Automatic analysis of trust over the course of a human-robot interaction using multimodal features and recurrent neural architectures

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Presentation Plan

- Part I : Introduction
- Part II : State of the Art
- Part III : A New Framework
- Part IV : Computational Models of Trust
- Part V : Conclusion and Perspectives

Part I

Introduction

I - Introduction

- The term **robot** was first coined in a play by Karel Capek
  It comes from the slavic word **robota**

- It was used to designate artifical beings that could be mistaken with humans

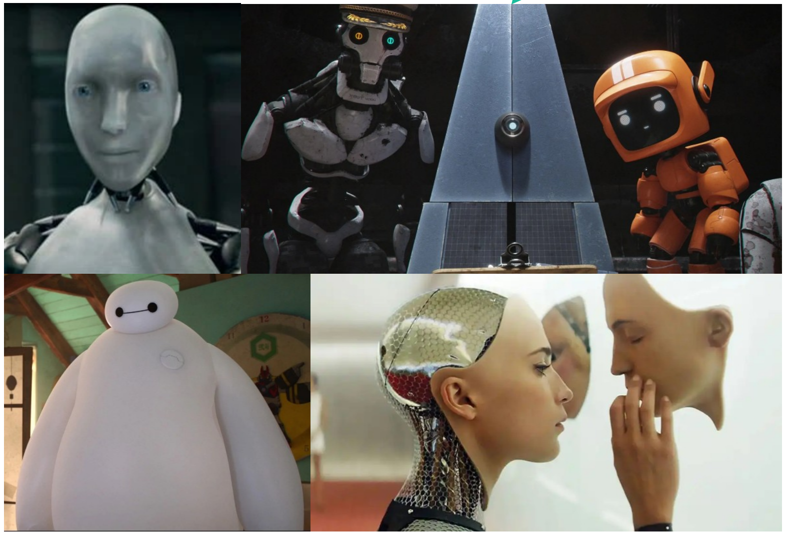
- In the play, robots happily work with humans, but eventually revolt and cause the extinction of the human race

I - Introduction

Media depiction

Discrepencies

Reality



- Autonomy
- Technical skills
- Social skills
- Emotionnal expressivity

User acceptance ?

Trust ?

Mori M, MacDorman KF (2012) The uncanny valley [from the field]. IEEE Robot Autom Mag 19:98–100

I - Introduction

What is Trust ?

Rousseau's definition :

« **psychological state** comprising the intention to accept **vulnerability** based upon **positive expectations** of the intentions or behavior of another »

- Too little trust (**undertrust)** → disuse
- Too much trust (**overtrust**) → potentially dangerous use

Denise M Rousseau et al. "Not So Different After All : a Cross-Discipline View of Trust". In: Academy of Management Review 23.3 (1998), pp. 393–404

I - Introduction

Trust has an impact on robot's acceptance and task performance

Trust should be monitored during the interaction

How to measure and model trust ?

John D Lee and Katrina A See. "Trust in automation: Designing for appropriate reliance Human Factors". In: Human Factors 46.1 (2004), pp. 50–80

I - Introduction

Trust is mostly measured through questionnaires filled by **users themselves** at the **beginning** and **end** of an interaction :

- Interpersonal Trust Scale (Rotter et al. 1967)
- Negative Attitude towards the Robot Scale (Syrdal et al. 2009)
- Trust Perception Scale - HRI (Schaefer 2016)
- Godspeed questionnaire (Bartneck et al. 2009)

Trust can also be measured through proxy measures (e.g . distance)

I - Introduction

- RQ 1: Which theoretical framework is applicable to perform a multimodal analysis of trust regularly throughout the interaction ?
- RQ 2: Do homogeneous segments of trust arise within the interaction based on observable behavioral cues ?
- RQ 3: How can we discriminate trusting segments from mistrusting ones with tangible behavioral cues ?

Part II

State of the art

II – State of the art

Definitions

- Bickmore et al. (2011)

« a process of uncertainty reduction, the ultimate goal of which is to reinforce assumptions about a partner's dependability with actual evidence from the partner's behavior »

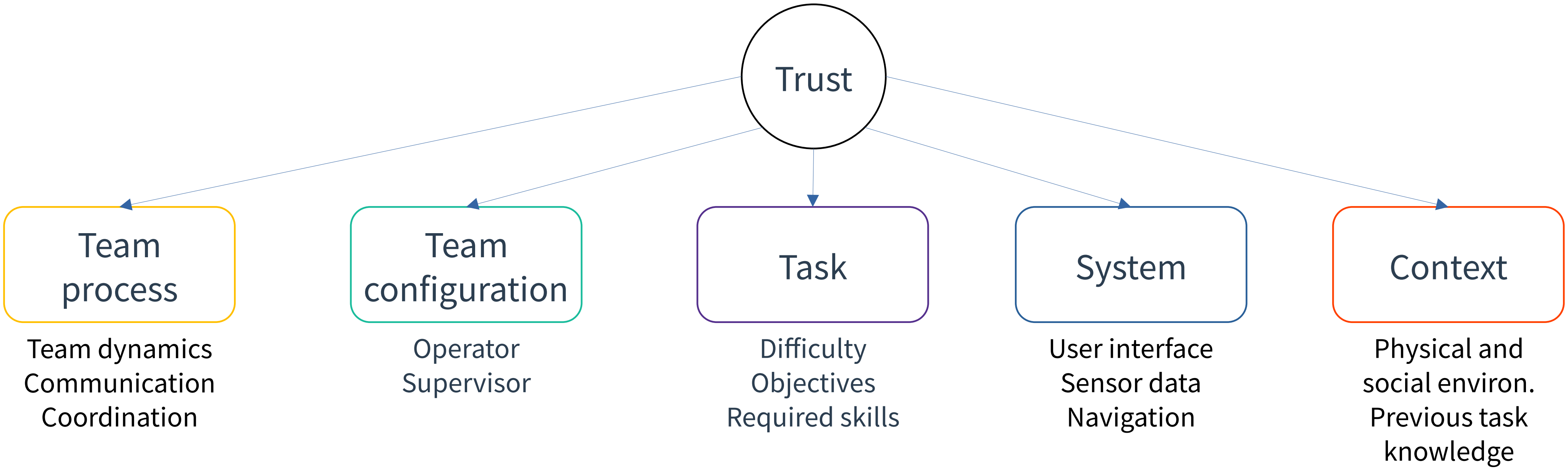
<u>Observation of the robot's :</u>
Technical skills
Social skills
Integrity
Benevolence

<u>Uncertainty about the robot's :</u>
Technical skills
Social skills
Integrity
Benevolence

Past ← → Future

II – State of the art

Models



Rosemarie E. Yagoda and Douglas J. Gillan. “You Want Me to Trust a ROBOT? The Development of a Human-Robot Interaction Trust Scale”. In: International Journal of Social Robotics 4 (3 2012), pp. 235–248

Measures

Trust is mostly measured through questionnaires :

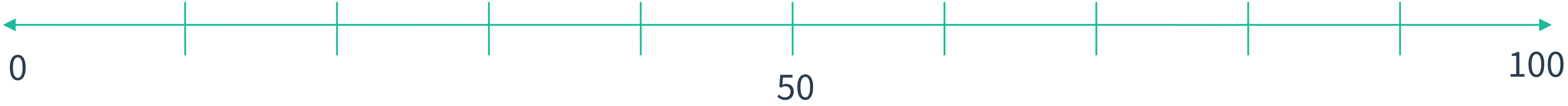
- ~~Interpersonal Trust Scale (ITS)~~ Used for human-human interaction
- Godspeed questionnaire Not a direct trust measure but all items have an impact on trust
- Negative Attitude towards the Robot Scale (NARS)
- Trust Perception Scale – HRI (TPS)

Questionnaires were used to determine trust antecedents and correlates

Trust Perception Scale - HRI

11-Likert scale

« What % of the time will the robot … »



Have errors	Provide appropriate information	Be unresponsive	Malfunction	Communicate with people	Provide feedback	Function successfully
Act consistently	Be reliable	Be predictable	Be dependable	Meet the needs of the mission	Perform exactly as instructed	Follow directions

* reduced to its 14 items

Each item is a **projection** of one of the robot's capabilities **given past interactions**

Schaefer, K. E. (2016). Measuring trust in human robot interactions: Development of the "trust perception scale-HRI." In Robust Intelligence and Trust in Autonomous Systems (pp. 191–218). Springer US.

