Programming approaches for the smart connected world

The world is turning into a global “supercomputer” consisting of sensors, smart devices, laptops, desktops, and (cloud) servers all connected via the Internet. A team led by computer sciences Professor Mira Mezini is developing new programming approaches that automatically deal with the complexity of this “world supercomputer” so that software developers can focus on solving real problems.

By Boris Hänßler

Our brain does amazing things. This is evident, for instance, on our daily drive through the city. We should really be overwhelmed by all the signals that flow into our sensory organs from every direction – engine noises, sirens, construction machinery, traffic lights, advertisements. And yet we sit behind the wheel, generally unaffected by it all. We can even listen to an audio book or mull over the day as we operate the clutch and change gears. That’s because our brain processes most signals automatically, so we don’t really take much on board. It is only in the event of danger that it raises the alarm, and then we become highly focused.

These capabilities could well be used by software development teams in their solutions. The convergence of Edge, In-Network and Cloud Computing in a kind of “world supercomputer”, the availability of data and information, and advances in artificial intelligence may have tremendous potential for innovation in addressing urgent societal challenges. However, the complexity of the “world supercomputer” continues to grow, while the programming approaches that are familiar in the software development industry date back to the 1990s. As a result, software developers are often concerned with solving the technical challenges in the application in addition to modelling and solving the actual societal problems associated with them. Plus, their solutions to the technical challenges are often unreliable or suboptimal. A research team led by Professor Mezini of the Software Technology Group at the Technical University of Darmstadt is therefore developing a programming approach that independently solves some of the technical challenges of the “world supercomputer”. The current implementation of the approach is called REScala (www.rescala-lang.com).

A simple example: In a food warehouse, a program is supposed to continuously document the temperature using three sensors distributed in the room, and then calculate the average room temperature. The sensors automatically transmit their data to the software every time there is a change in temperature. For external events such as these, developers have hitherto used so-called callback functions. Unlike normal functions, which are always called at the same time during the execution of the program, a callback is not executed until an event occurs. This can be a mouse click on a website, or just the incoming signal from a sensor. In the example of food storage, this would mean that every time a temperature value arrived, the average temperature would have to be recalculated to ensure it is up-to-date.

“The researchers” fix some of the shortcomings of the previous programming techniques with REScala. These are basically geared towards a synchronous programming model. Put simply, in this model, software systems control the order in which their tasks are performed. But in today’s systems, such as a smart home or networked production, the process flow is no longer determined by the program itself and instead defined by the interaction with incoming data and events. In the traditional model, programs want to control when what data arrives and what happens to it, but external events do not wait for the program to become ready – the programs no longer control what is going to happen next.

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In this process, it affords automatic reliability and consistency, thus greatly simplifying the software. REScala comes at the right time. Countries around the world are currently building the fifth generation mobile network, with research being carried out into the sixth – with potential transmission rates of up to one terabit per second. In addition, new accelerator chip sets will drive edge computing, and thus the Internet of Things, immensely in the coming years. As a result, more and more machine learning applications can process data locally. Decentralised intelligence is tremendously important, both from an economic and from an environmental point of view, as well as in terms of data sovereignty. It is likely to change society as radically as the smartphone did. REScala can help to pave the way.

REScala, at its core, works a bit like Excel. If you change a value in an Excel spreadsheet, all its dependent values automatically change. This means users can concentrate on modelling the connections in the data. How calculations are performed in the background to efficiently and continuously produce correct up-to-date results makes no difference to the users. They rely on the automation working reliably for them. REScala applies this idea to general-purpose programming by extending the Scala programming language. However, in doing so, it rethinks the idea to ensure automation in a world where data and computations are globally distributed, where calculations are concurrent without central coordination, and where the communication infrastructure is unreliable. Strict consistency is an unsolvable problem in such an environment. However, REScala ensures as much consistency as is necessary and possible in every situation – if no connection is available at the moment, then all the changes are recorded locally and consistency is restored at the next opportunity. This is called “eventual consistency”. REScala ensures this level of the application state consistency “by-design”. On top of this, it enables developers to declare application-level invariants that must hold no matter what from which is derives parts of the application, where stronger consistency is needed and automatically ensures it.

