

Group Intelligence in Social Robots

PhD Thesis Defense

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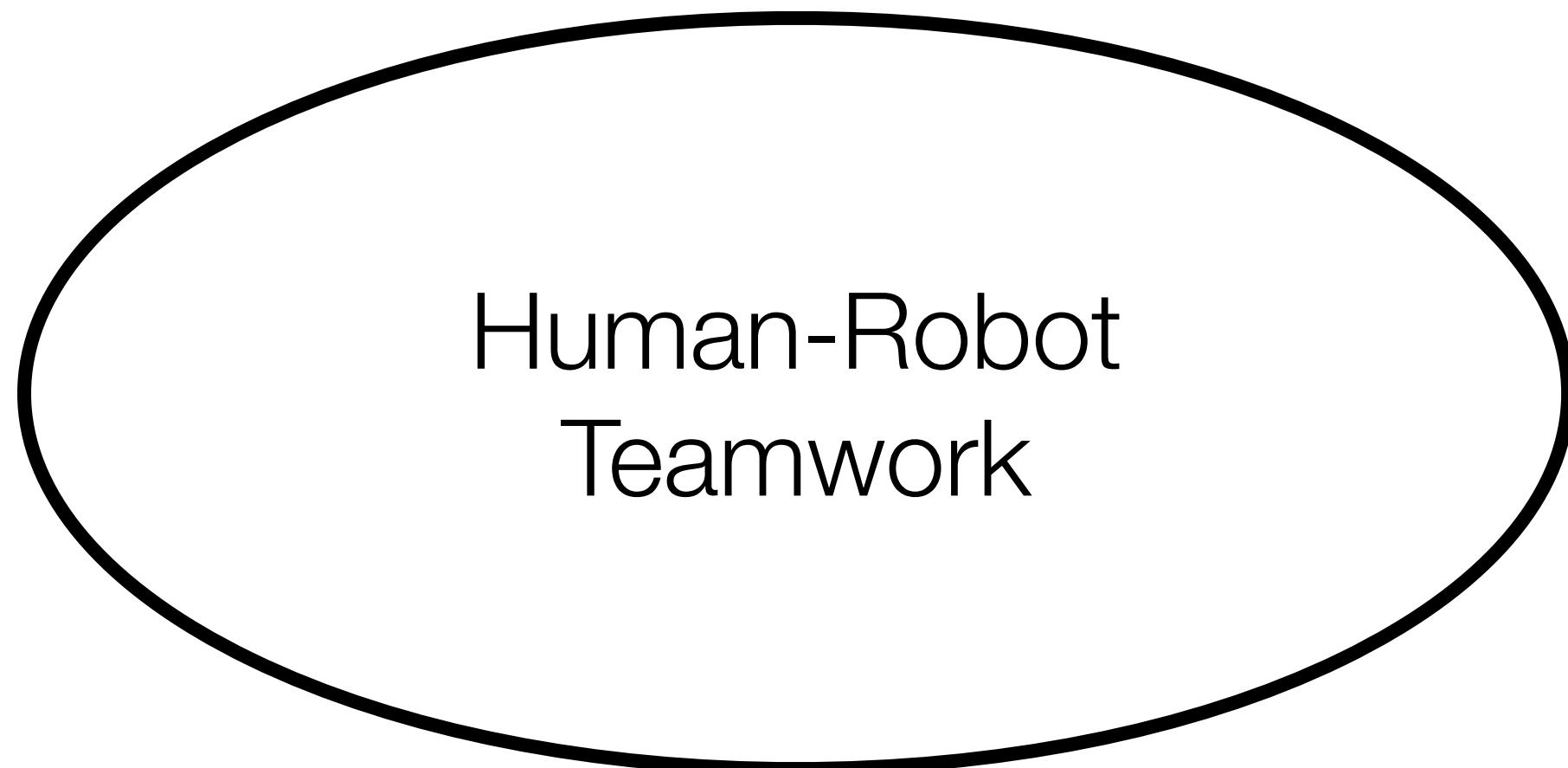
Junior Researcher at GAIPS Lab, INESC-ID