Pros	Cons
• Direct measure of the participant's perception of the robot • Comprehensive list of items	• Only participants themselves can fill the questionnaires • Subjective interpretation of items • Time-consuming • Requires interrupting the interaction • Discrepancy between what participants think and how they behave

Automatic trust analysis methods

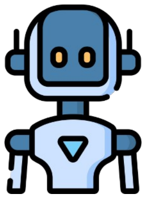
Very few multimodal computational of trust in HRI

- Previous studies mostly focused how the robot’s behavior impacts participants’ trust
- Behavioral studies focused on the robot’s behaviors and not the participants
- Continuous measures of trust are scarce

II – State of the art

Automatic trust analysis methods

Prisonner’s Dilemma



Interaction for 5 minutes then exchange coins. Can keep or give a certain amount. The other receives double of what is given.

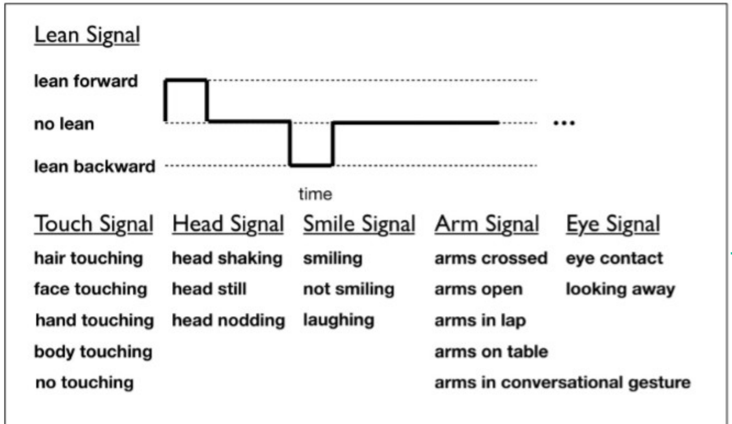
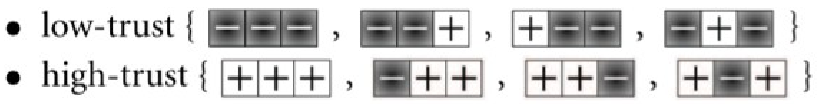


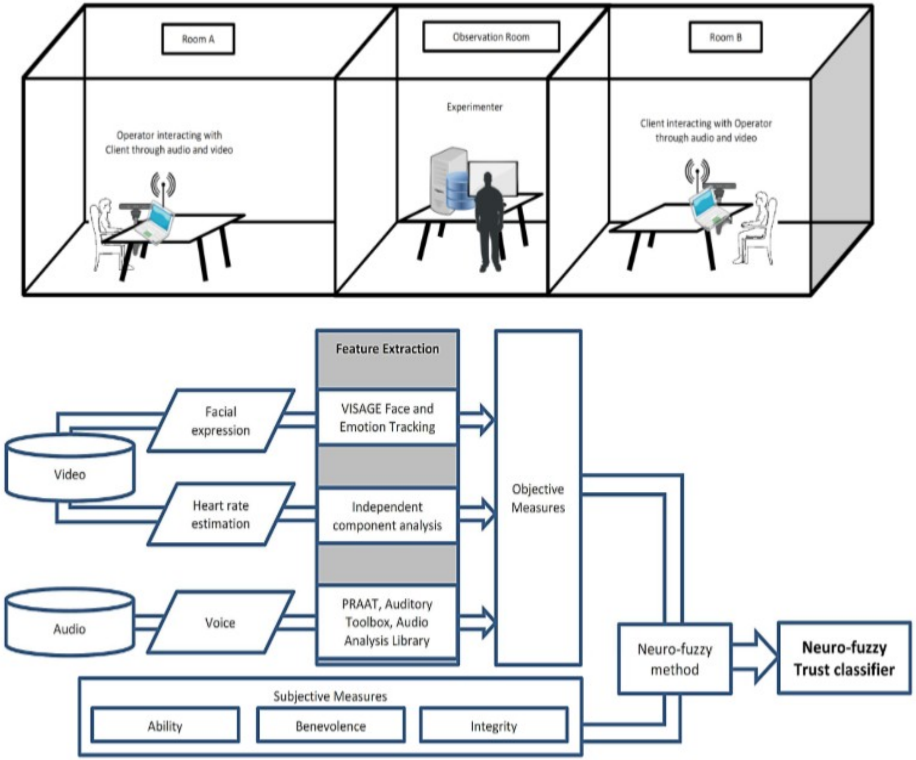
FIGURE 3 | Annotated nonverbal behaviors of participants. Gestures within a category are mutually exclusive.

Hidden Markov Models



Jin Joo Lee et al. “Computationally modeling interpersonal trust”. In: Frontiers in Psychology 4 (2013).

Automatic trust analysis methods



Significant contributors for trust estimation

Facial Expression	Sad, Anger, Fear
Heart Rate	RRV-Min, RRV-Mean, LF/HF ratio, RRI-Range, RRI-Mean, RRV-Median, RRVDistr-Median, RRI-Median, RRVDistr-Range, RRVDistr-Max
Voice	MeanVoicePower, VoicePitch-Range, Formants-Range, StdSpectralCentroid, VoicePitch-Min, VoiceRatio, VoiceFreq-Peak, Formants-Std, VoicePitch-Std, VoicePitch-Max, Formants-Min, Formants-Max, StdByMeanZeroCrossing, TeagerWave-Mean, StdEnergyEntropy, TeagerWaveFreq-Mean, VoicePitch-Mean
Misc. Information	Ethnicity, Attribute

Halimahtun M. Khalid et al. “Exploring Psycho-Physiological Correlates to Trust: Implications for Human-Robot-Human Interaction”. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting 60.1 (2016), pp. 697–701

Takebacks

- Trust should be analyzed in a multimodal fashion
- Some specific behaviors are indicative of a certain type of trust
- Facial expressions and vocal descriptors play an important role in trust prediction

Part III

A New Framework

III – A New Framework

Paradigm Shift

Trust is a result of the state of the interaction, and is oriented towards both the content and the format of the interaction, defined as :

“form of affiliation and credit characterized by a set of behaviors that are intentional or not, expressive or propositional”

