

Breaking Barriers Through Technology Webinar



26th February 2025

An African Perspective on Culturally Competent Social Robotics: Why DEI Matters in Human-Robot Interaction

David Vernon
Carnegie Mellon University Africa

www.vernon.eu



On the Impossibility of Speaking of Africa

Speech by the former President of the Federal Republic of Germany,
Horst Köhler

"I would like, if I may, to clear up one misunderstanding right away:
Horst Köhler is not an Africa expert

...

the more I learned about Africa, the more I realised how much
there was still to learn"

[Essential Reading for Non-Africans]



Federal Ministry
of Education
and Research



German-African Cooperation in Education and Research

BMBF Africa Days
16 – 18 March 2014

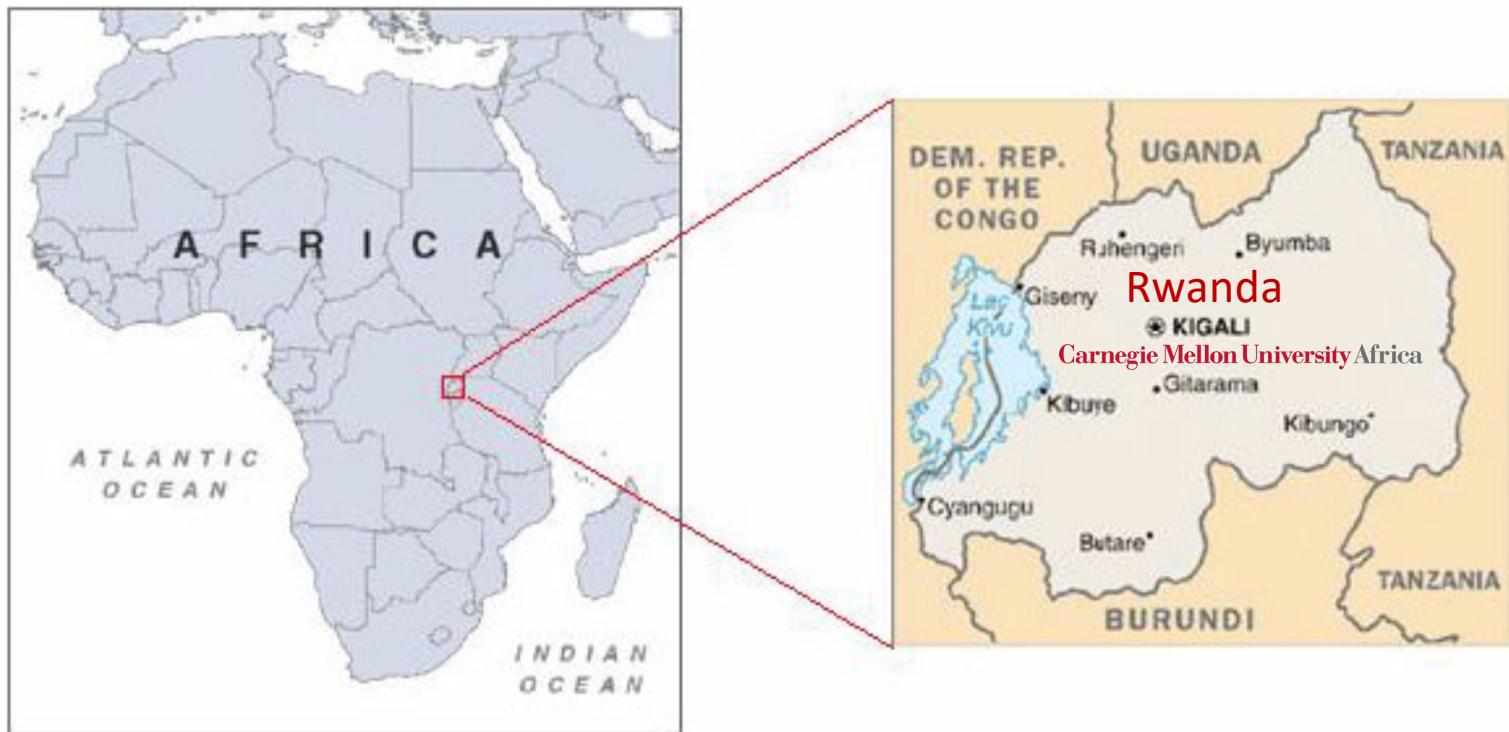


On the Impossibility of Speaking of Africa

David Vernon is not an Africa expert



www.africa.engineering.cmu.edu



RWANDA ELEVATION MAP

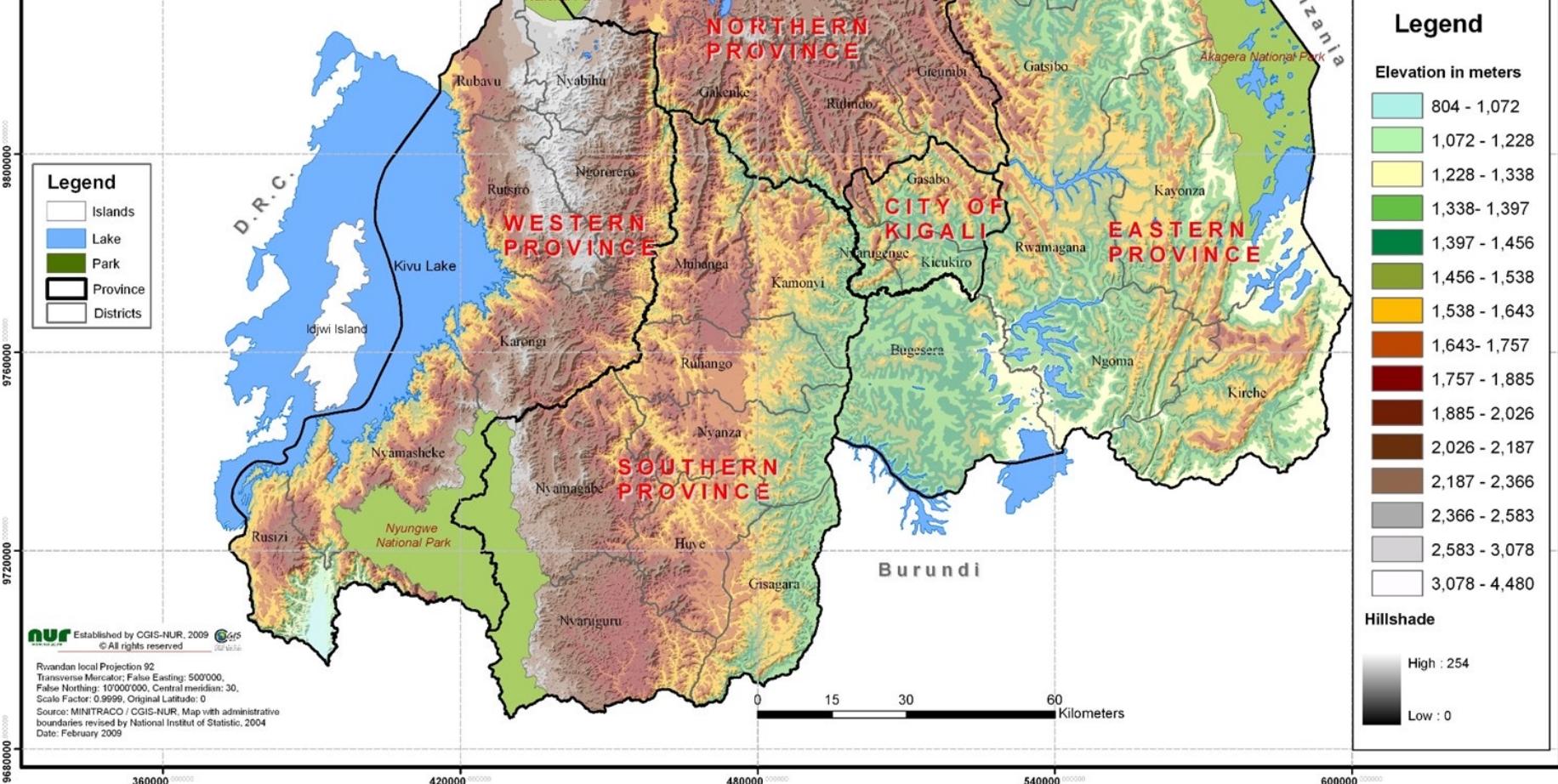






Photo credit: Tallis Woomert



Photo credit: Tallis Woomert



Photo credit: Tallis Woomert



ROAD

04 MAR 2022

Globe Riders: Africa gearing up for 2025 UCI Road World Championships in Rwanda

COOKIE SETTINGS





The Future of Work

Kigali, Rwanda

Africa is the youngest and fastest-growing continent in the world. By 2030, there will be 375 million young people in the job market in Africa. Within a few decades, this demographic boom will push Africa's workforce to more than a billion people, the largest in the world. There is a significant gap between the number of young people seeking work and the employment opportunities available to them. Young people will face challenges finding formal employment and a pathway out of poverty. The theme of this year's PARC is ***The Future of Work***. Students are challenged to create solutions for job creation and workforce innovation in Africa.

 Download PARC Letter of Notice (English & French)





PARC 2024 : Senegal

The Pan-African Robotics Competition (PARC) 2024, held from July 22 to 29 in Senegal, continued its tradition of being the largest robotics competition in Africa.

This year's theme, "The Future is Now," challenged participants to develop technological innovations propel the African continent into 5th Industrial revolution. The Competition attracted 94 teams from 25 African countries. 33 of these talented teams came to Senegal for the final rounds from July 22 to July 29.

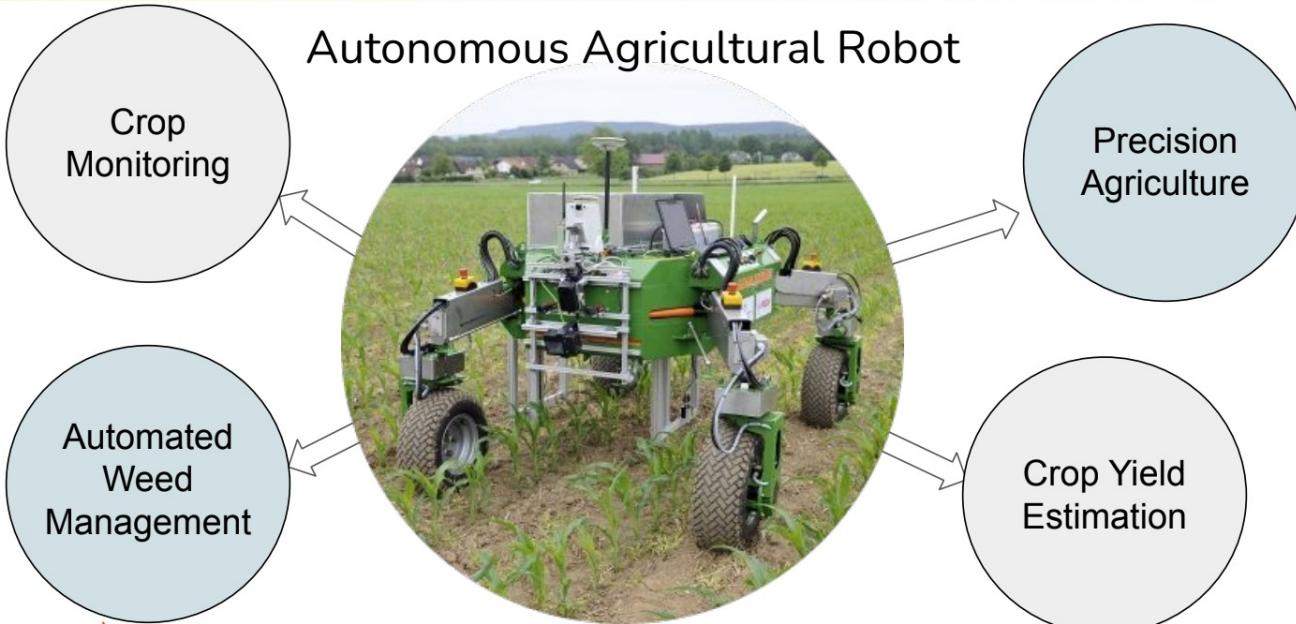


It's more than a Robotics Competition IT'S LIFE CHANGING

Dear Mr. Sidy, it is my pleasure to meet you again a few years after participating in the Robotics Camp. Three years later, I am pursuing my studies in Electrical Engineering at École Polytechnique de Montréal, and I must admit that my participation in this camp is one of the factors that pushed me in the field of engineering.” – PARC Participant

[Read PARC 2024 Activity Report](#)

Challenge Description



2024 Engineers League

| Virtual Kick-Off Meeting

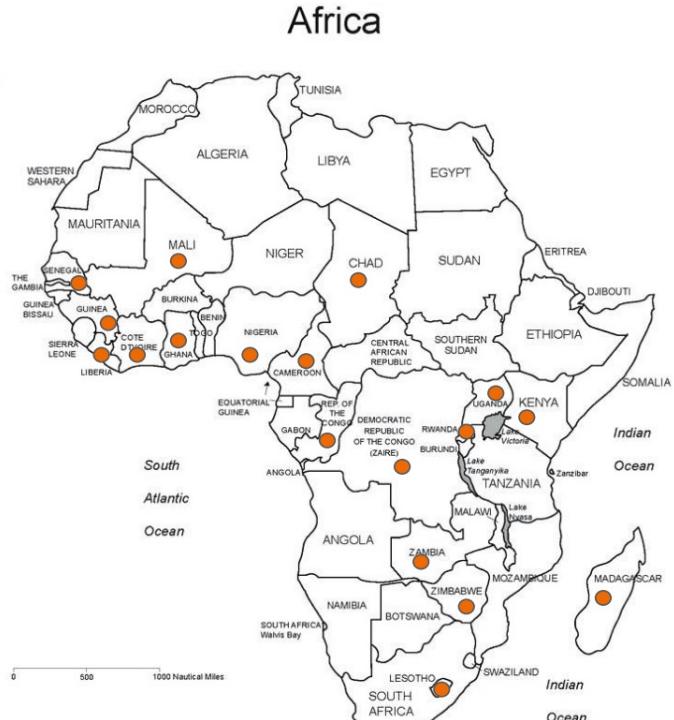
**ROS
Gazebo
OpenCV
Python
Matlab**

Meet the 2024 Teams!

- 38+ teams
- 18+ participating Countries



2024 Engineers League





Benin
Cameroon
Egypt
Ethiopia
India
Kenya
Nigeria
Rwanda
South Africa
Tanzania
Togo
USA
Zambia
Zimbabwe



66 Registered Teams

201 Participants



**IRCAD AFRICA: THE AFRICAN CENTER OF
EXCELLENCE IN MINIMALLY INVASIVE SURGERY**



**IRCAD
(Research Institute against
Digestive Cancer)**

"IRCAD (Institut de Recherche contre les Cancers de l'Appareil Digestif - Research Institute against Digestive Cancer) was founded in 1994 in Strasbourg, France by Prof. Jacques Marescaux a surgeon fascinated by technology."

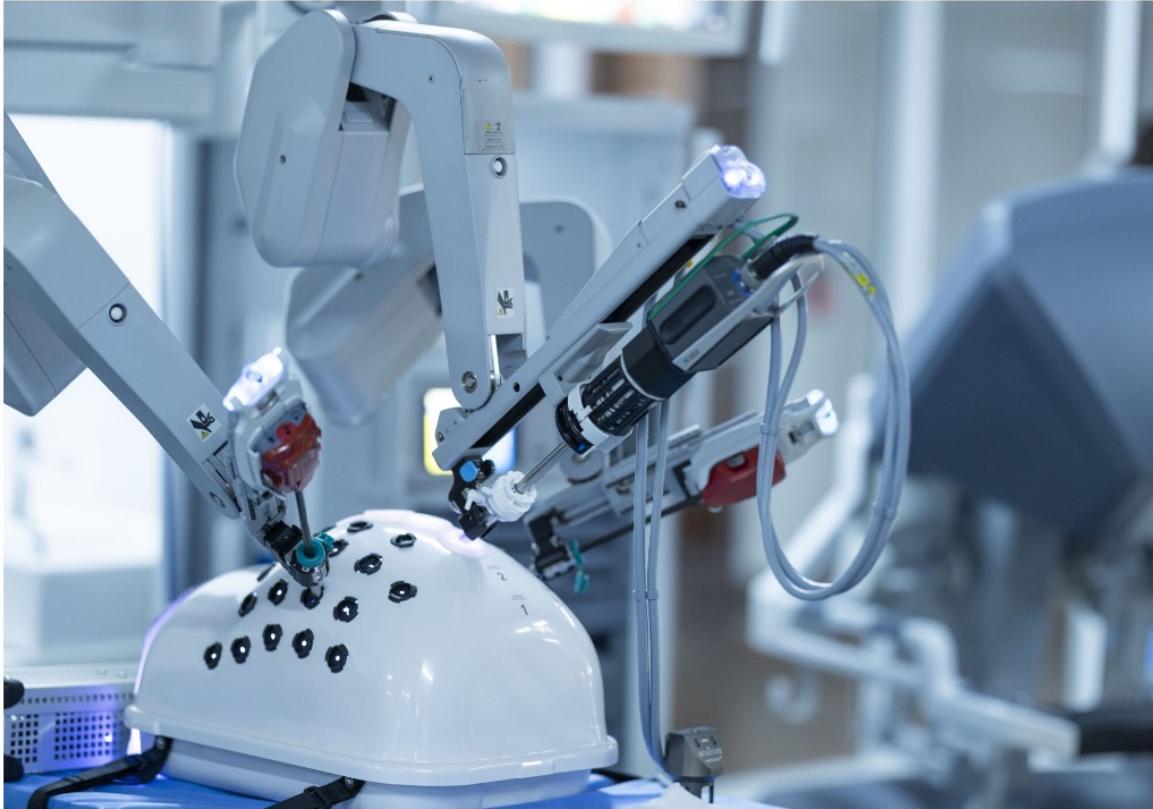
IRCAD-There is no better way to learn





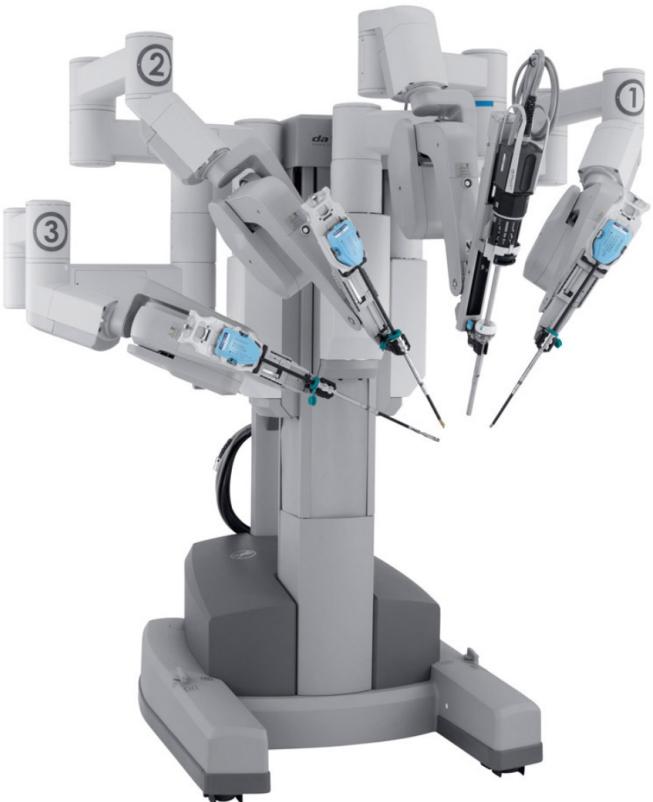
@ircad.africa

[www.ircad.africa](http://www ircad.africa)



EXPERIMENTAL OPERATING ROOMS

16 laparoscopic operating tables



Da Vinci

The da Vinci is a surgical robot designed for minimally invasive procedures. It has four arms equipped with surgical instruments and cameras that a physician controls remotely from a console.

CREATOR

Intuitive Surgical 

COUNTRY

United States 

YEAR

1999

TYPE

Medical

Source: <https://robots.ieee.org/robots/davinci/>

THE DA VINCI SURGICAL SYSTEM



Patient Side Manipulators: robotic arms teleoperated by the Master Tool Manipulators, they mount the surgical tools.

Endoscopic Camera Manipulator: robotic arm that is also teleoperated by the Master Tool Manipulators, it holds the endoscope.



An Ubtech CRUZR service robot deployed by ZoraBots Africa Ltd. to check the temperature of travelers arriving at Kigali International Airport, Rwanda.