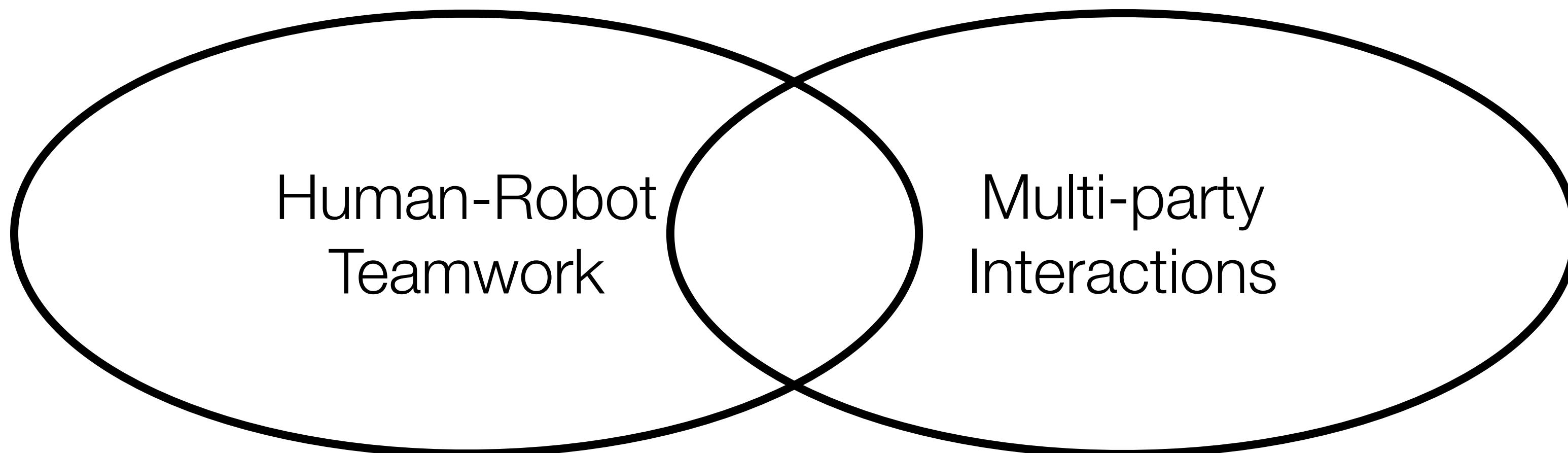
Motivation & Contributions