- Alignment
- Affiliation
- Credit
- Competence

M. Hulcelle, G. Varni, N. Rollet and C. Clavel, “TURIN: A coding system for Trust in hUman Robot INteraction,” 2021 9th International Conference on Affective Computingand Intelligent Interaction (ACII), Nara, Japan, 2021, pp. 1-8

Paradigm Shift

Interactional Trust relates to the ecological validity of the robot as an autonomous agent during a social interaction

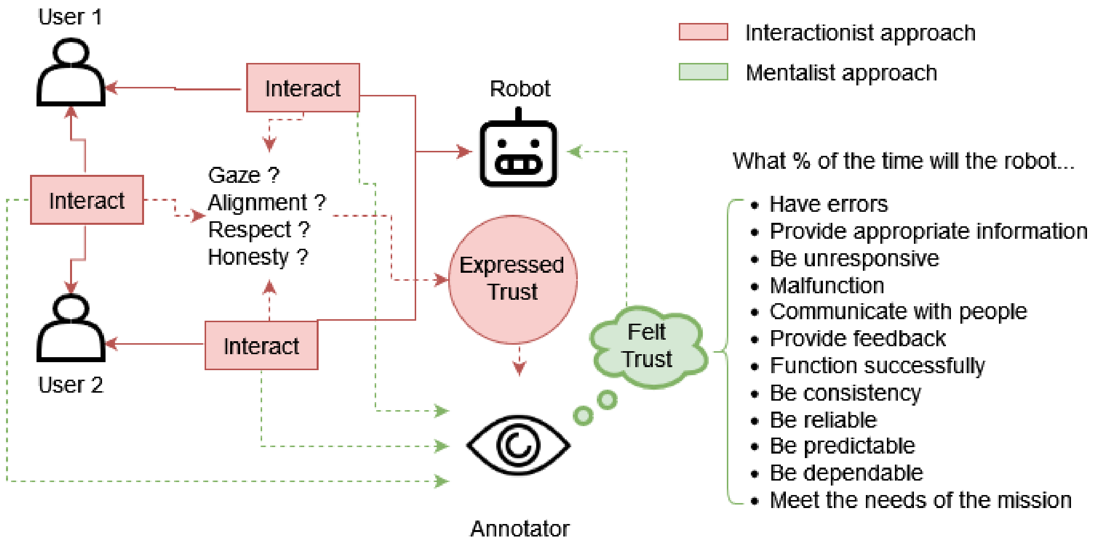
It is thus observable at different bases :
- the robot's capacity to maintain a fluid and progressive interaction
- its skill in accomplishing a specific action at a given moment
- its knowledge

❌ No pre-observation assumption that should be validated with post-analysis statistical tests.

➡ The observer determines the relevance of each participant's action in relation to trust, and to the interaction's history and context.

Paradigm Shift

Difference between trust expressed through behaviors and trust felt by participants



M. Hulcelle, G. Varni, N. Rollet and C. Clavel, "Comparing a Mentalist and an Interactionist Approach for Trust Analysis in Human-Robot Interaction," International Conference on Human-Agent Interaction (HAI '23), 2023, Gothenburg, Sweden

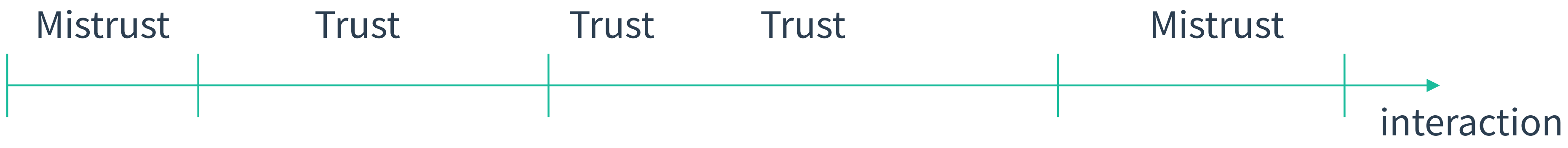
III – A New Framework

Coding Scheme

Coding scheme for Trust in hUman Robot INteraction (TURIN)

Segmentation situated in the interaction dynamics :

- Start at the single behavioral act
- Acts referring to changes in behavior should be assigned to a trust category
- Consecutive acts of the same category are aggregated



Coding Scheme

Coding scheme for Trust in hUman Robot INteraction (TURIN)

Trust

Trusting

- Display of naturalness, fluidity of the interaction
- Vulnerability acceptance
- Friendliness display
- Acknowledging the partner's competence

Mistrusting

- Uneasiness
- Doubt / confusion
- Aggressiveness
- Unwillingness to cooperate

Neutral

Behaviors that are inconclusive

M. Hulcelle, G. Varni, N. Rollet and C. Clavel, "TURIN: A coding system for Trust in hUman Robot INteraction," 2021 9th International Conference on Affective Computingand Intelligent Interaction (ACII), Nara, Japan, 2021, pp. 1-8

Coding Scheme

Coding scheme for Trust in hUman Robot INteraction (TURIN)

Trust

Gaze ?
Intonation ?

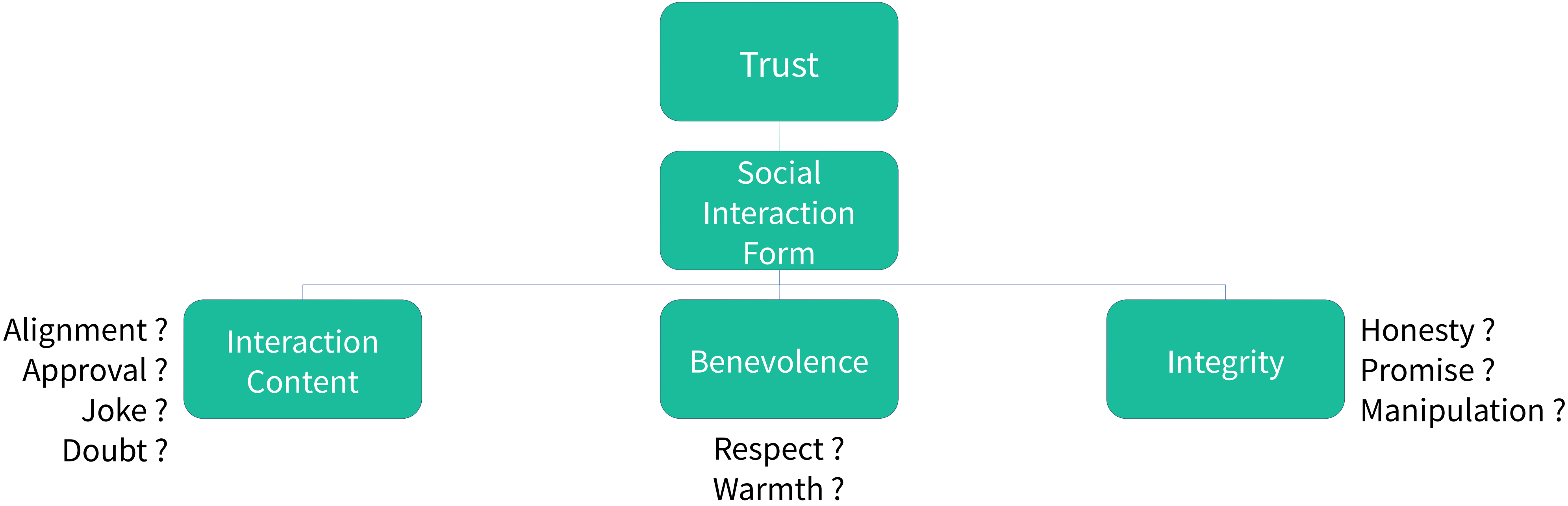
Social Interaction Form

F-formation ?
Speaking turn ?

