Intelligent Machines are Taking Us Into the Future

Cluster of Excellence “Cognition for Technical Systems”

Cutting-Edge CoTeSys Research in a Cluster of Excellence

The “Cognition for Technical Systems” Cluster of Excellence (CoTeSys) is one of 37 large-scale research projects taking place at German universities and funded by the federal and state governments under the Initiative for Excellence. The program finances top-level research and young, up-and-coming scientists with the aim of making Germany more internationally competitive as a research location. Research groups from across the country competed for the title of Cluster of Excellence – and the CoTeSys team under the aegis of Technische Universitaet Muenchen (TUM) was successful in 2006 (coordinated by Prof. Dr.-Ing./Univ. Tokio Martin Buss). The CoTeSys Cluster comprises some 100 scientists from TUM, LMU Munich, the Universität der Bundeswehr München (UBM), the Max Planck Institute of Neurobiology in Martinsried and the DLR Institute of Robotics and Mechatronics in Oberpfaffenhofen. Funding was initially allocated until 2012. Since the research project is long term in nature, CoTeSys has submitted a proposal for the subsequent funding phase.

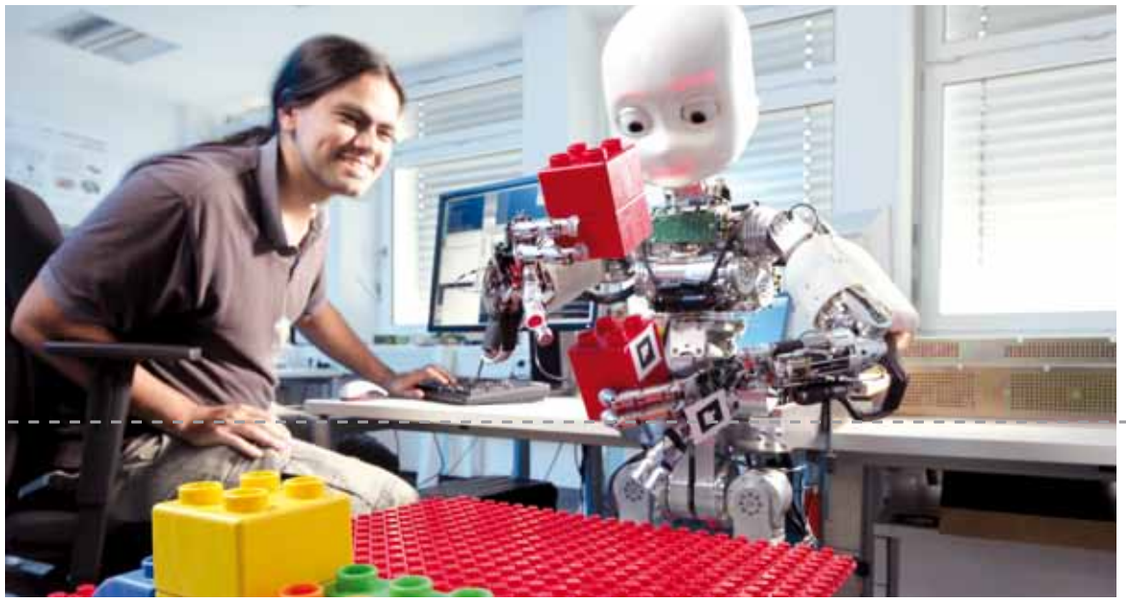
Our Vision for the Future: Service Robots as Helpers in any Situation

Seeing ‘PR2’ rolling through the supermarket doing the shopping or Rosie and James making pancakes together can give you a first impression of what robots are already capable of. But this is only the beginning. In the future, they will be an integral part of our lives, they will help us in many different ways. In order to collaborate with us successfully, robots need to be able to recognize their surroundings and behave flexibly, intuitively and independently. The CoTeSys Cluster of Excellence is working intensely on enabling them to do precisely this.

There are a number of societal and economic megatrends that demonstrate the role intelligent machines will play in the future. As one of these megatrends, the German population pyramid will soon have been turned upside down. According to the Federal Statistical Office, almost half of the total population will be over the age of 50 by 2035, while one in three Germans will be over 60 – and of course the nursing care sector needs to adjust to this situation. In this area, service robots could take on physically demanding tasks and more. Intelligent engineering can make a valuable contribution in industrial manufacturing, too – especially for small and medium enterprises, where highly specialized and customized products will increasingly gain significance. Here, universal robots can plan assembly sequences autonomously and make adjustments from component to component – even on conveyor belts.