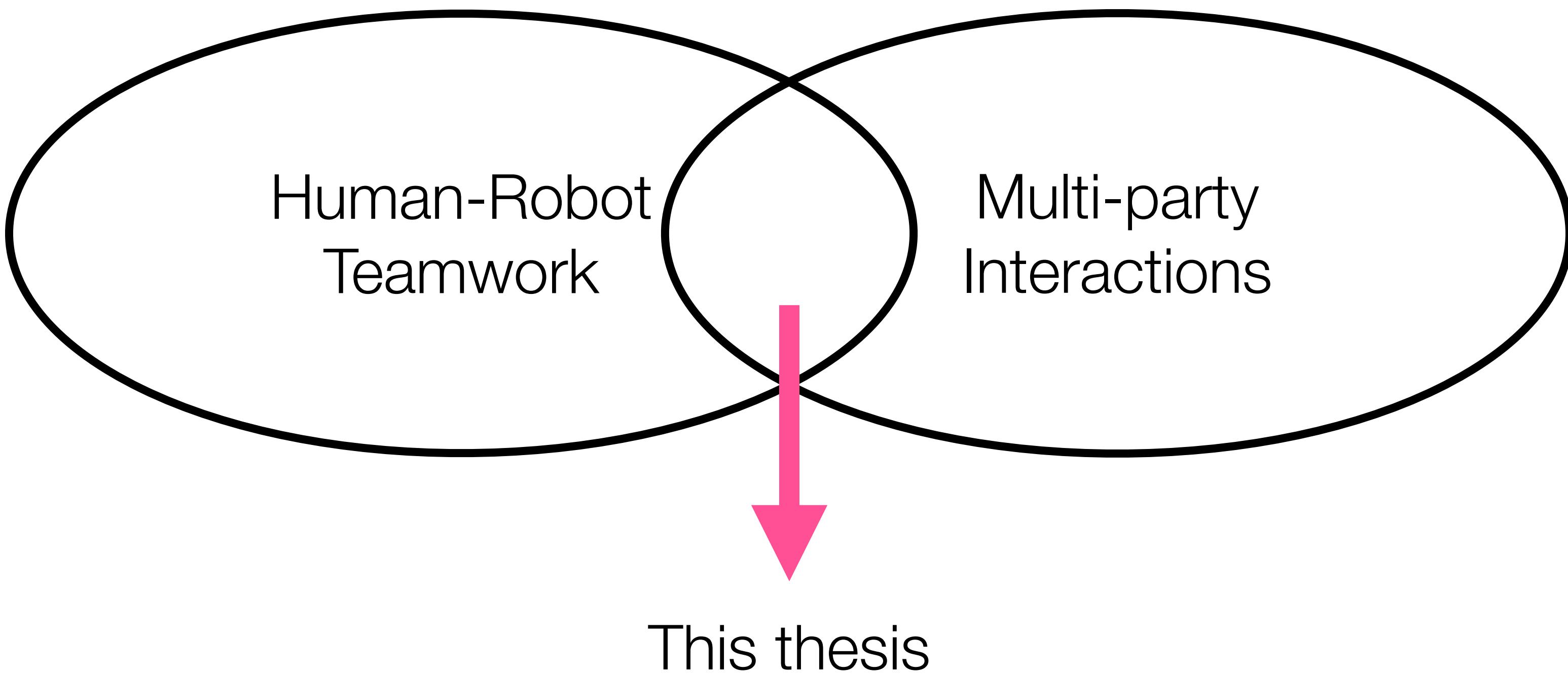
Teamwork



Teamwork & Multi-party

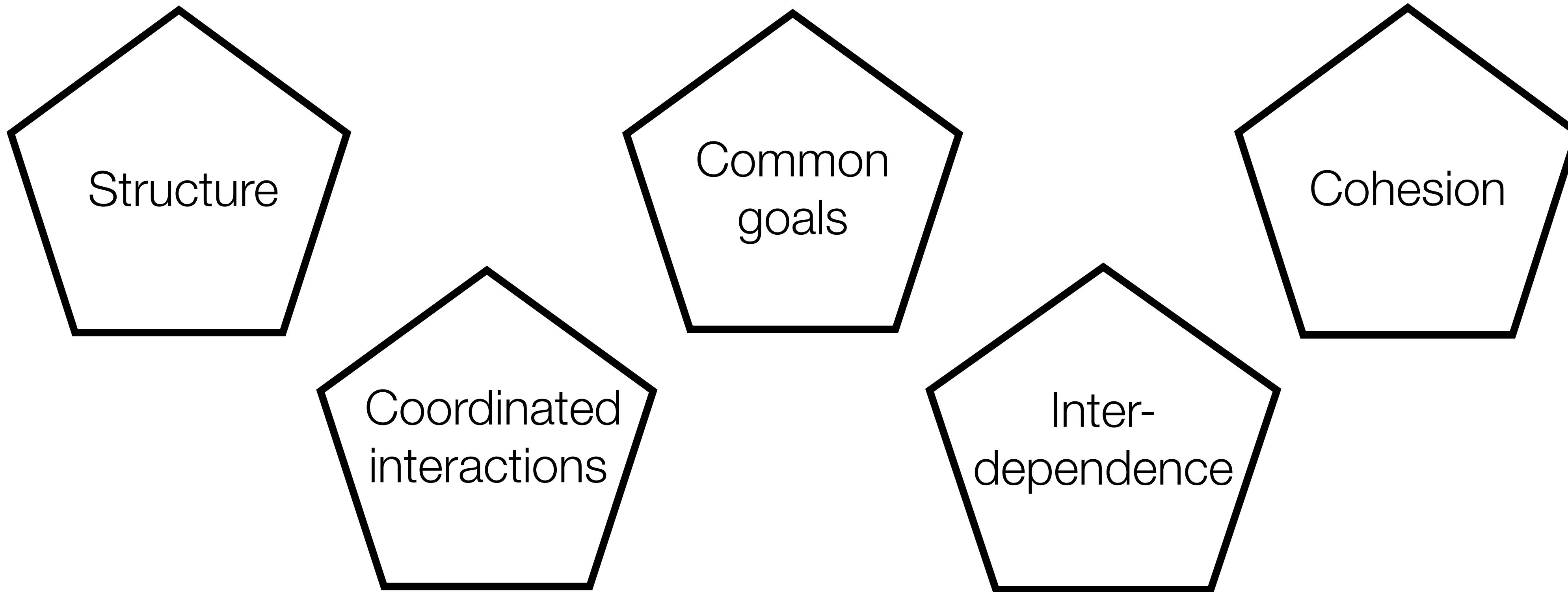