M. Hulcelle, G. Varni, N. Rollet and C. Clavel, “TURIN: A coding system for Trust in hUman Robot INteraction,” 2021 9th International Conference on Affective Computingand Intelligent Interaction (ACII), Nara, Japan, 2021, pp. 1-8

Coding Scheme

Coding scheme for Trust in hUman Robot INteraction (TURIN)

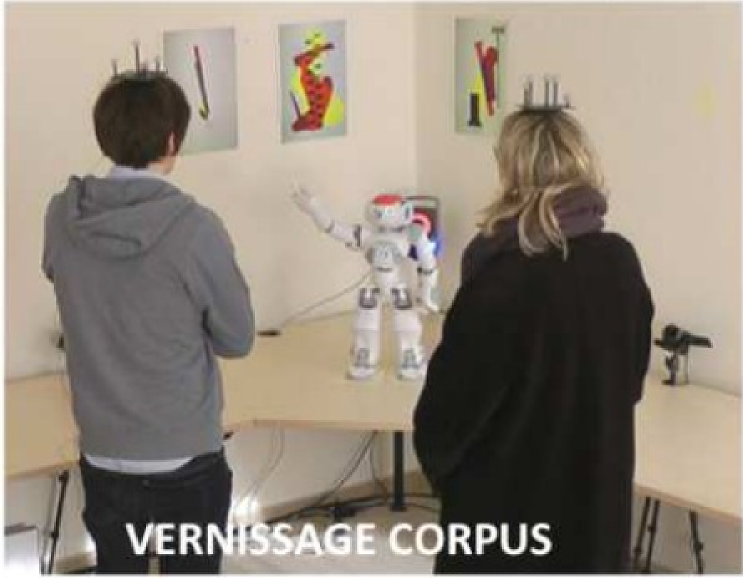


Roger C Mayer, James H Davis, and F David Schoorman. “An integrative model of organizational trust”. In: Academy of Management Review 20.3 (1995), pp. 709–735
Erving Goffman. "The presentation of self in everyday life. 1959." Garden City, NY 259 (2002).

Coding Scheme

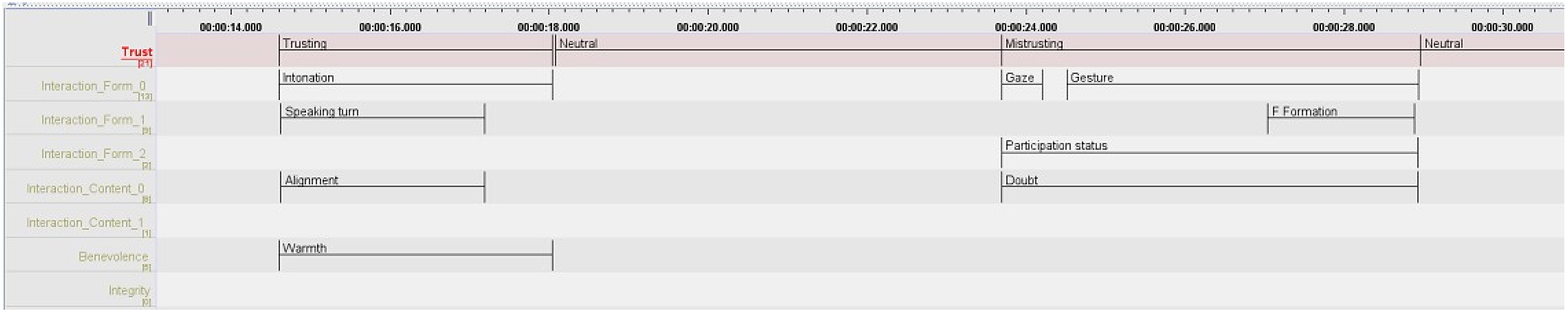
Vernissage corpus

- 10 interactions
  - Quick introduction
  - Vernissage
  - Self-presentation
  - Art quizz
- Recordings
  - Video from 3 different angles
  - Audio for each participant and robot
  - Head pose and rotation



Validation of the corpus :

- Two expert annotators
- Annotated the 1st minute of 3 interactions
- ELAN software



Trusting example

Mistrusting example

Peter Wittenburg et al. "ELAN: A professional framework for multimodality research". In: 5th international conference on language resources and evaluation (LREC 2006). 2006, pp. 1556–1559.

Coding Scheme

Segment category	IRA (κ)	Mean duration (s)	Std (s)
Mistrusting	0.79	4.6	2.2
Trusting	0.64	2.1	1.5
Neutral	0.45	4.7	4.6

- Easier to recognize errors and disfluencies in the interaction
- Neutral segments are considerably longer → more disagreement within
- Segments are short
  - Focus on behavioral changes for the unitizing
  - Beginning of interaction : trust needs to be calibrated

Jacob Cohen. “A coefficient of agreement for nominal scales”. In: Educational and psychological measurement 20.1 (1960), pp. 37–46

III – A New Framework

RQ 1: Which theoretical framework is applicable to perform a multimodal analysis of trust regularly throughout the interaction ?

- Interactionist Sociology theories through their inductive methods
- We conceived a coding scheme TURIN that can unveil trust dynamics through the observation of participants' behaviors

III – A New Framework

RQ 2: Do homogeneous segments of trust arise within the interaction based on observable behavioral cues ?

We proposed a segmentation method based on the observation of behavioral cues that indicate trust and highlights homogeneous segments of trust.

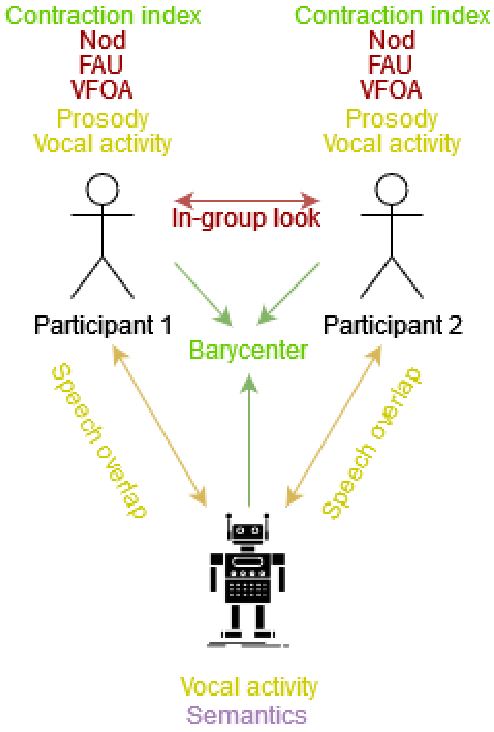
Part IV

Computational Models of Trust

Feature Design and Extraction

Features extracted from 4 different modalities :

