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Research • Career insights • Activities

Can robot teams work together and adapt to solve problems and save lives?

Dr Hao Zhang

When robots hit the slopes: team 'skiing' in the mountains.

Can robot teams work together and adapt to solve problems and save lives?

From saving lives in disaster zones to inspecting infrastructure and exploring distant planets, teams of robots are beginning to transform how we tackle complex challenges. But will these robot teams be able to learn, adapt and work together in the same way that humans can? **Dr Hao Zhang** from the **University of Massachusetts Amherst** in the US is exploring how robot teams can become more resilient, intelligent and cooperative by learning from human teamwork.

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Field of research
Robotics

Research project
Autonomous Group Introspective Learning and coopEtition (AGILE) for Cross-Capability Multi-Robot Adaptation

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PROFILE

Talk like a ...
roboticist

Coopetition — engaging in both cooperation and competition to improve performance and outcomes

Cross-capability multi-robot adaptation — the ability of a group of robots with different skills and specialisations to work together, solve problems and adapt to new situations

Fault tolerance — a system's ability to continue operating effectively when some of its parts fail

Introspection — the ability to observe and examine one's own thought processes and motivations

Lifelong autonomy — the ability of a robot to continually adapt and learn throughout its lifetime, without input from humans

Robots provide many services for us, from delivering packages to exploring other planets; however, many tasks are too complex for a single robot to handle alone. Teams of robots, especially those with complementary abilities, could tackle much bigger and more difficult challenges in a range of situations and environments.

For example, in the aftermath of a natural disaster, such as an earthquake or a tsunami, teams of robots could search areas that are too dangerous for humans to enter. "Drones can scout an area from above, ground robots can navigate through debris or rough terrain, and specialised robots can manipulate objects or access confined spaces," explains Dr Hao Zhang from the University of Massachusetts Amherst. "Robot teams can offer efficient, robust and adaptive solutions to societal challenges, not just in disaster response but also in space exploration, agriculture, manufacturing and infrastructure inspection."

Lifelong autonomy

For robot teams to be truly useful in the real world, they need to be made up of robots that can learn from experience, adapt to new situations and improve their performance over time without human input – a concept known as lifelong autonomy. "This is essential for long-term deployment outside of controlled settings, enabling robots to handle unforeseen situations, recover from failures, and evolve alongside changing tasks and teammates," explains Hao.

Developing lifelong autonomy is difficult and involves creating robots that can accurately perceive the world

Robots housed in Hao's research laboratory.

around them, reflect on and assess their own performance, and continually learn and adapt to new situations. Robots must have these abilities of perception, introspection and adaptation if they are to work effectively as part of a team.

Assembling a team

For robot teams to succeed, they must coordinate a range of different abilities, communicate effectively and make joint decisions – all while avoiding errors and working safely. The robots must adapt to the evolving behaviour of their teammates in real-world environments where conditions can change quickly and robots can malfunction. This level of problem solving and improvisation is difficult enough to achieve in single robots, let alone teams of robots with a range of skills and capabilities.

To develop successful robot teams, Hao is drawing on key insights from social psychology and human teamwork. "Humans are the most adaptable species on Earth," says Hao. "Collective intelligence, emerging from collaboration, shared effort and internal competition, allows human teams to adapt swiftly to unexpected changes in their environment or composition." Whether in sports teams, multi-national companies or academic research groups, functional heterogeneity – the useful range of skills and abilities within a team – enables people to tackle complex tasks effectively.

In contrast, robot teams lack this level of adaptability. "One project that we are working on, called Autonomous Group Introspective Learning and coopEtition (AGILE) for Cross-Capability Multi-Robot

> ***"Robot teams can offer efficient, robust and adaptive solutions to societal challenges."***

Adaptation, aims to enable diverse robot teams to respond effectively to novel situations and complex failures," says Hao.

Group introspection

One of the key goals of AGILE is to help robots reflect on how well they are working together as a team. "Autonomous group introspection refers to the ability of a team of robots to collectively monitor, analyse and understand their own behaviors, roles and performances without human intervention," explains Hao.

