THE DATA SCARCITY PROBLEM IN UNDERSTANDING OLDER ADULT MOBILITY

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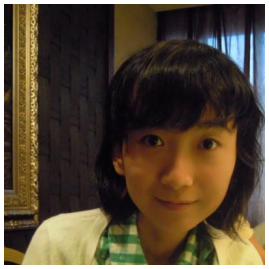
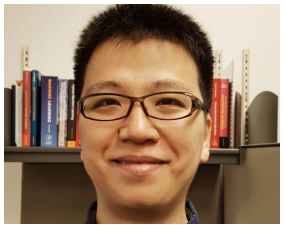
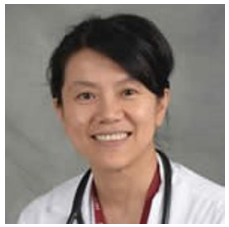
Acknowledgement



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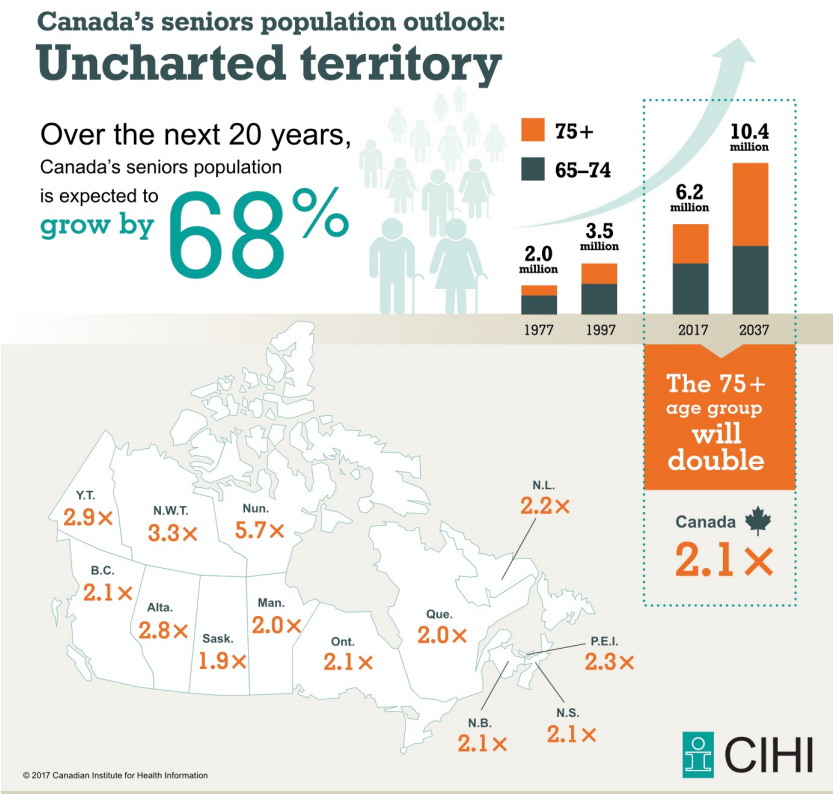
Canada's Aging Population

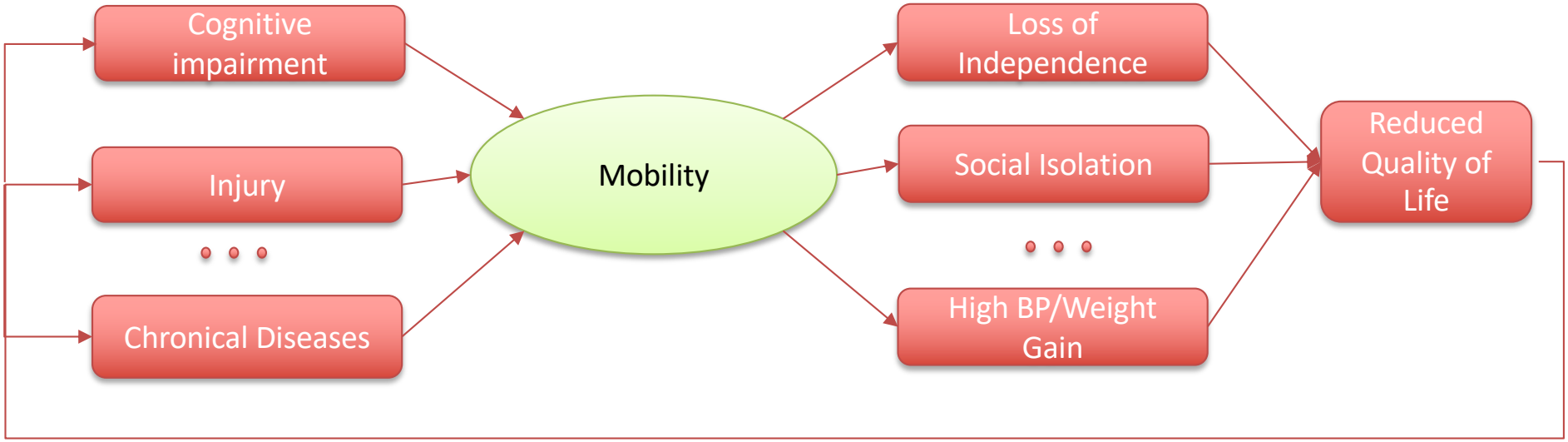


- Older adults (65 years+) will make up over a quarter of Canadian population by 2041
- 90 percent of Canadians aged 65 and over live with at least one chronic disease or condition
- Approximately 20 to 30 percent of Canadian seniors experience at least one fall each year
- In 2011, as many as 747,000 Canadians were living with Alzheimer's or related dementias, and that by 2031, this figure could increase to 1.4 million