About Practice Areas Services + Capabilities Centers Impact Experts Emerging Issues COVID-19 Research + Response

IMPACT

Using Satellite Images and Artificial Intelligence to Improve Agricultural Resilience

<https://www.rti.org/impact/using-satellite-images-and-artificial-intelligence-improve-agricultural-resilience>

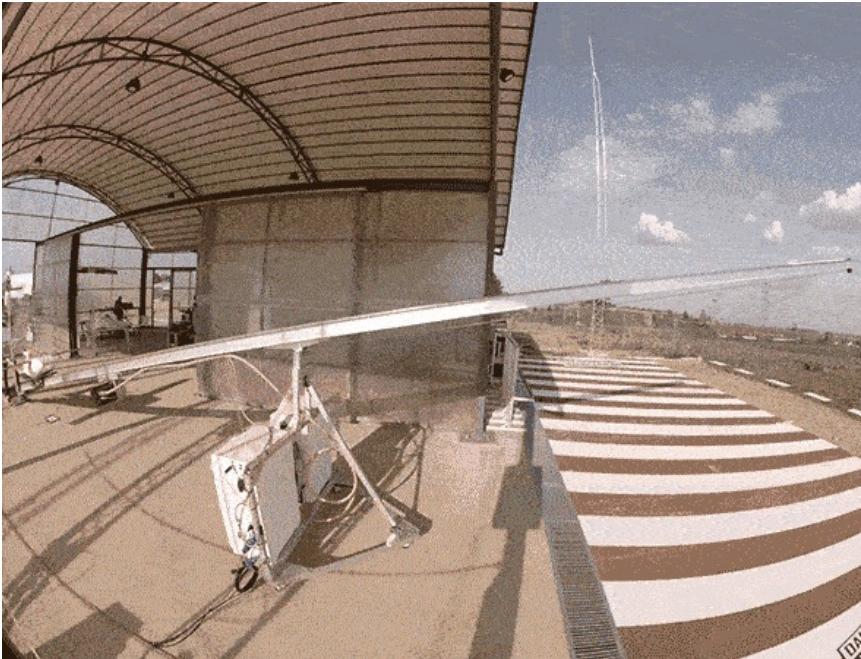
In the Air With Zipline's Medical Delivery Drones

Commercial operations in Rwanda prove the company can deliver emergency blood packs in minutes, rather than hours

By Evan Ackerman and Michael Koziol

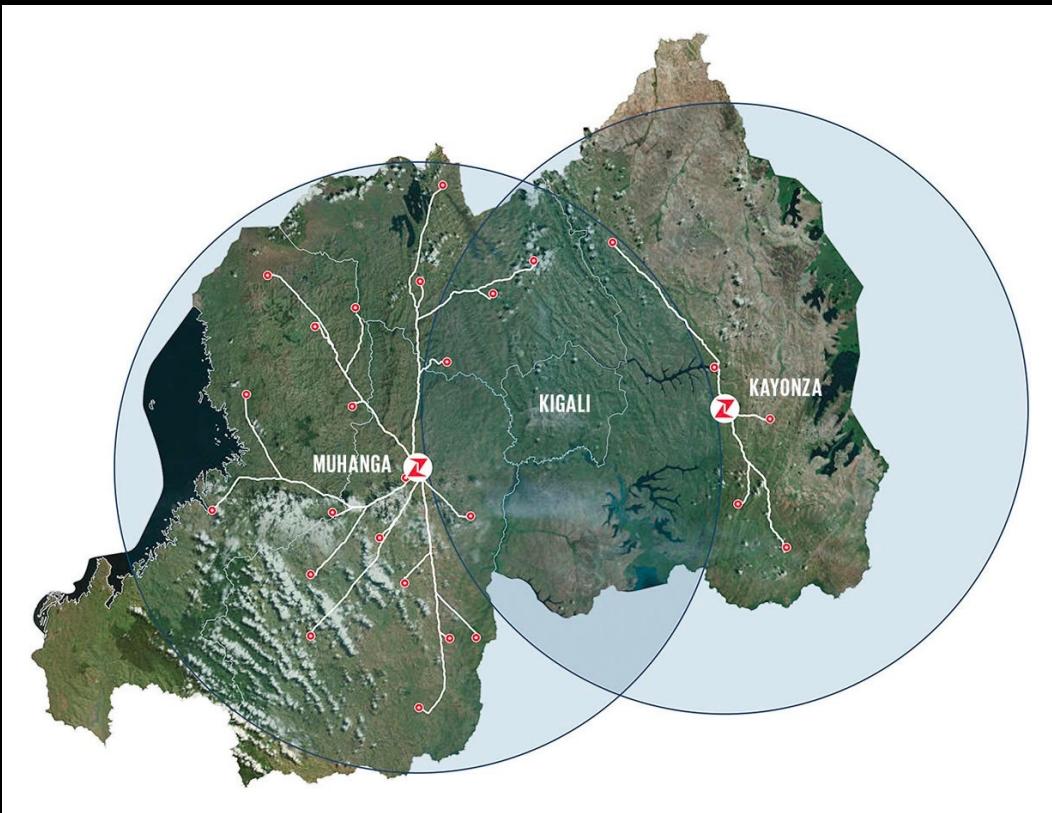
TECH EXPEDITION

East Africa's Big Bet On Drones



Gif: IEEE Spectrum

Zipline Medical Delivery Drones

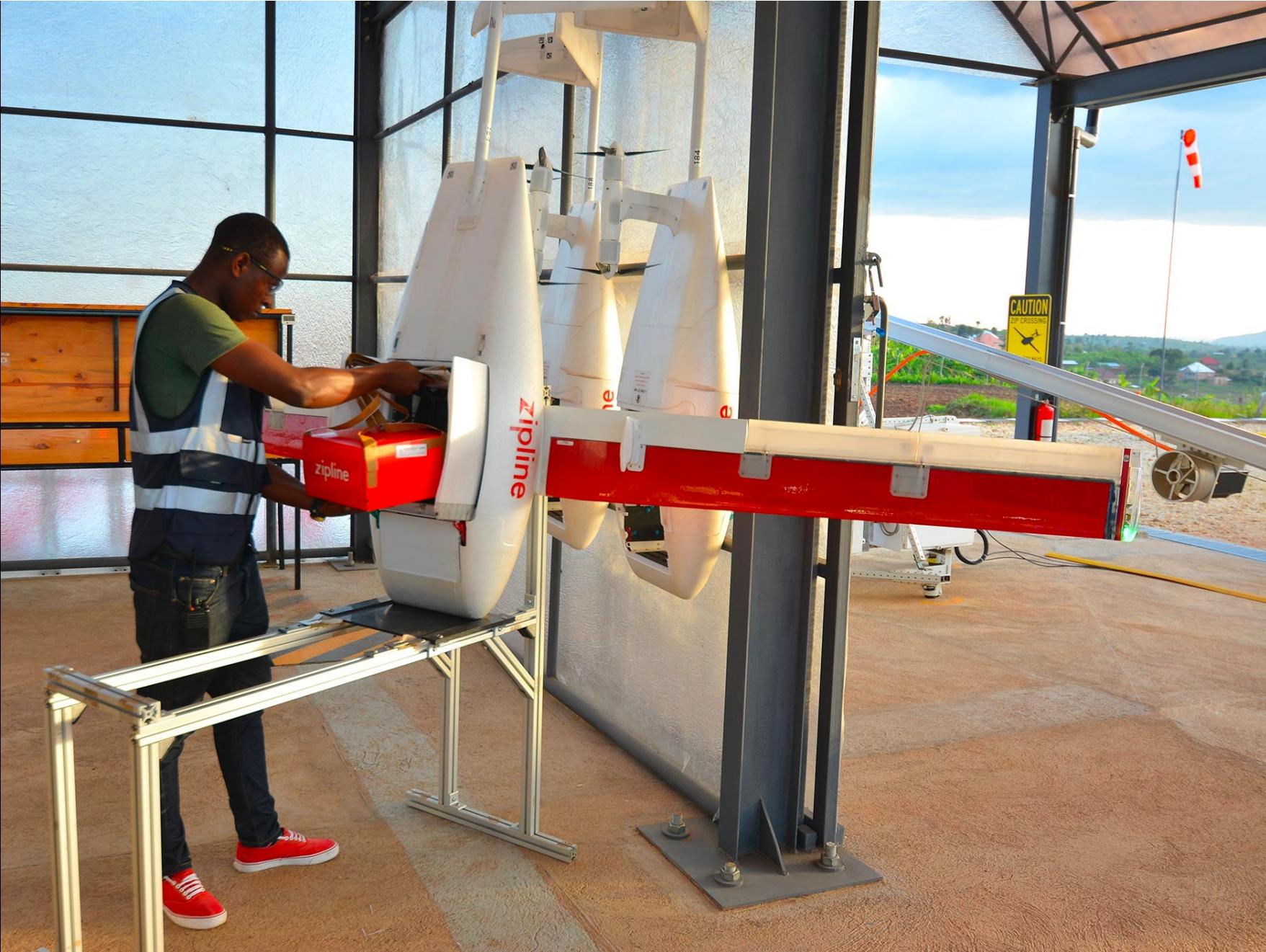


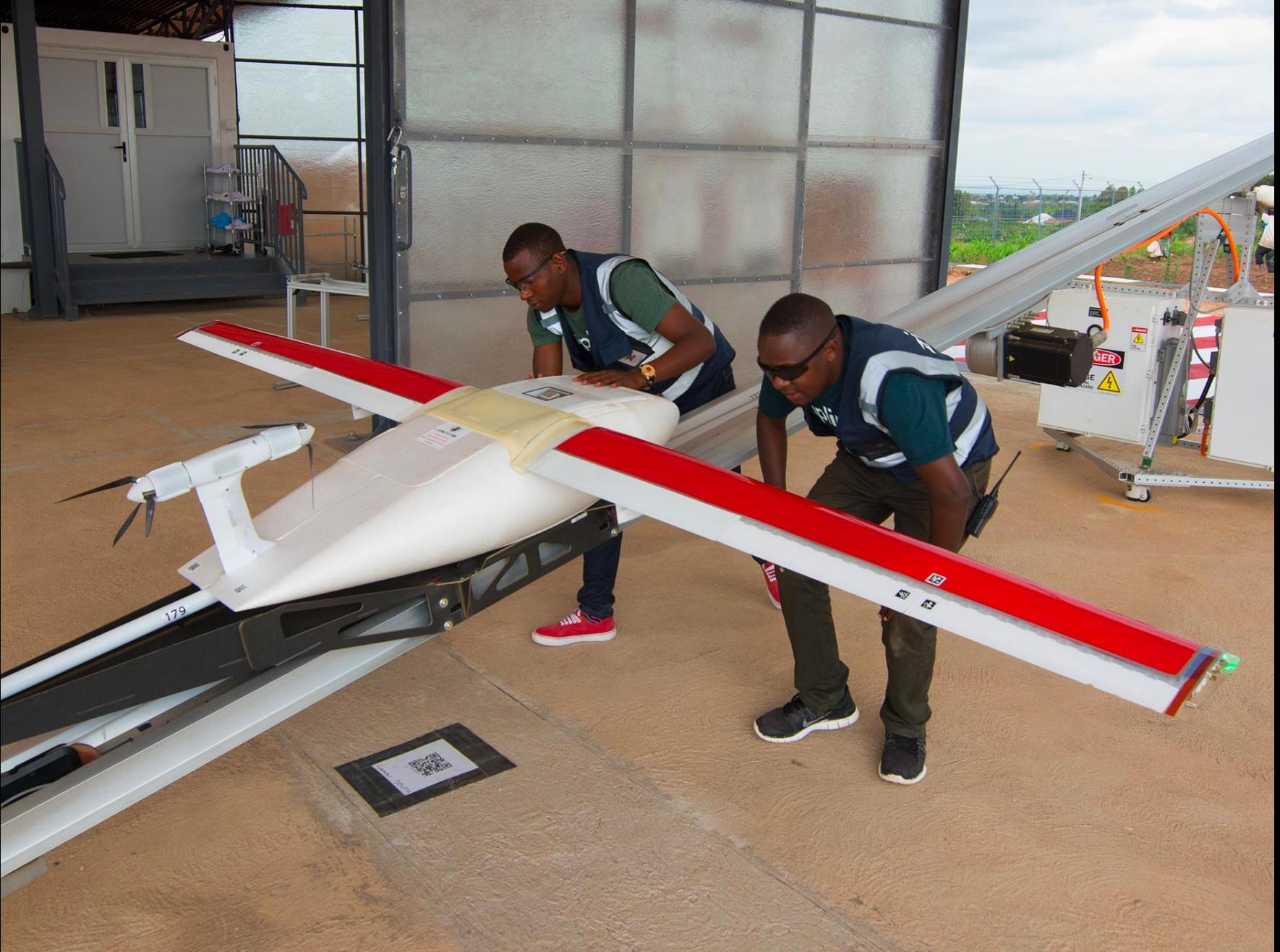
<https://spectrum.ieee.org/robotics/drones/in-the-air-with-ziplines-medical-delivery-drones>























Keza Education Future Lab



Keza Education Future Lab (KEFL) is a social driven company that supports the achievement of MINEDUC and its affiliated institution REB in providing quality education by improving the use of science and technology among children. KEFL aims to build on successful foundations in the use of ICT for kids by introducing them to robotics and programming at an early age.

Get in touch

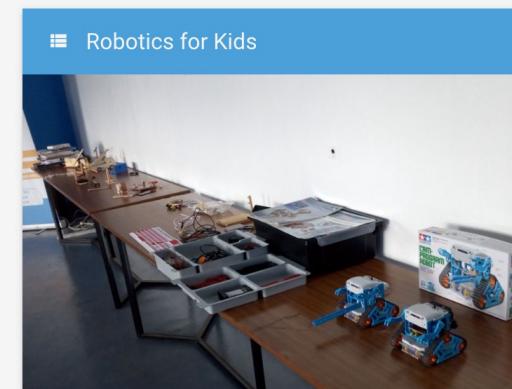
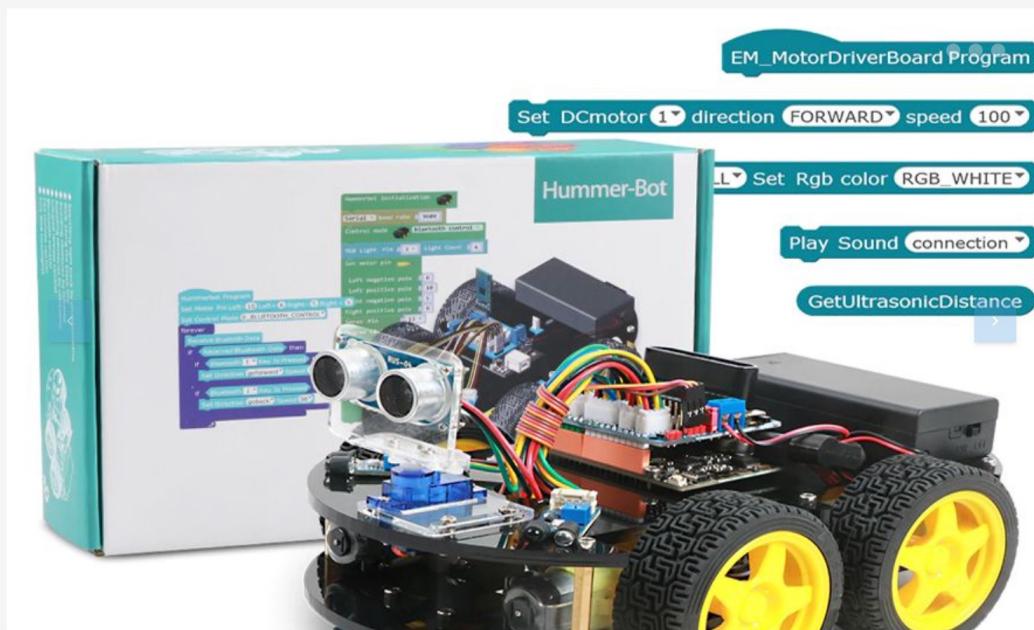
Tel: +250786701376
Email: Keza.info@gmail.com
Website: keza-education.rw
Office Adress: Bibare-Ingeri-St No 192
Kimironko, Gasabo,
Kigali City

Kids are engineers



Robotics

With our Robotics programs, your child will enjoy exciting projects that use 21st century skills.



Robotics for Kids

	Age group	7 - 13 Years old
	Language	English
	Level	Primary education

26 pilot schools involved in the Rwanda National Robotics Program 2024



https://www.instagram.com/rwandaict/p/C_5LPBiA-OF/?img_index=1
<https://en.igihe.com/news/article/robots-to-be-integrated-into-student-learning-programs>

26 pilot schools involved in the Rwanda National Robotics Program 2024



Ministry of ICT and Innovation | Rwanda ✅
@RwandaICT

...

This week, we celebrated a major milestone in the National Robotics Program! 🎉 We handed over 452 robotics kits to 26 piloting schools as part of the sandbox experiment. 33 trained teachers are ready to kick off this trimester, transforming how students learn. Big thanks to @Rwanda_Edu, @giz_rwanda, and our solution providers for their continued support in making this a success! 🤖📚 #STEM #Innovation #Education #Rwandan



11:35 AM · Sep 14, 2024 · 5,428 Views

<https://x.com/RwandaICT/status/1834888620534104561>

To find out more

Robotics and Artificial Intelligence in Africa

By David Vernon

Artificial intelligence (AI) provides many opportunities for social and economic empowerment in developing countries. However, when one thinks of Africa, robotics does not spring immediately to mind as the most relevant application of AI, considering that the continent typically has high unemployment and fast-growing populations. Nevertheless, some countries in Africa have embraced robotics on the basis that it has an important role to play in their economic development. In this article, we explore this role and the ways in which Africa can best exploit the opportunities afforded by intelligent automation and robotics. It also highlights strategies to offset the threats posed by global factors, such as premature deindustrialization.

The Growing Impact of AI in Africa

There is an increasing awareness of the positive impact that AI will have on developing countries, including sub-Saharan Africa, in sectors such as agriculture, health care, and public and financial services [1]. AI has the potential to drive economic growth, development, and democratization, thereby reducing poverty, increasing education, supporting health-care delivery, increasing food production, expanding the capacity of the existing road infrastructure by increasing traffic flows, improving public services, and bettering the

quality of life for people with disabilities [2]. AI can empower workers at all skill levels to be more competitive [3], [4]. Specifically, it can be used to augment and enhance human skills—not to replace or displace humans—and to do so at all levels, enabling average and low-skill workers to fit better in high-performance environments and take on more complex responsibilities.

Africa's biggest economic challenge is to equip large sections of its economy with average workers who are primed to perform tasks far better than most employees are currently managing to do. In South Africa, approximately 31% of employers cannot fill their vacancies [4]. AI will make technology easier to adopt and harness [1], [4]. In the health-care sector, AI helps address the shortage of doctors through telemedicine and access to medical supplies through drone deliveries [5]. In agriculture, AI (including machine learning, remote sensing, and data analytics) has the potential to improve productivity and efficiency at all stages of the value chain, enabling small-holder farmers to increase their income through higher crop yields and greater price control, detect and precisely treat pests and diseases, monitor soil conditions and target fertilizer applications, create virtual cooperatives to aggregate crop yields, broker better prices, and exploit economies of scale. Internet of Things (IoT) platforms may offer cost-effective ways to achieve those benefits [6]. For example, Microsoft is applying its Farmbeats platform [7] in developing countries by lowering the cost associated with

densely deploying sensors, exploiting sparsely distributed sensors and aerial imagery to generate precision maps, and replacing expensive drones with smartphones attached to hand-carried, low-cost, tethered helium balloons [8].

Premature Deindustrialization

On the downside, factory and call-center work will slow as tasks are replaced by AI-enabled automation, including robots, which will add pressure to unemployment rates that are already high in developing countries, including those in Africa [5]. This will be exacerbated by growing populations, reducing opportunities still further. Africa's population is large and expanding fast: most of its people are young and urban with a median age of 19.5 years, compared to Germany (47.1), the United States (38.1), and China (37.7), and the youth population is set to reach 225 million by 2055 [5]. Kenya, Nigeria, and South Africa, for example, are projected to have approximately 5.5%, 8.5%, and 12.5%, respectively, of their workforce displaced by automation [9]. A report by the Oxford Martin School at the University of Oxford, United Kingdom, and Citigroup, New York, summarizes the situation in Africa in stark terms [10]:

In most of sub-Saharan Africa, the manufacturing share of output has persistently declined over the past 25 years. The share of jobs in manufacturing is even smaller: just over 6% of all jobs. This figure barely changed over the course of the three decades

Digital Object Identifier 10.1109/MRA.2019.2946107
Date of current version: 11 December 2019

[Page](#) [Discussion](#)[Read](#) [Edit](#) [View history](#) [★](#)

AI and Robotics in Africa

(Redirected from [Artificial Intelligence, Robotics, and Machine Learning in Africa](#))

signifies a recently added item

Robotics in Africa [\[edit\]](#)

[African Robotics Network \(AFRON\)](#)

All-girls robotics team from Ghana wins World Robofest Championship in the U.S.

Award-winning professor ignites passion for STEM learning in Africa

Awarri "Our mission is to enable the development and adoption of advanced AI & Robotics technology on the African continent"

Culturally competent social robots target inclusion in Africa

Fundi Bots robotics for kids classes, motivating STEM education generally

Humanoid robot Sophia addresses Africa technology summit in Rwanda

IRCAD in the press

MIT-Africa Robotics Boot Camp

Pan-African Robotics Competition General Overview

Pan-African Robotics Competition 2023 AgTech Challenge uses more advanced tools, e.g., ROS, Gazebo, and OpenCV, and Scout robot from AgileX.

Reflect Robotics

Research Institute against Digestive Cancer (IRCAD)

Robofest 2019

Robotics and Artificial Intelligence in Africa IEEE Robotics & Automation Magazine, Vol. 26, No. 4, pp. 131-135, December 2019.

Robotics for Kids

Robotics in Education in Africa Ayorkor Korsah, Ashesi University, Ghana, Plenary speaker at the 2015 IEEE International Conference on Robotics and Automation

Robots at reception: South African hotel turns to machines to beat pandemic

Robots in Africa. What does this mean for the continent?

Ryonic Robotics

Ubtech CRUZR service robot deployed by ZoraBots Africa Ltd. to check the temperature of travellers arriving at Kigali International Airport, Rwanda.

Working with Robots as Colleagues: Kenyan Perspectives of Ethical Concerns on Possible Integration of Co-bots in Workplaces

ZoraBots Africa Ltd.

Robotics Education in Africa [\[edit\]](#)

Carnegie Mellon University Africa website and video

ICRA 2015 - Robotics in Education in Africa

Keza Education Future Lab for kids aged 3 to 14

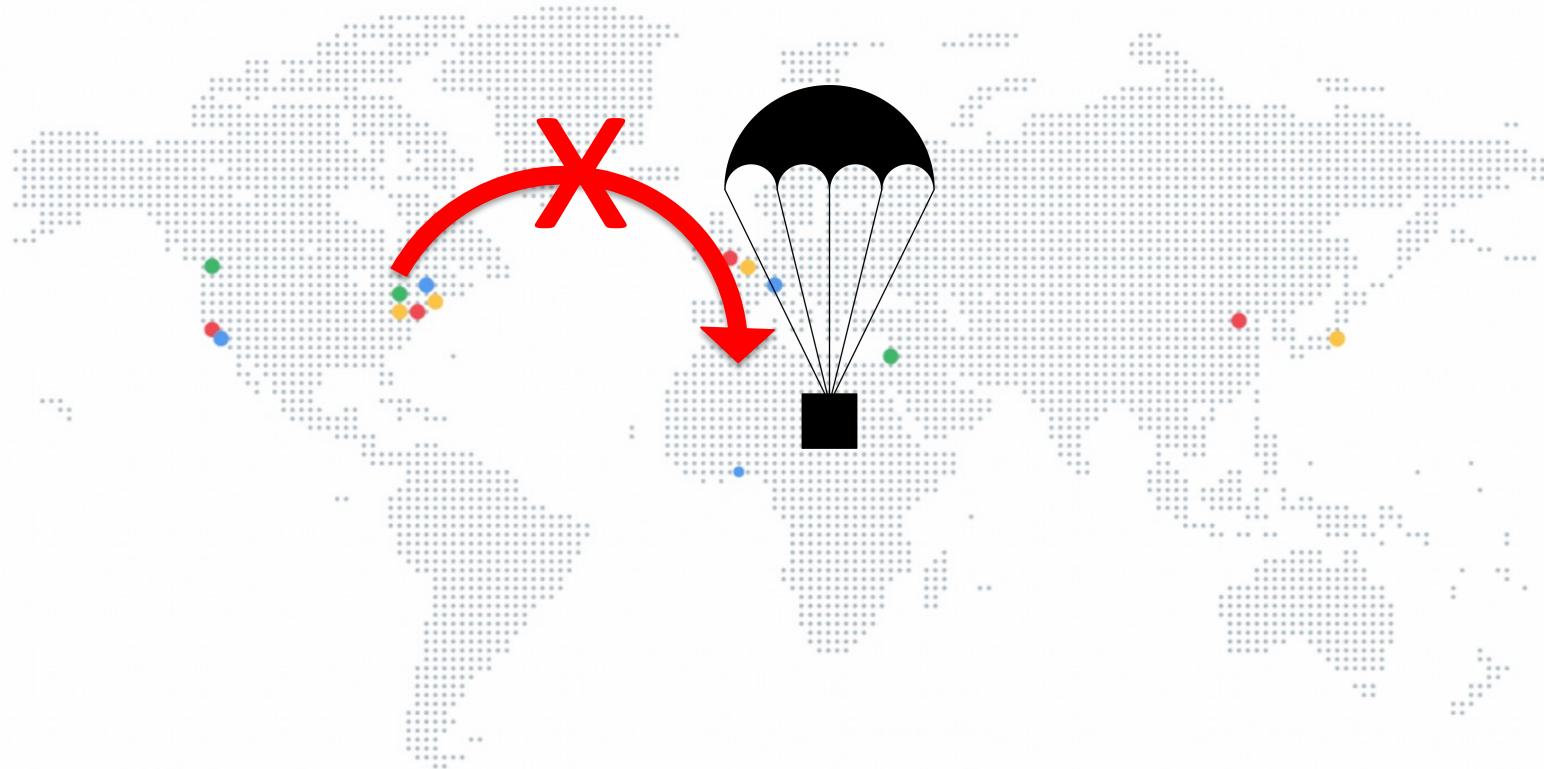
Leapr Labs

Mtoto Robotics (part for Leapr Labs)

Artificial Intelligence, Robotics, and Machine Learning in Africa

www.vernon.eu/wiki/Artificial_Intelligence,_Robotics,_and_Machine_Learning_in_Africa

One more thought ...