By sharing what they see, what they are doing and how their tasks are progressing, robots can collectively figure out if something is not working, adjust their roles and come up with new plans. For example, if one robot malfunctions, group introspection would allow the team to replace the broken robot with another teammate that has similar capabilities. This kind of shared awareness enables resilient, flexible and efficient teamwork, allowing robot teams to work together effectively on complex tasks in the real world.

Coopetition

As strange as it may seem, a healthy level of competition within a team can improve teamwork. "Cooperative competition – or coopetition – allows robots to collaborate toward a shared goal while simultaneously competing to pursue individual objectives and optimise their own performance," explains Hao. Cooperation allows the team to tackle objectives that are too complex for individual robots to solve by themselves, while competition encourages each robot to continually improve their performance. "This balance allows the robot team to efficiently allocate tasks to individual team members when solving complex problems, enhances its resilience to individual failures and improves its adaptability in evolving environments," continues Hao.

Looking to the future

Currently, AGILE focuses on developing teams of robots that can collectively make decisions and coordinate their actions effectively. But the project's next steps aim even higher. Hao hopes to develop collaborative perception, enabling robots to use their own sensors to monitor the health and abilities of their teammates in real time. The AGILE project will also explore human-robot teaming, allowing people and robots to work together safely by combining their unique strengths. "If successful, AGILE will mark a critical step toward building resilient robot teams capable of near human-level adaptability, transforming multi-robot applications through greater fault tolerance, agility and adaptability," says Hao.

About *robotics*

"Robotics is an exciting field at the intersection of engineering, computer science and artificial intelligence (AI), with the potential to transform nearly every aspect of society," says Hao. "It is a field where cutting-edge innovation directly shapes real-world impact." As robots become more intelligent and autonomous, the next generation of roboticists and engineers will play a crucial role in shaping how they are developed and used. Career opportunities in robotics range from designing robotic hardware and developing AI software to working in research labs, startups, industry or government.

However, robotics is not without its challenges. "One of the most challenging aspects of robotics is mastering its interdisciplinary nature," says Hao. "Another major challenge lies in handling the complexity and unpredictability of real-world environments." The real world is full of obstacles, noise and changing conditions, and is far more complex than controlled lab environments or computer simulations. "Overcoming these challenges requires deep expertise in a core discipline, such as AI for robot adaptation, alongside the ability to synthesise knowledge across fields and build integrated systems through interdisciplinary collaboration," explains Hao.

To support the next generation of roboticists, Hao leads the Program for Robotics Outreach on Gender and Racial Equity in School and Society (**PROGRESS**) which is dedicated to promoting robotics among young and underrepresented aspiring roboticists. "PROGRESS offers a variety of engaging educational activities designed to spark interest in robotics and STEM across many age groups," says Hao. "Key components include hands-on introductory robotics workshops, lab tours and live demonstrations, mentorship for school robotics teams, and school outreach events." PROGRESS also supports teachers with training and resources to bring robotics into the classroom. By making the field more inclusive and accessible, Hao and the PROGRESS team are helping to ensure that the future of robotics reflects diverse perspectives and talents.

Pathway from school to *robotics*

"To work in robotics, you need to to build a strong foundation in mathematics, physics and computer science at school," says Hao. "At the college and university level, pursue courses in programming, AI, control systems, mechanical and electrical engineering, or robotics."

Experiences such as internships, robotics clubs or summer programmes can provide valuable hands-on skills and insight into real-world robotics applications.

The Robotics Education & Competition Foundation (**recf.org**) offers student-focused events like the VEX Robotics Competitions and VEX IQ Challenge, where teams design, build and program robots to compete in themed challenges.

Explore careers in *robotics*

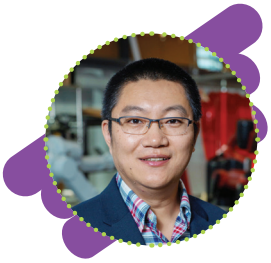
"Roles in this field include robotics engineers, AI specialists, mechanical engineers and human-robot interaction designers, with opportunities in industries such as manufacturing, logistics, healthcare, space and research," says Hao.