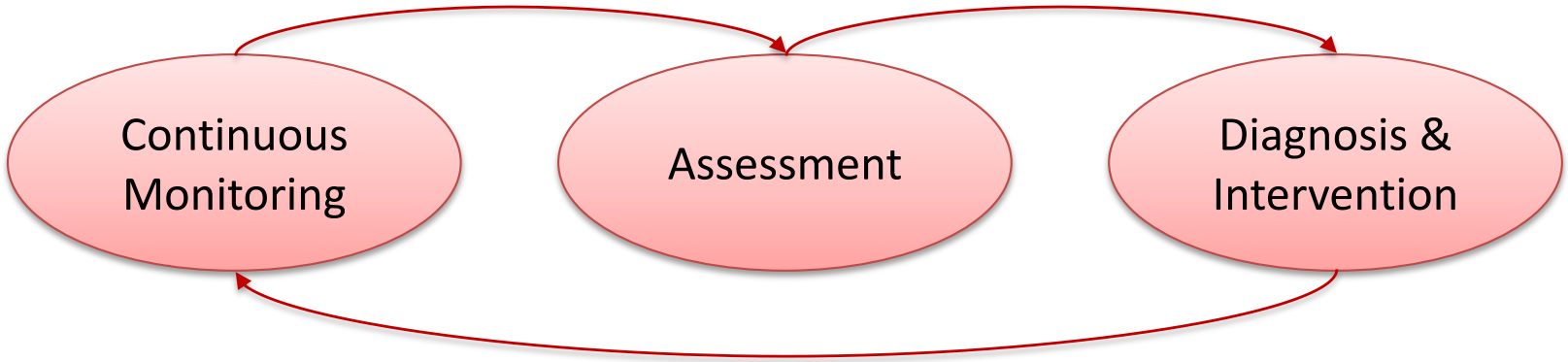
https://www.canada.ca/en/employment-social-development/programs/seniors-action-report.html

Functional Mobility as the Sixth Vital Sign

- What is functional mobility?
  - Movements: walking, climbing stairs, exercising
  - Daily activities: eat, cook, dressing, personal hygiene
  - Participation in society: ability to drive, accessibility to public transportation
- Mobility limitations can lead to adverse outcomes



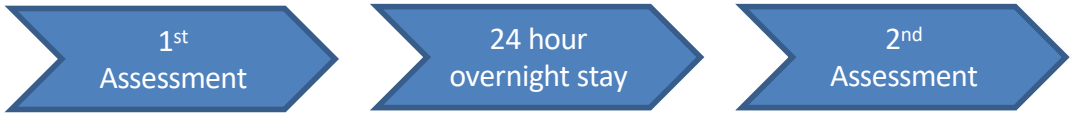
Close the Loop with Human-in-the-Loop



- Monitoring: device cost, availability, placement and adherence
- Assessment: data, modeling and representation
- Intervention: older adults, caregiver, clinicians (and public policies)
- **Training**: the "hammer" mindset and exclusivity of quantitative methods among engineering students

A Case Study: Quantitative Assessment of an Early Mobility Protocol for In-patients

- Cohort: 25 older adults, 17 females (65.4%), with an average age of 79.6 (±8.1), 13 with gait aid (walker, roller, cane)
- Devices: actigraph, mox, fitbit versa, metaware sensor
- Placement: waist, thigh, ankle