Intelligent Robotics: Looks Easy. In Reality it's Highly Complex

Why do robots have such trouble making the simplest of hand movements?



Research group of Prof. M. Beetz

ICub diligently practices with Lego blocks.

Carefully and gently, ICub the robot picks up two Lego blocks and joins them together. His big dark eyes and soft features give him the look of a small child. But unlike his human role models who can pile building blocks one on top of the other with ease, ICub finds the task difficult. He makes several attempts, correcting his hand position frequently. The big challenge for the little robot lies in synchronizing his visual, cognitive and fine sensory skills.

Flexibility Required

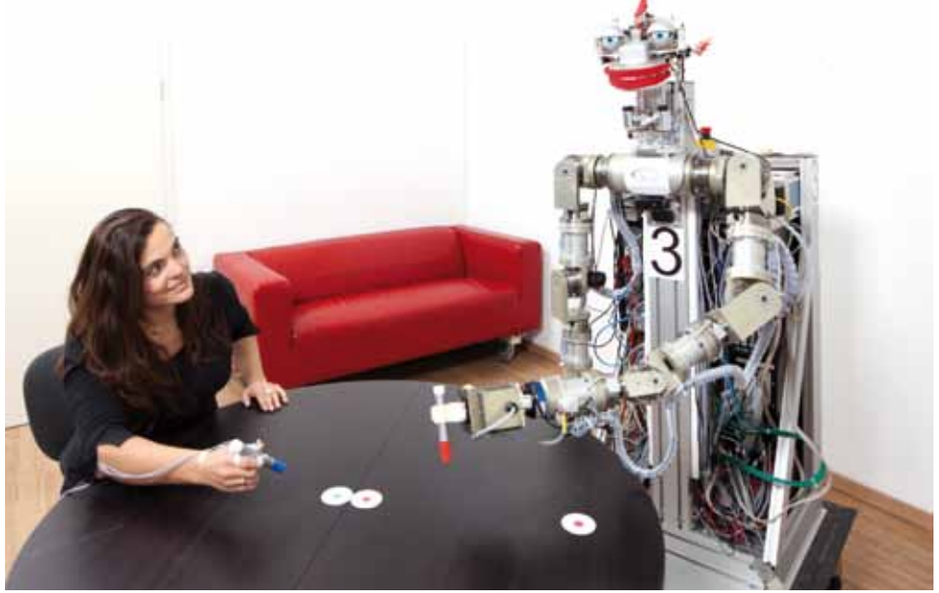
Why do robots have such trouble with apparently trivial tasks? After all, there are supercomputers that can beat world chess champions and triumph over quiz champs. The difference is in the capacity for cognitive action. While it may seem that what the supercomputer does, requires a high level of intelligence, it is ultimately all based on a number of fairly simple algorithms. Robots, on the other hand, need a far more complex set of skills in order to interact flexibly with humans. They have to be able to perceive their surroundings and recognize individual objects. And intelligent robots need to be able to learn from experience and apply implicit knowledge to new situations. If their dealings with humans are to be as natural as possible, robots need to understand facial expressions and gestures, to respond to them appropriately and possibly even to show emotions themselves. All of these skills come automatically and naturally to people, whereas robots must painstakingly learn them first.

Our Solution: Living Interdisciplinarity

Implanting cognitive skills in robots is an extremely time consuming and highly complex business. So complex, in fact, that it is no longer possible for cognitive skills to be fully explored by any individual discipline alone, given what we know of the subject today. That is why CoTeSys combines the knowledge and expertise of many different disciplines, making it probably the most interdisciplinary cluster in its research field in the world. More than 100 scientists from the fields of biology, neurology, computer science, mechanical and electrical engineering, mathematics, physics and psychology work hand in hand on the development of intelligent service robots. And the practical implementation of scientific knowledge plays a key role: CoTeSys extracts methods from theoretical studies and transfers them to technical systems, where they can be tested in true-to-life scenarios. The interdisciplinary approach has proven to be an engine of innovation and facilitates the emergence of new structures in the research landscape. Living interdisciplinarity – it's an approach that means that, sooner or later, robots like ICub, PR2 and Rosie will no longer be playing with building blocks or making pancakes, they will be deployed as fully functional helpers.