Novelty



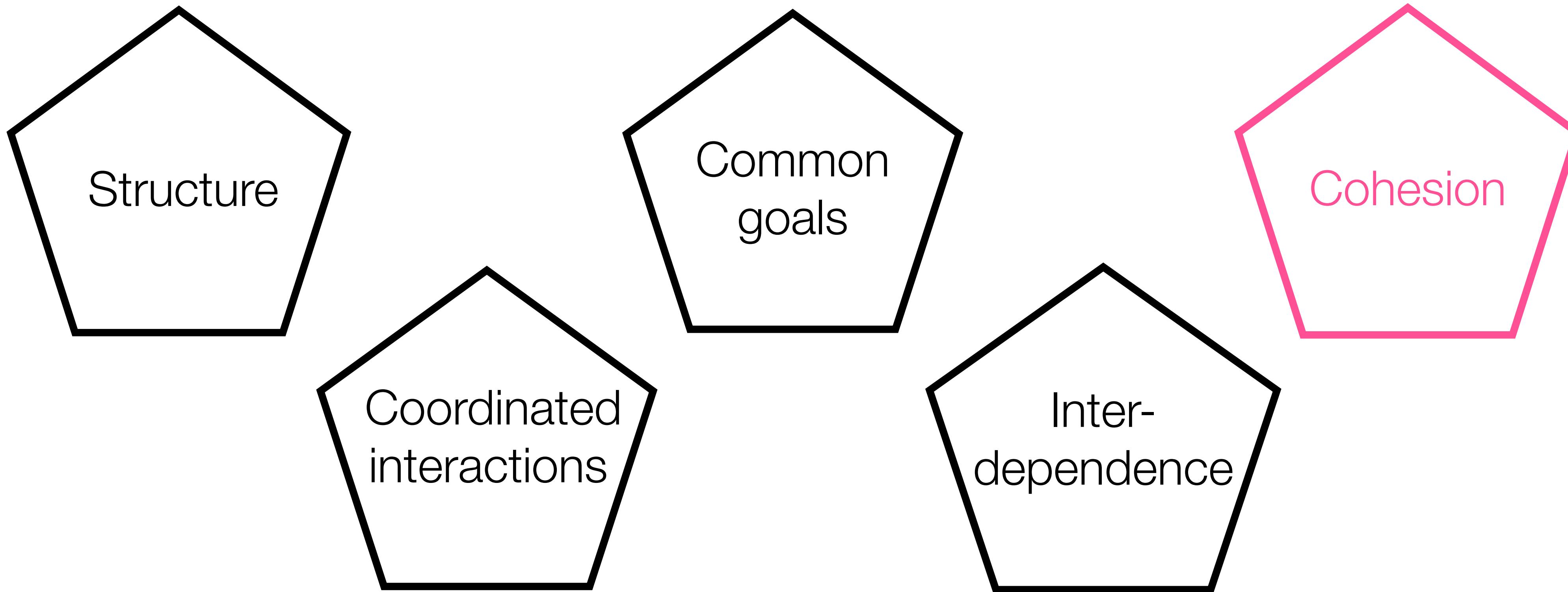
What is a Team?