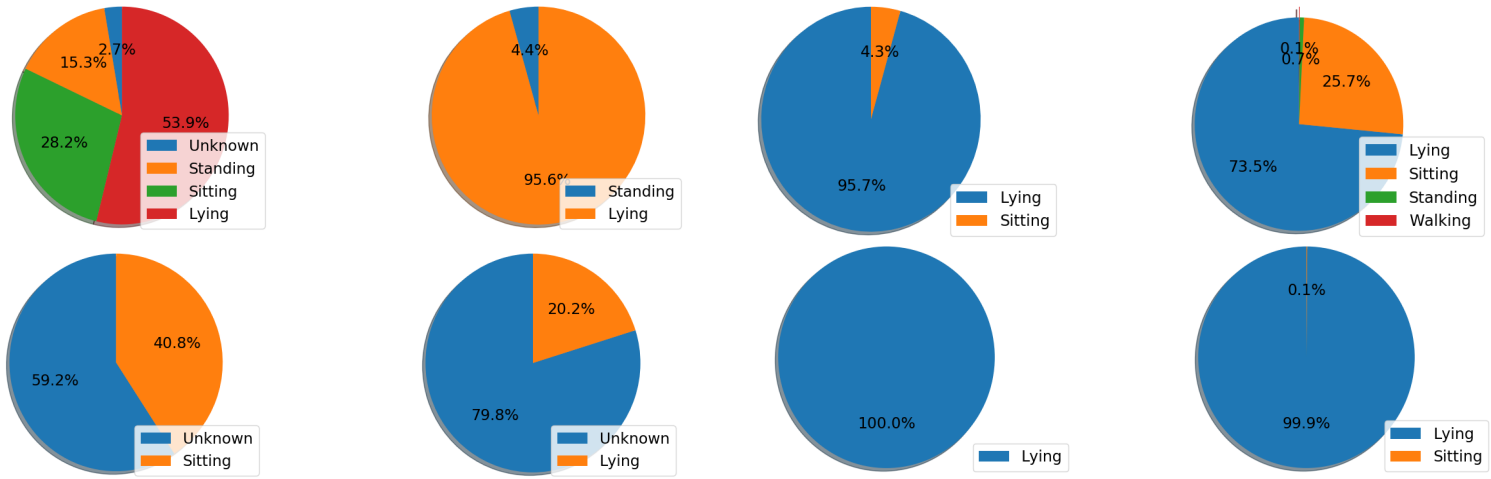


Feasibility Questionnaire	Answers n (%)
Have you ever used a device to measure physical activity in the past?	
Yes	1 (4%)
No	24 (96%)
Would you be willing to wear the device for a longer period, 5 to 7 days, as part of a research study?	
Very Likely	20 (80%)
Somewhat Likely	2 (8%)
Not Likely	3 (12%)
What part of the body would you prefer to wear the device?	
Waist	7 (29%)
Thigh	4 (17)
Ankle	14 (58%)
Which of these devices would you likely use?	
Actigraph	6 (24%)
Mox	4 (12%)
Versa	12 (48%)
MMC	2 (8%)
How easy would it be for you to remember to use the device every day?	
Very easy	10 (43%)
Easy	10 (43%)
Very difficult	1 (4%)
Difficult	2 (9%)
Do you think this device would interfere with your daily routine?	
No effect	16 (70%)
Minor effect	5 (22%)
Major effect	2 (8%)
Would you feel more motivated to move when wearing the device?	
Yes	15 (60%)
No	7 (28%)
No answer	3 (12%)

	Ankle	Thigh	Wrist
Test Accuracy	77.95%	85.71%	72.80%
	Ankle+Wrist	Ankle+Thigh	Wrist+Thigh
Test Accuracy	86.14%	87.93%	87.89%
	Ankle+Thigh+Wrist		
Test Accuracy	91.11%		

Afternoon

Midnight



Sub1 (with walker) Sub2 (independent) Sub1 (with walker) Sub2 (independent)

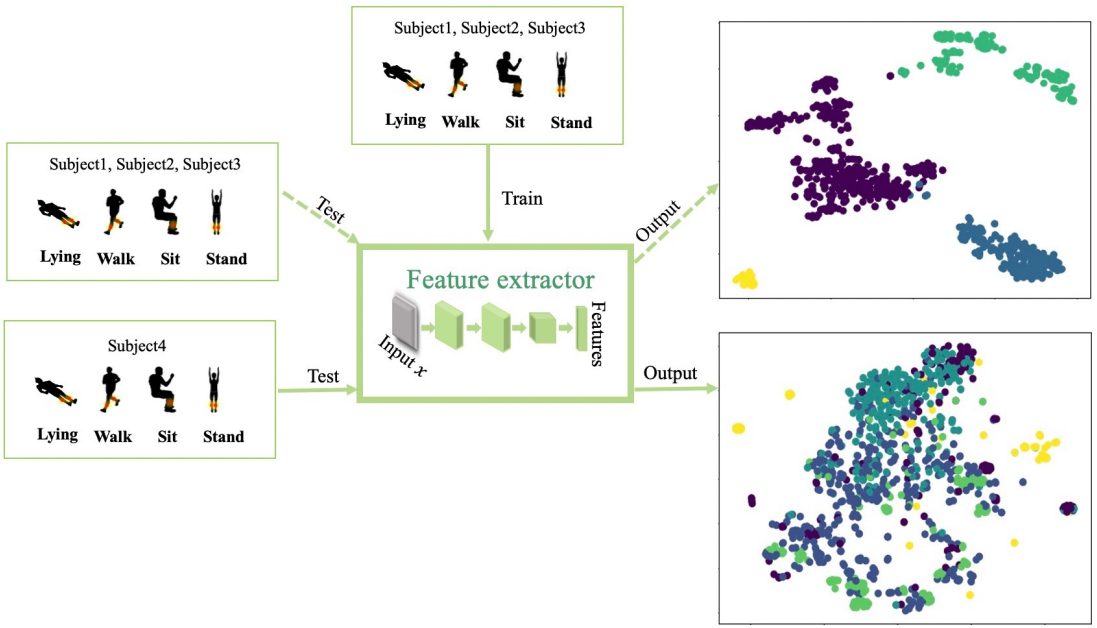
Results from ActiGraph software **Results from our model**