"There is already a lot being accomplished in cognitive science. But when it comes to converting the findings into technical systems we're still in the early stages. At the same time, the topic is now so complex that no single discipline can cope with it alone. As far as I'm concerned, CoTeSys is a good platform for different disciplines to work on a subject together."

(Tamara Lorenz, graduate student at LMU Munich)



Research group of Prof. S. Hirche

Grasping and Lifting Like Humans Do

How do robots learn human hand movements?

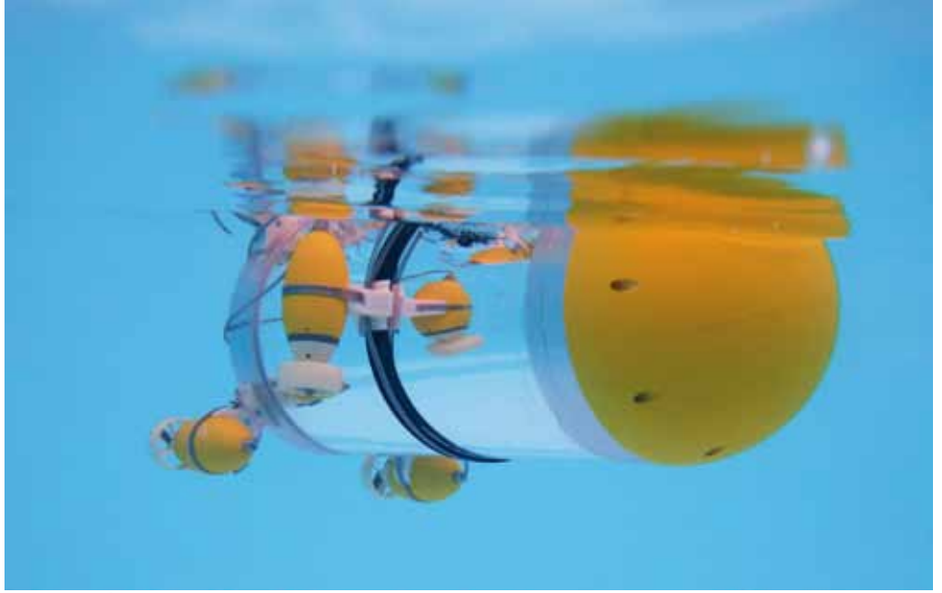
Intuitive movements are something robots need to learn.

One day, robots will even be able to carry out tasks involving intricate fine motor skills and do things like putting components together themselves. An ambitious aim, given that supposedly simple sequences of movements like grasping an object or opening a cupboard door can present major challenges for robots' hands. Things that humans do intuitively, without really thinking about it, are things that the intelligent machines first need to learn. Psychologists at CoTeSys therefore study the techniques human beings use to securely grasp objects of different sizes, shapes and weights. And they transfer their findings to the machines.

Psychology Helps

In a series of experiments with human subjects, sensors register the position, movement sequences, the force of the individual fingers, and the way the whole hand is held. They identify when humans use one hand or two and when they put their body to use in grasping or lifting objects. The movement sequences are later analyzed, abstracted and translated into mathematical algorithms. The robot uses these 'instructions' to decide how to coordinate its arms and hands in order to pick up an object. And how to avoid colliding with people or other objects when getting something out of a drawer, for example.

People feel better in the presence of a robot if it makes movements in a way with which humans are familiar. This prevents unexpected situations and movements, which in turn makes the interaction safer.



Research group of Prof. S. Hirche, Prof. L. van Hemmen

Modeled on a Fish

How robotics can learn from biology.

The little underwater robot, Snookie, will be able to move with complete safety and independence through unknown waters – even in strong pollution or absolute darkness. CoTeSys developed the necessary technology for this by learning from nature: the blind cave fish Astyanax mexicanus evolved the ability to navigate through murky waters without the power of sight.

Finding its Bearings without Eyes

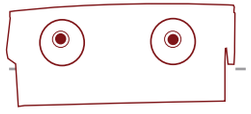
A lateral sensory organ along the body of the blind cave fish enables the animal to perceive the subtlest of differences in pressure and current as it swims along. It uses them to reconstruct a picture of its surroundings. Snookie the submarine may not have an actual organ to do this, but what it does have are tiny sensors in its nose that can pick up even minimal changes in the speed of the passing current. Using this information, the yellow robotic fish can explore its environment, detect obstacles and skillfully avoid them, all without any outside control. Whether it's wreck diving, caving expeditions or the search for crashed aircraft – the future holds a great many more exciting tasks in store for the Snookie team when it comes to integrating the robot's individual elements.