“unified, cohesive group”

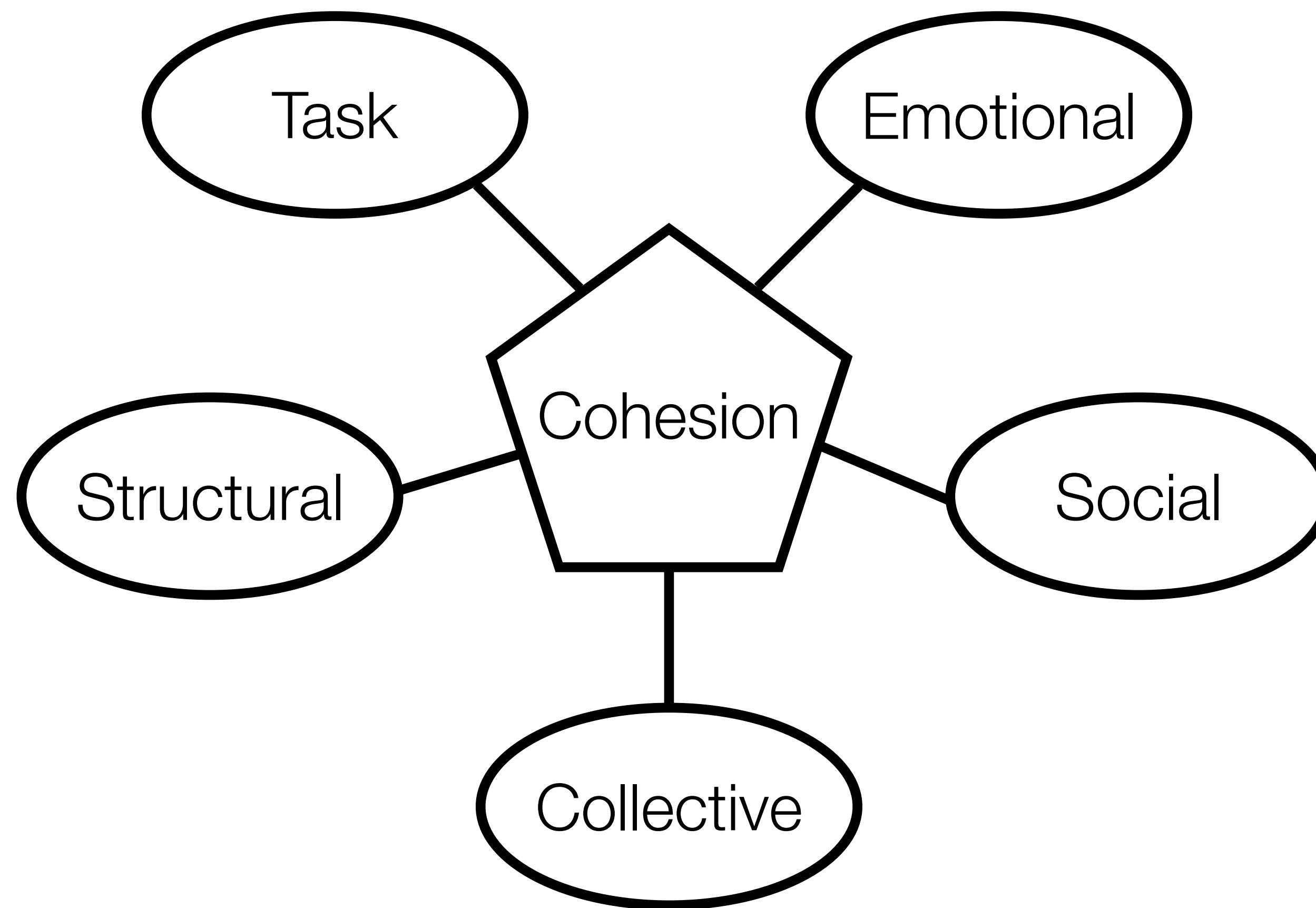


What is a Team?

