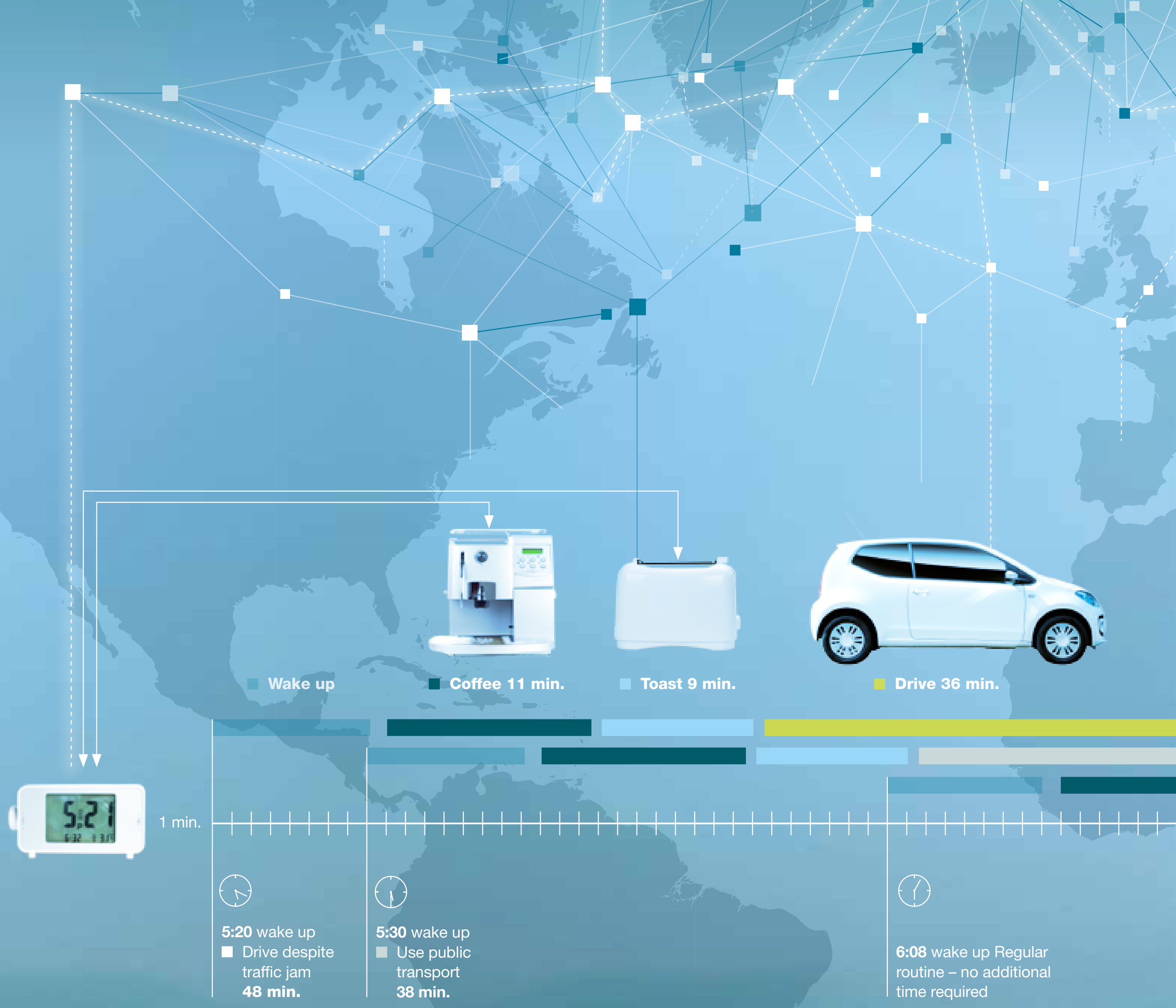
Connecting **the World**

In future, everyday objects will be linked via the Internet, enabling them to interact autonomously. To realize this vision, computer scientists are developing virtual models they can use to test practical implementation and monitor the security, safety and reliability of connected systems



