Thinking in Models

How do innovations come about?

**Interview with Prof. Dr. Guido M. Schuster,
Hochschule für Technik (HSR), Rapperswil, Switzerland**

Whether at home or in the office, our modern lives would be unthinkable without IT and electrical engineering. For industrial manufacturing, the rapid advances made in information and data processing technologies are the drivers of innovation, enabling intelligently controlled, automated processes – that have also long since made their way into laboratories. The range of applications open to the processing of digital signals is innumerably diverse: examples range from share price calculation to in-vehicle ABS systems, from hearing aids to next-generation sequencing or automated powder dosing. Behind these intriguing solutions are engineers and technicians who spend each day working to make day-to-day life easier for us all.

Generally, the users of all this equipment are entirely ignorant of the technology it contains – or the substantial contribution made to the whole by signal processing. q&more visited the HSR, situated picturesquely on the shores of Lake Zürich, to talk to the distinguished inventor and holder of innumerable patents Professor Guido Schuster, and learn about his work as director of the Sensor, Actuator and Communication Systems Master Research Unit.

Prof. Schuster, you have followed an unusual path to your present academic position: your professional career was characterised by alternating stints in industry and research, and began with an apprenticeship to qualify as a radio and TV technician. After completing a master's and doctorate in the USA, you then embarked on a highly successful and distinguished career. What drives you?

My main motivation is a love of theory. – As Kurt Lewin would say: "There's nothing more practical than a good theory." It's what my line of work's all about. Signal processing is a relatively complex subject. It's wonderful to be able to apply a theory and generate something practical. I'm fascinated by the power of signal processing theory on the one hand and the sheer diversity of available applications on the other.

Guido M. Schuster completed an apprenticeship as a radio and TV electrician before studying electronics, instrumentation and control technology at Neutechnikum Buchs (Switzerland), graduating as the year's best student in 1990. He completed both his master's degree and his later doctorate (1996) at Northwestern University, Evanston, Illinois (USA). He then joined the Network Systems Division at U.S. Robotics (later 3Com) in Illinois, where he worked on the team developing the SIP VoIP standard. Later, he co-founded 3Com's Internet Communications Business Unit, becoming its Senior Director and Chief Technology Officer in 1999. During this period, he developed the first commercial SIP internet phone system, which was marketed in 2000. From 1998 to 2000, he was an adjunct professor at Northwestern University. Appointed Professor for Electrical Engineering at Switzerland's Hochschule für Technik, Rapperswil (HSR) in 2000, he has headed its "Sensor, Actuator and Communication Systems" Master Research Unit since 2007. Schuster's specialist field is digital signal and image processing.

He is the holder of over 60 international patents, the author of over 60 articles in international journals and the recipient of many prestigious accolades, including 3Com's Inventor of the Year (1999), the IEEE Signal Processing Society's Best Paper Award (2001) and the FUTUR Technology Transfer Innovation Award (2006, 2007 and 2008).

At its heart, your work consists of the conception and development of theoretical models. What is their significance – and what's your basic strategy?

Identifying a technical solution to a problem in the human world – the "real world" as we see it – is difficult: this world behaves unpredictably – even, I would suggest, "strangely". Models have the task of describing this practical physical and technical reality as a mathematical abstraction. As you begin your work, achieving a sound model is the all-important initial step: once achieved, you've won 50 % of the battle. To stay comprehensible, the model must be as simple as possible. Yet it must also be complex enough to encapsulate key aspects from the real world. Once the model is ready, it can then be amended and improved using the available mathematical tools – a process that continues until the real world behaves exactly as the engineer wants it to.

Your specialist field is digital signal and image processing. Can you give us an example of its application?

A typically fascinating example of this technology is the way your smartphone transmits the human voice. The problem facing us is as follows: digital voice recordings generate such a high volume of data per second – namely 64,000 bits – that this volume cannot be sent directly over the air. Only about 13,000 bits can in fact be sent per second. So your phone now does something interesting and uses a rather surprising model: using the vocal sound waves, it calculates a mechanical model of the mouth and vocal cords – which move and vibrate during speech, respectively – and thus generates a more compact dataset that can be transported easily over the mobile phone network. Using sound waves as input, the phone estimates the position of the mouth (i.e. the resonator) 50 times per second – no joke! Here, 12 numbers are sufficient to describe the mouth's shape – from slightly open to wide open. There are also two other effects, namely the oscillation of the vocal cords for vowels ("yes/no" classification) and, if "yes", then at which vocal pitch. Sources of signal noise (sibilants such as ss, ch, zz, etc.) are also identified. The data transmitted thus not only represents sound waves but also the movements of the mouth and vocal cords. The listener's phone then puts this artificial mouth back together and plays back the voice – like a speaking doll.

> "Make everything as simple as possible, but not simpler."
>
> Albert Einstein

That's really very impressive. So how do such models come about – when do ideas occur to you?

Generally, the process is a very slow one. Consideration of a particular problem will yield a strategy. It's true: the first approach taken is almost always wrong. But you must start somewhere. I oppose single-minded project planning. When you know exactly what you are doing, there are two reasons: a) the problem is trivial; or b) you are refusing to use the project as a learning process. If you are willing to learn, however, and the problem is non-trivial, then you'll have a quite different angle on the problem after no more than six months. The key thing is embrace the planning process, to follow it as a continuous process – and to be prepared to learn.

During your time in the USA, you played a major role in VoIP (Voice over IP) technology – i.e. enabling the placing of phone calls over the internet – and received the "Inventor of the Year" award from 3Com for your work. How was this standard developed – and what are its technological benefits?