Body, Face, Voice, Semantics



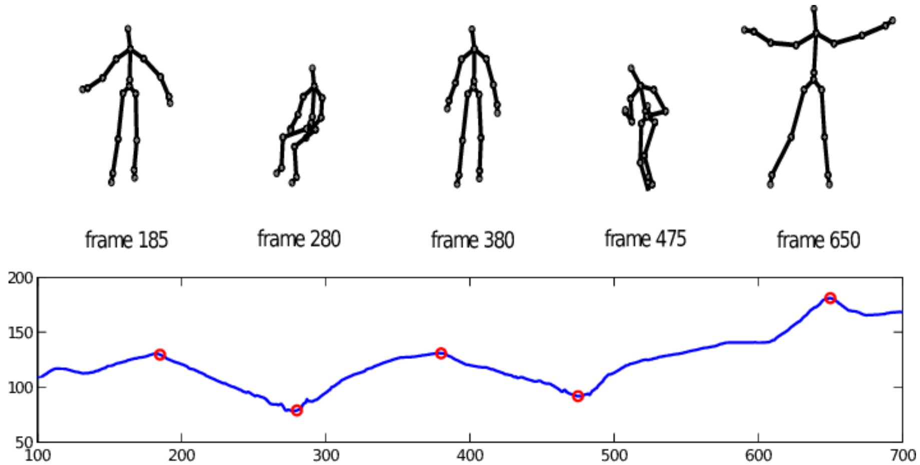
- Aggregate within a segment using the mean and standard deviation for continuous values
- Vector length of 222 :
  68 for each user, 79 for the robot, 3 for the dyads, and 4 for the triad

Automatic extraction   Manual extraction

Hulcelle, M., Varni, G., Rollet, N., Clavel, C. (2023). "Computational Multimodal Models of Users' Interactional Trust in Multiparty Human-Robot Interaction". In: Rousseau, JJ., Kapralos, B. (eds) Pattern Recognition, Computer Vision, and Image Processing. ICPR 2022 International Workshops and Challenges. ICPR 2022. Lecture Notes in Computer Science, vol 13643. Springer, Cham.

Body modality

- Contraction index : ratio between the area of a body's silhouette and its bounding box
- Barycenter of the group and kept the 2D point projected on the floor plane



Contraction index

IV – Computational Models of Trust

Feature Design and Extraction

Face Modality

<u>Nod :</u> time % within segment

<u>Facial Action Units :</u> activation value

<u>Visual Focus Of Attention :</u> binary indicator

left painting, central painting, right painting, Nao, other human, other, unclear

<u>In-group look :</u> time % within segment

Voice modality

- Vocal activity : binary indicator
  speech, silence, laughter
- Prosody :
  F0, F0', loudness, jitter, shimmer, spectral flux, first 4 MFCCs and their derivative
- Speech overlap : time % within segment

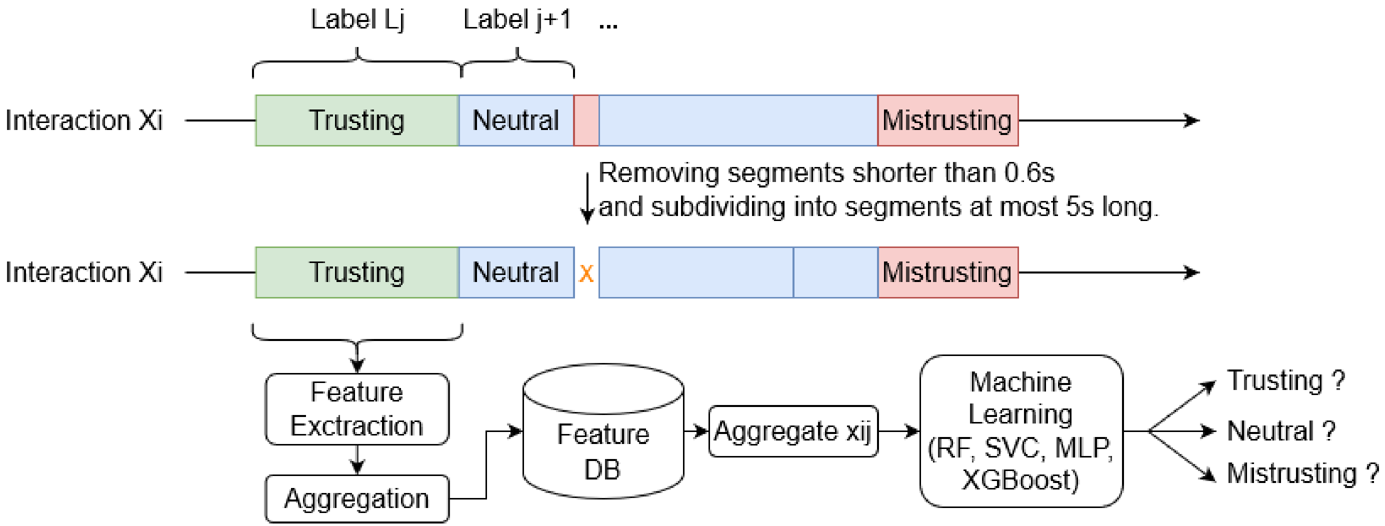
Semantics

Extracted with a TinyBERT : vector size 312

- PCA to reduce to vector size of 50 (99 % explainable variance)
- Propagate semantics in silent segments from previous one