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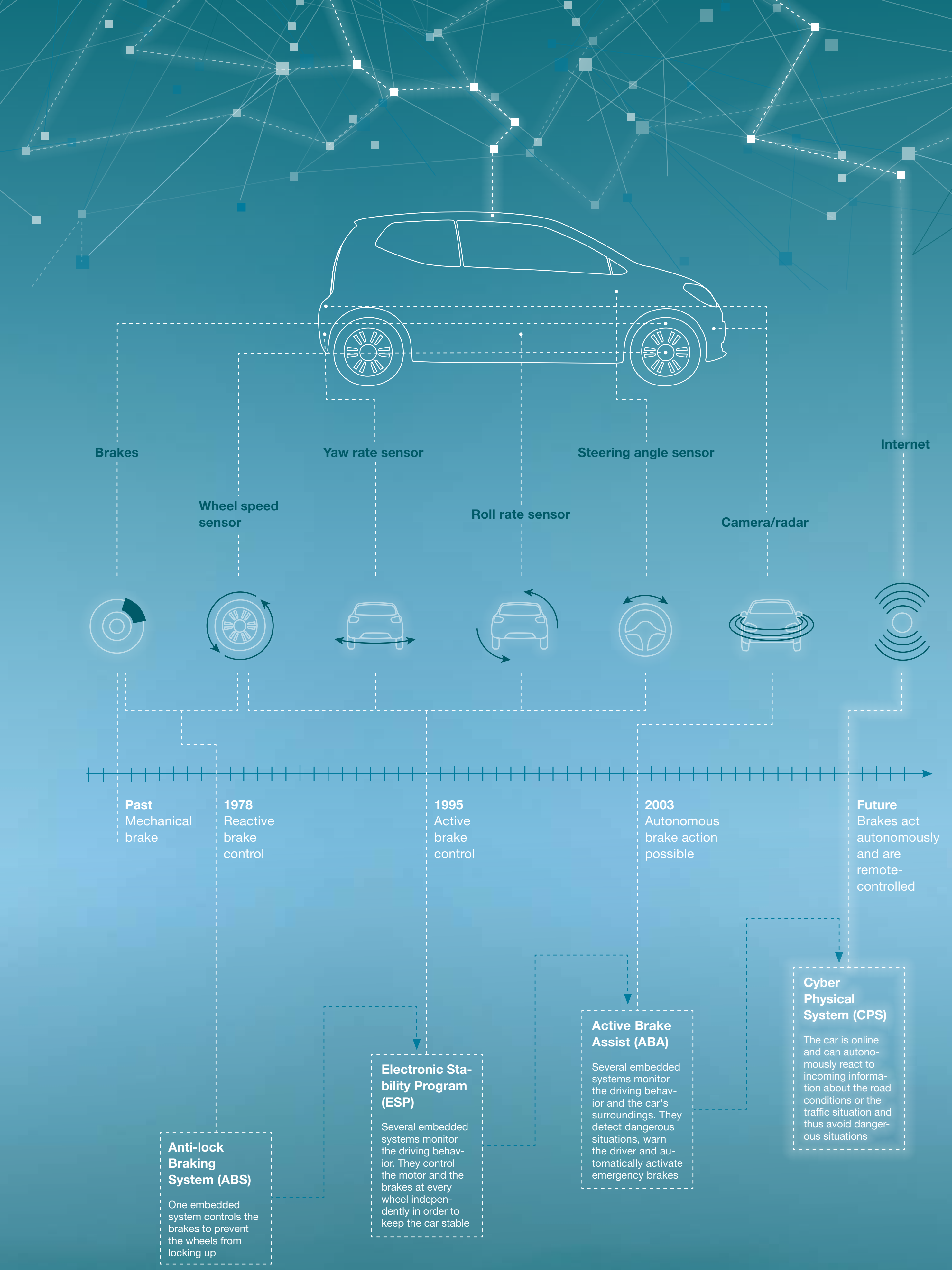