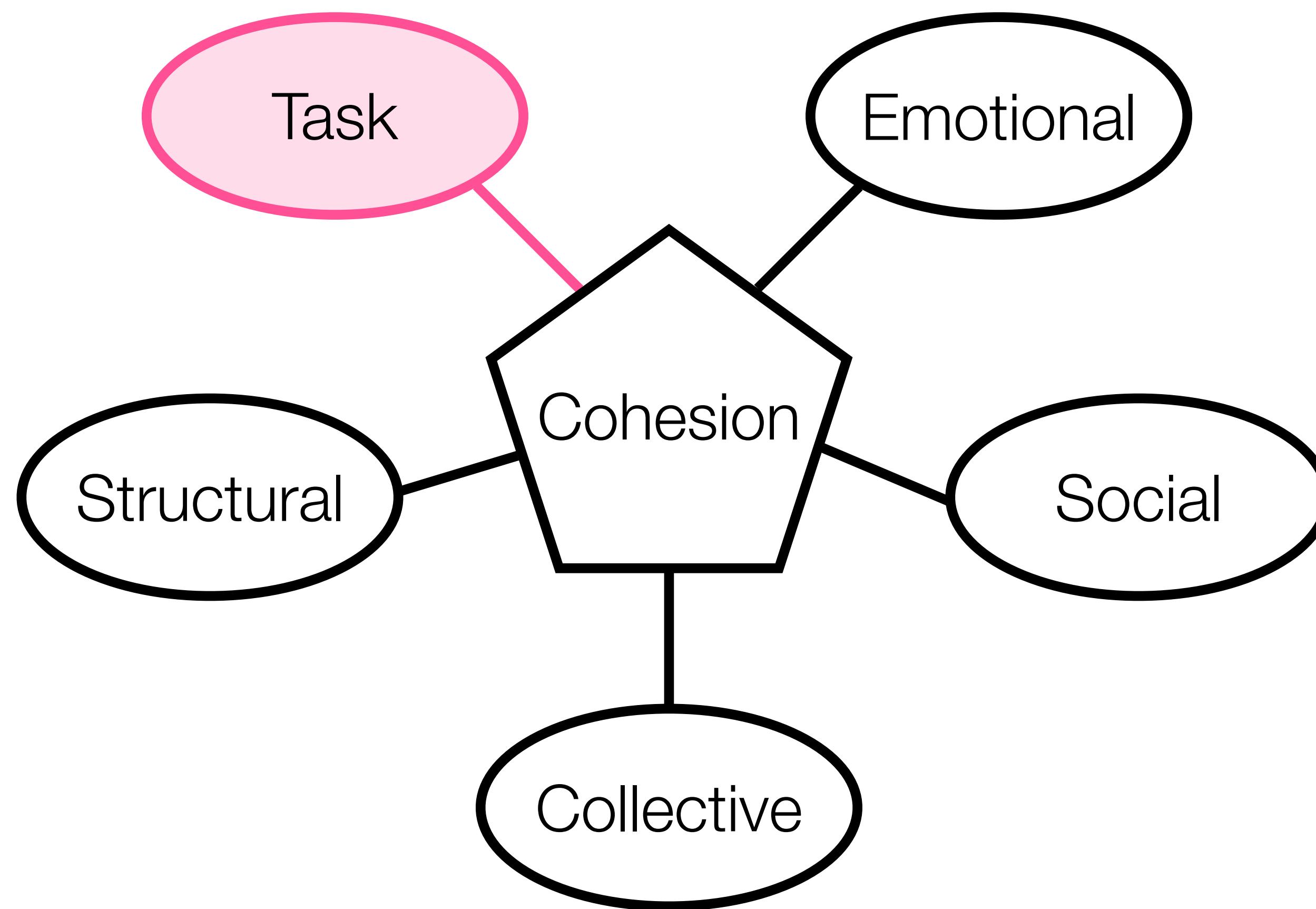
“unified, cohesive group”