IV – Computational Models of Trust

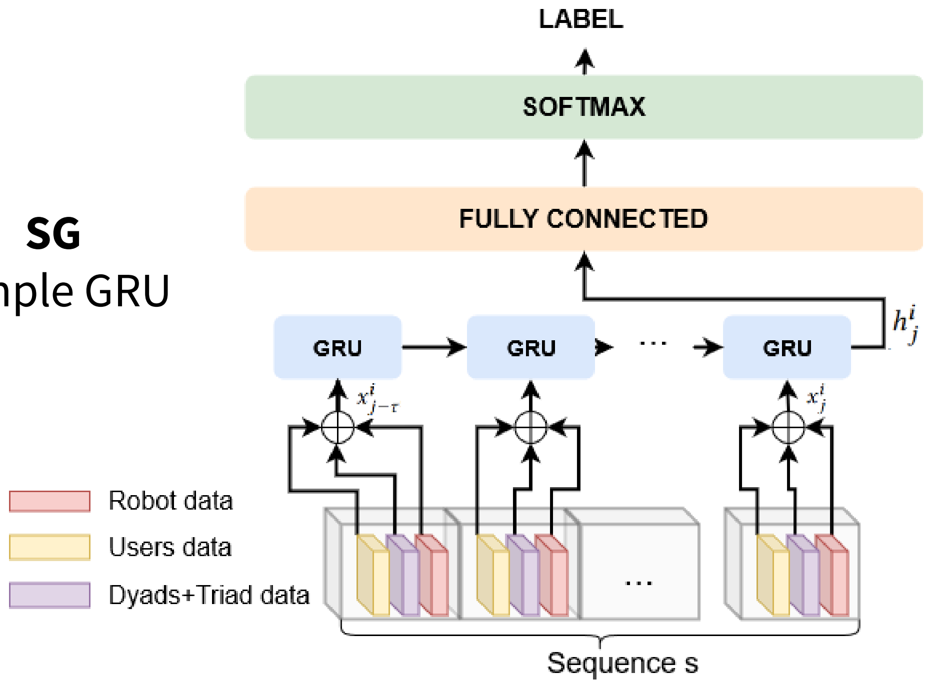
ML Models



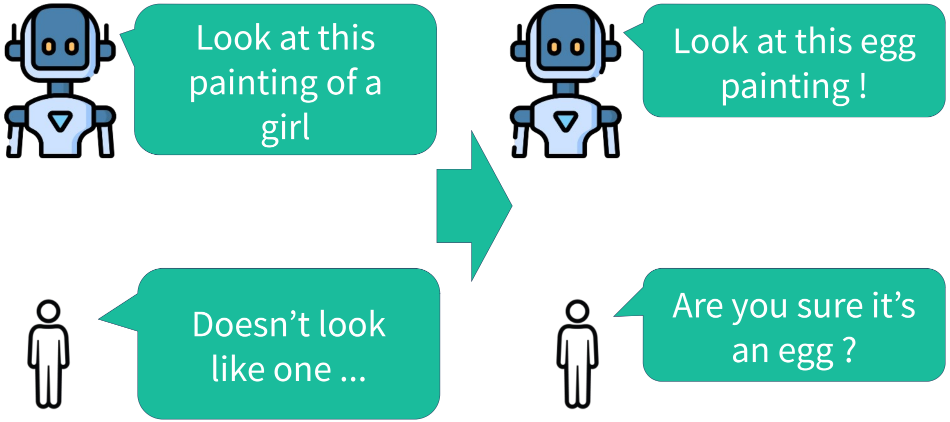
- 4 models : Ridge Classifier, Random Forest (RF), SVM-Classifier, Multi-Layer Perceptron (MLP)
- Two classification tasks
  - One-Vs-Rest
  - Multi-class
- Two fusion mechanisms :
  - Early-fusion
  - Late-fusion

IV – Computational Models of Trust

SG
Simple GRU

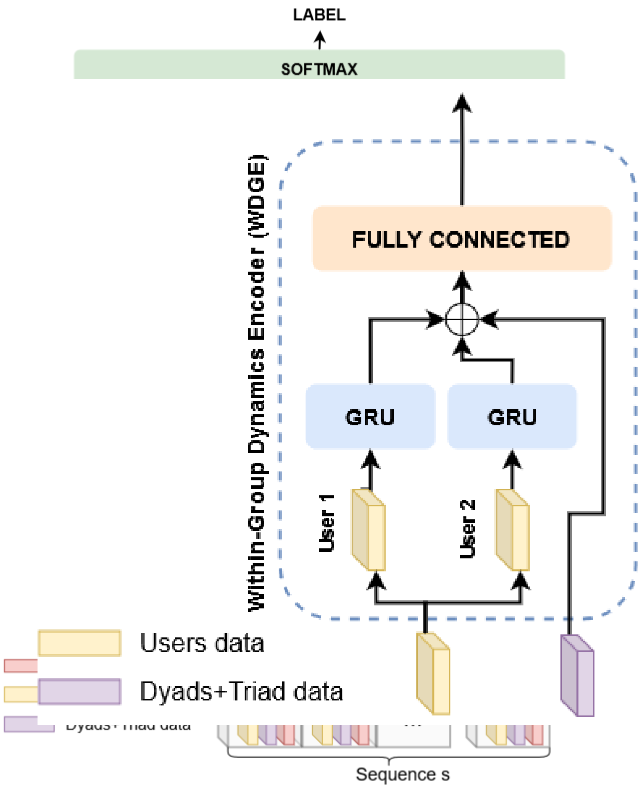


A1 [RNN] : participants' actions are relevant within the sequence of previous behaviors of all participants, and produced in response to another's speaking turn

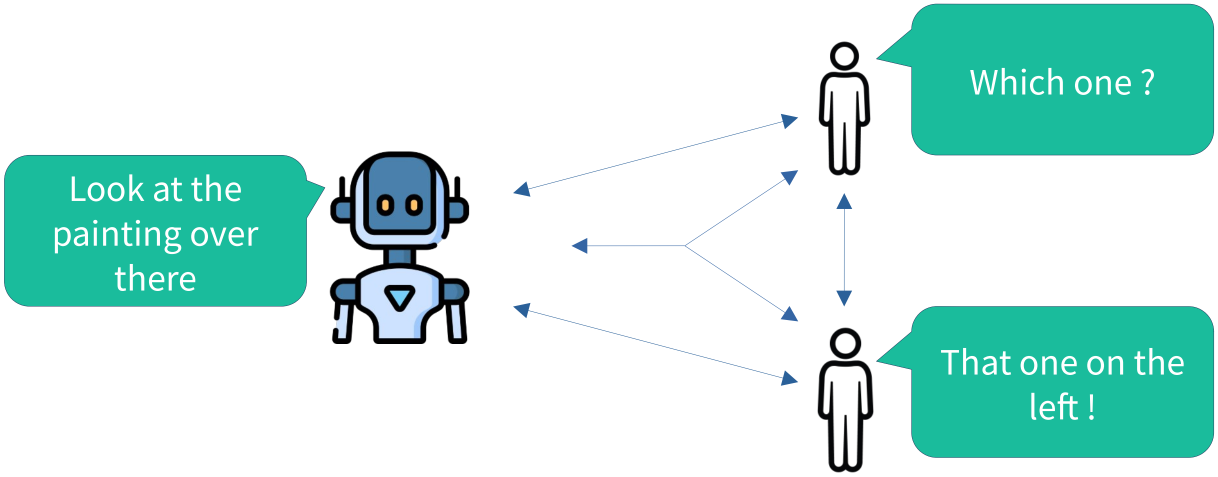


Charles Goodwin. "Conversational organization". In: Interaction between speakers and hearers (1981)
Erving Goffman. Forms of talk. University of Pennsylvania Press, 1981
Charles Goodwin et al. "Restarts, pauses, and the achievement of a state of mutual gaze at turn beginning". In: Sociological inquiry 50.3-4 (1980), pp. 272–302.

WGDE - SG



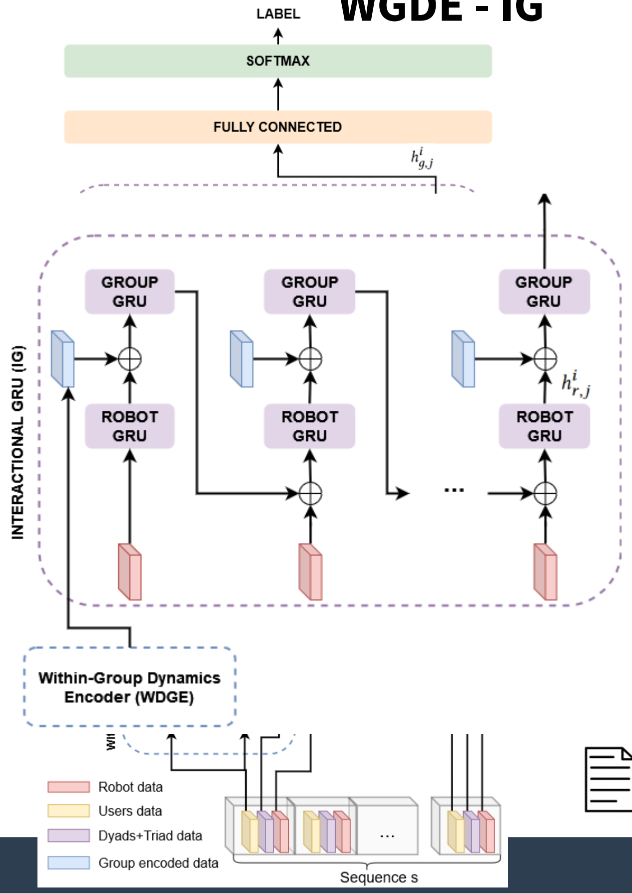
A2 [WGDE] : participants can either be speakers - addressing the whole group or a part of it - or be listeners - by actively or passively being engaged. It is necessary to analyze the interaction between all participants to fully understand the group dynamics