<https://www.blog.google/around-the-globe/google-africa/google-ai-ghana/>

https://www.kindpng.com/imgv/iiJhmwR_big-image-png-parachute-clipart-transparent-png/#gal_big-image-png-parachute-clipart-transparent-png_iiJhmwR_1805273.png

"We need African solutions to African problems"

Michel Bézy

The difference between Invention and Innovation
is Adoption

Jeremy Rose

Adoption depends on Trust

Trust

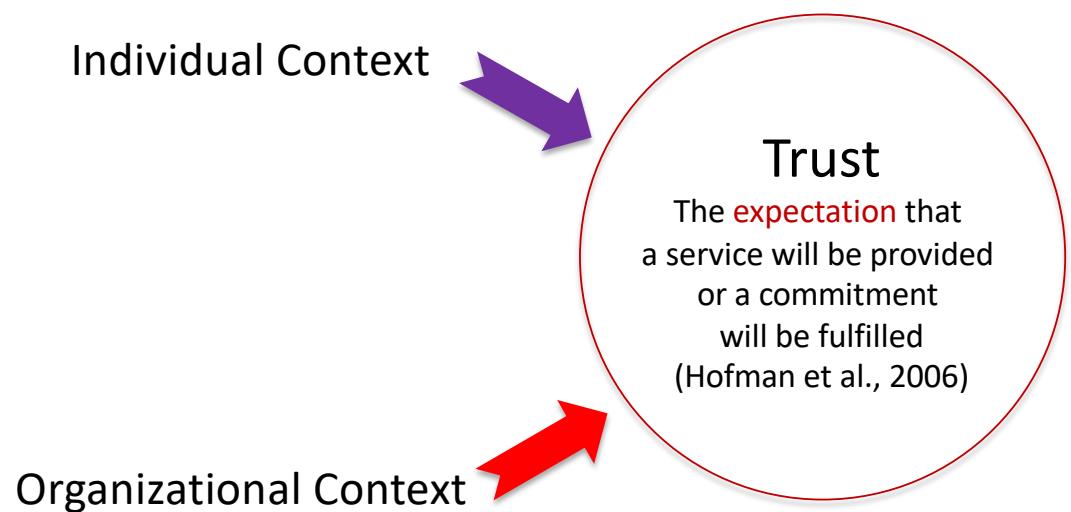
The **expectation** that
a service will be provided
or a commitment
will be fulfilled
(Hofman et al., 2006)

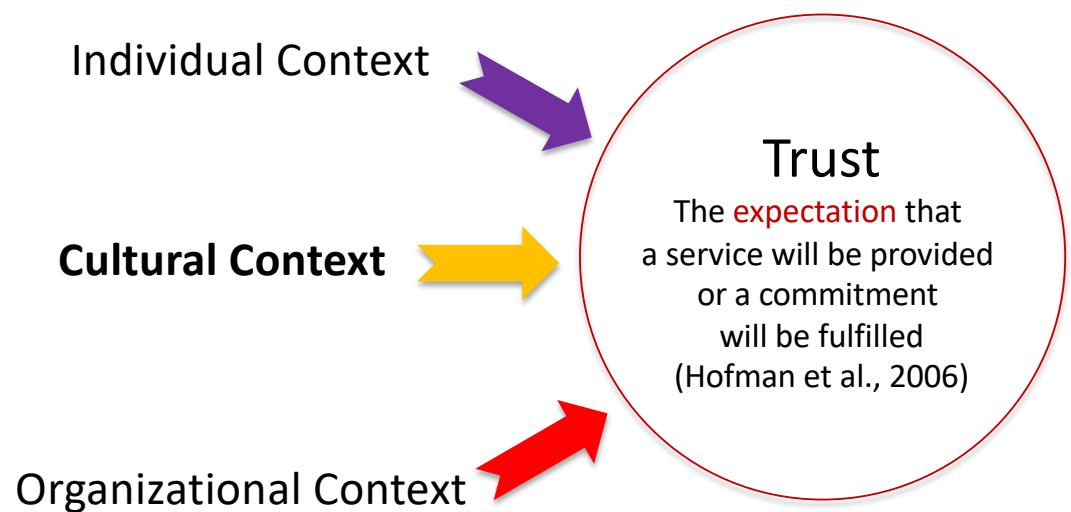
Individual Context

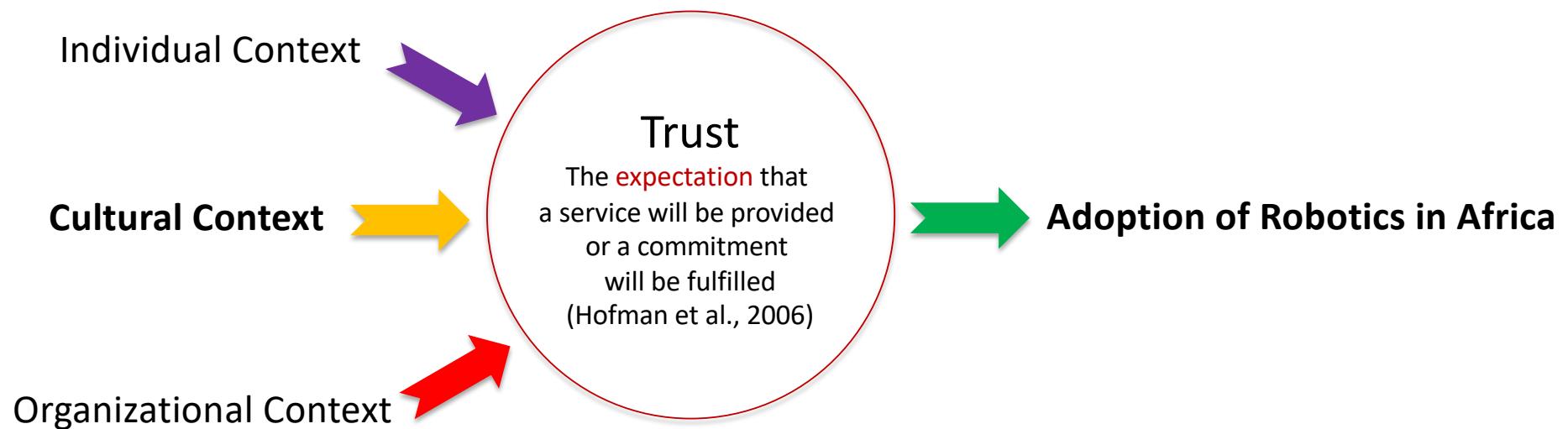


Trust

The **expectation** that
a service will be provided
or a commitment
will be fulfilled
(Hofman et al., 2006)







Adoption hinges on cultural competence

CSSR for

A red silhouette map of the African continent is positioned to the right of the word "for".

Culturally Sensitive Social Robotics for Africa

www.cssr4africa.org

Started in July 2023

CSSR for

Culturally Sensitive Social Robotics for Africa

Overview

Consortium

Contact

Work Plan

Deliverables

Software

News

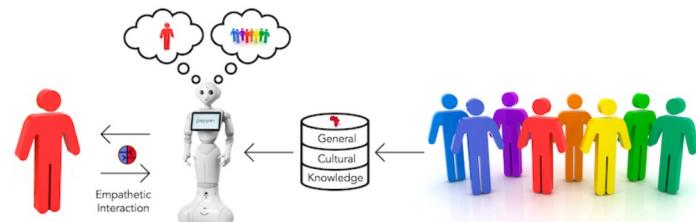
Wiki

Publications

The CSSR4Africa Project

While technological invention creates new ways of doing things, it is *innovation* that produces social and economic benefits through widespread *adoption* and the consequent change in the people's practices. Adoption depends on physical infrastructure, but it also depends on social infrastructure: the conventions that govern people's behaviour, the practices they find acceptable and unacceptable, and their sense of what is trustworthy. Cultural competence, i.e., an awareness of social norms and cultural expectations, is a key element in fostering this acceptance.

The need for technology to be culturally competent is perhaps best exemplified by the field of social robotics, a field that is growing quickly.¹ Social robots will serve people in a variety of ways: operating in everyday environments, often in open spaces such as hospitals, exhibition centres, and airports, providing assistance to people, typically in the form of advice, guidance, or information.



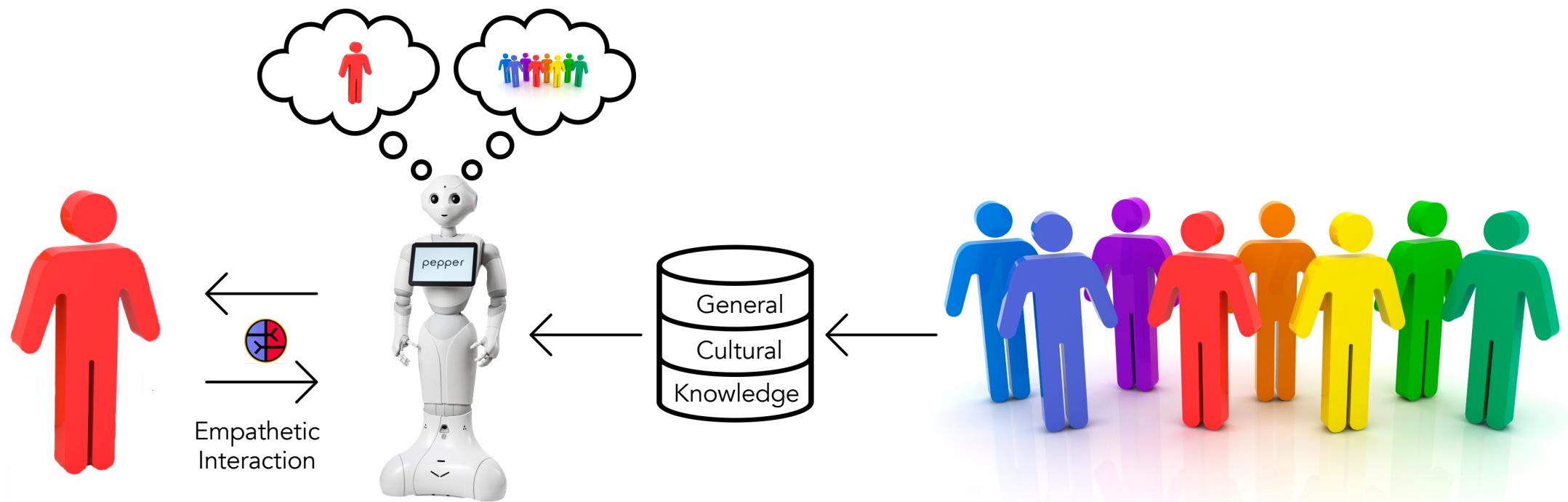
Loosely based on ethnographic research to acquire cultural knowledge about acceptable modes of communication, the CSSR4Africa project will equip robots with the ability to interact sensitively and politely with people in Africa using spatial, non-verbal, and verbal modes of communication.

¹The global social robotics market was valued at \$1.98 billion in 2020 and is expected to reach \$11.24 billion by 2026 ([Global Social Robots Market 2022 – 2027](#)).

This project is funded by the [African Engineering and Technology Network \(Afretec\)](#) Inclusive Digital Transformation Research Grant Programme.

Figure based on (Bruno et al., 2017); see [Overview](#).

www.cssr4africa.org



Graphic based on work by Bruno et al. (2017)

Culturally Competent Social Robot

{Bruno et al, 2017}



Cultural knowledge representation

Culturally Competent Social Robot

{Bruno et al, 2017}



Cultural knowledge representation

Culturally sensitive planning and action execution

Culturally Competent Social Robot

{Bruno et al, 2017}



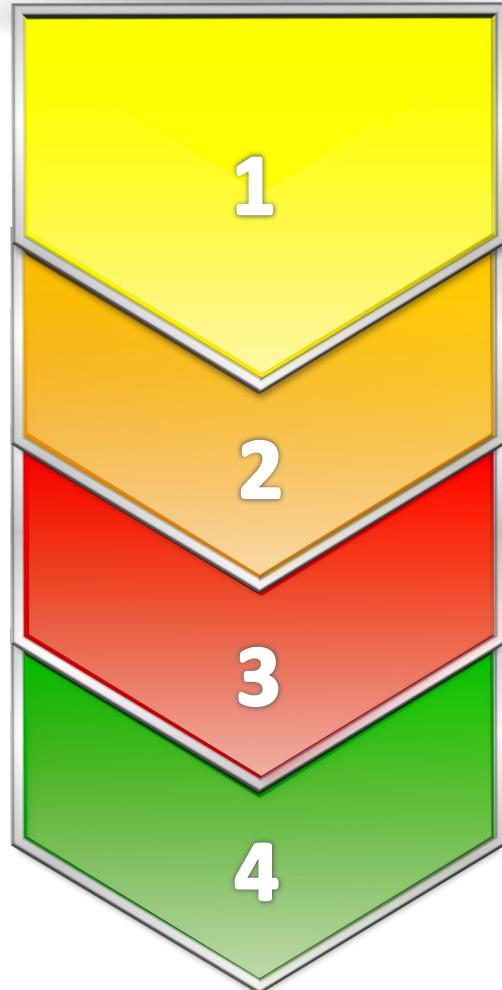
Cultural knowledge representation

Culturally sensitive planning and action execution

Culturally aware multimodal human-robot interaction

Culturally Competent Social Robot

{Bruno et al, 2017}



Cultural knowledge representation

Culturally sensitive planning and action execution

Culturally aware multimodal human-robot interaction

Culture-aware human emotion recognition

Culturally Competent Social Robot

{Bruno et al, 2017}



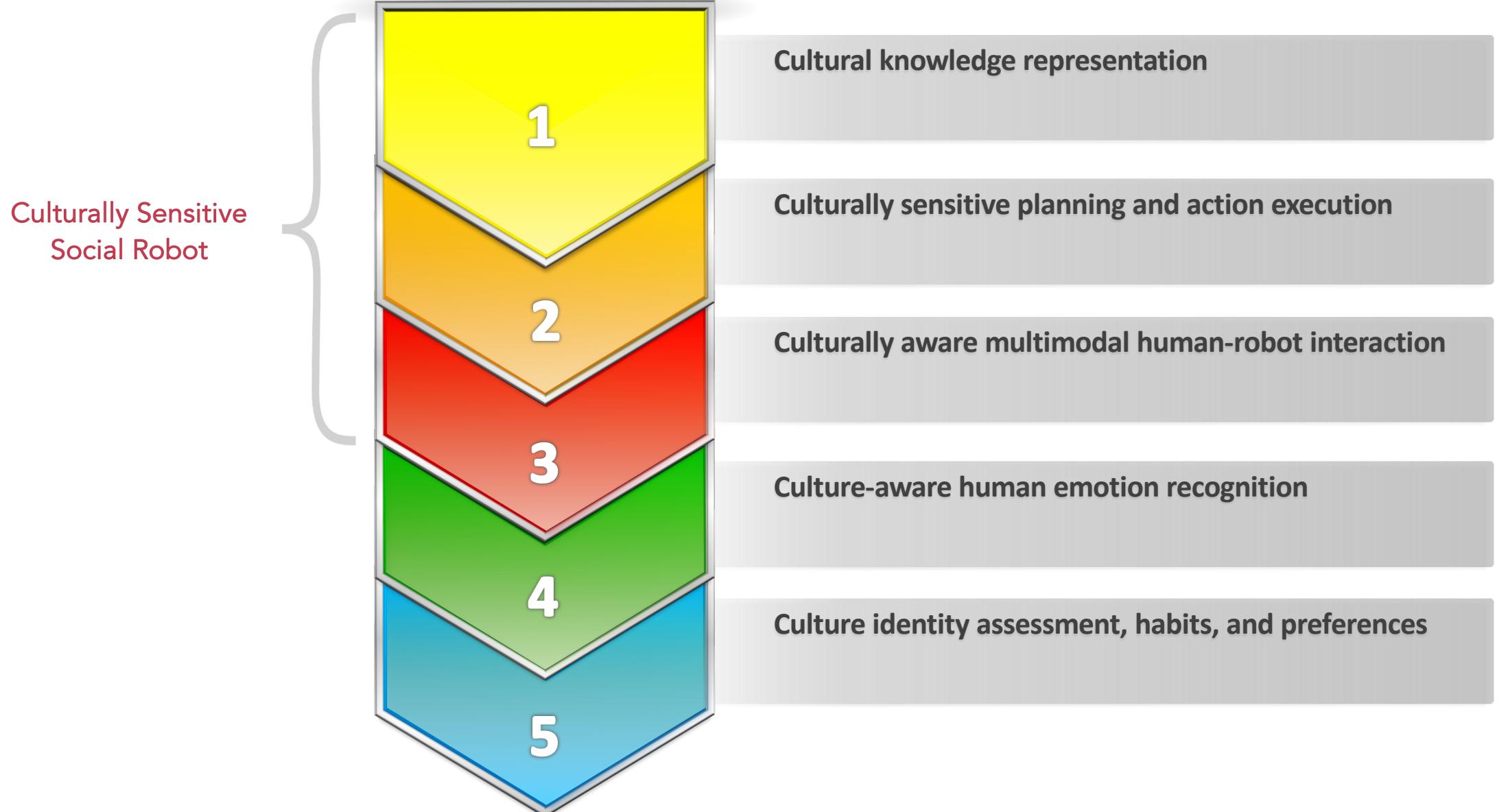
Cultural knowledge representation

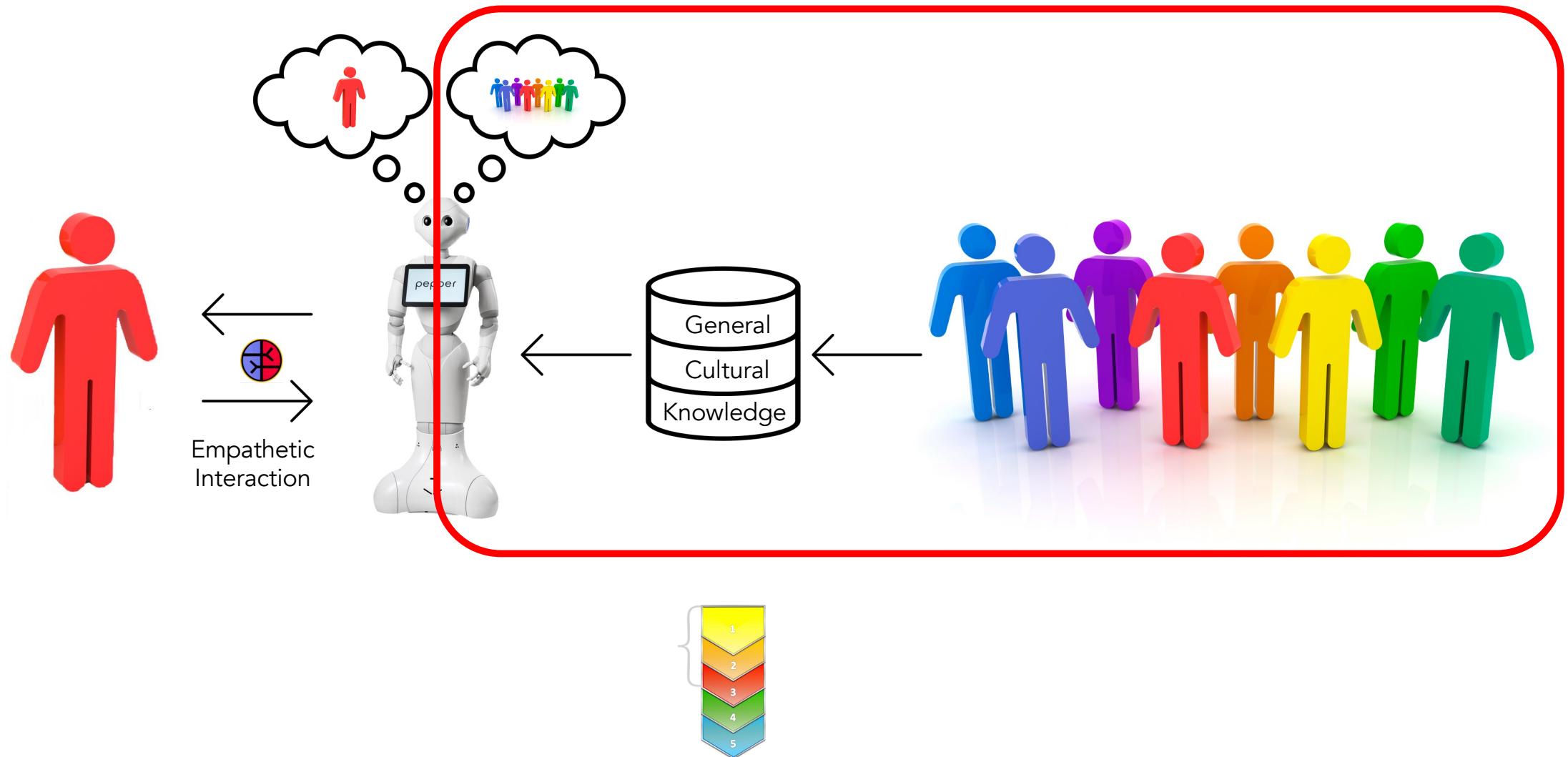
Culturally sensitive planning and action execution

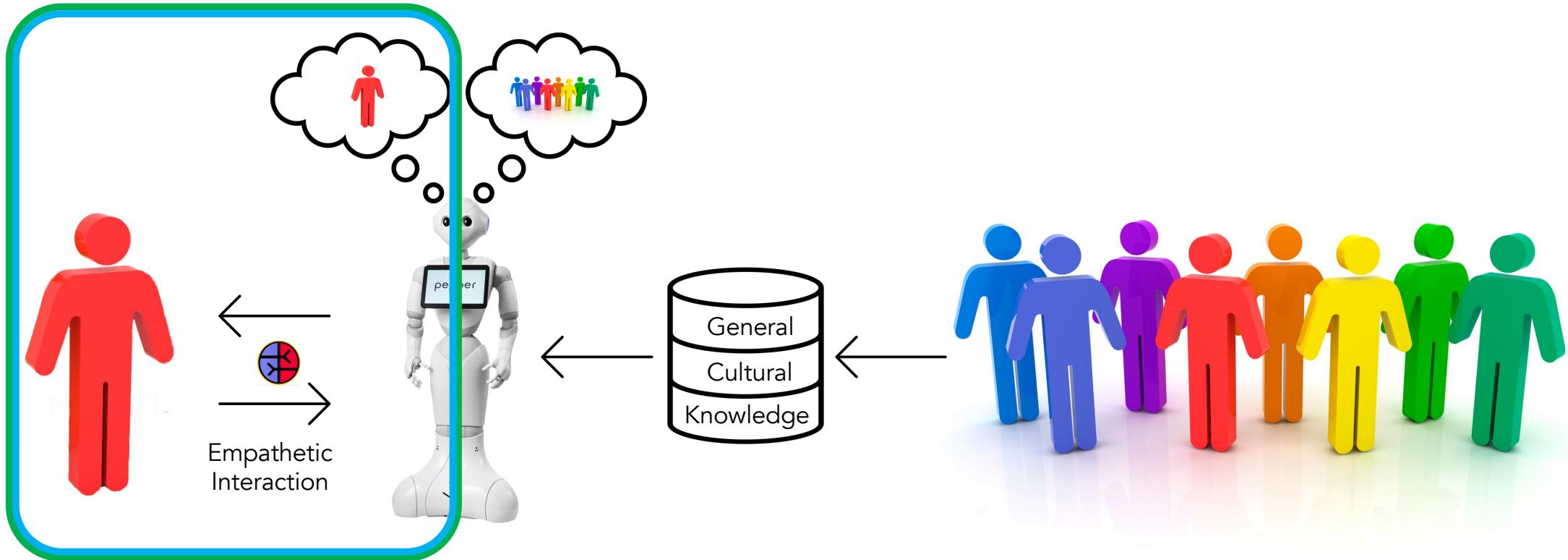
Culturally aware multimodal human-robot interaction