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Die Verknüpfung der Welt

Internet der Dinge – so nannten Experten ihre Vision, Gegenstände übers Internet miteinander zu vernetzen und im Hintergrund agieren zu lassen. Heute sind die Voraussetzungen hierfür weitgehend erfüllt. In modernen technischen Geräten und Maschinen stecken unzählige eingebettete Systeme: winzige Rechner, die mittels Software Daten und Signale verarbeiten oder auf Basis von Sensordaten Zustände überwachen und Prozesse regeln. Forscher möchten diese um Aktoren erweitern und durch Informationstechnik miteinander verbinden: zu sogenannten cyber-physischen Systemen (CPS). Damit entsteht eine neue virtuelle Ebene, die ortsunabhängig intelligente Anwendungen und wissensbasierte Dienstleistungen ermöglicht.
Die Herausforderung für die Informatiker liegt darin, dass verschiedene Lebens- und Arbeitsbereiche miteinander verschmelzen und beim Entwurf von CPS die Komplexität steigt. Deshalb greifen sie auf virtuelle Modelle zurück, die einen Ausschnitt oder eine Situation aus der Realität in abstrahierter Form nachbilden. Der TUM Lehrstuhl für Software & Systems Engineering versucht, die Entwurfsarbeit mit Theorien zur formalen Modellierung von Systemen zu unterstützen, und erprobt darüber hinaus, in welchem Umfang diese dann praktisch eingesetzt werden können.

Zertifizierte Werkzeuge für die Software-Entwicklung
Ziel ist ein Baukasten, der auf einem geprüften mathematischen Regelwerk beruht, aus dem die Software-Entwickler standardisierte Werkzeuge kreieren können. Eines der Werkzeuge, die aus den Arbeiten des TUM-Lehrstuhls hervorgegangen sind, ist Autofocus. Das ist ein Programm, welches die gesamte Entwicklung eines Systems abdeckt und die rechnergestützte Software-Entwicklung unterstützt. Es reicht von der Beschreibung und Analyse der Anforderungen über das Design des jeweiligen Systems, die Software-Validierung und -Verifikation bis zur Codegenerierung.

Pilotprojekt erfolgreich
In einem Projekt mit einem Industriepartner haben die TUM Forscher mithilfe von Autofocus die elektronische Türsteuerung eines führerlosen Zugsystems an Zug– und Bahnsteigzugängen nachmodelliert. Inzwischen hat Autofocus den Praxistest bestanden: Das Programm hat Fehler in der Spezifikation der Türsteuerung nachgewiesen und Schwachstellen aufgedeckt. Als Nächstes soll Autofocus nicht nur Testfälle für die Türsteuerung in bestimmten Situationen erzeugen. Die Forscher werden sich auch ein Software-Programm automatisch generieren lassen, mit dem sie anschließend das echte System testen können. *Evdoxía Tsakiridou*

Link
http://livinglab.fortiss.org www4.in.tum.de

Connected to the Internet, tomorrow's automobiles will become cyber-physical systems. Take the example of the braking system. Back in the 1970s, the mechanical brake was assisted by a single embedded system (ABS). In the next stage of brake evolution (ESP), several embedded systems worked together to keep the vehicle stable. Since the start of the millennium, automobiles have been able to react autonomously in the event of an emergency, thanks to the active brake assist (ABA) feature. This system uses cameras or a radar to monitor the immediate surroundings and apply the brakes if the vehicle is too close to another object. In the future, automobiles will be able to exchange information with other vehicles via the Internet. This will enable them to pre-empt situations or events that they have not yet detected – such as a slippery road surface 100 meters ahead

The conveyor belt stops in front of a filling machine. A hose descends and the plastic container below it promptly fills up with pink liquid. It then moves on to the next station, where the bottle is fitted with a pump dispenser and sealed. Meanwhile, a yellow liquid is now flowing into the next container at the filling line.
In this liquid filling plant, production is effectively driven by the product. Every product package is equipped with an RFID chip that acts as an electronic label, communicating with machines and the control center. It is able to "tell" them what each bottle should contain (pink handwash or yellow dish detergent), which packaging is required, which container the product should go in and when the product must reach the wholesaler at the latest.