Snookie the robotic fish uses this sensor to find its bearings

Research group of Prof. G. Rigoll

Reading People's Wishes in Their Eyes

Eye contact is a part of natural communication.



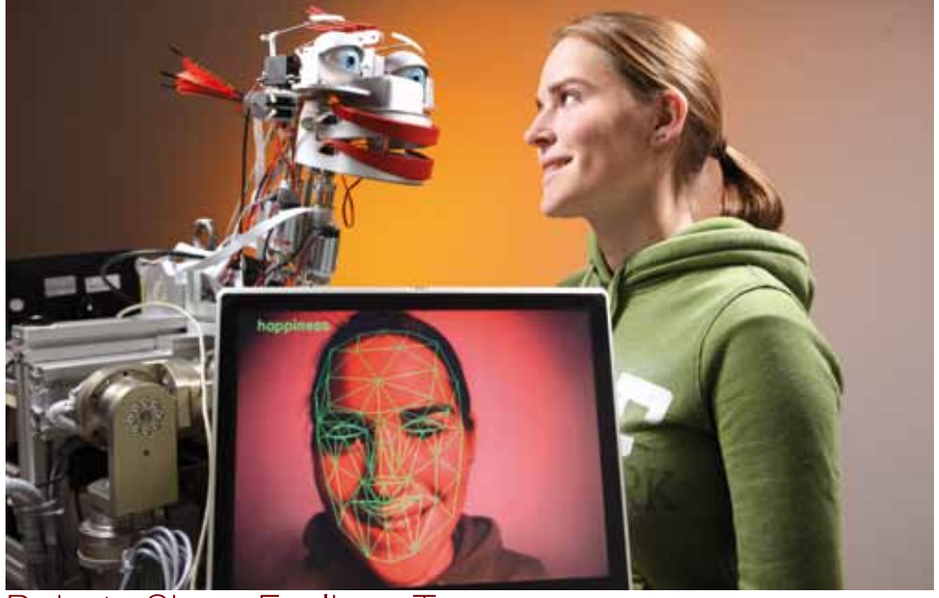
On a par with humans: the eyes of Elias the robot

Instead of rigidly and monotonously repeating precisely defined activities in a factory setting, the robots of the future will be able to interact flexibly with people and other machines. The aim of service robotics is to actively support people in their work and daily lives. But can living with a machine really work? Elias the robot is learning to detect and interpret people's expressions for this very purpose. For as we all know, the look in a person's eyes says a lot about their intentions.

His little robot eyes are as fast as a human's and employ modern eye-tracking technology to follow the eye movements of the person he's interacting with. Elias will thus be able to detect a person's intentions and wishes even before they are voiced.

Interpreting Expressions

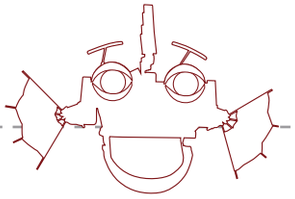
For people who are old or sick in particular, Elias could become a valuable partner, reminding them to take important medicines or able to summon help in an emergency. To enable man and machine to live together without the risk of frustration, Elias is learning to understand people's natural speech patterns and interpret human gestures and facial expressions. After all, a robot, like a person, needs to be able to discern when its help is needed. And when it should make a discreet withdrawal.



Research groups of Prof. M. Buss and Prof. B. Radig

Robots Show Feelings Too

And need to understand a person's mood.



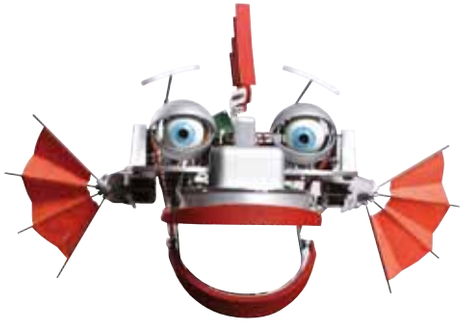
Eddie shows what mood he's in.