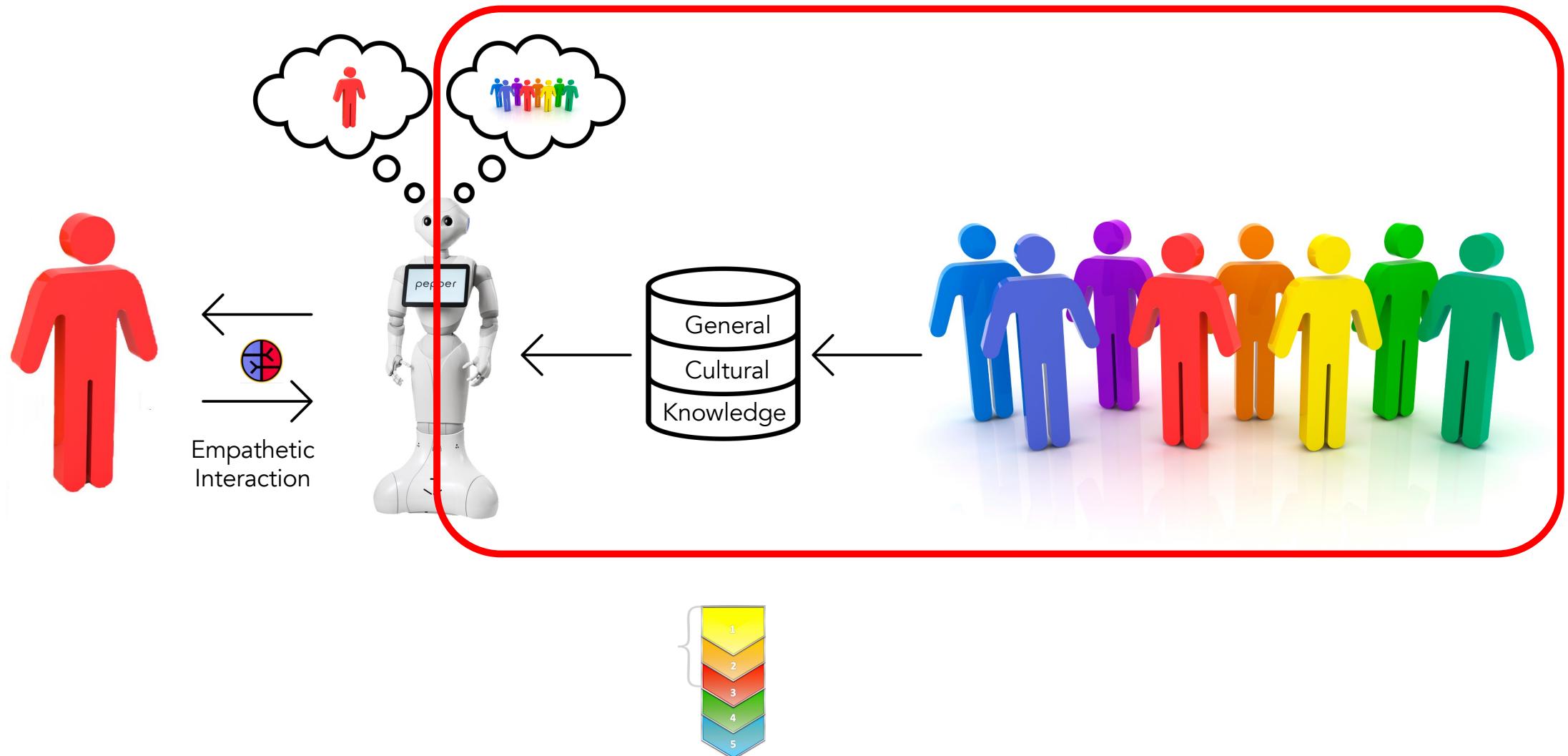
Culture-aware human emotion recognition

Culture identity assessment, habits, and preferences



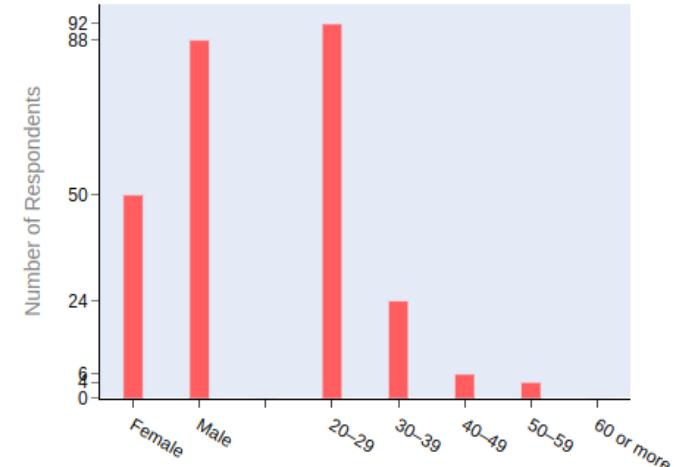
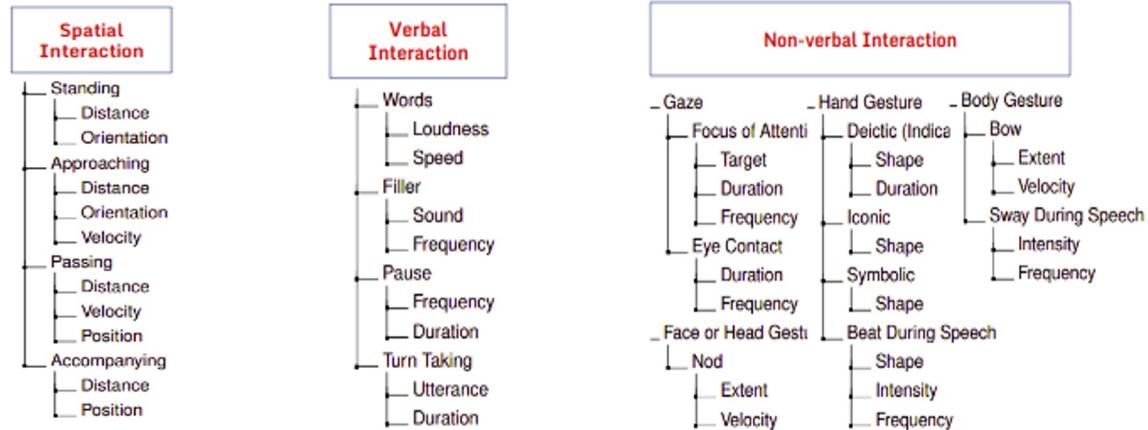




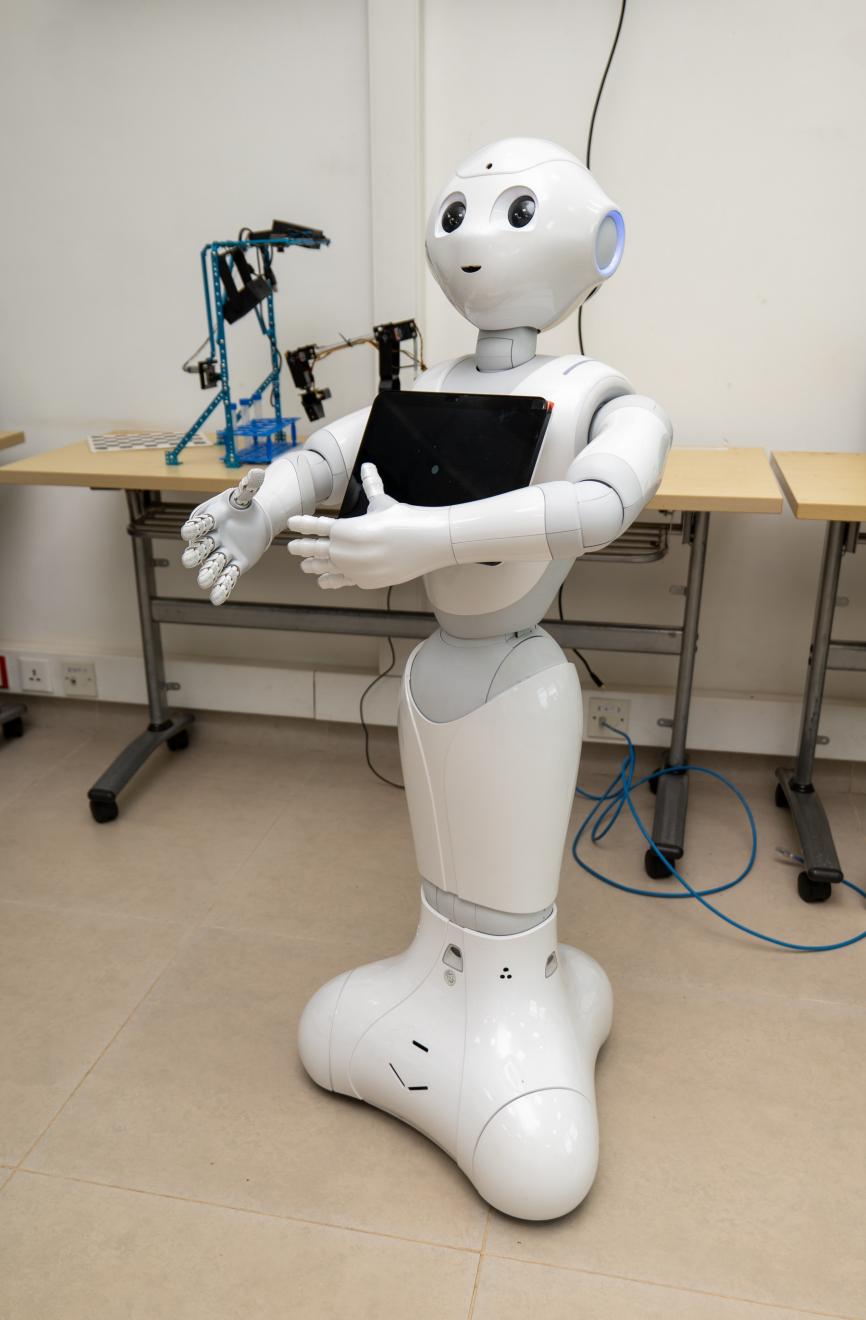


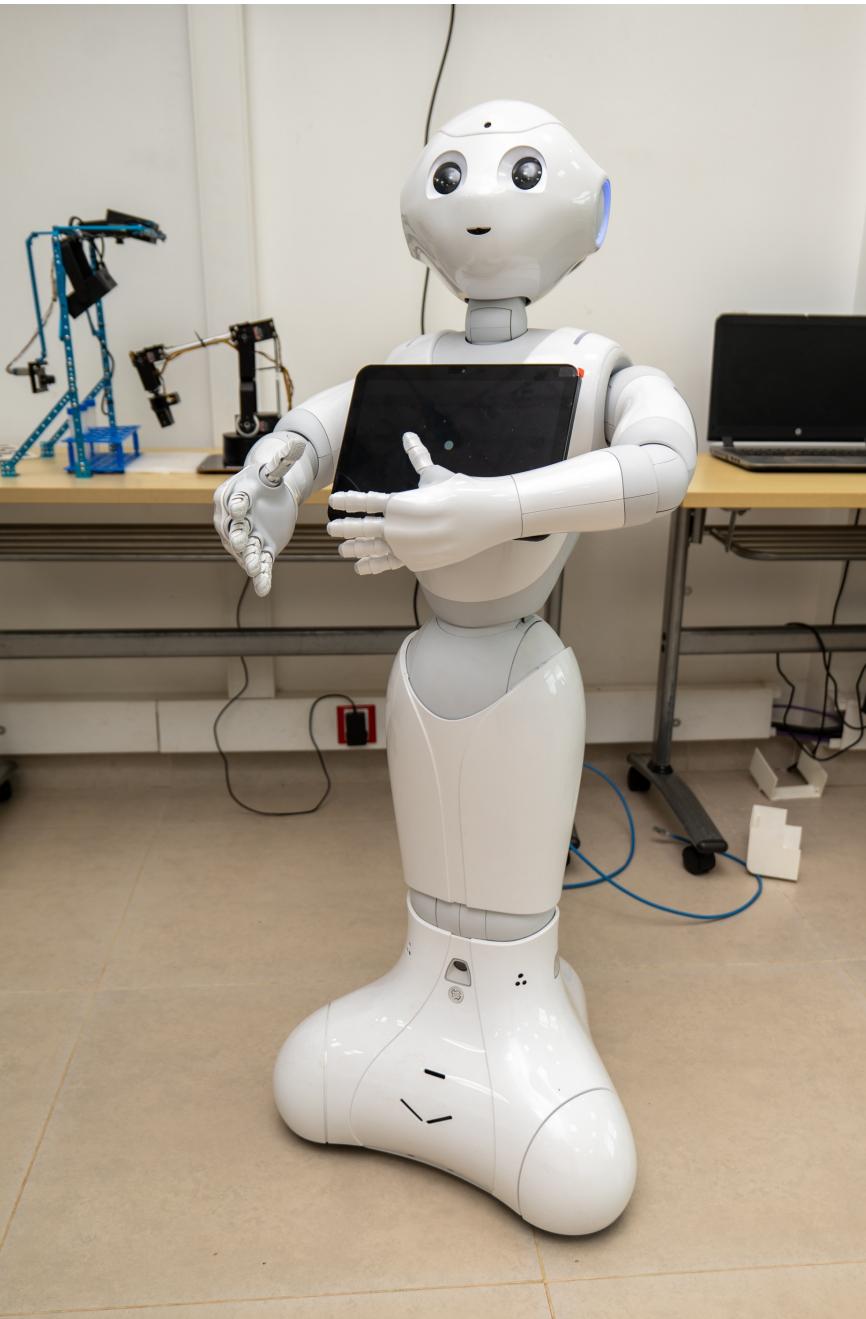
Pilot Survey of Rwandan Cultural Knowledge

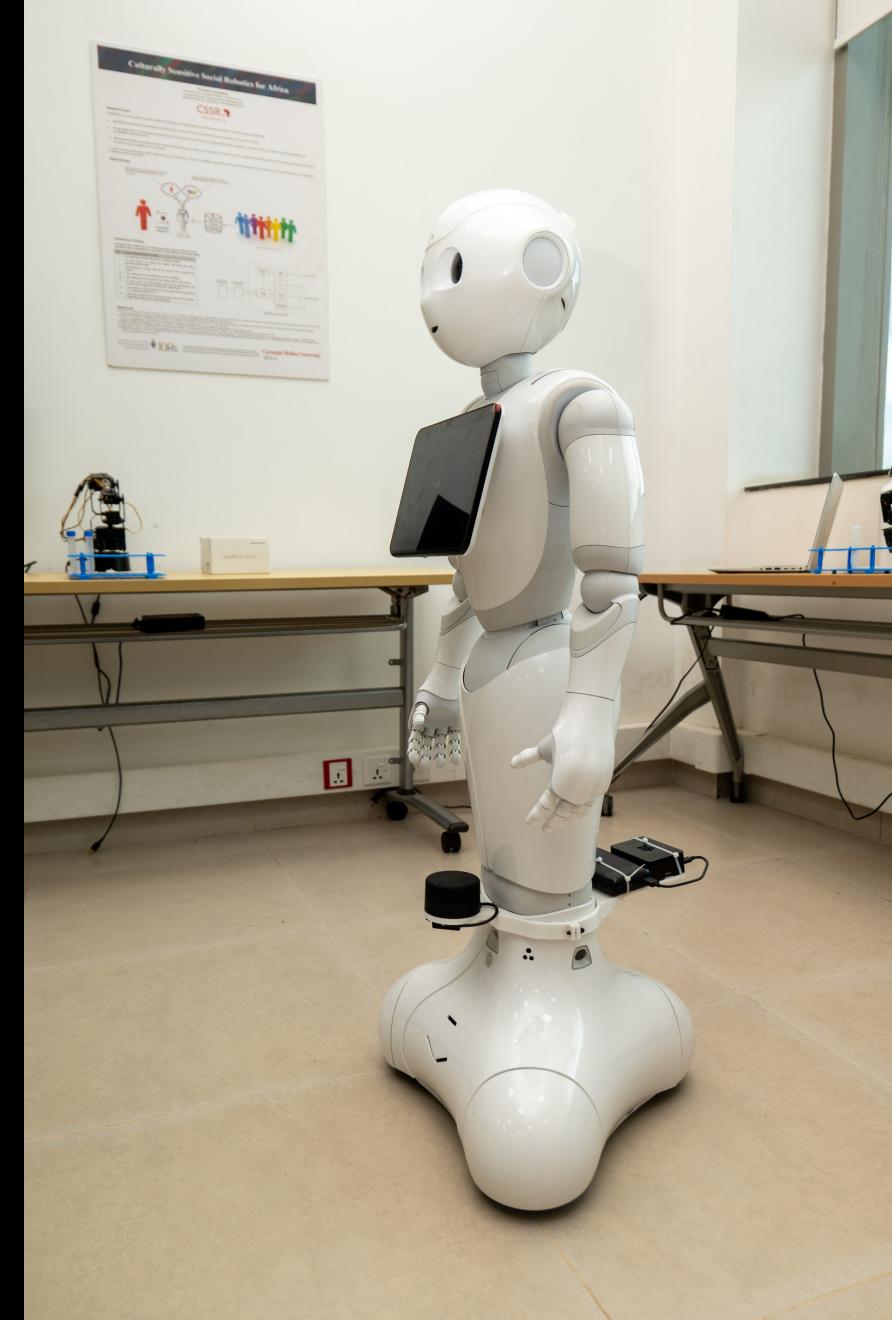
- Online survey with 59 questions (English and Kinyarwanda)
- Conducted at Carnegie Mellon University Africa
- 143 responses (108 in English, 35 in Kinyarwanda)