The IEEE Robotics and Automation Society (**ieee-ras.org**) provides insights into the latest research, publications and professional development opportunities in robotics.

NASA's Robotics Alliance Project (**robotics.nasa.gov**) shares educational programmes, competitions and internship opportunities for aspiring roboticists.

The Robot Report (**therobotreport.com**) is a leading source of news, trends and analysis about the robotics industry, ideal for keeping up to date with the latest advances and career opportunities.

A mentor's moment: Hao guiding his PhD student.



Meet *Hao*

I have been a huge fan of robots since I was a young child, inspired by comics and TV shows like *Transformers, Knight Rider, Gundam* and many others. I was captivated by the imagination and futuristic technology they portrayed, and as I grew older, I became fascinated by the deeper questions about humanity that these stories explored. This passion has been a driving force behind my decision to pursue a career in robotics.

I love that my job gives me the opportunity to help shape the future of robotics in ways that positively impact society. I also find it incredibly rewarding to work with students; they bring fresh perspectives, creativity and energy that constantly inspire me and help me stay curious and open-minded.

Strong motivation, curiosity, persistence and being a team player have enabled me to lead a successful career as a roboticist. I have a deep, long-standing passion for robotics that continues to drive me forward. Curiosity fuels my desire to explore new ideas, learn continuously and stay at the forefront of a rapidly evolving field. Persistence has helped me navigate the inevitable challenges and setbacks that come with complex research and development. And being a team player has been crucial, as robotics is inherently interdisciplinary and collaborative.

I like to unwind by spending time outdoors. I'm a big fan of skiing in the winter. In the summer, I enjoy tennis, biking and short hikes. These activities help me reset both physically and mentally, and they give me the energy and clarity to stay focused when I return to work.

Hao's *top tips*

1. Stay motivated and curious, and don't be afraid to learn from others, or from your own trial and error.

2. Growth in robotics often comes from persistence and a willingness to explore the unknown.

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Robotics

with Dr Hao Zhang

Talking *points*

Knowledge

1. What are some real-world situations where teams of robots are currently being used or could be used in the future?
2. What is collective intelligence?

Comprehension

3. Why might one robot not be enough to complete complex tasks in real-world environments?
4. What does the term 'lifelong autonomy' mean, and why is it essential for robots working in unpredictable situations?

Application

5. How could a team of robots use their different abilities to respond to a natural disaster such as an earthquake?
6. How might robot teams benefit from applying teamwork strategies used by humans?

Analysis

7. What types of challenges do robot teams face in unpredictable or changing environments?
8. How are 'autonomous group introspection' and 'coopetition' similar, and how do they differ in helping robot teams function better?

Evaluation

9. How might relying on robot teams in high-stakes situations (e.g., disaster response) affect human responsibility and ethical decision-making? What might the consequences be if a robot team makes a wrong decision, and who should be held accountable?
10. If robot teams become highly autonomous and adaptable, what skills might humans need to work alongside them in the future? What new roles do you think humans might play in industries where robot teams are common?

Activity

Hao and his team are developing robot teams that can think, learn and adapt – much like human teams do. Through the Autonomous Group Introspective Learning and coopEtition (AGILE) for Cross-Capability Multi-Robot Adaptation project, they are teaching robots how to reflect on their own performance, work together and even compete in healthy ways to solve complex problems.

- Choose a real-world problem where robot teamwork would be useful (e.g., rescuing people after an earthquake, repairing a damaged space station, exploring the deep ocean, inspecting dangerous infrastructure, such as bridges and power plants, farming in hard-to-reach terrain, etc.)

- Devise a team of three different robots, each with a unique ability. For each robot, answer the following:
  - What is the robot's special ability (e.g., flying, scanning, lifting, navigating rough terrain, etc.)?
  - What is its specific role in solving the problem?
  - How will it work together with the other robots?