A large part of interpersonal communication is non-verbal. But even for humans, it is not always easy to correctly interpret other people's facial expressions. For Eddie the robot, discerning and acquiring human emotions poses an even greater challenge: emotions are things he does not have an intuitive command of, and must painstakingly learn. So Eddie analyzes human facial expressions on the basis of defined marker points in order to identify how the person he's with is feeling. And his unique robot face can mirror the feelings he detects.

Eddie Raises his Comb

When his owner smiles at him, Eddie pulls his cherry-red lips into a broad grin, too. But if his owner looks annoyed, Eddie raises the cockscomb on his head. In the interests of making the man-machine communication as natural as possible, Eddie is currently learning to deploy his emotions to suit the specific conversational situation.

Whether it's a waiter in a restaurant or a mechanic in an auto repair shop, Eddie will be able to cooperate with people and help them in their work. In order to avoid accidents, he will also need to be able to judge and interpret the facial expressions of his human partner so that he can react flexibly to different situations.



From Routine Processes to Flexible Action – Learning in the Kitchen

How do robots learn to find their way around a kitchen?

The kitchen helpers of tomorrow.

Research group of Prof. M. Beetz

Rosie rolls her 200 kilos over to the kitchen counter. She's been asked to make a pancake. On the Internet she finds instructions for how to make them using ready-made pancake mix. Her partner in the kitchen is James, a robot just like her. The two have an unusual task to work on together: they are practicing cognition – the act of independently planning, taking action and making decisions. The tasks the scientists from the CoTeSys Cluster of Excellence set them are deliberately abstract. The robots have to find out all by themselves which individual steps they need to take to complete the task.

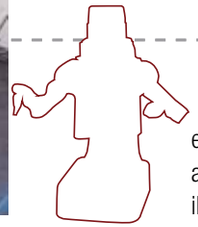
They use the Internet to find information on the objects they need to use. Their research on making pancakes reveals not only what the pancake mix looks like, but also where they are most likely to find it: James looks for the product, marked as perishable, in the refridgerator.

Practice Makes Perfect

The two of them learn new things in their other practical tasks, too. Just like people, they always use the same movements for similar tasks. They have optimized these routine processes by practicing them a great many times. If they do not have a suitable movement up their sleeve, they think up a new one. Often, this is not yet very graceful or may even be impractical. Like when a robot makes movements with its arm that no human can copy. However, the robot will keep the movement in mind in order to work on it and improve it later.

Works with Drawers, Hatches and Doors

James and Rosie can also remember specific objects. James, for example, remembers which drawers he has already opened. And he knows exactly which direction he has to pull them in and how much force he has to apply. When it comes to unfamiliar objects he reverts to the more general program for opening hatches and doors.

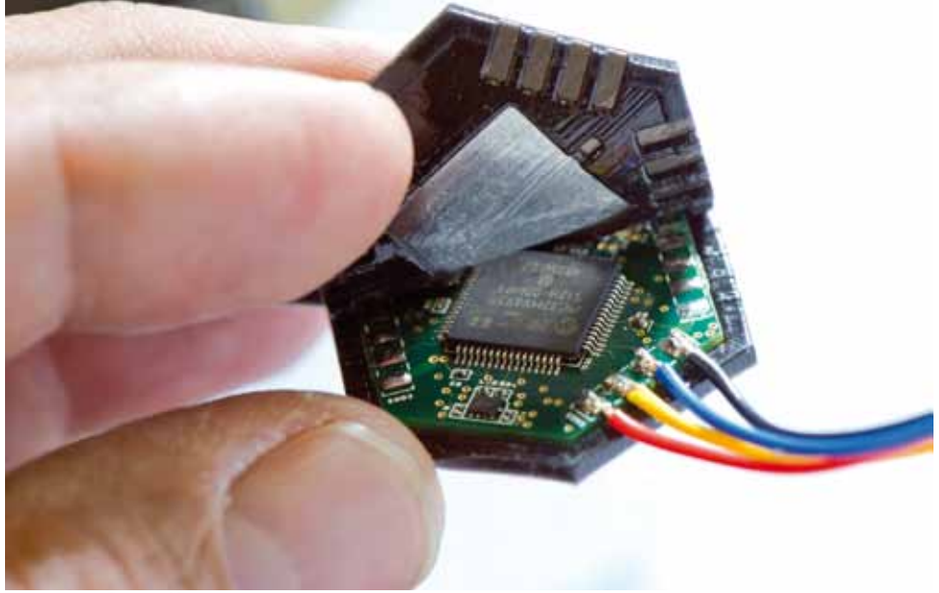


Taking in their surroundings based on the data from their sensors is by no means easy for the robots. Although Rosie and James are each fitted with two cameras and can therefore see in three dimensions, even robots are not immune to optical illusions. So they apply their prior knowledge when interpreting and selecting data.