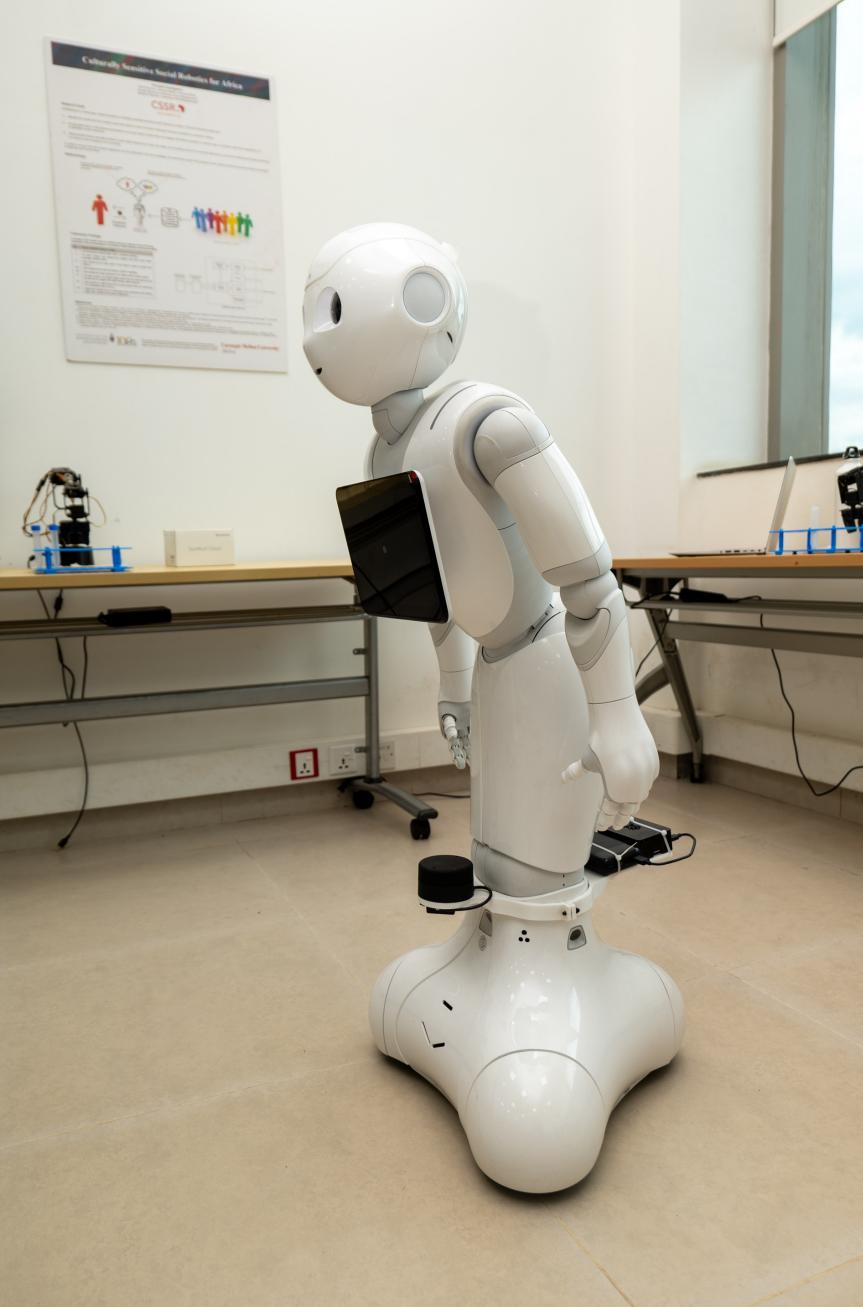


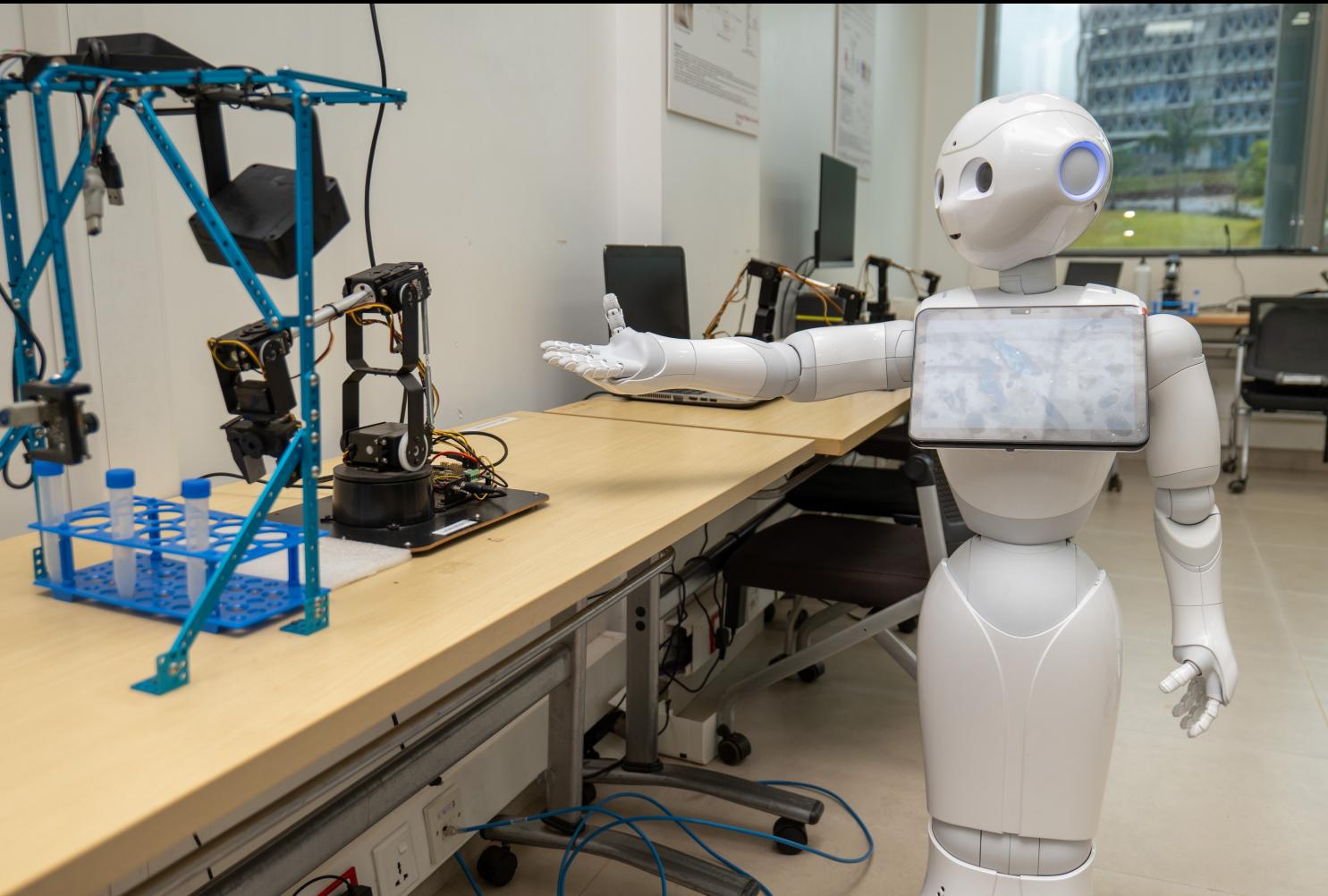






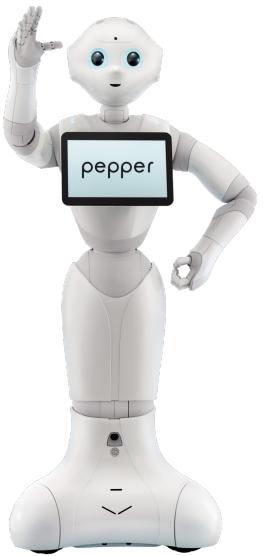






No.	Socio-cultural Norm or Trait
1	All interactions should begin with a courteous greeting.
2	The younger interaction partner should enable a greeting to be initiated by an older person.
3	The younger interaction partner should bow when greeting an older person or when rendering a service.
4	One should not wave at someone from a distance; one should move towards them to greet them.
5	To show respect, one should bow slightly and lower gaze when greeting someone older.
6	To show respect, one should raise both hands and lower gaze a little when greeting.
7	One should suspend work or movements and pay attention when addressed.
8	One should use an open palm of the hand to point to people and objects.
9	One should not point an upward facing palm of the hand at someone.
10	One should not use the left hand to point to anything.
11	One should not use the left hand to hand something to someone.
12	To show respect, one should hand over and accept gifts with two hands and do so from the front, facing the recipient.
13	It is respectful to use local languages and they should be used for verbal interaction when possible.
14	One should use formal titles when addressing someone.
15	One should engage in a preamble before getting to the point, as being too forward may be regarded as disrespectful.
16	One should not interrupt or talk over someone when they are speaking.
17	One should not interrupt or talk over someone when they are speaking.
18	One should keep intermittent eye contact; lack of eye contact depicts disrespect as it shows divided attention during the interaction.
19	One should not make persistent eye contact with an older person.
20	One should not make eye contact when being corrected.
21	To show respect, one should shake hands with the right hand and use the left arm to support the right forearm when doing so.
22	One should not walk far ahead of an older person, unless leading the person (in which case, one should walk slightly to the side).
23	One should not walk between two or more people who are conversing; it is considered rude to do so.
24	An appreciation of rhythmic sound and movement is valued.
25	Behaviours should focus on fostering social connections and relationships; they should not be purely functional.

A Sample of African Culture-specific Knowledge

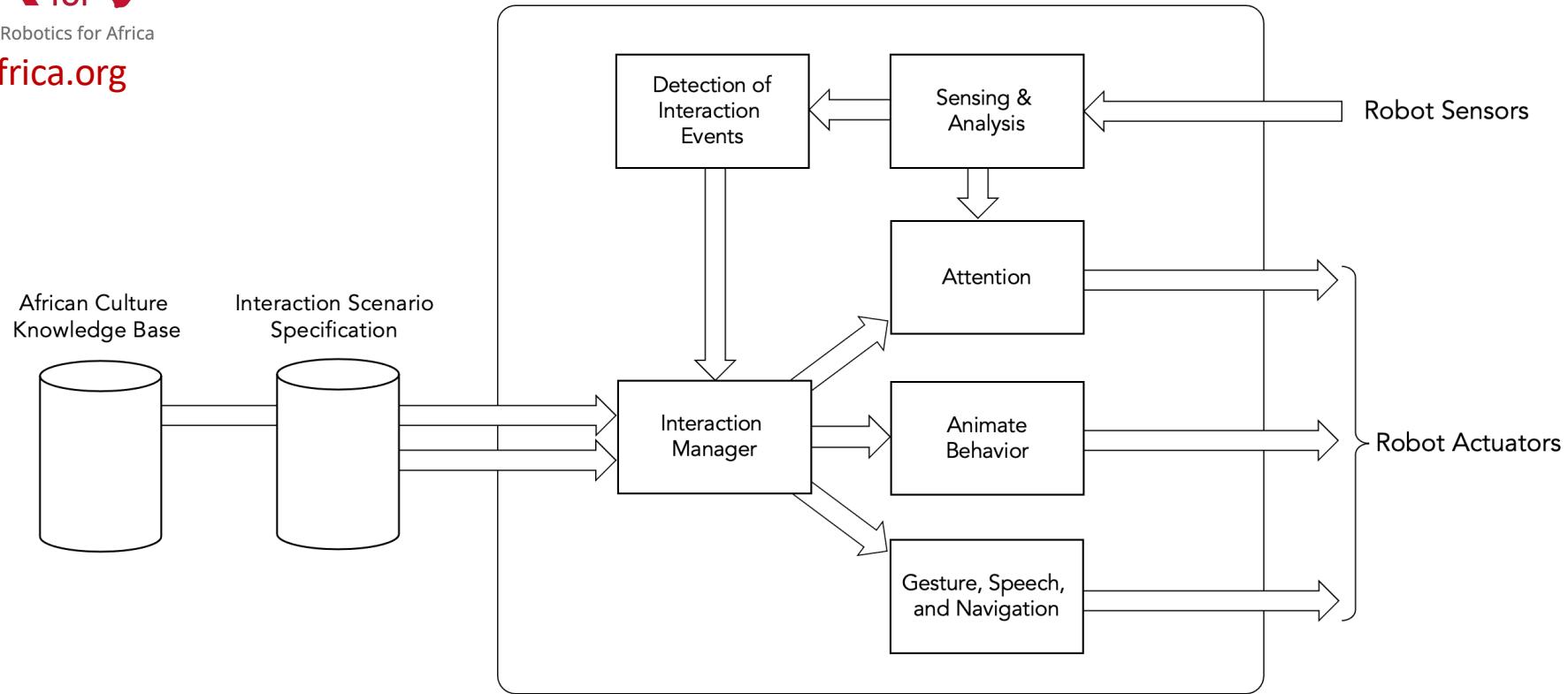


Spatial,
Non-verbal,
Verbal
Interaction

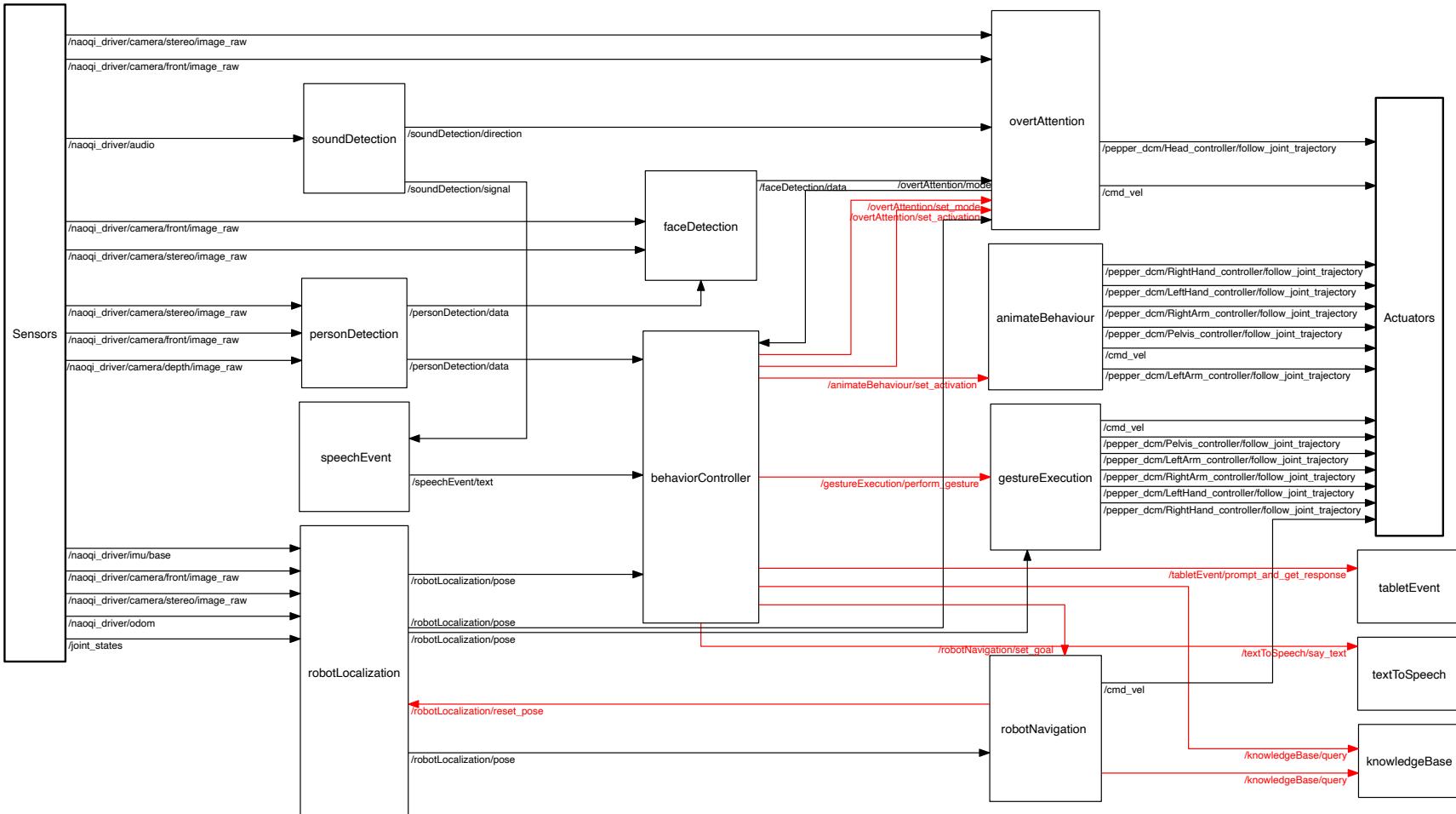
Design Pattern	Culturally Competent Behavior
Initial Introduction	The robot should acknowledge the presence of the person. The robot should initiate an interaction with a slight bow. The robot should greet first and should use a formal greeting. The robot should respect personal and intimate distances during interaction.
Reciprocal Turn Taking	The robot should respectfully give the initial turn to the human interaction partner. The robot should give priority to older people; it should not interrupt and it should let the other person finish their turn.
Didactic Communication	Pointing a hand directly at someone is disrespectful. For deictic gestures, the robot should use its left hand. The robot should gesture with an open palm rather than pointing a finger.
Personal Interests and History	The robot should avoid trying to share personal history since it will be perceived to be inauthentic. The robot should focus on and highlight its functional usefulness.
In Motion Together	The robot should explicitly say "Please come along" to remove any ambiguity of intention. The robot should not walk too far ahead when showing the way.
Recovering from Mistakes	The robot should apologize profusely. The robot should slightly bow when introducing itself and after it makes a mistake.
Physical Intimacy	Personal space should be entered only with prior consent. The robot should not pass in between two people that are interacting.
Claiming Unfair Treatment or Wrongful Harm	To enhance the perception that the robot is being respectful, the robot should not be aggressive by claiming unfair treatment.

A Sample of Africa-centric Design Patterns for Social Robots

After (Kahn et al, 2008)



Abstract system architecture for a culturally sensitive social robot



ROS system architecture for a culturally sensitive social robot
(all software will be on GitHub at <https://github.com/cssr4africa/cssr4africa>)

Minimum Jerk Model

$$CF = \frac{1}{2} \int_{t_1}^{t_2} \left[\left(\frac{d^3x}{dt^3} \right)^2 + \left(\frac{d^3y}{dt^3} \right)^2 \right] dt$$

Cost function being minimized



Joint position $\theta(t) = p_s + k \left[10(t/d)^3 - 15(t/d)^4 + 6(t/d)^5 \right]$

Joint velocity $\dot{\theta}(t) = \frac{k}{d} \left[30(t/d)^2 - 60(t/d)^3 + 30(t/d)^4 \right]$

Joint acceleration $\ddot{\theta}(t) = \frac{k}{d^2} \left[60(t/d) - 180(t/d)^2 + 120(t/d)^3 \right]$

$$0 \leq t \leq d$$



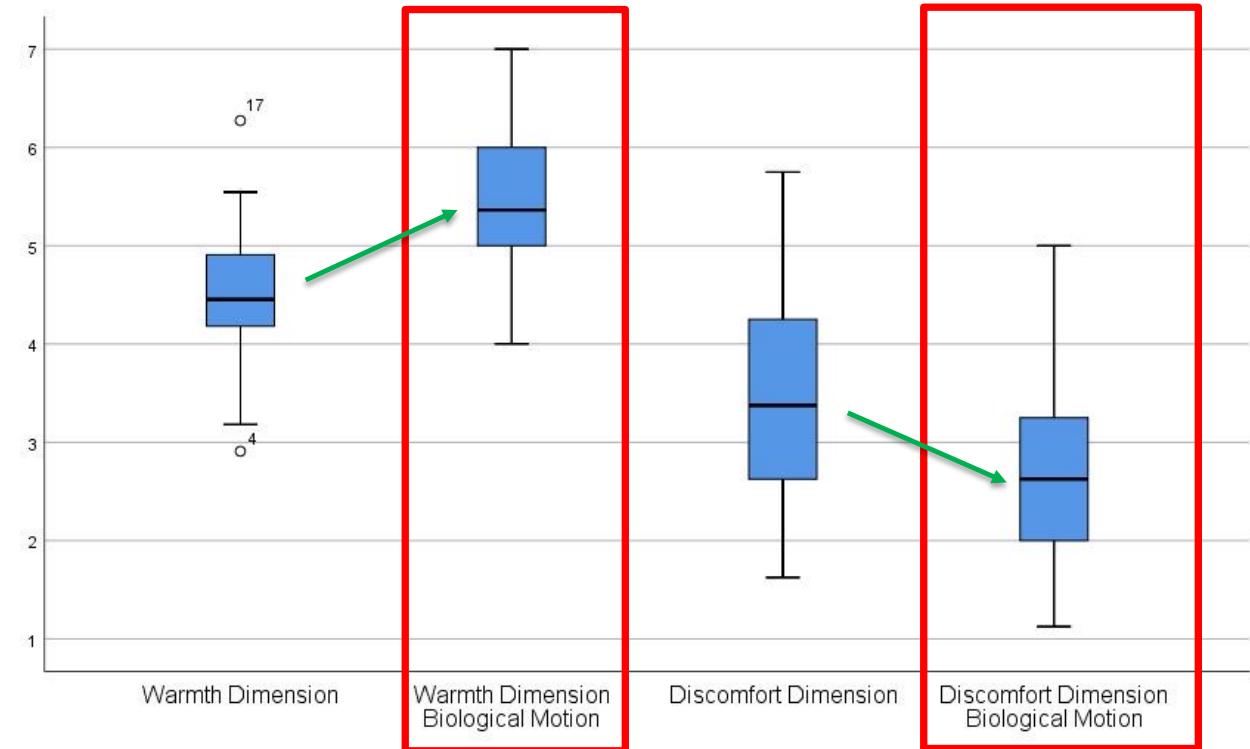
Biological Motion for Engaging Gestural Communication in Social Robots

Biological motion during human-robot interactions

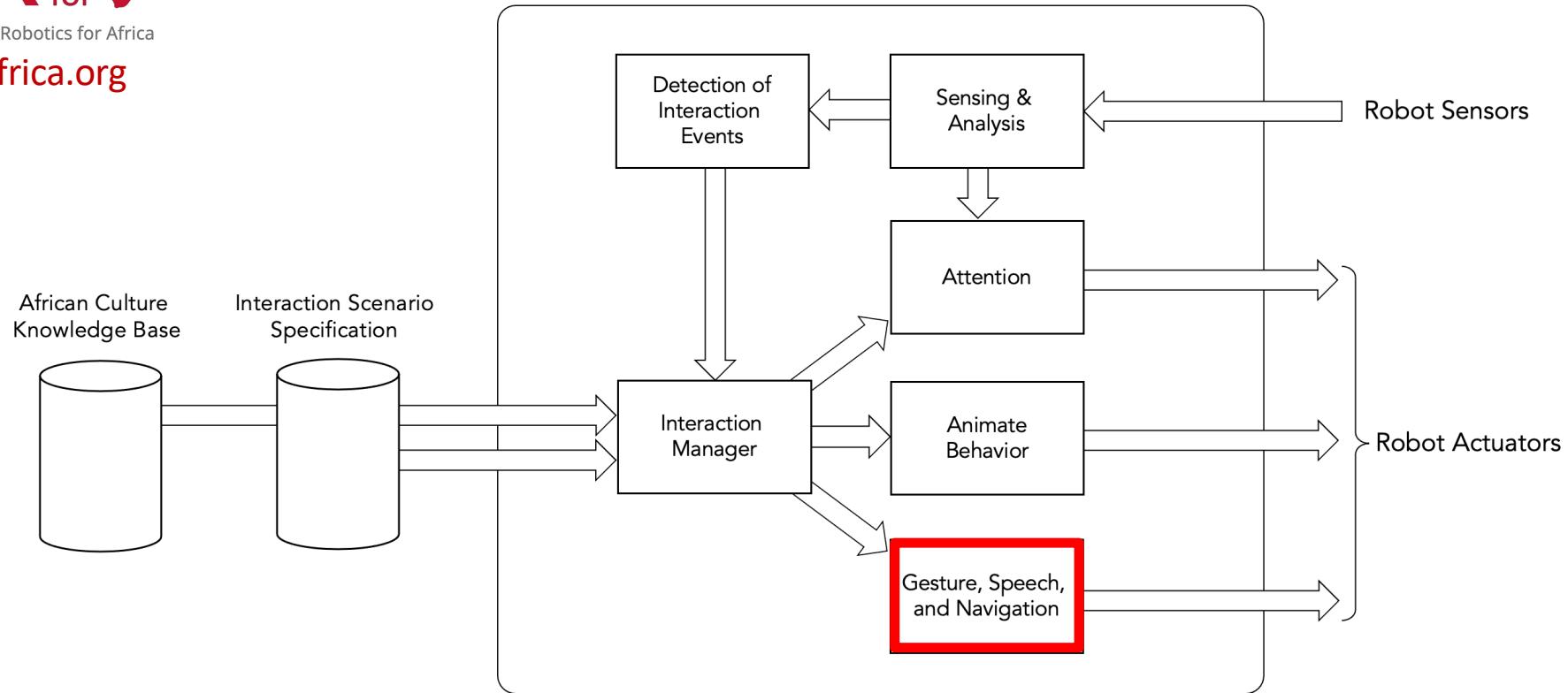
Warmth **increased** on average by 14%

Discomfort **reduced** by 13%

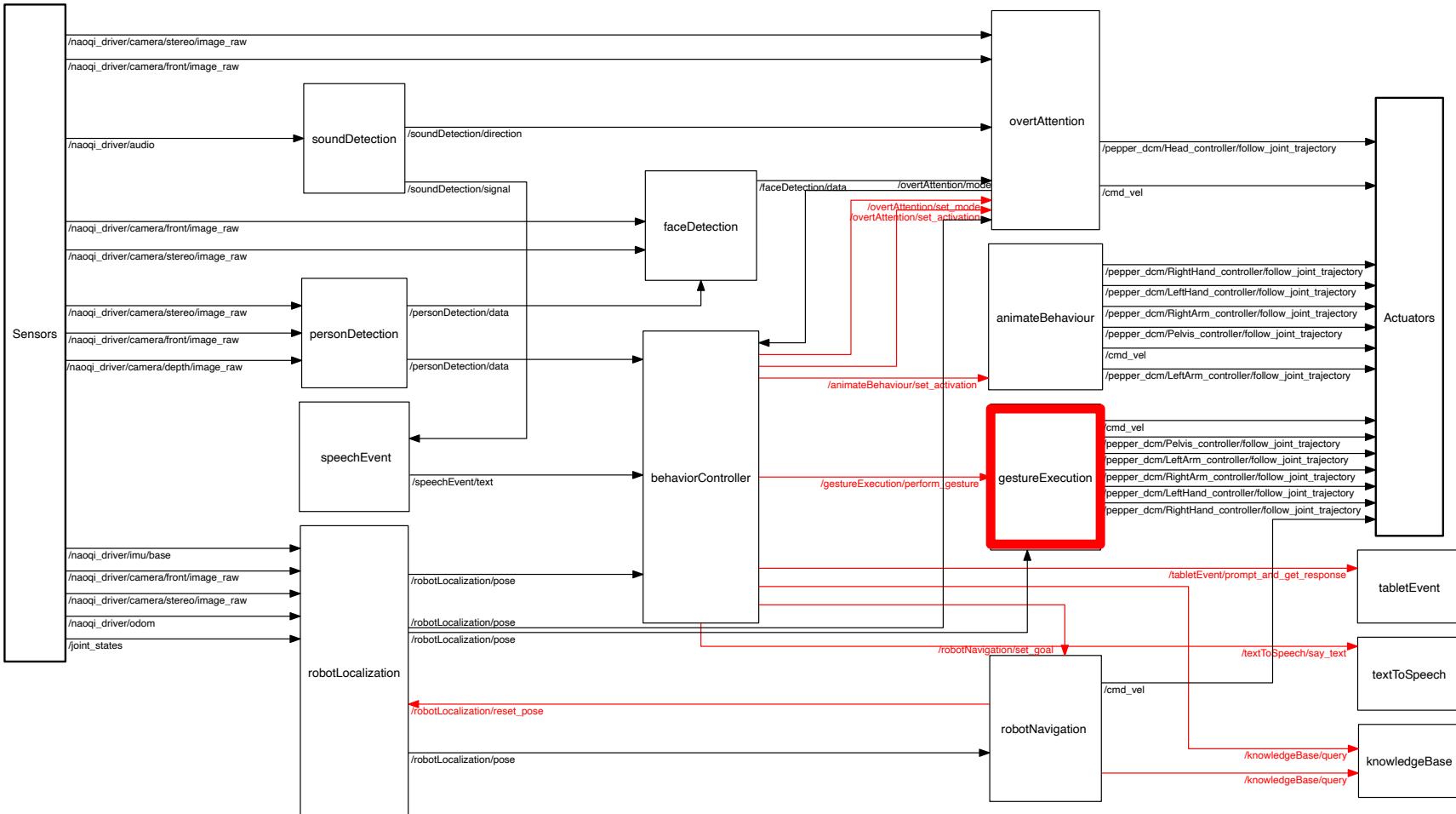
(assessed using a variation of the RoSAS metric)



Biological Motion for Engaging Gestural Communication in Social Robots



Gesture subsystem in the abstract system architecture



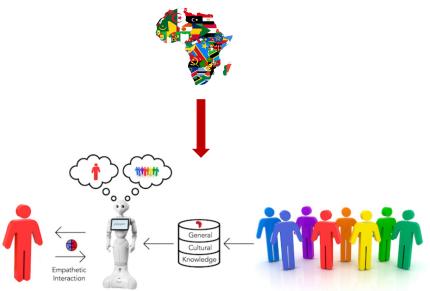
Gesture subsystem ROS system architecture

Rwandan Culture Survey for Culturally-Sensitive Social Robotics for Africa

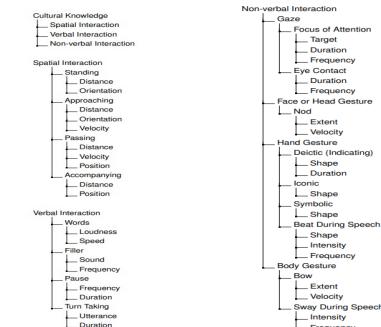
Eyerusalem Birhan and David Vernon
Carnegie Mellon University Africa, Kigali, Rwanda

Research Goals

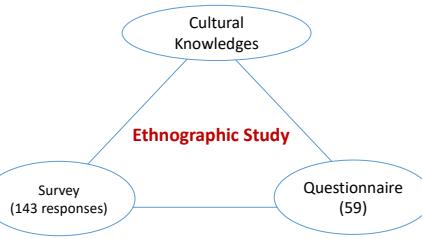
Identify the verbal and non-verbal social and cultural norms of human interaction that are prevalent in African countries, specifically **Rwanda**.