Future factories are part of a large network

In the factory of the future, products are active information vehicles and equipment is networked. People and machines work together. Assistance systems display steps on a monitor for staff to follow. Components communicate with ▷

Theoretical groundwork for the development of complex software systems is the subject of Professor Manfred Broy's research. Manfred Broy heads the Chair for Software & Systems Engineering at TUM's Informatics Department. He is engaged in several initiatives for the advancement of technologies based on cyber-physical systems: As a member of the scientific advisory board of Plattform Industrie 4.0, a German initiative for the advancement of Industry 4.0 technologies, and as a member of the information and communication technologies network of acatech, the German national academy of science and engineering

machines and transmit data on their current status. Usage and sensor data is analyzed in real time, allowing faults or wear and tear to be predicted and prevented. All this, in turn, optimizes the production process, increases capacity utilization and improves product quality. In the future, plants will only produce what has actually been ordered. And customers will receive tailored goods, such as T-shirts or sports shoes, at mass-production prices.

The evolution from embedded to cyber-physical systems

At present, this scenario is still a vision, named Industry 4.0 in Germany's "High-Tech Strategy," referring to the fourth industrial revolution. At the same time, it describes part of the cyber-physical world, in which researchers anticipate that physical objects will be connected via the Internet and able to interact autonomously in the background. Technical devices and machines already feature embedded systems today – tiny computers that use powerful software to process information and signals or harness sensor data for status monitoring and process control. Expanding these systems to include actuators and connecting them up creates a new, virtual environment, enabling smart applications and knowledge-based services independent of location.
Professor Manfred Broy from TUM's Informatics Department gives a good example: "A car is currently a closed physical system, complete with electronic controls and embedded software. If, however, it communicates over a network to warn drivers behind about an accident or a patch of ice, it becomes a cyber-physical system."
Experts predict that, in the future, information and communication technologies will link up isolated physical systems in our everyday and working lives. Outlining the evolution from embedded to cyber-physical systems (CPS), the head of the Software & Systems Engineering Chair explains: "Cyber-physical systems are set to gain more and more ground in all areas of life – from intelligent power supply through smart logistics and transportation systems to ▷

Picture credit: Eckert

smart digital homes. And, one day, it will reach the point where systems can control and optimize themselves."

Mastering the complexity of cyber-physical systems

The design of closed physical systems remains relatively straightforward because it focuses on a specific scope. Like building a house, an underlying architecture describes the structures of the overall system – its components (hardware, mechanics, software) and their configuration and interaction, as well as the properties of software elements and the functions to be executed. In a factory, for instance, these structures would include equipment and systems, control and data communication software, transport and storage facilities, and the setup and interplay between these various building blocks during production. The factory turns into a CPS with the additional integration of IT systems connected to the outside world via communication networks. This enables it to interact or join forces with other facilities. If a company receives a major order that requires increased capacity, for instance, it could delegate part of the production work to a subsidiary. It is therefore particularly important that key information – such as instructions for retrofitting equipment, details of the production process, new measured values and set points, etc. – can be exchanged reliably and in real time between facilities, even if the network is overloaded.

From a technical perspective, CPS merges the previously discrete disciplines of machine building, electrical engineering and information technology into an overarching system of systems, forming ecosystems. The result is a dramatic increase in complexity, as the various domains intertwine. When buying a T-shirt via the Internet, for instance, this would apply to plant and production planning, the communication network and energy supply, the online shop, production status, and shipment tracking for the customer. Researchers are thus grappling with a raft of issues: What might CPS architectures look like? How should the human-machine interface be designed? And, last but not least, development and technical implementation pose plenty of challenges on the engineering side.

Smart grid architecture

Researchers at fortiss, a Munich-based institute affiliated with TUM, are investigating a possible cyber-physical architecture concept for an intelligent power network. In the Smart Energy Living Lab project, whose other participants include municipal utilities company Stadtwerke München, the fortiss office building functions as part of a decentralized network with a photovoltaic system on the roof. Staff members can use an app to call up data on power generation and consumption, while also receiving notifications about open windows or doors and energy-saving tips.

