Co-X Panel Discussion

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ABSTRACT
Robots as co-protectors, co-inhabitants, co-workers, co-integrants, or more generically, "Co-X" will improve effectiveness, efficiency, safety, security, and improve quality of life in the coming years. In-keeping with the theme of PerMIS'10, which investigated the role of performance assessment in evaluating intelligent systems that co-exist with humans, a panel discussion was held focusing on the Co-X vision. This document synthesizes the discussions held during this session

Keywords
Co-X, Performance Metrics, Standards, Human-Robot Collaboration

1. INTRODUCTION
Robots that work safely in collaboration with and close proximity to humans, complementing and augmenting their abilities may usher in new benefits economically and societally. Robots as co-protectors, co-inhabitants, co-workers, co-integrants, or more generically, "Co-X" will improve effectiveness, efficiency, safety, security, and improve quality of life in the coming years. This year's theme for PerMIS was investigating the key role of performance assessment in developing intelligent systems that can **co-exist** with humans towards improving the quality of our lives intertwined with automation. In-keeping with the theme, a panel discussion was held focusing on the Co-X vision. This document synthesizes the discussions held during this session.

A mix of panelists representing various domains and application perspectives were invited:

- Greg Dudek, McGill University
- Ken Goldberg University of California – Berkeley
- Helen Greiner, CyPhy Works
- Howard Harary, National Institute of Standards and Technology
- Susan Hill, Army Research Laboratory
- Paul Oh, Drexel University
- Holly Yanco, University of Massachusetts – Lowell

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The PerMIS'10 panel members were given the following charge: Considering the Co-X vision, discuss the implications for research and development as well as strategies for realizing this vision.

Panelists were asked to consider questions along the following lines:

- How to achieve this Co-X vision: do you believe that there are cross-cutting common technologies underlying co-X systems that serve the diverse application domains? In other words, are there basic competences that should be the focus of initial efforts prior to adding the domain-specific capabilities?
- What are desired qualities of a Co-X system?
- What are the underlying infratechnologies (building blocks, standards, metrics, development tools)?
- What are strategies to advance this vision?
    - Examples may include open innovation platforms, and/or competitions, ...

What role could/should performance metrics, performance evaluations, and standards play in advancing a Co-X vision?

2. THE CO-X VISION
Elena Messina began the discussion with an overview of the Co-X concept. Robots that are able to work side-by-side with humans will spur a growth in the robotics field. New applications and domains will be made possible, leading to robots becoming more mainstream and commonplace. Co-X robots can enable humans to transcend their limitations. They complement human abilities and also augment their capabilities. Humans and Co-X robots should be able to interact in a natural fashion, meaning forms of verbal speech and gestures should be understood by the robots.

An initial list of domains of participation for Co-X includes manufacturing and logistics, medical and healthcare, defense and security, housekeeping, mining, agriculture, and transportation. Myriad other possibilities exist, such as space exploration.

Co-X robots will work in close proximity with humans and may physically interact with humans. Therefore, safety concerns are paramount. Other cross-cutting concerns are cost and societal acceptance.

Examples of capabilities that Co-X robots require are:

- Direct Human-Robot Communication
    - Natural language, gestural, neural
    - Rich Semantic Understanding
- Robust functioning in complex, unstructured, dynamic environments

- Variable Levels of Autonomy
- Learning and Adaptation
    - In situ learning for communication, behavior, preferences
- Dexterous manipulation: Human-like and beyond
- Mobility: Human-like and beyond
- Strength, accuracy, rapidity of response/execution

These capabilities are made possible by underlying infrastructural technologies, as enumerated in the CCC Robotics Roadmap [1]. Examples are perception, autonomous navigation, novel mechanisms and actuators, human-like dexterous manipulation, intuitive and safe interfaces, and skill acquisition. The Co-X vision is indeed consonant with the CCC roadmap Synthesis, as illustrated in Figure 1.