Cultural knowledge Ontology



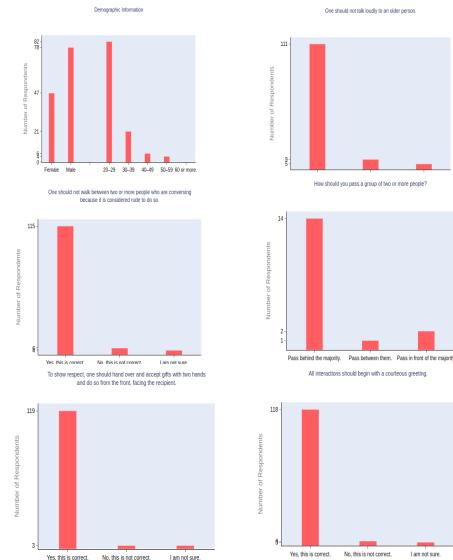
Method



Sample Questions

No.	Question
2-1	To show respect, one should lower gaze when greeting someone older.
2-3	One should keep intermittent eye contact; lack of eye contact depicts disrespect as it shows divided attention during the interaction.
2-4	One should not make persistent eye contact with an older person.
2-6	One should use an open palm of the hand to point to people and objects.
2-7	One should not point an upward-facing palm of the hand at someone.
2-8	One should not use the left hand to point to anything.
2-9	To show respect, one should bow slightly when greeting someone older.
2-12	One should not use the left hand to hand something to someone.
2-14	To show respect, one should shake hands with the right hand and use the left arm to support the right forearm when doing so.
2-15	An appreciation of rhythmic sound and movement is valued.
2-16	To show respect, one should bow slightly and lower gaze when greeting someone older.
2-17	The younger interaction partner should bow when greeting an older person or when rendering a service.
3-1	What distance should you keep when passing someone?
3-2	How should you acknowledge someone when passing them?
3-3	How should you pass a group of two or more people?
3-6	When showing someone younger than you the way, where should you position yourself?
3-7	How should you address someone who is older than you and who you haven't met before?
3-21	Would you use a face, head, hand, or body gesture to express gratitude?
3-22	Would you use a face, head, hand, or body gesture to express agreement?
3-23	Would you use a face, head, hand, or body gesture to express respect?
3-28	Is there a face, head, hand, or body gesture you should not use?
3-29	Would you use a hand or body gesture while speaking to someone?
3-30	Would you use a hand or body gesture while listening to someone?

Results



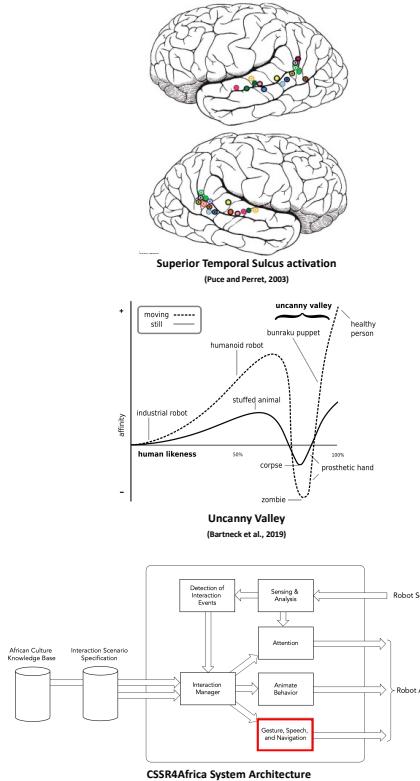
References

- B. Bruno, C. T. Recchuto, I. Papadopoulos, A. Saffiotti, C. Kouologlou, R. Menicatti, F. Mastropietro, R. Zaccaria, and A. Sgorbissa, "Knowledge representation for culturally competent personal robots: requirements, design principles, implementation, and assessment," *Journal of Social Robotics*, vol. 13, no. 3, pp. 515-538, 2019.
- West, V. Evers, "Exploring cultural factors in human-robot interaction: A matter of personality?" in *Comparative Informatics Workshop*, University of Amsterdam, 2011.
- I. Papadopoulos, A. Saffiotti, F. Pecora, N. Y. Chang, Y. Lim, H. Kamide, J. Lee, C. Papadopoulos, and A. Sgorbissa, "Cultivating a positive attitude towards robots based on user acceptance," *International Journal of Social Robotics*, vol. 12, no. 4, pp. 1107-1120, 2020.
- J. van Doorn, M. Menken, and A. L. Noble, "The role of human-robot interaction in consumers," *Journal of Services and Automation*, vol. 17, no. 3, pp. 450-460, 2021.
- T. Neumann, K. Koswatta, and K. Rand, "Cultural factors and their influences for social robots," *International Journal of Social Robotics*, vol. 15, no. 2, pp. 230-245, 2023.
- J. Wirtz, P. G. Patterson, and W. H. Kurn, "Customers' acceptance of artificially intelligent service robots," *Journal of Service Research*, vol. 25, no. 1, pp. 50-65, 2023.

Biological Motion for Gestural Communication by Social Robots

Adedayo Akinade and David Vernon
Carnegie Mellon University Africa, Kigali, Rwanda

Significance of Biological Motion



Method

Models of Biological Motion

$$\text{Minimum Jerk} \quad [Chan et al., 2021]$$

$$CF = \frac{1}{2} \int_{t_1}^{t_2} \left[\left(\frac{d^3x}{dt^3} \right)^2 + \left(\frac{d^3y}{dt^3} \right)^2 \right] dt$$

Cost function being minimized

$$\text{Two-thirds Power Law} \quad [\text{Viviani and Flash, 1995}]$$

$$V(t) = K(t) \left(\frac{R(t)}{1 + \alpha R(t)} \right)^{\frac{2}{3}}$$

Velocity Gain Factor ($\alpha > 0$)

Empirical value $\frac{2}{3}$

Radius of Curvature

$$\text{Decoupled Minimum-Jerk} \quad [\text{Huber et al., 2009}]$$

$$r_z(t) = \sum_{k=0}^5 a_{kz} t^k$$

Trajectory in z-direction

$$r_{xy}(t) = \sum_{k=0}^5 a_{kxy} t^k$$

Trajectory in xy-direction

Trajectory Generation

Form of trajectory that minimizes jerk

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

Boundary conditions

$$\theta(0) = p_s; \quad \dot{\theta}(0); \quad \ddot{\theta}(0) = 0$$

$$\theta(d) = p_f; \quad \dot{\theta}(d); \quad \ddot{\theta}(d) = 0$$

Joint positions

$$\theta(t) = p_s + k \left[10(t/d)^3 - 15(t/d)^4 + 6(t/d)^5 \right]$$

Joint velocities

$$\dot{\theta}(t) = \frac{k}{d} \left[30(t/d)^2 - 60(t/d)^3 + 30(t/d)^4 \right]$$

Joint accelerations

$$\ddot{\theta}(t) = \frac{k}{d^2} \left[60(t/d) - 180(t/d)^2 + 120(t/d)^3 \right]$$

$$0 \leq t \leq d$$

Results

Impact Assessment

Non-biological (Control) gestures

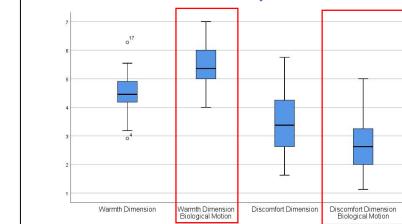
Condition 1

Biological motion profile

Condition 2

Warmth	Discomfort
Organic	Awkward
Sociable	Scary
Emotional	Strange
Compassionate	Awful
Happy	Dangerous
Feeling	Aggressive

RoSAS Assessment Variables
Carpinella et al., 2017



References

- A. Akinade, T. Halle, F. Munganga, C. Tucker, and D. Vernon, "Culturally Competent Social Robots Target Inclusion in Africa," in *Robotics for All*, 2020.
- C. Carpinella, A. Wyman, M. Perez, and S. Strossner, "The Robotic Social Attributes Scale (RoSAS): Development and Validation", in *12th ACM/IEEE International Conference on Human-Robot Interaction*, 2017, pp. 254–262.
- N. Chan, J. L. P. G. de Luca, and J. E. Grotticelli, "An experimental study and mathematical modeling of motion models for unconstrained handovers: towards generating humankind-like motions for human-robot handovers", in *Proceedings of the 2016 IEEE/RSJ International Conference on Humanoid Robots*, 2020, pp. 356-361.
- M. Huber, C. Gitter, and M. Giese, "A fast and robust trajectory generator for biological motion", in *IEEE/RSJ International Conference on Humanoid Robots (Humanoids)*, 2009, pp. 639-644.
- C. Bartneck, M. Zoghbi, F. Eysal, T. Kanda, M. Keijzer, and S. Sabanovic, "Human-Robot Interaction: An Introduction", 2019.
- Puce and D. Perrett, "Electrophysiology and brain imaging of biological motion", in *Philosophical Transactions of the Royal Society B: Biological Sciences*, 2005, pp. 103-118.
- P. Viviani, and T. Flash, "Minimum-jerk, two-thirds power law, and isochrony: converging approaches to movement planning", *Journal of Experimental Psychology: Human Perception and Performance*, 1995, 21(1), pp. 32-53.

Behavior Trees for Culturally Sensitive Social Robots: African Culture Case Study

Ibrahim Jimoh, Heran Equbay, Clifford Osano, Tsegazeab Tefferi, and David Vernon
Carnegie Mellon University Africa, Kigali, Rwanda

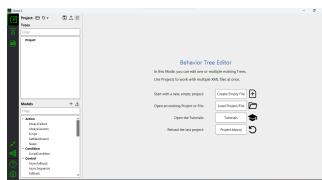
Overview

The goal of this project is to explore the use Behavior Trees to implement robot missions for a culturally sensitive social robot in Africa.

Cultural sensitivity in social robots' interaction is essential for fostering trust, ensuring respectful interactions, and enhancing user experiences. However, developing robots that can dynamically adapt to different cultural norms presents significant challenges.

Behavior Trees (BTs) were invented as a tool to enable modular AI in computer games but have received an increasing amount of attention in the robotics community in the last decade. Compared to other approaches, such as hierarchical finite state machines, they have clear advantages in terms of modularity, reusability or expandability. By developing a comprehensive and up-to-date cultural knowledge database and integrating these cultural norms into behavior trees and enabling dynamic adaptation, robots can achieve a higher level of cultural competence.

Frameworks and Tools

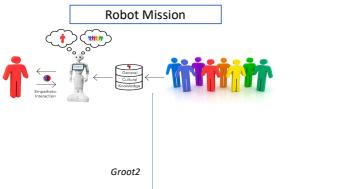


BehaviorTree.CPP 4.6

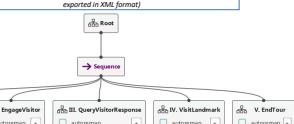
The C++ library to build Behavior Trees.
Batteries included.

*BehaviorTree.CPP 4.6 – library for
implementing Robot Mission Interpreter*

Methodology



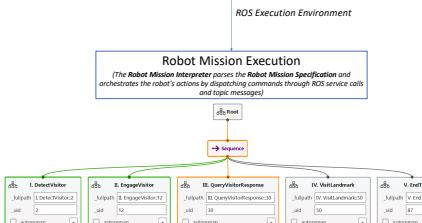
Robot Mission Specification



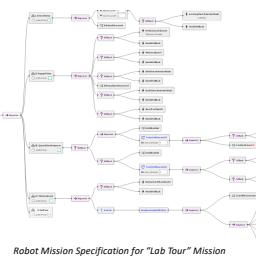
JavaServer Pages

Robot Mission Interpreter

(A C++ implementation utilizing the *BehaviorTree.CPP* library to construct and manage Behavior Tree nodes from the *Robot Mission specification*)



Preliminary Results



Digitized by srujanika@gmail.com

Robot Mission Execution simulation, using stubs and drivers, and without including Cultural Knowledge

References

- P. Zantout and D. Vernon, "Culturally Sensitive Human-Robot Interaction: A Case Study with the Pepper Humanoid Robot," in *2023 IEEE AFRICON*, Nairobi, Kenya: IEEE, Sep. 2023, pp. 1–6.

M. E. E. Stukins, J. Strudwick, C. & R. M. Moore, "A survey of behavior trees in robotics and AI," *AI & SOCIETY*, vol. 35, no. 1, pp. 1–20, Jan 2020, doi: 10.1007/s00146-019-00540-z.

M. Colledgehead and N. Oren, *Trees in Robotics and AI: An Introduction*. CRC Press, 2018.

B. Louise, E. A. Björklund, A. C. Kuo, and P. Alves-Oliveira, "Designing for culturally responsive social robots: An application of a participatory framework," *Frontiers in Robotics and AI*, vol. 9, 2022. [Online]. Available: <https://frontiersin.org/articles/10.3389/frobt.2022.983408>.

B. Bruno, Recchitello, C.T., Papadopoulos, I. et al. Knowledge Representation for Culturally Competent Social Robots. In: *Proceedings of the 2019 International Conference on Intelligent Systems and Soft Computing (Intech)*. Int. Conf. on Intelligent Systems and Soft Computing (Intech), 2019, pp. 515–528. [Online]. Available: https://doi.org/10.1007/978-3-030-05195-8_49.

D. Fagouri, 2013, "bebop2CPP library," <https://github.com/pelegshabtai/bebop2CPP>

Carnegie
Mellon
University
Africa

Semantically Modulated joint Episodic-Procedural Associative Memory

Muhammed Danso & David Vernon
Carnegie Mellon University Africa, Kigali, Rwanda

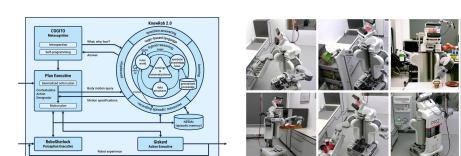
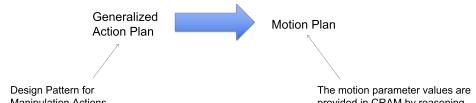
Overview

The goal of this research is to give the CRAM Robot Cognitive Architecture the ability to automatically perform new everyday pick-and-place tasks (Vernon et al., 2021). This is achieved by integrating three schools of thought in cognitive science.

1. The **situation model framework**: composable behavioural episodes, dual process theory (System 1 & 2), working memory, and cognitive maps (Schneider et al., 2020).
2. **Ideo-motor theory**: goal-directed, prospectively-guided action and joint episodic-procedural memory (Stock and Stock, 2004)
3. **Semantically-primed episodic future thinking**: episodic memory is used to imagine future states (Atance and O'Neill, 2001, Schacter et al. 2012)).

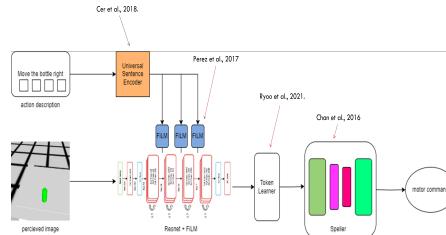
This is achieved using a **deep multi-modal neural network**. This memory produces composable behavioural episodes in the form of the parameters of a CRAM generalized action plan. This allows CRAM to automatically perform new pick-and-place tasks on the basis of **an image of the current scene** (as perceived by the robot) and **a quasi-natural language action description**.

Methodology



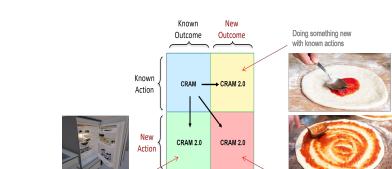
Method

Model

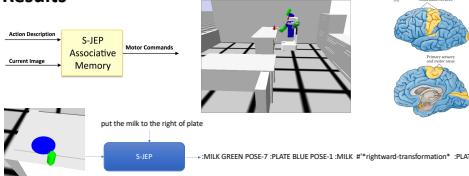


Technique

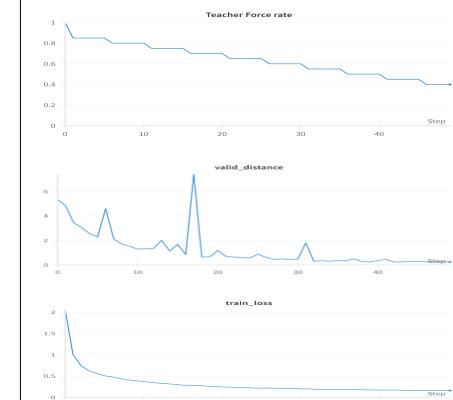
High-Level Action Description → Generalized Action Plan → Motion Plan



Results



Results

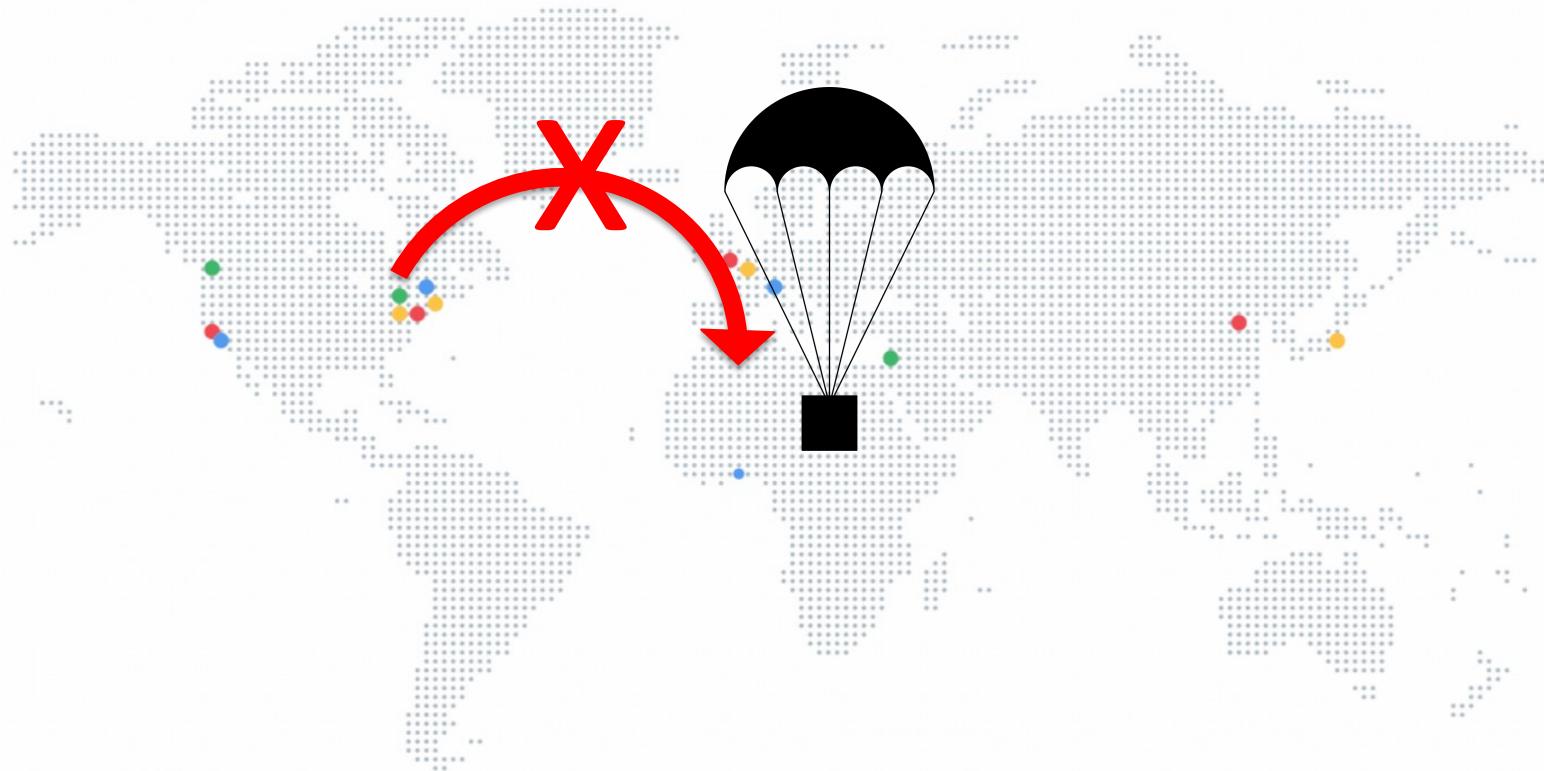


References

- C. M. Atance and D. K. O'Neill, "Episodic future thinking," *Trends in Cognitive Sciences*, vol. 5, no. 12, pp. 533–539, 2001.
- D. Cer, F. Y. Yang, S. yi Kong, N. Hua, N. Limtiaco, R. S. John, N. Constant, M. Guajardo-Cespedes, S. Yuan, C. Tar, Y.-H. Sung, B. Strope, and R. Kurzweil, "Universal sentence encoder," *Vol. abs/1803.11175v2*, 2018.
- W. Chou, J. Li, and J. Gao, "FiLM: Visual reasoning with a general conditioning layer," *CoRR*, vol. abs/1709.07871, 2017.
- M. S. Ryoo, A. Piergiovanni, A. Arbab, M. Deghani, and A. Angelova, "Tokenlearner: Adaptive space-time tokenization for videos," *Neural Information Processing Systems*, 2021.
- D. L. Schacter and D. R. Addis, "The cognitive neuroscience of constructive memory: Remembering the past and imagining the future," *Philosophical Transactions of the Royal Society B*, vol. 362, pp. 773–786, 2007.
- W. X. Schneider, D. R. Addis, and D. M. Altmann, "Remembering the future: A cognitive neuroscience perspective," *ZfB-Mitteilungen*, (1), 21–34, 2020.
- D. L. Schacter, D. R. Addis, D. Hassabis, V. C. Martin, R. N. Spreng, and K. K. Szpunar, "The future of memory: Remembering, imagining, and the brain," *Neuron*, vol. 76, pp. 677–694, 2012.
- A. Stock and C. Stock, "A short history of ideo-motor action," *Psychological research*, 68(2–3):176–188, 2004.
- D. Vernon, J. Albert, M. Beetz, S.-C. Chou, H. Ritter, and W. X. Schneider, "Action Selection and Execution in Everyday Activities: A Cognitive Robotics & Situation Model Perspective," *Topics in Cognitive Science*, pp. 1–19, 2021.