"We are in the process of developing a software architecture for a virtual power plant, joining up small local producers to form a large collective utility," reports project leader Dr. Markus Duchon. However, connecting producers and consumers and bundling several smaller storage batteries into a virtual interim storage solution for surplus green electricity is only part of the story. The IT specialists are also looking for mechanisms that will stabilize the network if a system is down or consumption suddenly increases. "The solution lies in pooling the various power sources into self-organizing groups," describes Duchon. An optimization program calculates the set values for each individual system based on a target for the overall cluster. The control center no longer needs to intervene as management of the individual systems has been dropped down. This hierarchical structure reduces the data traffic as well as control and optimization effort. At the same time, the flexibility and scalability of the network increases.

Standardized tools

To date, the disciplines mentioned have relied on their own (virtual) models when planning their specific systems. These models provide an abstract simulation of a real-world moment or situation, describe the properties of the required system and create a design blueprint. However, harmonized interplay between mechanical and electronic systems and software can only be checked once the final product is available. If it transpires that this interplay is not working as planned, subsequent reintegration can be extremely complex.

"Cyber-physical systems are set to gain more and more ground in all areas of life – from intelligent power supply and smart logistics and transportation systems to smart digital homes. And, one day, it will reach the point where systems can control and optimize themselves." *Manfred Broy*

Researchers believe the solution lies in developing a comprehensive system model to support these three disciplines. This integrated approach brings two worlds together, merging abstract IT models for information processing with physical models focused on space and time. The challenge lies in modeling applications that fulfill precise, real-time requirements (such as in a chemical plant, in which all parameters and processes must be observed exactly) and run via dynamic communication networks whose behavior is modeled based on probabilities.
"Essentially, we develop theories into formal system models and examine to what extent their practical implementation is feasible," explains Broy, outlining his research focus. Developing new, computer-based design methods for networked technical systems is another priority – on one hand to reduce complexity, and on the other to devise and test new functions.
In their efforts to implement cyber-physical systems, the TUM researchers are able to draw on groundwork for model-based development of embedded systems. Backed by Germany's Federal Ministry of Education and Research (BMBF), a joint project with partners in science and industry aims to develop a software platform for embedded systems (SPES) by 2020.