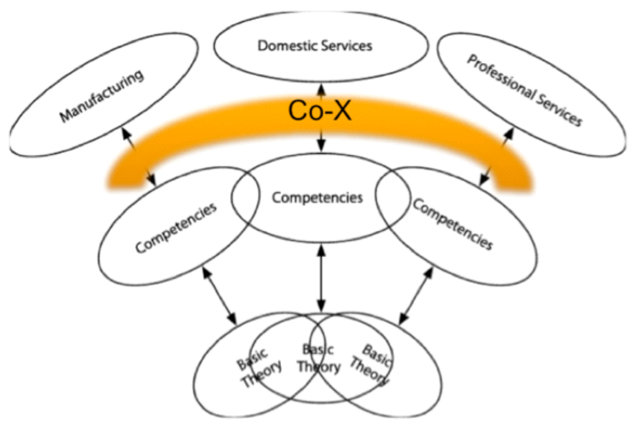

Figure 1. Co-X Cross-cutting capabilities underlie all the application domains for the next generation robotics. Figure adapted from the Robotics Roadmap [1]. The attributes of Co-X are pre-requisites for success in the intended application domains (manufacturing, domestic, professional).

3. Summary of the Panel Discussion

The discussion with the panelists was wide-ranging, with active audience participation as well. General themes emerged from the panel. They included contextual issues (general technological and societal trends), key technologies for enabling Co-X, and strategies for stimulating progress towards Co-X.

3.1 Contextual Issues

Technology is changing quickly, which influences the mindset of young persons. A panelist spoke of the gap between the class of 198X (the Megabyte generation) and 2015+ (the Terabyte generation). Certainly, advances in computational power, as well as sensors and mechanisms, enable much more complex algorithms and capabilities for robots. The pace of technological advancement is accelerating as well, implying that we will attain the minimum raw computation power (and storage capacity) in the next few decades for implementing general-purpose robots. Correspondingly, there has been an erosion of boundaries in the information age. For instance, the distinction between products and services is blurred in cell phones. Social media has eroded the boundary between producers of content and users, and companies like Amazon[1] straddle information technology media, communications, and consumer electronics. It is hard to predict now how Co-X robots will be applied once they become a reality.

3.2 Competencies and Technologies that Underlie Co-X

One panelist suggested that we should ask for a toolbox of fundamental competencies that can be used for Co-X development. Simultaneous localization and mapping (SLAM) is an example of a fundamental competence that would be part of the toolbox. It was suggested by an audience member that the competencies that robots should have be complementary to human competencies. Perception is an example where humans have certain strengths (e.g., able to understand very complex scenes with our eyes) and weaknesses (e.g., our eyes only work within certain parts of the spectrum and have limited range/resolution).

The need for humans and robots to operate as a team was a recurring theme from the panelists, not surprising when talking about Co-X. Many roboticists have not considered the human in the loop when designing their robots; this needs to change. A seamless interaction between the human and the robot in real-world environments is desired. This interaction necessitates that robots have adjustable levels of autonomy and very flexible means of communicating with humans. The robot must know when the human needs assistance and when it needs to ask the human for help.

Handing off control between the human and robot is a particularly thorny aspect of interaction. For instance, if the robot has a failure and the human has to pick up where it left off, how does the robot convey information about itself, the environment, and the status of its assigned task? In general, successful communication will require the robot to know what to tell the human as well as when it's appropriate to tell the human – in other words the system has to have to have competent articulation capabilities in this regard.

The robot should provide feedback confirmation when it receives instructions from a human. Gestures are a natural means of communicating (and may be essential in certain domains, such as noisy factory floors or during military operations where silence may be critical). Voice recognition and natural language understanding are technologies that are being developed for non-robotics domains and could be leveraged for Co-X.

3.3 Strategies for Advancing the State-of-the-art to Achieve Co-X

The panel suggested various strategies for accelerating the pace of progress. A strong roadmap was suggested as a necessary tool to provide guidance to the community. The semiconductor industry created a roadmap [2] that took many years to develop, with input from many, and which is updated on a regular basis. This has served them very well as they have made steady progress towards achieving the technical goals.[2] The Robotics Roadmap is a great start, but greater detail is needed.