Selected Publications

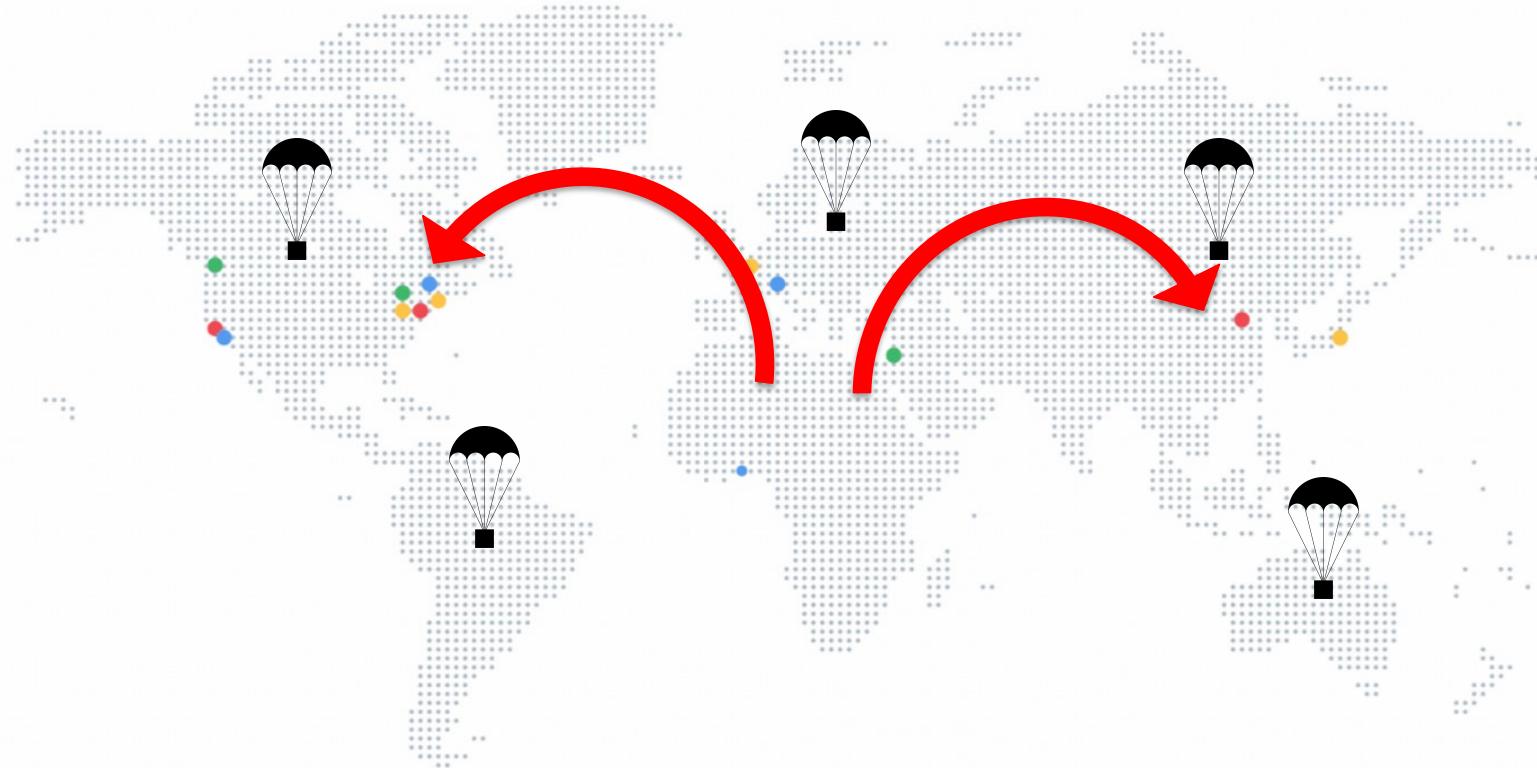
- D. Vernon, "An African Perspective on Culturally Competent Social Robotics: Why DEI Matters in HRI", IEEE Robotics and Automation Magazine, in press.
- D. Vernon and G. Sandini, "The Importance of Being Humanoid", International Journal of Humanoid Robotics, 20th anniversary issue, February, Vol. 21, No. 1, 2024.
- A. Akinade and D. Vernon, Biological Motion for Gestural Communication in Social Robots, accepted for presentation at Robotics in Africa Forum, IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS), Abu Dhabi, UAE, October 17th, 2024.
- E. Birhan and D. Vernon, Surveying Rwandan Cultural Knowledge for Respectful Human-Robot Interaction in Africa, accepted for presentation at Robotics in Africa Forum, IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS), Abu Dhabi, UAE, October 17th, 2024.
- I. O. Jimoh, H. S. Equbay, C. Onyonka, T. Tefferi, and D. Vernon, Behavior Trees for Culturally Sensitive Social Robots: African Culture Case Study, accepted for presentation at Robotics in Africa Forum, IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS), Abu Dhabi, UAE, October 17th, 2024.
- M. Danso and D. Vernon, A Realization of the Situation Model Framework in the CRAM Cognitive Architecture with Deep Learning, accepted for presentation at Robotics in Africa Forum, IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS), Abu Dhabi, UAE, October 17th, 2024.
- A. Akinade, Y. Haile, N. Mutangana, C. Tucker, and D. Vernon, "Culturally Competent Social Robots Target Inclusion in Africa", Science Robotics, 2023.
- P. Zantou and D. Vernon, "Culturally-Sensitive Human-Robot Interaction: A Case Study with the Pepper Humanoid Robot", Proc. IEEE Africon, Nairobi, Kenya, September, 2023.
- P. Zantou and D. Vernon, "Inclusion Drives Sustainable Development: The Case of Social Robotics for Africa", Poster Presentation, ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies - COMPASS, August 2023.
- C. Delmus Alupo, D. Omeiza, and D. Vernon, "Realizing the Potential of AI in Africa: It All Turns on Trust", in Towards Trustworthy Artificial Intelligence Systems, M. I. Aldinhas Ferreira, O. Tokhi eds. Intelligent Systems, Control and Automation: Science and Engineering. Springer, 2022.



<https://www.blog.google/around-the-globe/google-africa/google-ai-ghana/>

https://www.kindpng.com/imgv/iiJhmwR_big-image-png-parachute-clipart-transparent-png/#gal_big-image-png-parachute-clipart-transparent-png_iiJhmwR_1805273.png

Personalization, contextualization, and cultural-sensitivity
are **global concerns** because they underpin **adoption** everywhere



<https://www.blog.google/around-the-globe/google-africa/google-ai-ghana/>

https://www.kindpng.com/imgv/iiJhmwR_big-image-png-parachute-clipart-transparent-png/#gal_big-image-png-parachute-clipart-transparent-png_iiJhmwR_1805273.png

OPINION

An African Perspective on Culturally Competent Social Robotics

Why Diversity, Equity, and Inclusion Matters in Human-Robot Interaction

By David Vernon

Artificial intelligence (AI) and robotics are playing a central role in driving the Fourth Industrial Revolution in Africa, powering the digital transformation of African economies through technological innovation. However, successful innovation requires trust, acceptance, and widespread adoption. In turn, these depend on sociocultural factors. This is particularly true in the case of social robotics, where cultural competence is pivotal for adoption. We provide examples of culture-specific knowledge derived from diverse social and cultural norms in African countries and explain how this impacts social robots if their behavior is to be acceptable. We conclude by unwrapping the concepts of diversity, equity, and inclusion, and we explain how culturally competent social robotics can impact each of these three issues.

SOCIOCULTURAL FACTORS UNDERPIN THE FOURTH INDUSTRIAL REVOLUTION IN AFRICA

AI is having an increasingly positive impact in Africa in many sectors, such as energy, health care, agriculture, public services, and financial services. It has the potential to drive economic growth, development, and democratization, reducing poverty, improving education, supporting health-care delivery, increasing food production, improving the capacity of existing road infrastructure by increasing traffic flow, improving public services, and

improving the quality of life of people with disabilities. AI can empower workers at all skill levels to make them more competitive.

AI forms the foundation of the Fourth Industrial Revolution, Industry 4.0. Countries around the world have prepared AI strategies to ensure they are in the vanguard, leading the revolution. The scope of these strategies is extensive, embracing the research and development necessary to advance AI science and engineering, the strategies for promoting innovation, and the standards required for the ethical use of AI. While most of the effort to develop and exploit AI happens in developed countries, there is increasing awareness of its relevance to developing countries, with some countries, such as Rwanda, creating national AI strategies and hosting a World Economic Forum Center for the Fourth Industrial Revolution (C4IR). (South Africa also hosts a World Economic Forum C4IR.) Africa, a continent comprising 54 countries, launched a 10-year plan in 2022 for the digital transformation of its economies (the Digital Transformation Strategy for Africa, 2020–2030; see [1]).

The Fourth Industrial Revolution and digital transformation require innovation, something that is not as straightforward as it might seem. Rose [1] distinguishes among creativity, invention, and innovation. Creativity can lead to the invention of a novel idea or artifact, but innovation carries the creativity and inventions into wider use: the diffusion of that invention and its widespread adoption, leading to

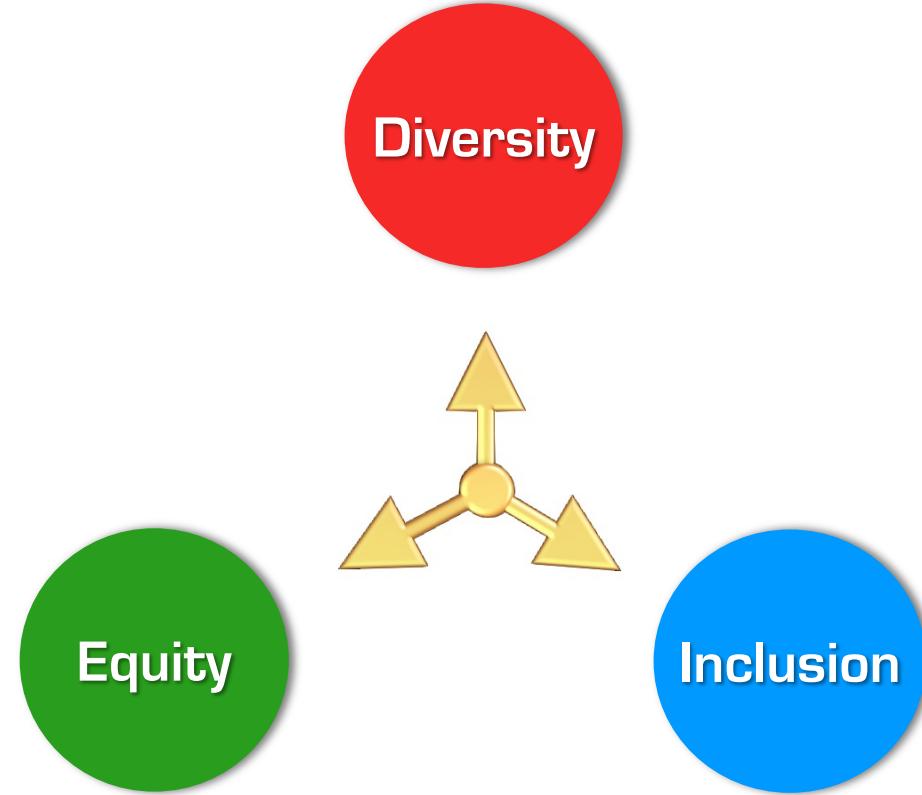
substantial social change in the practices of a community of people. He captures this in an equation: “innovation = invention + exploitation + diffusion,” where the invention is commercially developed; exploited; and, significantly, adopted in a wider community of users.

Successful innovation depends on infrastructure. Rose [1] notes that “infrastructure is the unnoticed precondition for technology innovation.” There are two forms of infrastructure, the physical and the social. The physical infrastructure includes the availability of electrical power, communications networks, or Internet connectivity, something that is taken for granted in developed countries but that cannot always be assumed in developing countries. Of equal importance is social infrastructure, which includes the social conventions that govern people’s behavior and the practices they find acceptable and unacceptable. Social infrastructure heavily impacts whether or not an invention is adopted and becomes an innovation that can yield benefits for the local community. Social infrastructure includes trust and people’s sense of what is trustworthy.

Hoffman et al. [2] define trust as “the expectation that a service will be provided or a commitment will be fulfilled,” emphasizing the importance of expectation in their definition. Expectations are grounded in the sociocultural experience of those whose trust is required. The importance of the cultural context in building trust is emphasized by Lee and See [3]. They define culture as “a set of social norms and expectations that

Digital Object Identifier 10.1109/MRA.2024.3433169

1070-9932/24©2024 IEEE

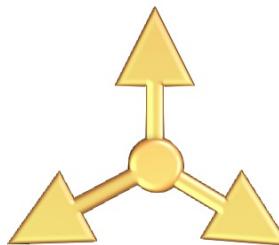


The many **different dimensions** in which people differ & identify

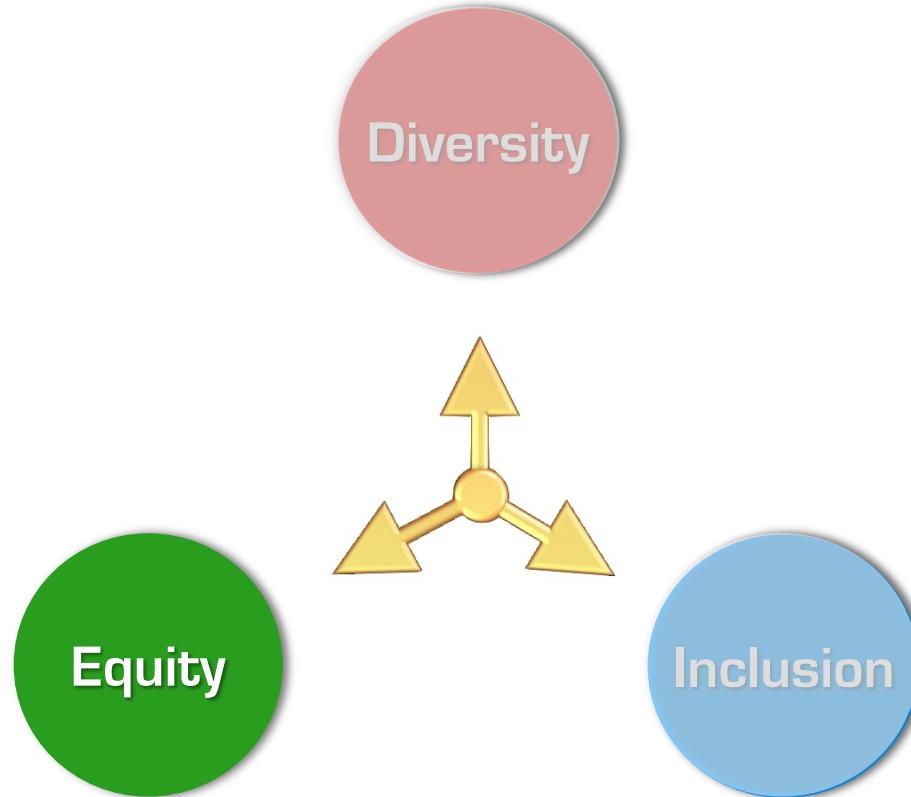
Gender, sexual orientation, race, culture, socio-economic status, traditions, education, age, religious and spiritual beliefs, nationality, ethnicity, experience, physical ability

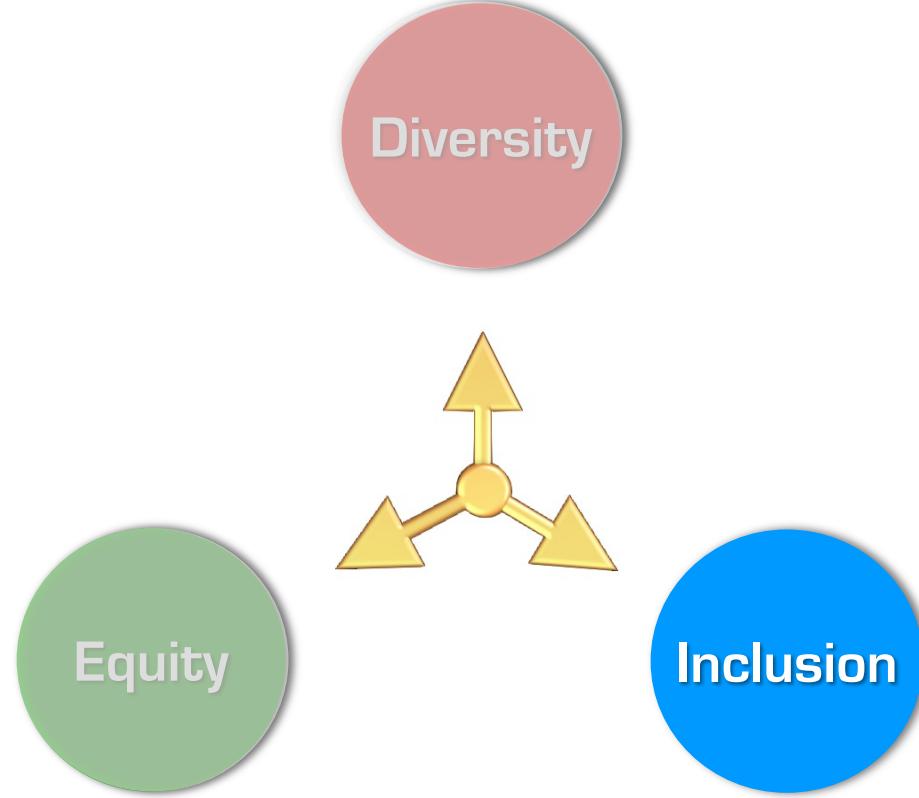


Creates opportunities for greater **mutual understanding** of the contribution that a person of each background can make



It is the act of **empowering**,
the process that leverages the
potential latent in diversity





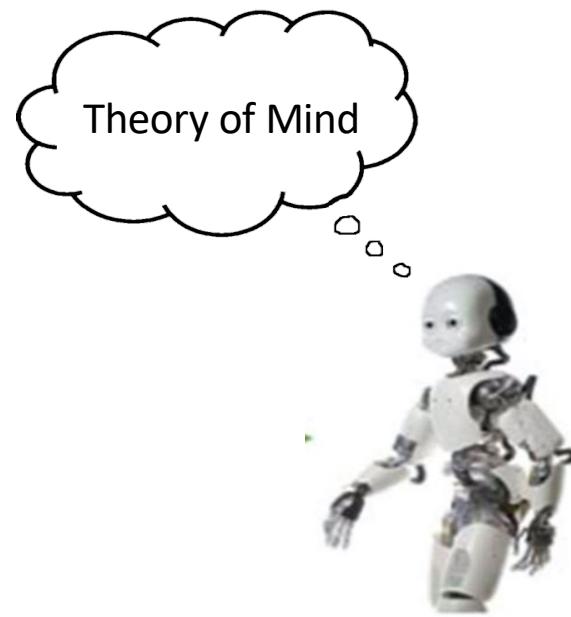
Means that each person feels they **belong** in that environment and that their place is valued

This is achieved by **empathy**

"The highest form of knowledge is **empathy**,
for it requires us to suspend our ego and live in another's world"

George Eliot
Pen name of Mary Ann Evans

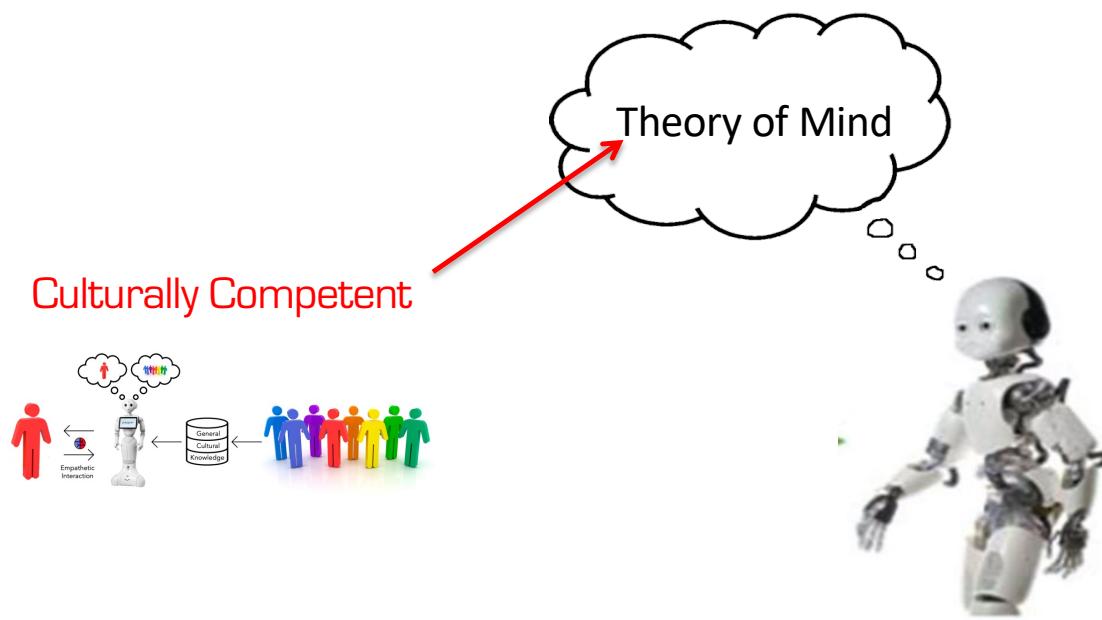
"The highest form of knowledge is **empathy**,
for it requires us to suspend our ego and live in another's world"



George Eliot
Pen name of Mary Ann Evans

"The highest form of knowledge is **empathy**,
for it requires us to suspend our ego and live in another's world"