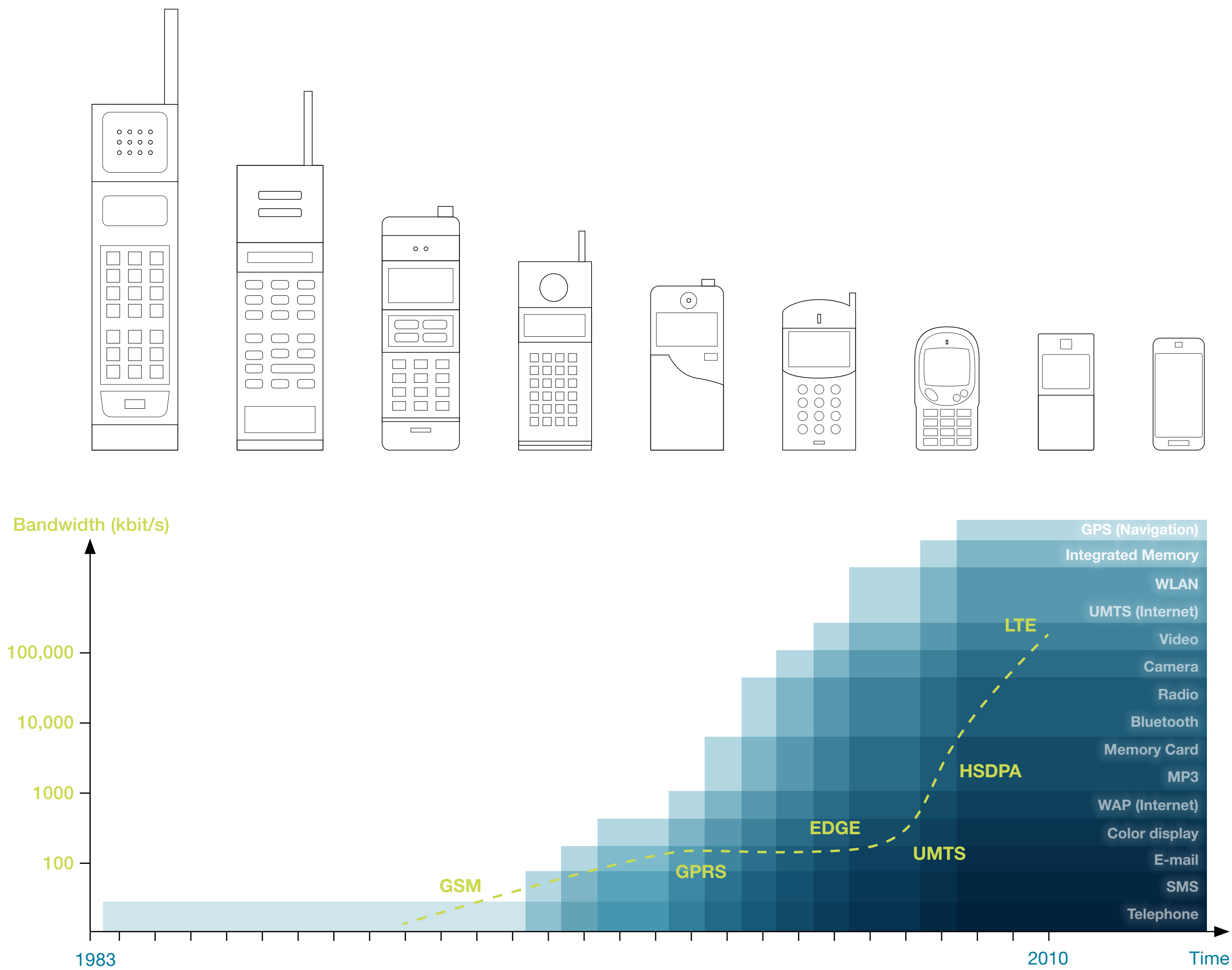
Theories for formal system models

In the same way that bricklayers, plumbers and electricians all refer to the same plans when constructing a new building, the aim is to incorporate information from the three disciplines here into a shared underlying model. Ideally, the result will be a design kit based on a verified mathematical – and thus reliable – set of rules. Developers can then use this to create standardized tools, for instance to generate program codes for individual systems or analysis and inspection methods, or for upstream testing of software and components.
One of the tools to emerge from this Chair's efforts is a program called Autofocus, which extends along the entire ▷

Picture credit: Eckert

Human interaction with cyber-physical systems: In the future, networked software services will shape just about all aspects of our lives. We will use Web-based services to do everything from arranging to go for a drink with friends through working out how best to get there to checking that everything is OK back at home. These services will have access to our data, working out the shortest route for hay fever sufferers, automatically activating our home automation systems, or transmitting blood work details to our doctor to support long-term therapies

Graphics: edundepp



Highly capable mobile devices are one of the prerequisites for the future trend toward cyber-physical systems. Within 30 years, mobile phones developed from devices that were 30 cm long and offered 30 minutes of talking time to smartphones that feature many standard computer functions

development cycle of a system and supports computer-aided software development. It covers everything from describing and analyzing requirements and designing the actual system to software verification and validation, code generation included.

In a project with an industry partner, TUM researchers used Autofocus to replicate the electronic door control functionality of a driverless train on arrival and departure. In other words, it looked at train and platform access. "We wanted to find out whether the formal model behind Autofocus would work, so we put the tool and our methods to the test with a concrete application," reports project leader Dr. Wolfgang Böhm. As a first step, the participants used Autofocus to convert the technical description or specification of the door control system – for instance, exactly when and how long the doors should open – into a formal language. The next, computer-assisted stage involved modeling the functional architecture to describe system behavior and operation in relation to the environment, but disregarding internal design.

Autofocus – a successful pilot project

"The tool helps reduce complexity and makes it quicker for users to identify errors. That means we are contributing to a product's quality right from the beginning of development," emphasizes Böhm. Autofocus passed its field test with flying colors, detecting errors in the automatic door control specification and discovering and exposing vulnerabilities. The industry partner was able to review their system architecture as a result. In the research project now under way, the project partners will derive test cases for the door control system in specific situations and use Autofocus to automatically generate a suitable software program, which they can then use to test the real system. *Evdoxía Tsakiridou*

Graphics: ediundsepp