Challenge 1: Data Availability

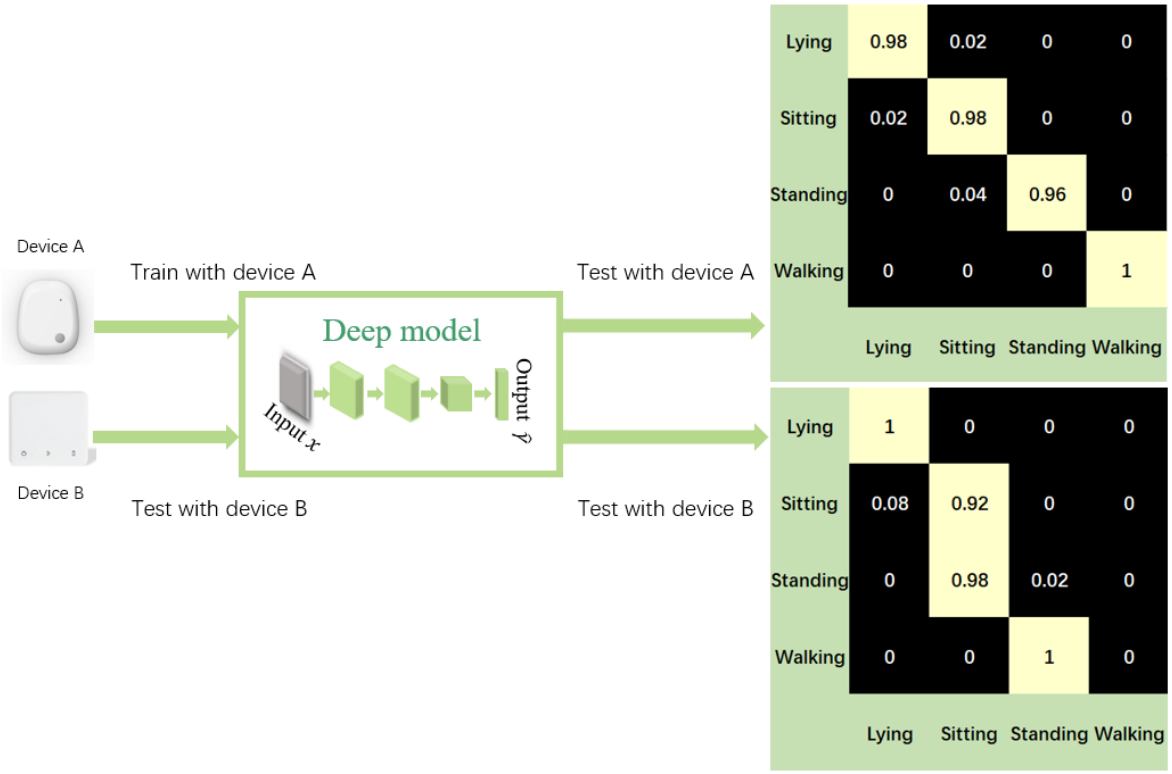
- Human activity recognition datasets with accelerometer/gyroscope measurements

Dataset	Sampling rate	#Sensors	Placement	#Activities	#Subjects	Missing classes	Balanced	Length (in mins)
PAMAP2	100 Hz	1	dominant side's ankle	8	8	Yes	No	31.71
USCHAD	100 Hz	1	right hip	10	14	No	Yes	29.54
WISDM	20 Hz	1	pant pocket	7	51	Yes	Yes	20.80
MobilityAI-PhaseI	50 Hz	4	waist	4	25	Yes	No	15.29
UTD-MHAD	50 Hz	2	right wrist, right thigh	6	9	No	Yes	1.49
WHARF	32 Hz	1	right wrist	7	17	Yes	No	7.78
MHEALTH	50 Hz	2	chest, left ankle	10	10	No	Yes	9.51
RealWorld	50 Hz	7	chest, forearm, head, shin thigh, upperarm, waist	8	15	No	Yes	71.75
MobilityAI-PhaseII	30 Hz	2	wrist+thigh or, wrist+ankle	4	30	No	No	1455.29
ExtraSensory	40 Hz	2	wrist, not fix	6	60	Yes	No	6289.1

Challenge II: Subject Diversity



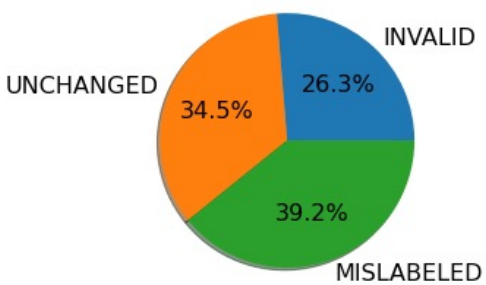
Challenge III – Device Diversity



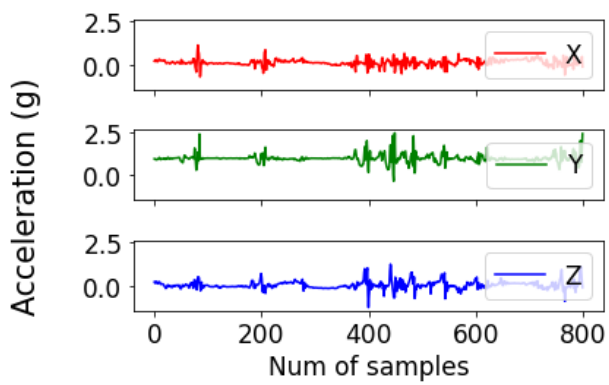
Challenge IV: Controlled vs Free-living

- Interfering activities
- Labelling errors

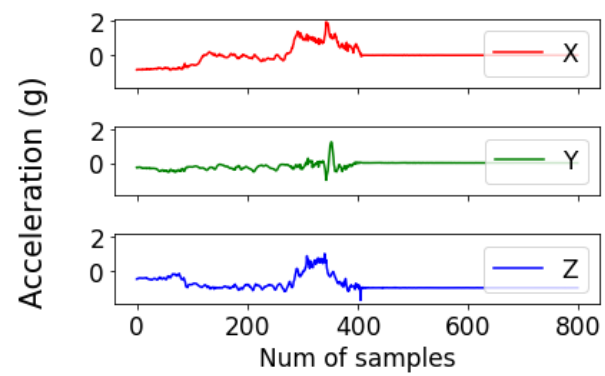
	walking	strolling	cleaning	cooking	eating
walking	75.28%	3.46%	3.46%	2.35%	1.67%
	running	exercise	go upstairs	go downstairs	
running	79.92%	19.66%	0.21%	0.21%	
	standing	cooking	cleaning	shower	dressing
standing	56.79%	8.47%	7.51%	5.35%	5.34%
	at home	at school	at work	at party	at gym
at home	96.71%	1.49%	1.27%	0.27%	0.26%