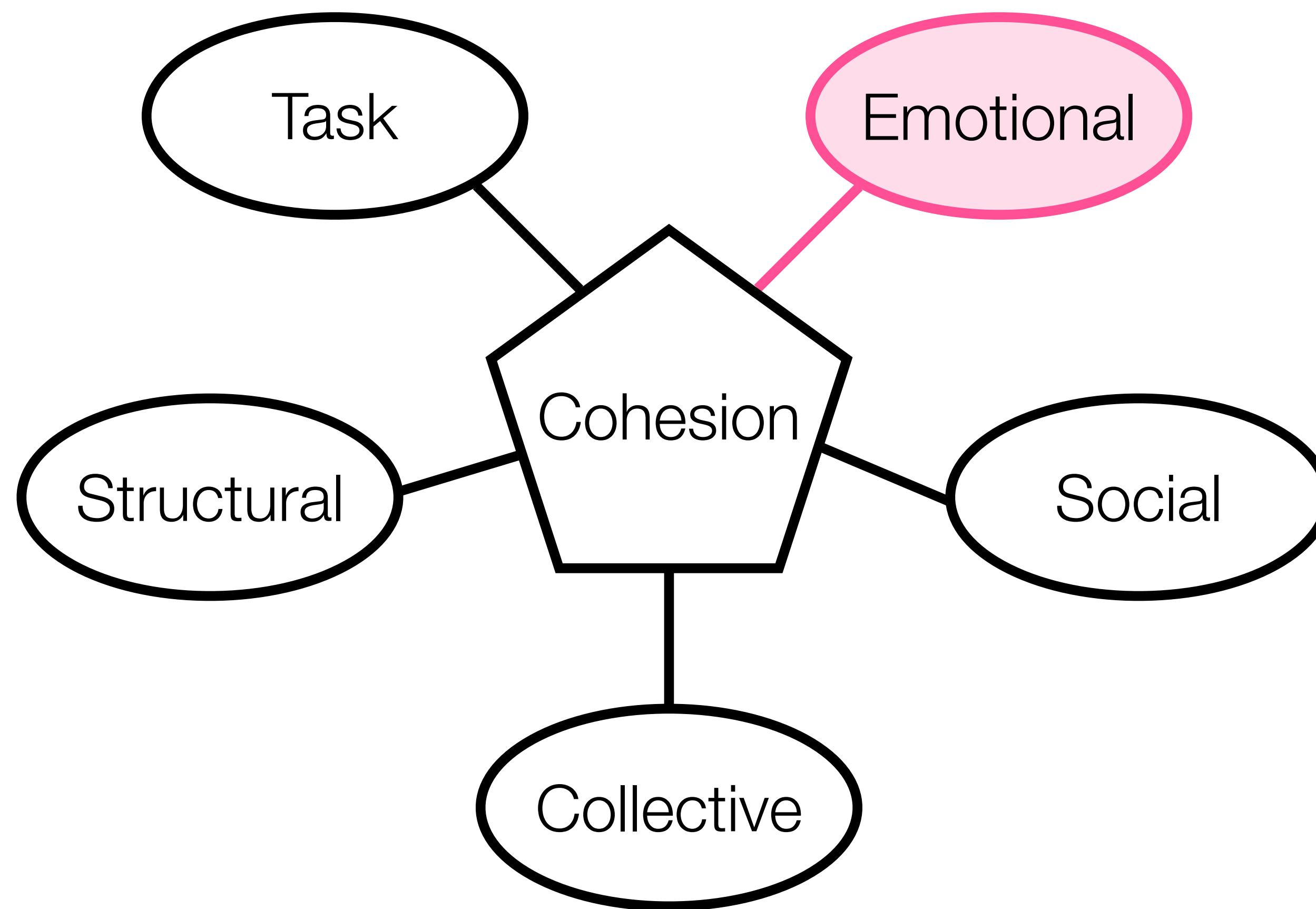
What is Cohesion?



