weather patterns,” he says. “Only then can we effectively manage emergencies by forecasting problems, giving warnings, and dispatching help when and where it’s needed.”

Six Units and Two Platforms

The Think Tank uses a design process called the “Six Units and Two Platforms” model to develop new open complex giant systems. Firstly, an interdisciplinary approach termed “metasynthesis” is used to examine the current information available about the problem. Then this information is integrated with technology, in a process Xue calls “man–machine integration and man–web integration.” The information comes from the six units of the system: the Think Tank Unit, the Big Data and Intelligence Unit, the Expert Database Unit, the Network and Information Unit, the Model Unit, and the Six Units and Two Platforms Unit.
The mind behind the Think Tank

While Yonggang Qian was growing up, he knew little about his father's career, but he was very aware of his father's work ethic. Tsien reminded his son of the finest of Chinese scholars because of his relentless pursuit of knowledge. Qian describes his father's approach to research as “unremitting exploration,” remarking, “We call his old age the ‘Golden Old Age’ because, long after his retirement, he still explored everything from systems engineering to social science and behavioral science.”

Tsien's boundless curiosity aided his development of systemology, a theory that regards all systems as a complete organism rather than a set of discrete parts. He provided a set of new methodological principles and procedures for the research of modern science and technology, explains Xue. “Systematology avoids the problem of a reductionist approach, where you can only see the parts but not the whole, and overcomes the disadvantage of a holistic approach, where you can only see the whole but not the parts.” Scientific thought has progressed from reductionism to holism and then to systematology, he says.

“Complexity, integration, and the emergence of modern society have enabled human beings, using the theories of systematology, to undertake the historical mission to improve our ability to understand and reconstruct the world, so as to generate a new round of scientific, technological, and industrial renovation,” observes Xue.

Qian is keen to see the Think Tank change the way his country tackles social problems. He recalls his recent meeting with a business team in northern China, who used the Think Tank’s methods and changed their approach from reductive to holistic in order to fix their problem. Every year in Gansu province, there are floods at the base of the Qilian Mountains that threaten the livelihoods and homes of the local residents, he explains. The area also has large expanses of desert that are difficult to irrigate, he adds. “Since both floods and deserts can be seen as disasters, this company applied the Think Tank’s systematic thought process for management to turn them into valuable resources,” he says. The team used the melted snow that flooded the ground to irrigate the desert, which in turn has stimulated local economic development, allowing local winemakers to more easily water their vineyards, for example.

Tsien’s idea was that large-scale agricultural projects could be developed if people think about how all the elements that influence agriculture fit together, says Qian. “This team has developed new systems for irrigating dry land that are based on theories developed by Tsien, who advocated that agricultural systems should be knowledge-based and rely on our intellectual understanding of the environment and how different parts interact,” he says.

Moving forward

A key concern of the Think Tank is how Tsien’s ideas can be understood from a historical perspective in order to help the country’s policymakers navigate a period of fast economic growth. According to Xue, the world is going through a period of adjustment, as countries try to avoid falling into the “Kindleberger Trap” a situation in which a powerful country fails to take on the role of providing global public goods, which include a stable climate, financial stability, and freedom of the seas. This problem was inevitable, Xue explains, because reductionist theories such as Newton’s Three Laws of Motion and Einstein’s Theory of Relativity have dominated our way of understanding the objective world since human society entered modern times. Even the three industrial revolutions man has experienced in the last two centuries—through steam engine technology, electric power technology, and information technology—have not changed things, because the philosophy that drove these comprehensive leaps in science, technology, engineering, and industry is no longer adequate to solve the global problems we are facing today, Xue believes.

“The world is becoming more and more diversified and its complexity is increasing rapidly,” says Xue. “Take climate change for example. This is a problem that we understand in its separate components. But we cannot solve it simply by understanding those components. We need a holistic, systems approach of the kind that Tsien advocated.”