Extrasensory dataset



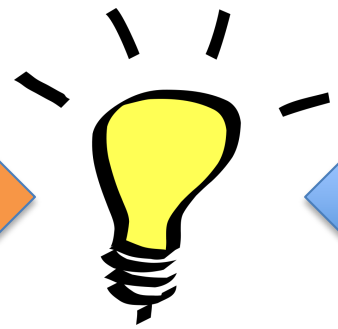
A standing trial



A walking trial

Our Approach

Challenges

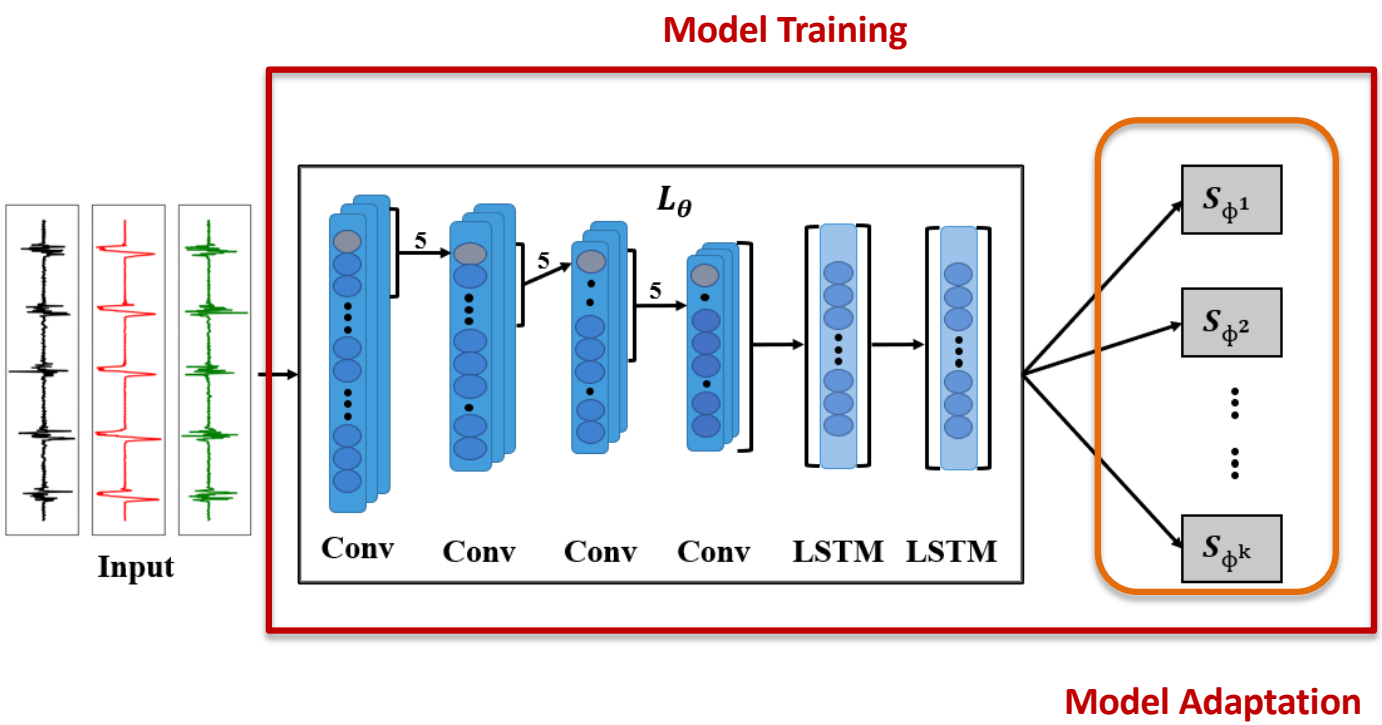


Solutions

- Data Availability
- Subject Diversity
- Device Diversity
- Controlled vs Free-living

- Cross-modality data synthesis
- Invariant feature learning
- Learning with label noise

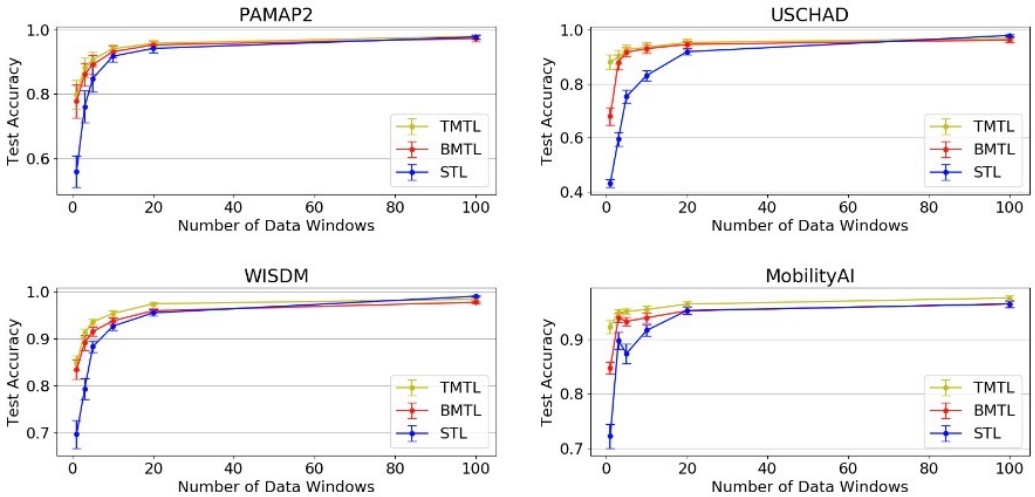
Invariant Feature Learning Framework for Sensor-based Human Activity Recognition