REScala developers simply describe how asynchronously arriving data and events are combined and processed by composition of functions, whose execution is activated automatically. Application developers are not concerned with the timing and order of execution of individual computational modules. REScala ensures that they execute automatically whenever necessary to adjust their state to the arrival of new data and events. In this process it affords automatic reliability and consistency, thus greatly simplifying the software.

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*The author is a technology journalist.*
Taking sustainable production to the next level

If industry wants to face up to the challenges of the energy transition, it must rethink production – a complex transformation process that TU Darmstadt supports with new digital and AI-based solutions. The scientists behind it are application-oriented, interdisciplinary and holistic. Their common goal: to promote emission reductions, resource conservation and flexible energy use technologically. And in doing so, also to contribute to more companies putting environmentally and economically sustainable production on their strategic agendas. In the ETA Factory, researchers and their practical partners have a model factory on the Lichtwiese campus where they can validate their innovations and make them ready for practice.

On the way to an intelligent product

Intelligent and networked machines with the lowest possible carbon footprint protect the environment and save resources. Researchers at TU Darmstadt reveal how this works.

___ By Jutta Witte

How can networked production help to create transparency with regard to the resources used? What data is required for monitoring this, and how can it be used by companies so that they can apply it across all their locations? These were the initial questions with which researchers at TU Darmstadt launched the product “Agile resource-efficient production network”, ArePron for short. “Many predominantly medium-sized machine and plant manufacturers still cannot understand which resources they use at which steps in production, and how much energy they use in the process,” explains Professor Matthias Weigold, co-director of the Institute of Production Management, Technology and Machine Tools (PTW). With the agile production network that has now been established within the ArePron project, he and his research colleagues have come much closer to the goal of “more transparency”.

In this network, production machines from the two learning factories ETA (Energy Technologies and Applications in Production) and CiP (Center for Industrial Productivity) of TU Darmstadt are digitally linked, and individual components fitted with sensors for tracking their resource consumption. The operating data collected is sent to an IoT platform, where it is evaluated and visualised and the results are expressed in CO₂ equivalents. This makes it possible to understand how much carbon dioxide is emitted at which point, and individual components can be compared in terms of their carbon footprint. The project results are now available in the form of a practical guide for industrial application. “We have taken the first important step towards digital, sustainable production, which offers the opportunity to establish resource efficiency as a new target figure,” emphasises Professor Joachim Metternich, who heads the PTW with Matthias Weigold.

The mechanical engineering department at TU Darmstadt has long been committed to the development of “environmentally-friendly products” by means of a holistic calculation approach from the extraction of the raw material to disposal, and has already initiated successful solutions for this purpose. Beyond traditional numerical methods, digital technologies now offer new opportunities for an increasingly individual and precise life cycle assessment of products. The currently on-going research project DiNaPro demonstrates the potential. It is further developing the digital twin technology, which in the future will enable end-to-end mapping of the life cycle of products when operating IoT platforms. “Every component should be given a digital image that doesn’t just automatically show the actual state of a component...”
Taking sustainable production to the next level in operation in real time,” explains Professor Reiner Anderl, Head of the Department of Computer Integrated Design (DiK). “The digital twin is intended to provide information on all the data that is incorporated in the product.” The aim is to create assistance systems that will not only allow industrial companies to optimise their product planning and production, but will also be able to integrate CO₂ monitoring into the process control over the entire life cycle of a product.

Emissions, electricity consumption, wear: the intelligent product of the future will have to carry a lot of important information inside itself. It will not only enable companies to predict errors before they occur for “predictive maintenance”, reducing scrap, tool breaks and downtimes, but will also have to be a product that, thanks to its individual properties, can be continuously optimised. Experts at TU Darmstadt are already thinking beyond the technical questions. Smart products can offer lots of added values, for instance when companies use them to build new services and business models on them. That is why Anderl, Metternich and Weigold want to combine technologies and knowledge for sustainable industrial production on one platform in the future, which is a novelty in this country. The planned platform “data-based production” (DataPro) is intended not only to address the design of future production chains and their connection to an IoT platform, but also to the development of data-based production environments that generate new services and business models as well as the transfer of knowledge from applied research to companies.