There are numerous conceivable scenarios in which the intelligent robots could be deployed. The research team chose the kitchen because there are so many complex tasks to be done there. And because kitchens look fairly similar throughout Germany. The scientists can therefore test with relative ease how well Rosie and James apply their knowledge in similar rooms but on unfamiliar terrain.

"Many people have no idea how immensely difficult it is to translate cognitive skills into technology. On the one hand, we attach intelligence to things that are very easy to manage in terms of computational power. Yet on the other hand, it's the things that come naturally to us humans, like opening a fridge, that are the most difficult to realize from a technical point of view. Intelligent machines and robots are not yet a part of our living environment. But CoTeSys is exploring and working on all this."

(Prof. Michael Beetz, Board Member and Deputy Coordinator, CoTeSys)



Research group of Prof. G. Cheng

New Challenges Await

Initial successes on the path to developing a real helper.

These tiny tiles form the robots' sensitive skin.

We humans are pretty good at doing what we do. This is a realization the CoTeSys scientists arrive at time and again when they try to teach a robot apparently simple tasks like flipping a pancake. And nobody has yet managed to create a robot that can hammer a nail into the wall, either.

Creating copies of humans is not what the CoTeSys research aims to accomplish. Rather, the goal is to simplify the process of man and robot working together in a factory, a hospital setting or, one day, even at home; to make it safer and less complicated. The service robot of the future may come in many shapes and sizes but what it definitely should do is take a clearly defined set of tasks off its 'master's' shoulders.

Yet the scientists' machines still need to be given a number of capabilities before they can become real helpers. The development of a sensitive robot skin is one important step here. A CoTeSys team has developed little hexagonal tiles with sensitive sensors, which form a sensitive skin when fitted together. The way the artificial skin is touched may cause the robot to flinch spontaneously, for example. Not only will this help the robot find its way in unfamiliar surroundings, it can also help it learn its own physical dimensions, speeds and strength.

Scientists the world over are working on these areas, though they have only a rough idea of the results they can expect to see in five or in fifteen years. CoTeSys has set itself the goal of accelerating this process through interdisciplinary collaboration, and wants to mobilize cutting-edge science in tandem with application potential to get knowledge translated into products and services.

Research group of Prof. K. Diepold

Other Industries Benefit Too

Many branches of industry face similar issues.

Intelligent laser welding

Most people, when they think about robots, picture large, ungainly machines in enormous factory buildings, executing minutely defined tasks. The service robots of the future have nothing in common with this cliché. They will be able to move freely, communicate naturally and make their own decisions.

Research Required

There is still a lot of development work to be done before that point is reached: further research is needed in the field of materials and control engineering and mechatronics in particular. Arms and joints need to become lighter, for example, without losing any of their strength. In terms of sensory technology, scientists are primarily investigating touch detection by tactile sensors. Cutting energy consumption and manufacturing costs are other key aspects.

The automotive and aerospace industries are also working intensively on very similar topics and are making use of CoTeSys research findings. Thanks to its close cooperation and exchange with other institutions, CoTeSys is making an instrumental contribution to technology development and to strengthening Germany as a business location. The CoTeSys mission of taking the pressure off humans by developing intelligent machines is thereby being brought to bear in manifold ways.

Partners and Facts

Term: 2006-2012

Technische Universität München (lead university),
Ludwig-Maximilians-Universität (LMU),
Munich
Universität der Bundeswehr München (UBM),
Neubiberg
German Aerospace Center (DLR),
Oberpfaffenhoffen
Max Planck Institute of Neurobiology (MPI),
Martinsried

Excellence in Munich

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Baker & Harrison Translations
www.bakerharrison.de

“We develop intelligent robots that can take on a diverse range of tasks – but man remains at the center of all of our efforts. The machine should serve and help man, but it should not develop an undesired life of its own.”

(Dr. Uwe Haass, CoTeSys General Manager)