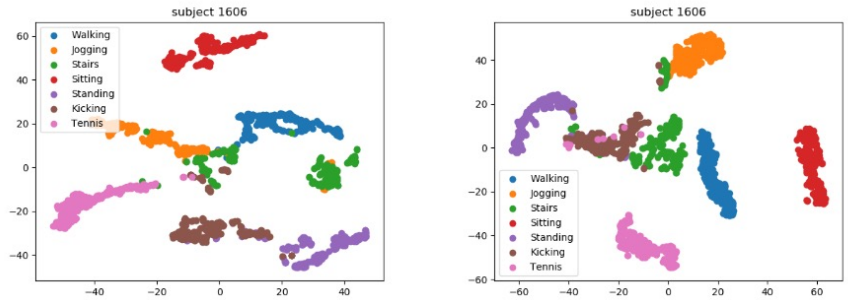


Triplet Multi-Task Learning model (TMTL)

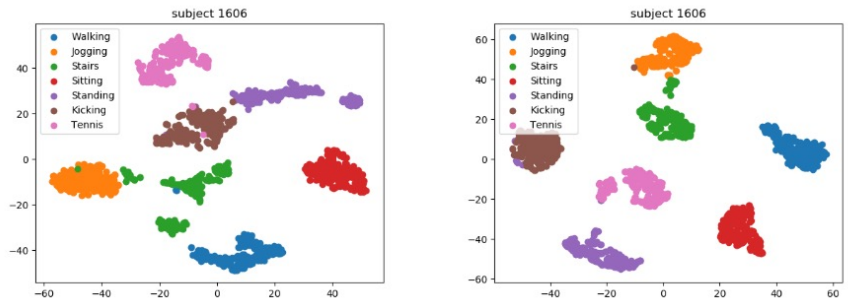
Hao, Yujiao, Rong Zheng, and Boyu Wang. "Invariant Feature Learning for Sensor-based Human Activity Recognition." *IEEE Transactions on Mobile Computing*

Performance





(a) PTM models



(b) BMTL and TMTL model

Evaluation on subject difference across 4 datasets

WISDM dataset

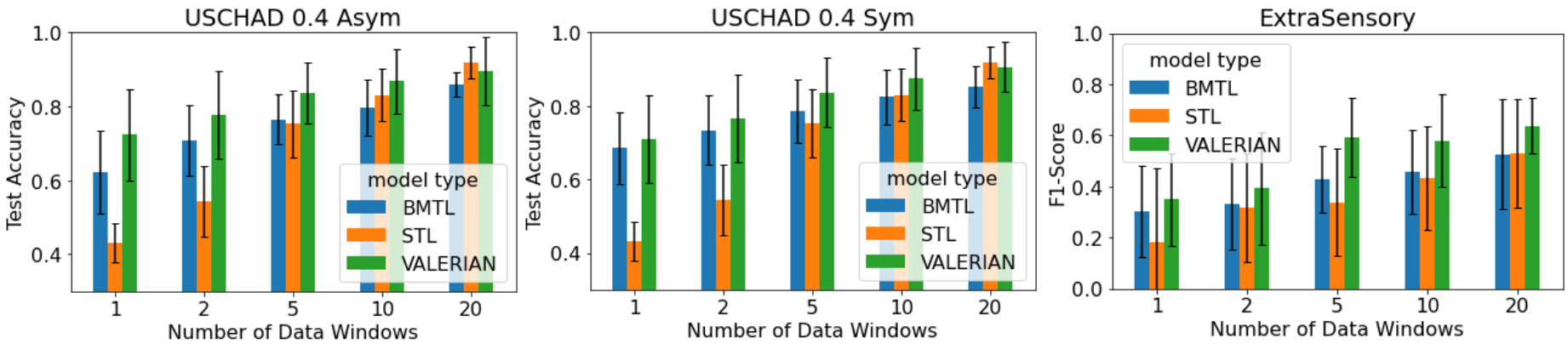
VALERIAN: Invariant Feature Learning for HAR in the Wild