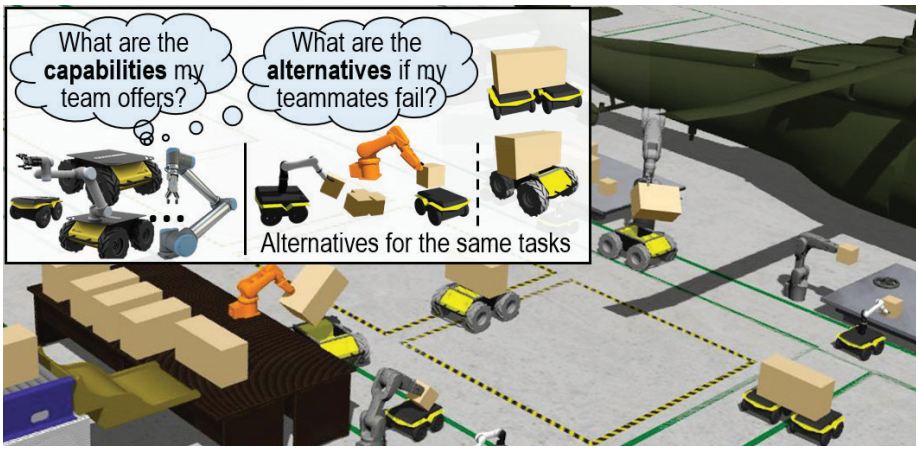
- Imagine your robot team is halfway through its mission when something goes wrong (e.g., one robot breaks down, the environment changes or the task becomes more difficult). Answer the following questions:
  - How will the team adapt using introspection (monitoring and adjusting their own behaviour)?
  - How might coopetition (working together while also optimising individual performance) help the team reassign tasks or solve problems more efficiently?
  - How does your team's collective intelligence help it overcome these challenges?

Reflection questions

- How did you decide what roles or abilities your robots should have?
- What was the most challenging part of designing a robot team?
- How did your robots demonstrate teamwork?
- Which human skills or behaviours do you think are hardest for robots to replicate?
- What risks or concerns could arise from relying on robot teams in critical situations?
- How might designing robot teams like this help solve real-world problems in the future?

More *resources*

- Explore the Human-Centered Robotics Laboratory's YouTube channel to see their robots in action: **youtube.com/@human-centeredroboticslab1553**
- Try out Robocode, a programming game where the aim is to develop a robot tank to battle against other tanks: **robocode.sourceforge.io**
- Explore the links on this list of helpful and informative resources for budding roboticists: **github.com/RoseCityRobotics/robotics-resources**



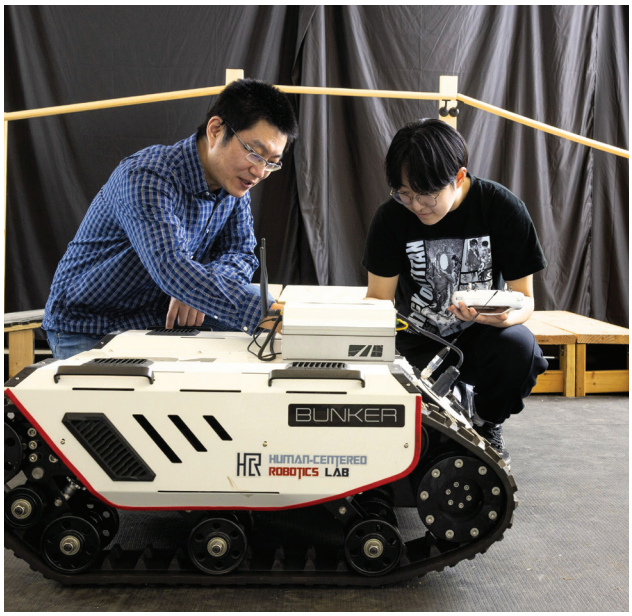


Photo *montage*

Top: *A moment of contact between Hao and the team's robotic dog.*

Middle row: ***Left:*** *AGILE enhances adaptability in robotic teams.*

Right: *A human and robot team on a subterranean mission.*

Bottom: *A mentor's moment: Hao guiding his PhD student.*

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