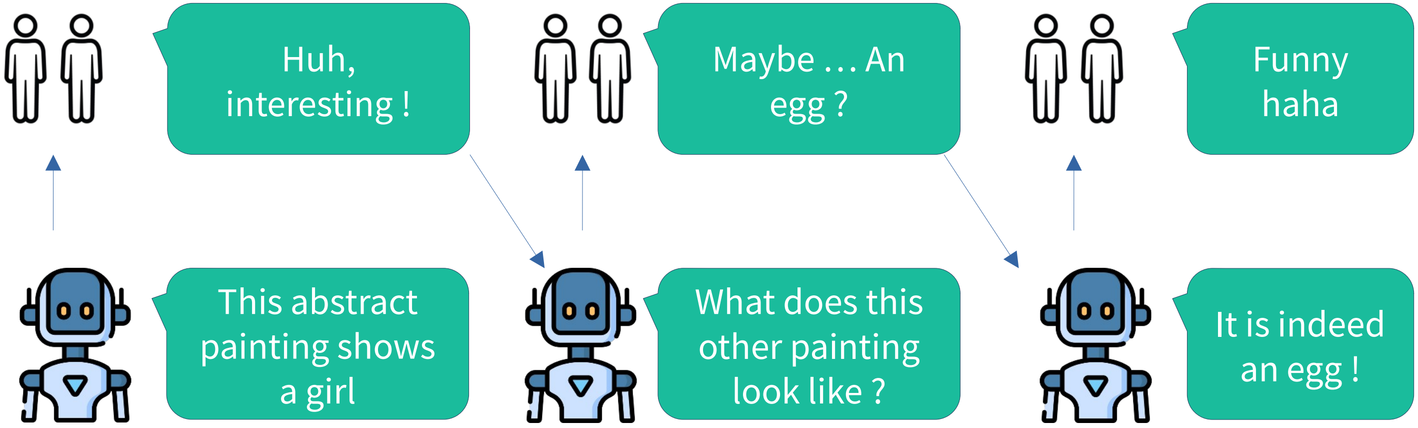
IV – Computational Models of Trust

ML Models

WGDE - IG



A3 [IG] : participants continuously exchange social signals shaping the interactional context which other participants use to build their answer, and hence renewing the context at each speaking turn



M. Hulcelle, L. Hemamou, G. Varni, N. Rollet and C. Clavel, “Leveraging Interactional Sociology for Trust Analysis in Multiparty Human-Robot Interaction,” International Conference on Human-Agent Interaction (HAI ’23), 2023, Gothenburg, Sweden

ML Models

Training without interaction history

- Leave-Three-Groups-Out cross-validation
- Augmentation with SMOTE to obtain a balanced training set
- ROC for the OVR task, F1 score for the Multiclass
- All modalities except semantics

IV – Computational Models of Trust

ML Models

One-Vs-Rest

Early-fusion	RF	MLP	SVM-C
Trusting-vs-rest	**0.72** ±0.04	0.70 ±0.04	**0.74** ±0.04
Neutral-vs-rest	**0.77** ±0.04	0.74 ±0.04	0.75 ±0.04
Mistrusting-vs-rest	**0.59** ±0.06	0.54 ±0.07	**0.58** ±0.06
Late-fusion			
Trusting-vs-rest	**0.67** ±0.04	0.60 ±0.04	**0.66** ±0.04
Neutral-vs-rest	**0.74** ±0.04	0.65 ±0.04	0.70 ±0.03
Mistrusting-vs-rest	**0.54** ±0.08	0.48 ±0.08	0.49 ±0.10

Multiclass

Fusion	Rand.	Maj.	RF	MLP	SVM-C
Early	0.38 ±0.03	0.52 ±0.05	**0.66** ±0.04	**0.65** ±0.04	0.60 ±0.04

One-Vs-Rest Late Fusion

	Body	Face	Voice
Trusting-vs-rest	0.54 ±0.05	0.62 ±0.04	**0.65** ±0.05
Neutral-vs-rest	0.57 ±0.03	0.65 ±0.03	**0.73** ±0.05
Mistrusting-vs-rest	0.46 ±0.08	0.51 ±0.06	**0.60** ±0.07

- RF performs better
- Early-fusion mechanism works best
- Voice modality is more important

- **Training with history**
- Leave-One-Group-Out cross-validation
- Augmentation 4x the dataset with Gaussian noise $\sigma = 2.10{-}3$
- Weighted random sampling during training with weights equal to inverse class proportions
- Regularization term with $\lambda = 1.10{-}2$
- All modalities

F1 score for all sequential models

	τ	1	2	3	4	5	6	7	8
Simple GRU	SG	0.733 ±.120	0.739 ±.119	0.733 ±.118	0.733 ±.127	0.735 ±.123	0.735 ±.125	0.734 ±.125	0.735 ±.124
Simple GRU (only human data)	SG (no robot)	0.621 ±.058	0.613 ±.081	0.621 ±.080	0.604 ±.095	0.597 ±.084	0.598 ±.092	0.603 ±.085	0.605 ±.087
Within-Group Dynamics Encoder + Simple GRU	WGDE-SG	0.726 ±.116	0.732 ±.119	0.723 ±.144	0.730 ±.141	0.724 ±.138	0.725 ±.146	0.723 ±.146	0.731 ±.148
Interactional GRU	IG†	0.730 ±.113	0.717 ±.105	0.695 ±.120	0.698 ±.163	0.694 ±.182	0.710 ±.145	0.689 ±.175	0.694 ±.188
Within-Group Dynamics Encoder + Interactional GRU	**WGDE-IG**	**0.730 ±.102**	**0.730 ±.098**	**0.715 ±.143**	**0.736 ±.124**	**0.735 ±.135**	**0.745 ±.110**	**0.730 ±.146**	**0.714 ±.137**

- Full model performs best
- No optimal history size (maybe due to the lack of data)

- **SHAP value analysis without history**
- Trusting :
  Nod more often, closer to the robot, tighten their lid more, more variations of contraction index, lower F0
- Mistrusting :
  Lower their brows more, more changes in VFOA, further away from the robot, talk more, higher speech overlap

- **Most common errors with history**
- Segments annotated « Alignment »
- Trusting :
  Gaze, Facial expression, F formation
- Mistrusting :
  Gaze, Facial expression, Intonation

Part V

Conclusion and Perspectives

V – Conclusion and Perspectives

RQ 1: Which theoretical framework is applicable to perform a multimodal analysis of trust regularly throughout the interaction ?

- Interactionist Sociology theories through their inductive methods
- We conceived a coding scheme TURIN

  → It can unveil trust dynamics through the observation of users' behaviors

  → Can be used as ground truth for computational models

V – Conclusion and Perspectives

RQ 2: Do homogeneous segments of trust arise within the interaction based on observable behavioral cues ?

We proposed a segmentation method based on the observation of behavioral cues that indicate trust and highlights homogeneous segments of trust.

V – Conclusion and Perspectives

RQ 3: How can we discriminate trusting segments from mistrusting ones with tangible behavioral cues ?

- A set of multimodal features. Some features carry more weight than others, and that some were more specific to a certain trust category.
- Early-fusion mechanism leads to quite optimistic performance in binary classification with traditional ML techniques.
- We designed a neuronal architecture to model interactional dynamics within the user-group, as well as between the robot and users, which led to increased performance.