Pretext tasks with unlabeled data:
1) noised 2) negated 3) rotated …

Multi-task meta-learning with early-learning regulation

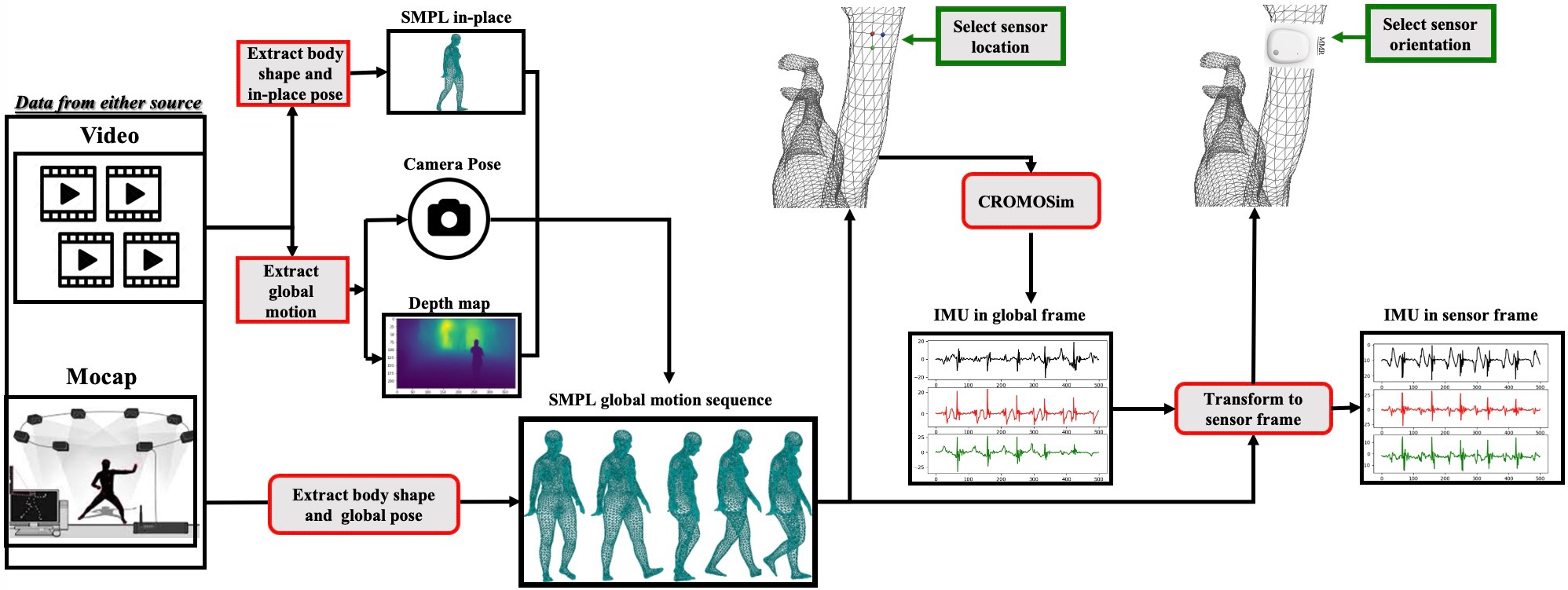
Updating task-specific layer with subject-specific labeled data

Performance



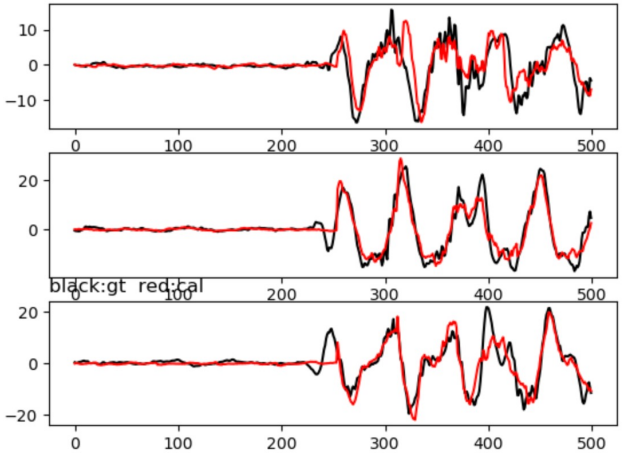
Dataset	USCHAD							
Noise type	Sym.				Asym			
Method/Noise ratio	10%	20%	40%	60%	10%	20%	30%	40%
SI	74.56 ± 14.88	72.1 ± 16.1	69.56 ± 15.89	65.09 ± 15.14	74.26 ± 16.07	73.44 ± 13.57	68.66 ± 13.56	65.35 ± 14.31
SI-ELR-last	30.78 ± 11.86	26.51 ± 9.61	23.49 ± 13.16	15.06 ± 2.93	59.07 ± 30.43	47.97 ± 22.51	27.01 ± 10.47	17.97 ± 4.55
SI-ELR-best	76.31 ± 15.14	71.06 ± 12.42	65.23 ± 8.85	58.28 ± 13.07	77.84 ± 15.41	70.48 ± 17.38	69.71 ± 20.43	58.49 ± 13.17
Butterfly	67.21 ± 22.47	66.34 ± 21.71	67.08 ± 22.11	21.35 ± 6.29	65.14 ± 15.25	52.44 ± 25.51	41.96 ± 28.15	37.89 ± 15.06
VALERIAN	84.83 ± 7.35	85.29 ± 8.44	83.65 ± 9.43	81.99 ± 7.63	85.71 ± 6.65	84.88 ± 8.11	84.81 ± 8.82	83.68 ± 8.18

CHROMSIM: A Deep Learning based IMU Simulation Pipeline



Evaluation

	Acc (m/s^2)		Gyro (rad/s)	
	calculated	CHROMSIM	calculated	CHROMSIM
Mocap extracted SMPL	3.185750689	**2.565089118**	1.617568258	**0.641220011**
Video extracted SMPL	139.8086945	**11.16831555**	6.648809864	**1.218742081**



CHROMSIM video vs GT

Performance on Downstream Tasks

- Human activity recognition
  - R2R: real data (RealWorld) in training
  - V2R: simulated data in training
  - Mix2R: mixture of simulated and real data for training
- Human pose estimation
  - Knee joint angle estimation

	R2R	V2R	Mix2R
IMUTube*	0.730±0.007	0.546±0.008	0.778±0.007
IMUTube	0.729±0.007	0.552±0.005	0.781±0.011
CROMOSim Lite	0.729±0.007	0.580±0.047	0.802 ±0.013
CROMOSim	0.729±0.007	**0.593±0.012**	**0.821±0.003**