In doing so, the three scientists are also looking at the added value that can arise for an industrial company that not only exploits the potential of digital technologies in manufacturing to reduce costs, increase efficiency and develop new business models, but also to anchor sustainability in the company’s strategy and culture. “In the end, the newly created transparency in the production environment can influence every level of an organisation,” Weigold believes. In the future, showing responsibility for greater sustainability with a verifiable life cycle assessment should also determine how a manufacturer and its products are judged on the market. And CO₂ emissions, as Anderl, Metternich and Weigold agree, have the potential to become a new currency for the economy.

Information
A large network of partner companies were involved in the research project “Agile resource-efficient production network” (ArePron, duration 2018 until the end of 2020) in addition to the Institute of Production Management, Technology and Machine Tools (PTW) and the Departments of Computer Integrated Design (DiK) and Materials Management and Resource Economics (SuR). ArePron and its follow-on project “Resource Optimization along the Product Lifecycle” (ReOptify, duration 01/2021 to 12/2021) are funded by the Hessian Ministry of Economics, Energy, Transport and Housing as well as by European funds (EFRE). PTW and DiK are also responsible for the planned projects “Model-based digitisation of sustainable production networks along the product life cycle” (DiNaPro, planned start 07/2021) and “Platform data-based production” (DataPro, duration 04/2021 to 03/2024).

For more information: www.arepron.com
The supply technology of an industrial plant consists of a variety of technical systems. Aside from the actual production chain, energy converters and storage systems must also be orchestrated in a complex system. Simple monitoring systems are commonly used for this purpose, which primarily document electrical consumptions. “This provides a rough overview of the plant’s total energy consumptions; it is not possible to assign consumption to individual plants, machines or products with these systems,” says Professor Matthias Weigold of the Institute of Production Management, Technology and Machine Tools (PTW) at TU Darmstadt. However, at a time when volatility is increasing along with the upturn in electricity generation from renewable sources such as wind and solar, far more flexible energy management systems are required as well as more efficient production facilities.

“There is much potential for more efficiency and flexibility in industrial manufacturing. We just need to raise it,” emphasises Professor Stephan Rinderknecht, Head of the Institute of Mechatronic Systems (IMS). A look at the ETA Factory shows how this can work. Within the project “PHI Factory”, a framework has been developed and tested on a real scale with which industrial companies can save costs and resources and also support the electricity grid with flexible energy management.

In cooperation with companies such as Bosch Rexroth and Software AG, the PHI Factory team has turned the ETA Factory into a fully digitised and energy-flexible model factory in which all energy and process data is monitored. “This also allows a prediction of energy consumption as well as providing greater transparency – like a weather forecast,” reports Weigold. Predictions of when the next peak load will occur are possible based on the system with a lead time of between 15 minutes and one hour. The forecast horizon for a single machine is only a few minutes. Coupled with weather and market data, production can be planned in an energy-optimised manner and the control mode of supply technology can be adapted flexibly and quickly to changing conditions.

One important component in the new energy management system is a new hybrid and highly efficient storage system that combines a flywheel storage system with a lithium-ion battery, taking advantage of both technologies. “If I want to store larger amounts of energy for a longer period of time I use the battery, and if lots of machines reach the load peak at the same time I use the other storage because it releases the energy quickly,” explains Georg Franke, research associate at the IMS. This means that the factory only uses the grid when it needs electricity, and can operate autonomously for one day, for example if there are low feeds-ins from renewable energy sources.

As well as the production plant, the electrically powered factory vehicles are also integrated in the system as a further consumer. Load peaks can be shifted when the vehicles are parked for charging, i.e. the charging process only starts when electricity is cheap or is no longer needed elsewhere. In the next step, the batteries of the electric vehicles are operated bidirectionally, i.e. they are also able to release energy into the network at the charging station. “This is a good example of how we will be able to exploit synergies between industry and the mobility sector in the future,” says Rinderknecht. “Without innovative solutions such as these for sector coupling, neither the energy nor the transport transition will be feasible in the long term.”