In developing VoIP, we knew at the outset that the technology is inherently less expensive. Alongside product quality, that's what counts for the consumer and ensures market success. Incidentally: the phone network has been fully digital since the 1970s. And yet, even today, telephone companies still manage to sell one bit of voice at a much higher price than one bit of data. If you can parcel voice up into data packets, then it simply becomes cheaper.

The first commercial venture – at U.S. Robotics, later purchased by 3Com – where we deployed our VoIP solution was a real piece of crazy business, but nonetheless very successful. In 1984, a US court ruling, the "Modification of Final Judgement" from Judge Green, resulted in the break-up of AT&T – the largest telco in history – into regional service providers, termed "Baby Bells", with AT&T itself as "Ma Bell" (provider of long-distance services). At the time, AT&T had commissioned U.S. Robotics to transform the traditional phone call, which for a long-distance call was handled and invoiced piecemeal over three companies (the two regional companies, plus the long-distance portion via "Ma Bell" AT&T), into an "Enhanced Service" and to transmit the call along the AT&T portion via VoIP at a higher tariff. That was the first business model – and it made millions.

As a result of recent leaks, the topic of transparency for data sent over the internet is a frequent topic of public debate. How would you comment?

On the topic of data monitoring, I can say that this didn't come as a surprise to long-standing industry insiders. Back in 1996, I'd already been confronted with the United States' CALEA law, which mandated that US telecommunications service providers grant the FBI access to unencrypted data streams in real time.

Since 1987, you've been the recipient of numerous prizes and accolades. One of these was the Association for Lab Automation's New Product Award, which was received in 2009 by the new Quantos automated dosing system. You had played a major role in developing this product during a collaborative venture with the Mettler-Toledo company. Quantos is now a very successful product for solid and liquid media dosing applications. Here, it proved possible to implement powder dosing – previously a complicated manual operation – as an automated procedure.
What were the challenges here?

For this assignment, the key difficulty was in developing an algorithm capable of handling the timing aspects of powder dosing. The basic principle involved in dosing is for a predefined quantity of powder to be weighed by the balance. The machine is able to record the mass of powder on the balance pan only after a specific period of

"Plans are nothing;
planning is everything."

Dwight D. Eisenhower

time, since the powder requires a certain amount of time to cascade down. The balance therefore has a delay parameter. The sensor component – i.e. the balance – now has the task of informing the powder doing unit – i.e. the "actor" – about the amount of powder the latter still has to dose so as to achieve the target weight.

The dosing head's true innovation is not so much the integrated RFID technology as its sophisticated apparatus, enabling the dosing of powder – a truly difficult medium to handle – in tiny quantities. Our task here was to design a process capable of steering and controlling this complicated operation.

Two methods were available. With Method A, the powder is dosed gradually, step-by-step: measurement is continuous throughout the process and stops once you approach your chosen target weight. This works really well but is insufferably slow.

With Method B, the powder is weighed as it falls onto the scales pan and a projected estimate is made of the point in time at which the target weight will be reached – at which point, the dosing operation can then be halted. To understand this, imagine steering a boat. The rudder's effect in the water is delayed – you need to plan ahead

when steering your boat. That's the tricky thing about boats – and the difference to driving a car.

That sounds perfectly plausible. But is there a catch?

The challenge here centred on the modelling of the initial situation: this is because the stream of powder behaves as a classically chaotic system. Knowledge of the initial state is absolutely vital – and is just what we don't have, since the powder's behaviour is inconsistent. As one example, the same command sent to the powder dosing head – e.g. "Open by 10 %" – can dispense a lot of powder one time and only a little the next.

The magic of the Quantos dosing system is that it is able to "learn from scratch" for each dosing operation. In the first few seconds of each operation, as the powder starts trickling out of the dosing head, the sensors make a precise estimate of the powder doser's current behaviour, thus predicting when the preset weight will be achieved. Using the underlying system model, this future event can be estimated with a high degree of precision. That's where the innovation lies.

To what extent does your research and teaching benefit from collaboration with industry – such as joint development projects?

We benefit tremendously, and these partnerships are very useful for teaching. We're always able to cite examples from real-world projects ongoing or recently completed and thus effectively illustrate solutions to problems. This is also motivational for students of such heavily theoretical material: the never-ending math sometimes makes them wonder if they really want to stay the course. For my part, I find interaction with industry to be both helpful and inspiring. I'm also fortunate to be a specialist in a field that has just the kinds of characteristics necessary to ensure this interaction runs smoothly. While the field is inherently complex and experts are fairly few in number, it has a huge range of applications.

To date, collaborative ventures have been few and far between where we've been unable to point to a theory whose application would improve the product. In research, we have entirely different options and time frames available to us for tackling a problem than the industrial engineer, who has to solve his or her problem in short order.

Other key accolade gained during your career was your 2001 Best Paper Award from the IEEE Signal Processing Society. Which paper won you the prize?

This prize came out of the blue. I received the award for a topic related to image processing – the demarcation of video objects – that I'd addressed in my dissertation. The MPEG-4 standard, which we worked on in 1996, is now a widely-implemented video standard. Our research was the first to provide a clean mathematical formulation and optimum solution to the demarcation problem.

Prof. Schuster, as a final question: what piece of advice would you give to up-and-coming researchers in technical and scientific disciplines to ensure that they enjoy success in the future?

It's a great job, and it's worth hanging on in there. It's something a lot more people should be doing. There are so many young and talented people who have the potential. They're needed and they're shaping our world. In the final analysis, everything that makes the world simpler, easier or more comfortable – including medicine and pharmacy – involves engineering. Above all: you have to enjoy what you do.

■ **gschuste@hsr.ch**

(The interview was conducted by Claudia Schiller for q&more.)
Photo (4): Claudia Schiller