	X	Y	Z
R2R	15.4550±0.6217	8.3279±0.4751	3.1384±0.0403
V2R	20.8303±1.2644	**7.7459±0.3409**	3.4441±0.1727
Mix2R	**13.9236±0.5875**	8.2440±0.6053	**3.0355±0.2971**

Smart Mobility on the Aging Population (sMAP)

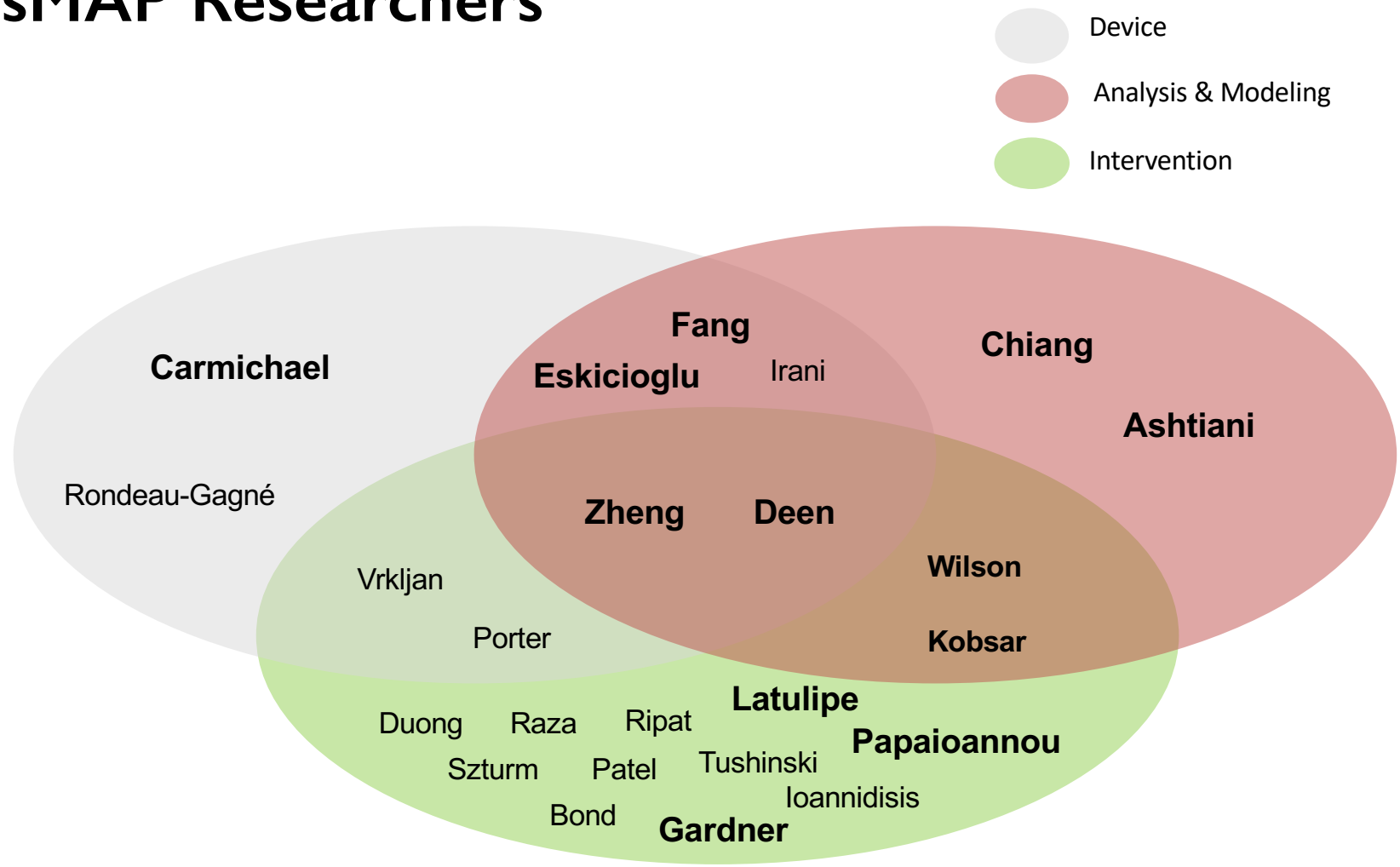
- Funded by NSERC Collaborative Research and Training Experience Program (CREATE) (~1.6M from 2020 to 2027)
  - "*... encourage collaborative and integrative approaches, and address significant scientific challenges associated with Canada's research priorities*"
- Centred around HQP training through the development of translational technologies to address mobility challenges faced by older adults

McMaster University

WINDSOR

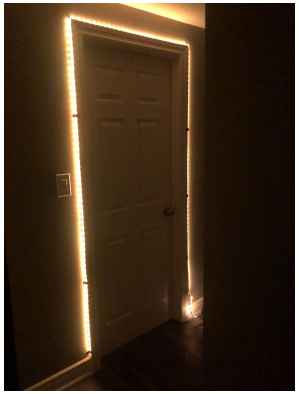
University of Manitoba

sMAP Researchers



Co-design with Older Adults

Smart Pillbox by Monica Malek and Alireza Fathollah Pour



Nightlight system by Ganesh, Jessica Rauchberg, Fiona Madden

Half–full by Andrew Mitchell, Katie Huckson, Zikai dou

Takeaways

The world's most valuable resource is no longer oil, but data

The data economy demands a new approach to antitrust rules

- Severe shortage of mobility data in clinical and free-living settings for older populations
- A multi-pronged approach is needed:
  - Methodology research: data-efficient models, physics and biomechanical simulations
  - Community-wide efforts: open data repository
  - Education
  - Policy and regulations