Furthermore, the flexible factory of the future will contribute to stable load management. “The system always knows how the network is doing at a particular moment,” says Franke. This not only promotes efficiency and sustainability but also offers economic benefits, for example when a production plant generates revenue by purchasing the surplus in the event of an oversupply from renewable energies. “So it is important that we always include economic issues as well as technology in our scientific considerations,” emphasises Rinderknecht.
Without methods of artificial intelligence such as machine learning, which was already used in the context of “PHI Factory”, it is not possible to achieve a holistic, company-wide, cross-sector energy management system that is adapted to the market. Within the “KI4ETA” project, which is just starting, solutions are now being sought to manage real-time data streams automatically and to operate production and supply in a factory with the use of AI algorithms, from the collection of data to the control of each individual machine.

“We want to provide energy managers and consultants and those responsible for production and infrastructure with tools to analyse complex factory systems and create low-carbon emissions,” Weigold states. An energy management platform that is easy to install and operate and can be further developed towards cloud and edge computing, the energetic coupling of entire sectors, automated transparent monitoring and AI solutions for energy optimisation: the new research project has much potential for springboard innovations.

The author is a science journalist and holds a doctorate in History.

Facts and figures:
The joint project “PHI Factory” (duration 12/2016 to 03/2020), in which the Institute for Production Management, Technology and Machine Tools (PTW), the Institute of Mechatronic Systems (IMS) and the Department of Electric Energy Supply using Renewable Energies (ES) of TU Darmstadt participated as well as the consortium partners of the ETA Factory, was supported by the Federal Ministry of Economics. The “KI4ETA” consortium, led by the PTW and in cooperation with the IMS and other industry and research partners is expected to launch in April 2021. Researchers at the PTW and the ETA Factory have also been contributing their expertise to the Kopernikus project “SynErgie” funded by the Federal Ministry of Education and Research (BMBF) since 2016.

For more information:
https://eta-fabrik.de/forschung/projekt/phi-factory/
https://www.kopernikus-projekte.de/en/projects/synergie

In the ETA factory at TU Darmstadt, research is being carried out on a real process chain in the metal processing industry to find innovative solutions for greater sustainability in production. For this purpose, the factory was equipped with a holistic energy monitoring system, into which several thousand data points from the machines and the factory building are integrated.
Artificial teeth are attached to the jaw with titanium screws. “But often the implant doesn’t embed well in the bone tissue,” explains Lukas Kluy, PhD student at the Institute for Production Engineering and Forming Machines at TU Darmstadt. In about eight percent of patients, the insertion actually lasts less than ten years. In the IdentiTi project, Kluy and his colleagues want to solve the problem with a nanostructured titanium alloy. It has a fine-grained surface, which the body’s bone cells are better able to adhere to.

The TU engineers produce the new screw material in a special process from a coarse-grained titanium alloy. The starting material is distorted in a machine at 300 degrees Celsius so that the internal structure breaks up and a new fine structure forms. “But the process requires a lot of energy,” says Kluy. Which is already evident from the machine’s thick power cables.

In Germany alone, over one million dental implants are fitted every year. If they were all to be made from the nanostructured material, the additional energy requirement would be considerable. Together with Andreas Wächter, who at the time was still a mechanical engineering student looking for a subject for his master’s thesis, Kluy wanted to make the production of the nano-alloy more energy efficient.

A process is usually energetically optimised once the individual steps have been determined. Then, for instance, waste heat is used here or there, a component insulated or the control technology optimised. But Wächter had a better idea: “Our process was still being developed, so then you can incorporate energy efficiency right from the start.” In the initial phase there is still a tremendous amount of design freedom, he explains, and measures to save energy can be implemented relatively easily and cost effectively. In this case, for instance, heating the alloy requires a tremendous amount of energy. “Simply by shortening the form in which the material is heated, we were able to halve the heating time,” explains Wächter. Overall, this reduced the energy consumption by twelve percent.

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A colleague at the institute is currently using the model to optimise a process of roll forming. The technology bends metal strips, for instance in vehicle construction or in the production of window frames.

Last year, their methodology won Wächter and Kluy second prize of the Hessian State Prize for innovative energy solutions. Since they want their idea to spread quickly, they are currently considering an open-access release of their model. Kluy emphasises: “The social benefits are far more important to us than making money from it is.” The model is ready for use, and he adds, “Anyone who is interested in it is welcome to get in touch.”

The author is a science journalist and holds a doctorate in Chemistry.