[1] Certain commercial companies, products and software are identified in this paper in order to explain our research. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the companies, products and software identified are necessarily the best available for the purpose.

[2] "'What technical capabilities need to be developed for the industry to stay on Moore's Law and the other trends?' The ITRS assesses the principal technology needs to guide the shared

Necessary prerequisites include benchmarks and standards. One panelist framed it as physics envy. It must be very clear what is being measured. This will allow for comparing different solutions against one another.

Another strategy suggested was coming up with challenges we want to take on as a community. We could circulate ideas through a white paper and get feedback from the various stakeholders. Challenges should have verifiable, measurable goals that we agree to as a community. Some asked whether the challenge approach was a good mechanism for aiming the research and moving it ahead; in fact, there has been good progress in the past decade without these challenges. Others noted that the goals should challenges (and their goals) must be carefully chosen since failing to achieve a goal can have negative consequences. Also, a clear winner can give the false impression that the problem is solved and that no more investments should be made in an area. Therefore the challenges should have a high bar, but also include achievable goals – both short and long term. Often there is excellent research that does not make the transition into products. The panel discussed how to bridge this gap. Having industry set the challenges was one possibility.

The idea of robotics challenges is not new, of course. Many are aware of the Defense Advanced Research Projects Agency (DARPA) Grand Challenges that featured autonomous vehicles navigating multi-terrain courses (2004 and 2005) as well as within an urban, multi-vehicle environment (2007). One panel member called attention to the fact that, in 1997 Ken Goldberg, along with Howard Moraff, organized a panel discussion as part of the IEEE International Conference on Robotics and Automation on "Grand Challenges in Robotics." Attributes of a Grand Challenge were listed as

- broad scope or large scale
- requires many teams and many efforts
- high risk
- high potential impact
- capture the imagination

The meta-challenges that will arise as a result of achieving the goal are still perfectly relevant today:

- acceptance by users
- human augmentation
- human-centered end-user technology
- zero-fault safety
- robust functionality
- performance matched to human intuition
- compelling applications

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research, showing the "targets" that need to be met. These targets are as much as possible quantified and expressed in tables, showing the evolution of key parameters over time. Accompanying text explains and clarifies the numbers contained in the tables where appropriate." [2] The following are a few examples of technology areas for which target values are defined for up to 15 years into the future: System Drivers Design Test and Test Equipment Process Integration, Devices, and Structures Emerging Research Devices and Lithography.

As a side note, another barrier to progress is the fact that robotics is at the mercy of so many technologies (e.g., batteries or other energy sources for robots are a limiting factor).

3.4 What is the Nature of Robotics Research?

The panel finished with a discussion of the nature of robotics research.

- Are roboticists bench scientists or applied scientists?
- Is the university the best place to address the end goals of Co-X?
- Or should academics focus on fundamental science?
- Is robotics theory or science?

The role of the "citizen scientist" was also debated. The sensor that was the game-changer for the DARPA Urban Challenge was developed by a couple of brothers who run a stereo speaker company. Thousands of smart phone applications are developed by citizens. There was no consensus on the role that citizen scientists can play in advancing the state of robotics. The sensor developers closed the gap between good fundamental research and moved it to commercialization. They did not perform the fundamental research.

4. CONCLUSIONS

Although there was not one hundred percent agreement, the panel generally espoused the need for fundamental competences to be developed, along with benchmarks and measures (standards) that are arrived at by the community. Having grand challenge problems can not only stimulate progress and excitement but also motivate other contributions. Detailed, well-defined roadmaps have proven to help muster progress within a major industry and should be considered for robotics as well. Ultimately, all agreed that the Co-X vision was worth trying to achieve.

5. REFERENCES

[1] "A Roadmap for U.S. Robotics: From Internet to Robotics," CCC and CRA (NSF-funded), 2009, http://www.us-robotics.us/

[2] Semiconductor Industry Association, The International Technology Roadmap for Semiconductors, 2009 Edition. http://www.itrs.net/Links/2009ITRS/Home2009.htm