George Eliot
Pen name of Mary Ann Evans

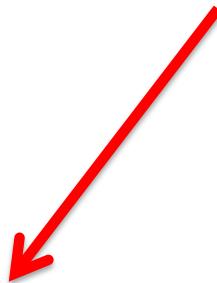


Culturally Competent Social Robotics

Culturally Competent Social Robotics

Motivated by
Polite Interaction

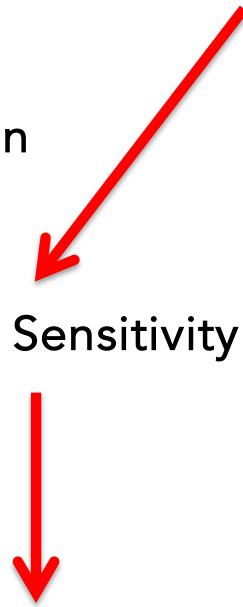
Cultural Sensitivity



Culturally Competent Social Robotics

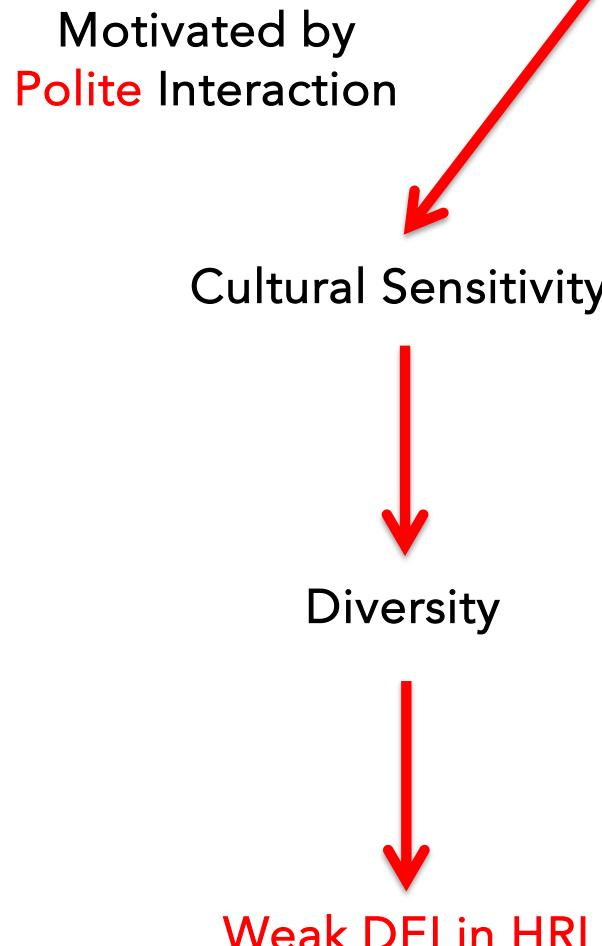
Motivated by
Polite Interaction

Cultural Sensitivity

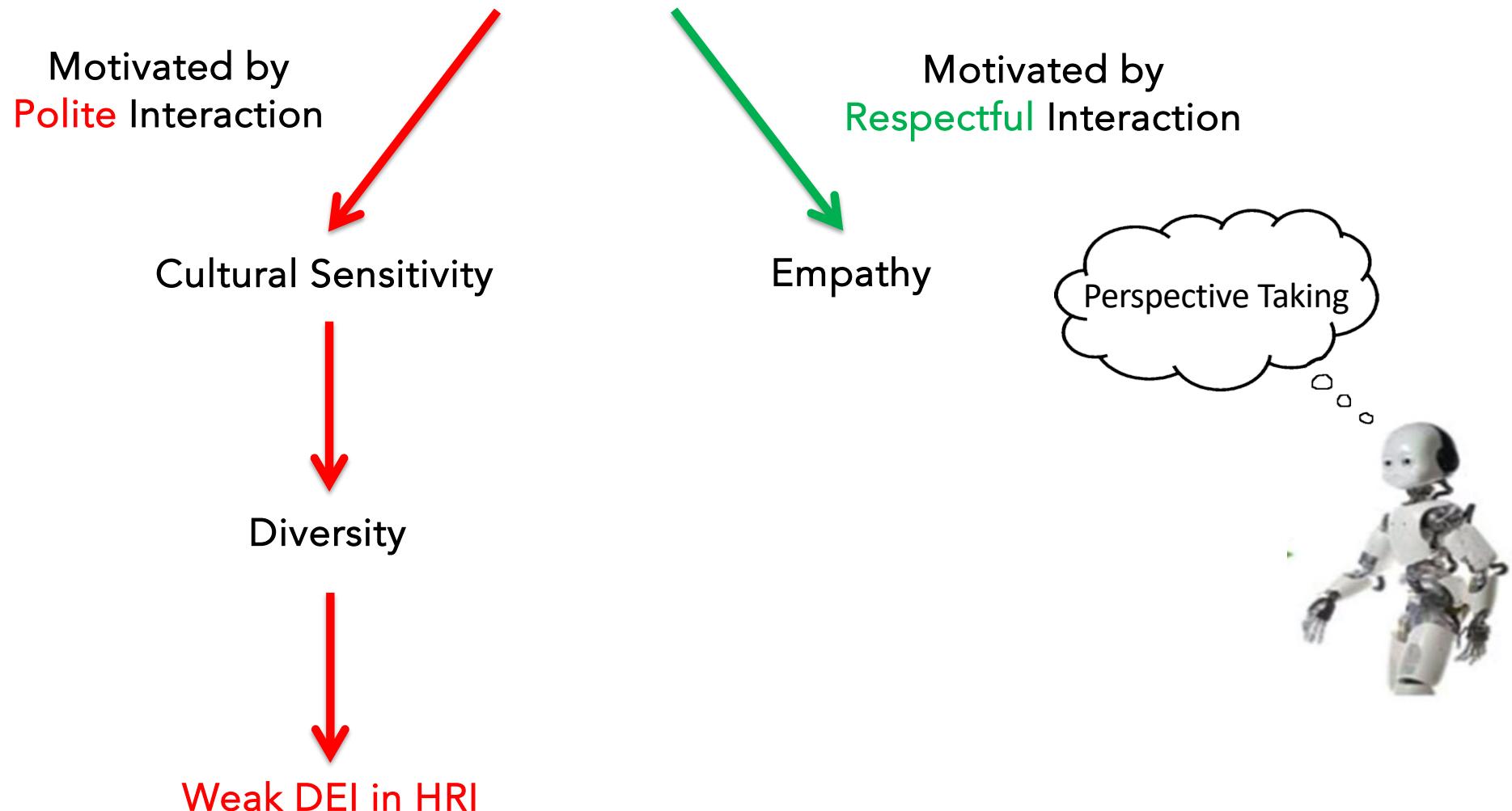


Diversity

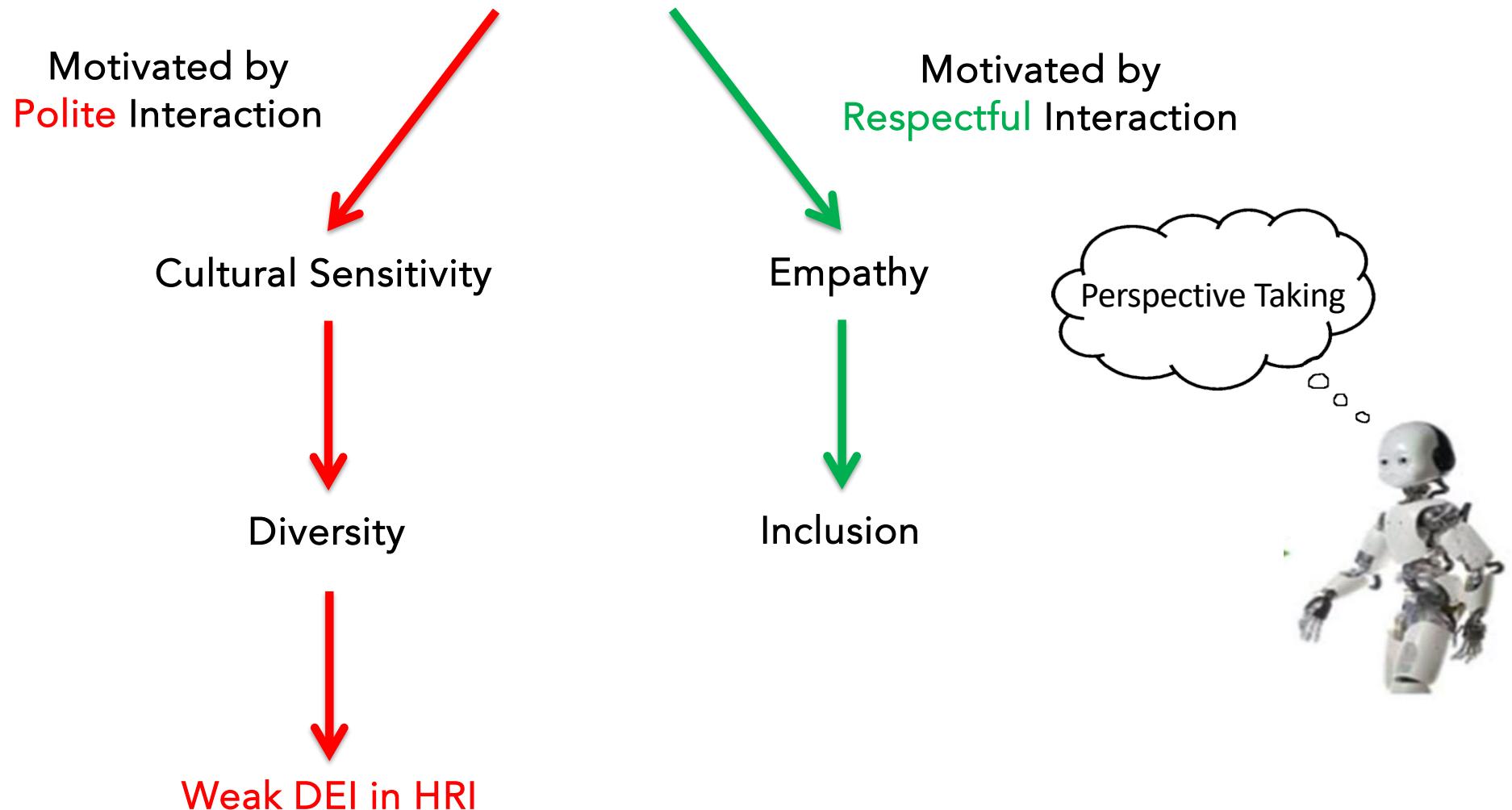
Culturally Competent Social Robotics



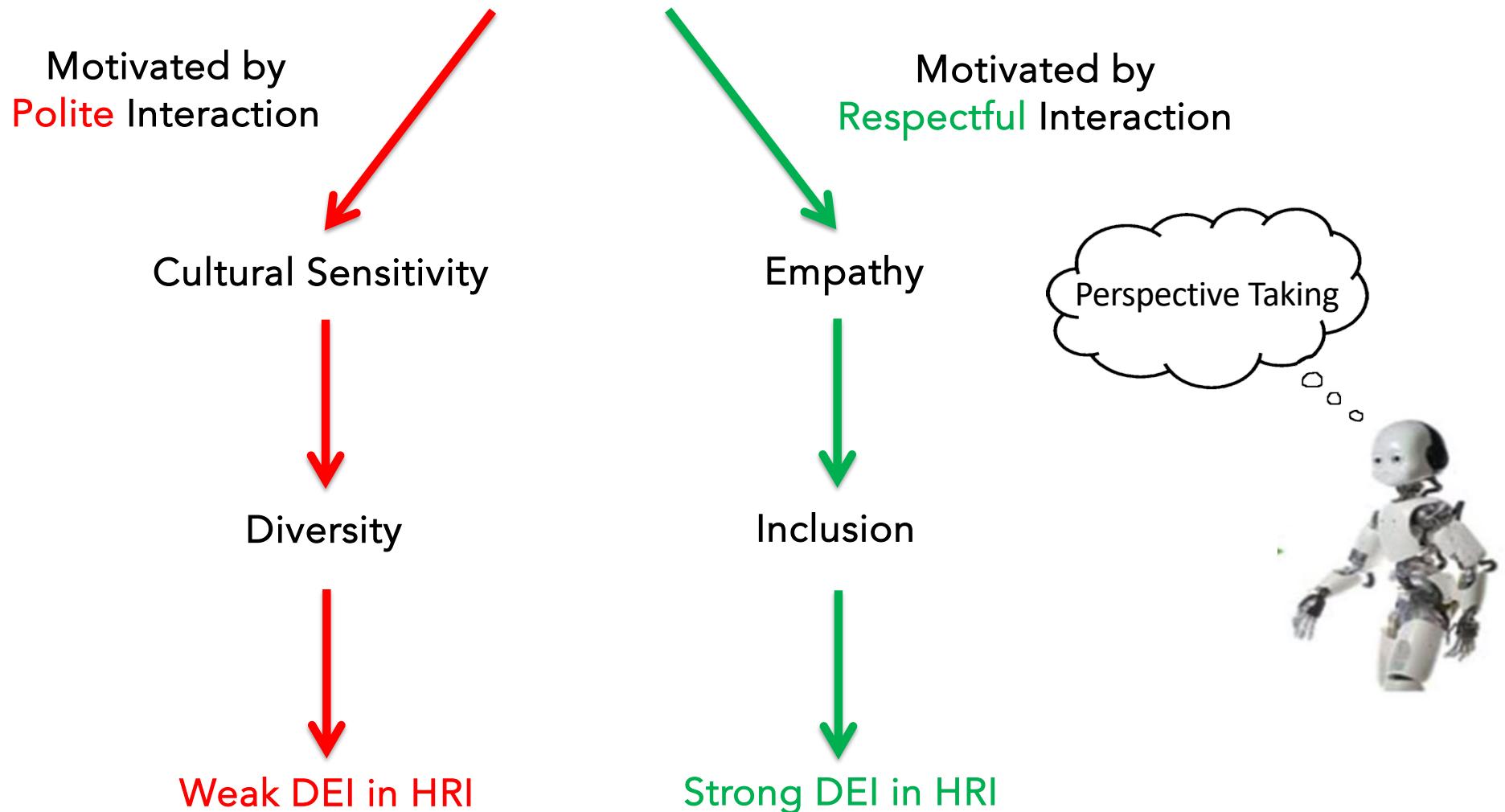
Culturally Competent Social Robotics

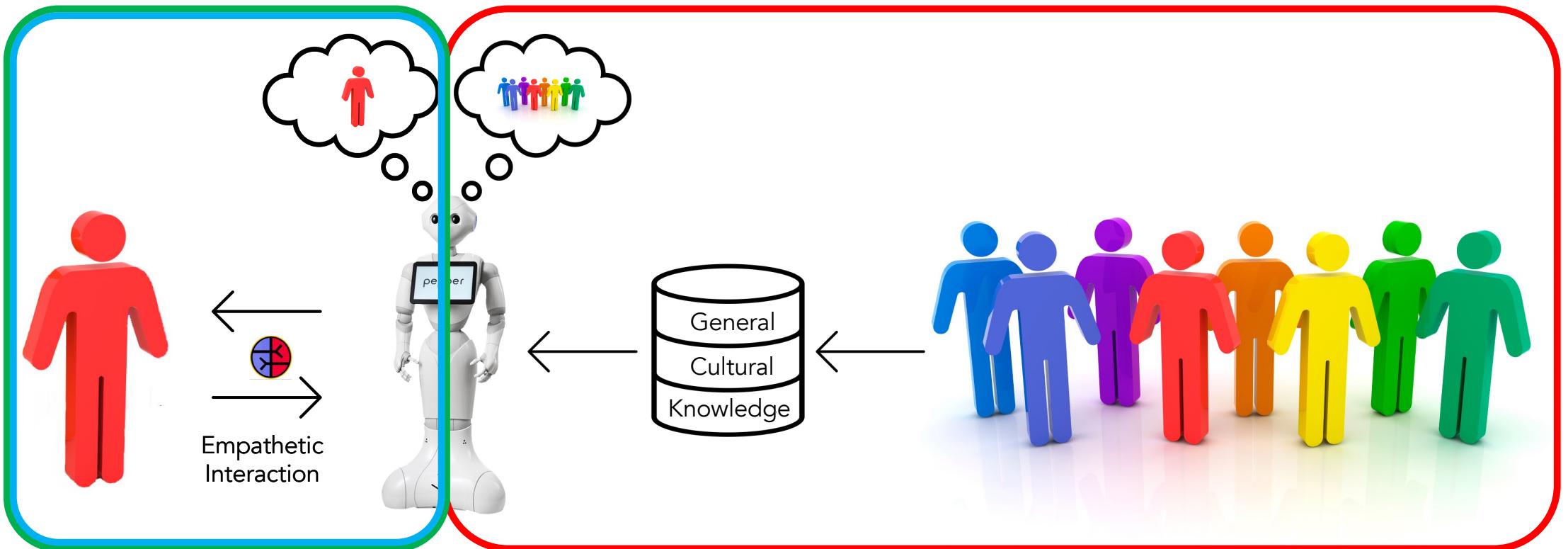


Culturally Competent Social Robotics



Culturally Competent Social Robotics





DEI is an ethical imperative

DEI is an ethical imperative

DEI in HRI empowers the individuals with whom the robots interact
by actively valuing the cultural heritage of those individuals

DEI is an ethical imperative

DEI in HRI empowers the individuals with whom the robots interact
by actively valuing the cultural heritage of those individuals

cf. the message conveyed in the IROS 2024 Opening Ceremony in Abu Dhabi:
The importance of preserving cultural heritage while pursuing technological innovation

<https://www.youtube.com/watch?v=md7YSiNl0aA>

HOME > SCIENCE ROBOTICS > VOL. 9, NO. 97



SCIENCE ROBOTICS

VOLUME 9 | ISSUE 97 | DEC 2024

[< PREVIOUS](#) [ALL ISSUES](#) [NEXT >](#)

ONLINE COVER: Artificial Intelligence—Solving Decision-Making Problems in Dynamical Systems. Autonomous robots need the ability to adaptively make decisions in unstructured and dynamic environments. Rivière *et al.* have now developed Spectral Expansion Tree Search, a real-time space planning algorithm that can construct representations of the real world and converge...

[VIEW MORE](#)

SPECIAL ISSUE

Highlighting diversity, equity, and inclusion in the field of robotics

FOCUS

Black in Robotics: Improving community and equity in the field of robotics

BY MONROE KENNEDY, AYANNA HOWARD • 11 DEC 2024

Black in Robotics thrives on recent successes, but sustained efforts rely on ongoing community participation.

ABSTRACT ▾

Promoting diverse and inclusive spaces with intentionality

BY MARQUISE D. BELL • 04 DEC 2024

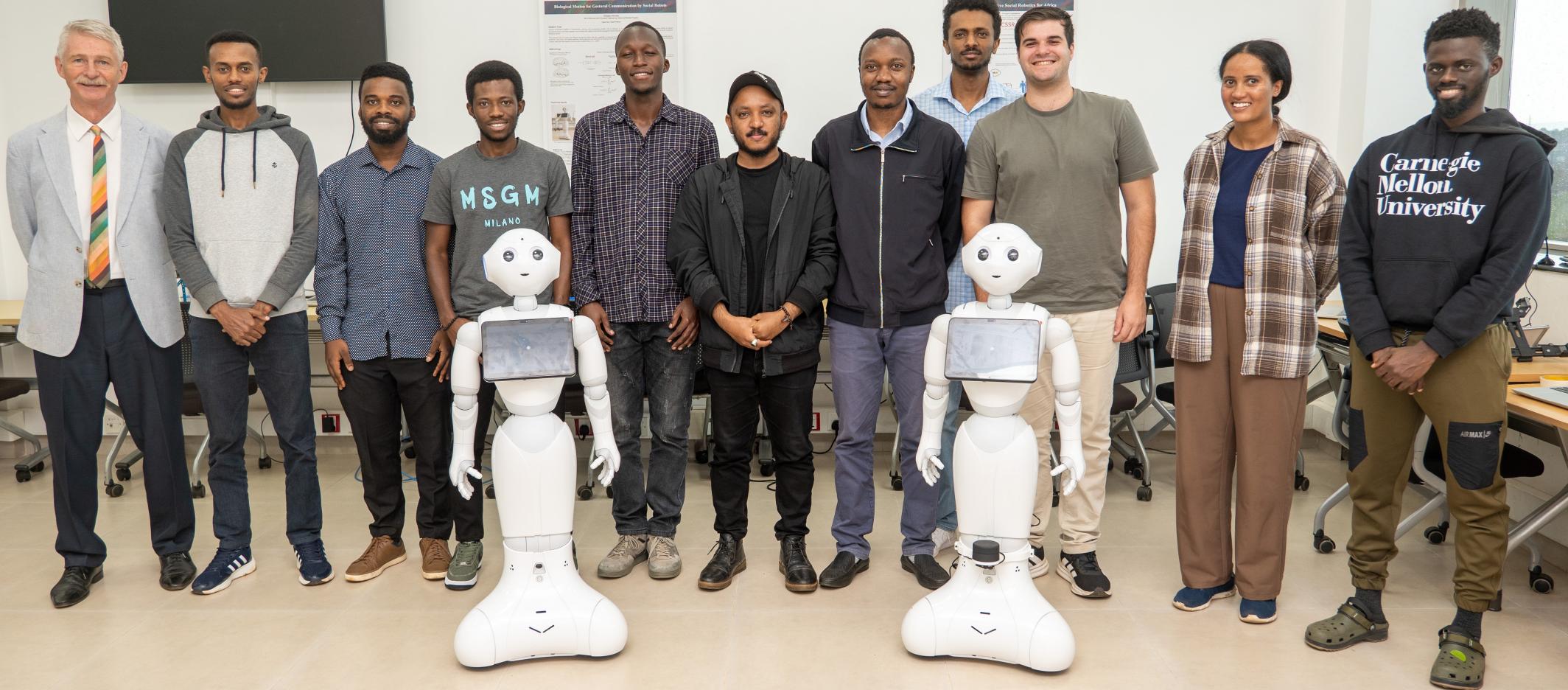
Developing spaces that foster and embrace diverse perspectives and backgrounds with intentionality benefits everyone involved.

<https://www.youtube.com/watch?v=md7YSiNI0aA>



Culturally Sensitive Social Robotics for Africa

www.cssr4africa.org



AI & Robotic Lab

Interns, Research Assistants, and Research Associates

2020 - 2024

Abraham Gebreselasie
Adedayo Akinade
Arisema Mezgebe Mihretu
Birhanu Shimelis Girma
Cedric Manouan
Clifford Osano
Daniel Barros
Denis Musinguzi
Deogratias Amani
Eyerusalem Birhan
Favor Aderinto
Heran Equbay

Ibrahim Jimoh
Kleber Kabanda
Medhn Hadush
Mihiretab Taye Hordofa
Muhammed Danso
Muhiirwa Richard
Natasha Mutangana
Pamely Zantou
Timothy Odonga
Tsegazaeb Taye Tefferi
Yohannes HaileArisema

Thanks to our collaborators

Dr. Pravesh Ranchod & Prof. Benjamin Rosman





This work was carried out as part of the
African Engineering and Technology Network (Afretec)

Afretec is managed by Carnegie Mellon University Africa
and receives financial support from the Mastercard Foundation



THANK
YOU!

Breaking Barriers Through Technology Webinar



26th February 2025

An African Perspective on Culturally Competent Social Robotics: Why DEI Matters in Human-Robot Interaction

David Vernon
Carnegie Mellon University Africa

www.vernon.eu