V – Conclusion and Perspectives

Other contributions

- All annotations collected on the Vernissage dataset made public
- Code of the sequential model soon available on Github

V – Conclusion and Perspectives

Perspectives

- ➔ Online trust detection
  - Different features ?
  - Computational cost ?
- ➔ Collecting data with a trust-specific scenario

V – Conclusion and Perspectives

Perspectives

- Refining TURIN and links with other social phenomenons
  - Alignment ?
  - Engagement ?
- Improving the models of interactional dynamics for trust
  - Different modules ?
  - Hierarchical architecture ?

Thank you for listening !

QUESTIONS

Engagement

“the process by which two (or more) participants establish, maintain, and end their perceived connection to one another” *C. L. Sidner, C. Lee, C. D. Kidd, N. Lesh, and C. Rich, “Explorations in Engagement for Humans and Robots”, Artificial Intelligence, pp. 140–164, 2005*

MHHRI Dataset to study this link ?
Dyadic interactions VS group interactions ?

Feature category	User’s mode	
	Speaker	Listener
Distance (front sonar, face distance, head position, engagement zone)	User	User
Gaze (direction, is looking at robot)	User	User
Head & Face (head angles, 17 face AUs)	User	User
Speech (voicing probability, F0 loudness, log-energy, 12 MFCCs, is robot speaking, speech duration)	User	Robot

Table 1: *Multimodal features used to detect user’s SED per category. Columns 2 & 3 show whether the features characterize the user or the robot depending on the user’s mode.*

Asma Atamna and Chlo ́e Clavel. “HRI-RNN: A user-robot dynamics-oriented RNN for engagement decrease detection”. In: Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH. Vol. 2020-Octob. 2020, pp. 4198–4202

QUESTIONS

Coding schemes we took inspiration from

- Act4teams
  - Thought unit
  - Exclusive coding
- DCS
  - Sentence level
  - Who speaks to whom ?
  - Function of the state in the interaction process
  - Affiliation/Dominance valence

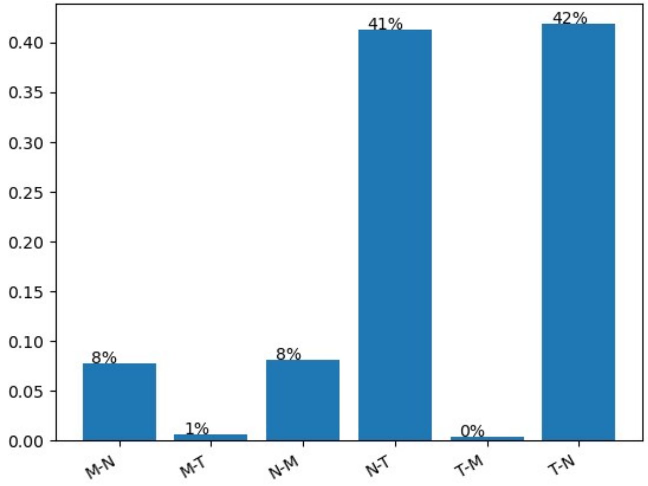
Problem-focused statements	Procedural statements	Socio-emotional statements	Action-oriented statements
Problem Describing a problem Connections with problems Defining the objective Solution Describing a solution Problem with a solution Arguing for a solution Organizational knowledge Knowing who Question	**Positive**: Goal orientation Clarifying Procedural suggestion Procedural question Prioritizing Time management Task distribution Visualization Summarizing **Negative**: Losing the train of thought (running off topic)	**Positive**: Encouraging participation Providing support Active listening Reasoned disagreement Giving feedback Humor Separating opinions from facts Expressing feelings Offering praise **Negative**: Criticizing/backbiting Interrupting Side conversations Self-promotion	**Positive, proactive**: Expressing positivity Taking responsibility Action planning **Negative, counterproductive**: No interest in change Complaining Seeking someone to blame Denying responsibility Empty talk Ending the discussion early

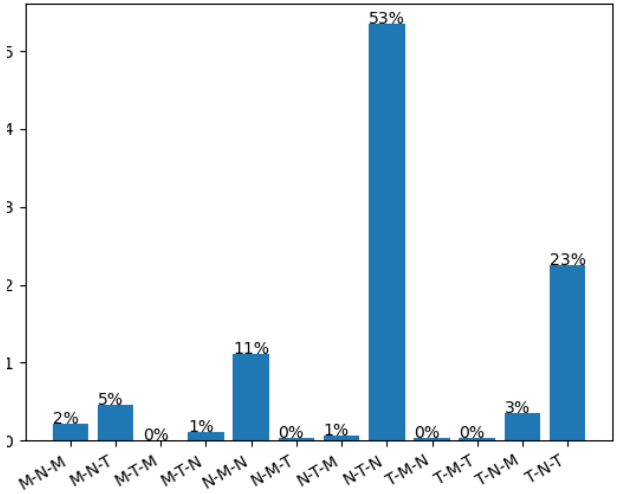
Additional codes:
Pause; laughter; incomprehensible; incomplete sentence (cut off by an interruption); other (not fitting any of the above codes)

QUESTIONS

Class distribution

LABEL	COUNT	AVERAGE LENGTH
Mistrusting	78	2.6s (±1.6s)
Neutral	604	4.1s (±1.4s)
Trusting	240	3.0s (±1.5s)





QUESTIONS

MPR Dataset « A Multimodal Multiparty Human-Robot Dialogue Corpusfor Real World Interaction »

- Multiparty Dialogue Management
- Boredom detection
- Surprise detection
- Repair detection

MPR2012	MPR2016
English 1st phase (WOZ) 20-Questions 2nd phase (automatic) Mimic gestures	English and Japanese 1st phase (manual, participants know) 20-Questions 2nd phase (automatic) 20-Questions Random irrelevant and irrational messages from the robot to induce surprised reactions

QUESTIONS

Steven Marsh computational model

Description	Representation	Value Range
Situations	$\alpha,\ \beta,\ \ldots$	
Agents	$a,\ b,\ c,\ \ldots$	
Set of agents	$\mathcal{A}$	
Societies of agents	$\mathcal{S}_1,\ \mathcal{S}_2\ \ldots$	
	$\mathcal{S}_n \in \mathcal{A}$	
Knowledge (e.g., x knows y)	$K_x(y)$	True/False
Importance (e.g., of α to x)	$I_x(\alpha)$	$[0,+1]$
Utility (e.g., of α to x)	$U_x(\alpha)$	$[-1,+1]$
Basic Trust (e.g., of x)	T_x	$[-1,+1)$
General Trust (e.g., of x in y)	$T_x(y)$	$[-1,+1)$
Situational Trust (e.g., of x in y for α)	$T_x(y,\alpha)$	$[-1,+1)$

$$T_x(y,\alpha) = U_x(\alpha) \times I_x(\alpha) \times \widehat{T_x(y)}$$

$$\widehat{T_x(y)} = \frac{1}{|A|} \sum_{\alpha \in A} T_x(y)$$

$$T_x(y,\alpha) > \text{Cooperation\_Threshold}_x(\alpha) \Rightarrow \text{Will\_Cooperate}(x,y,\alpha)$$

$$\text{Cooperation\_Threshold}_x(y,\alpha) = \frac{\text{Perceived\_Risk}_x(\alpha)}{\text{Perceived\_Competence}_x(y,\alpha) + \widehat{T_x(y)}} \times I_x(\alpha)$$