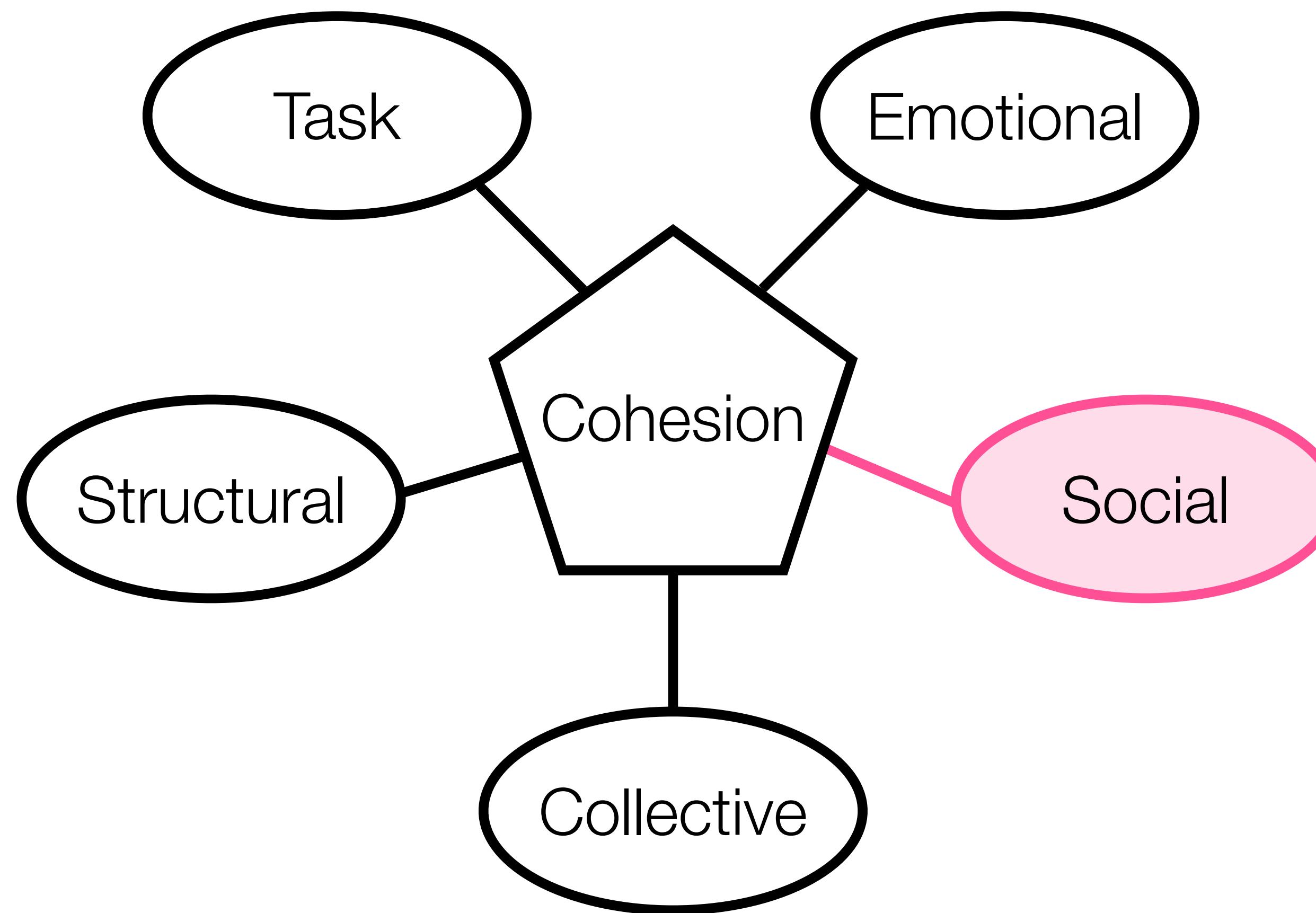
What is Task Cohesion?



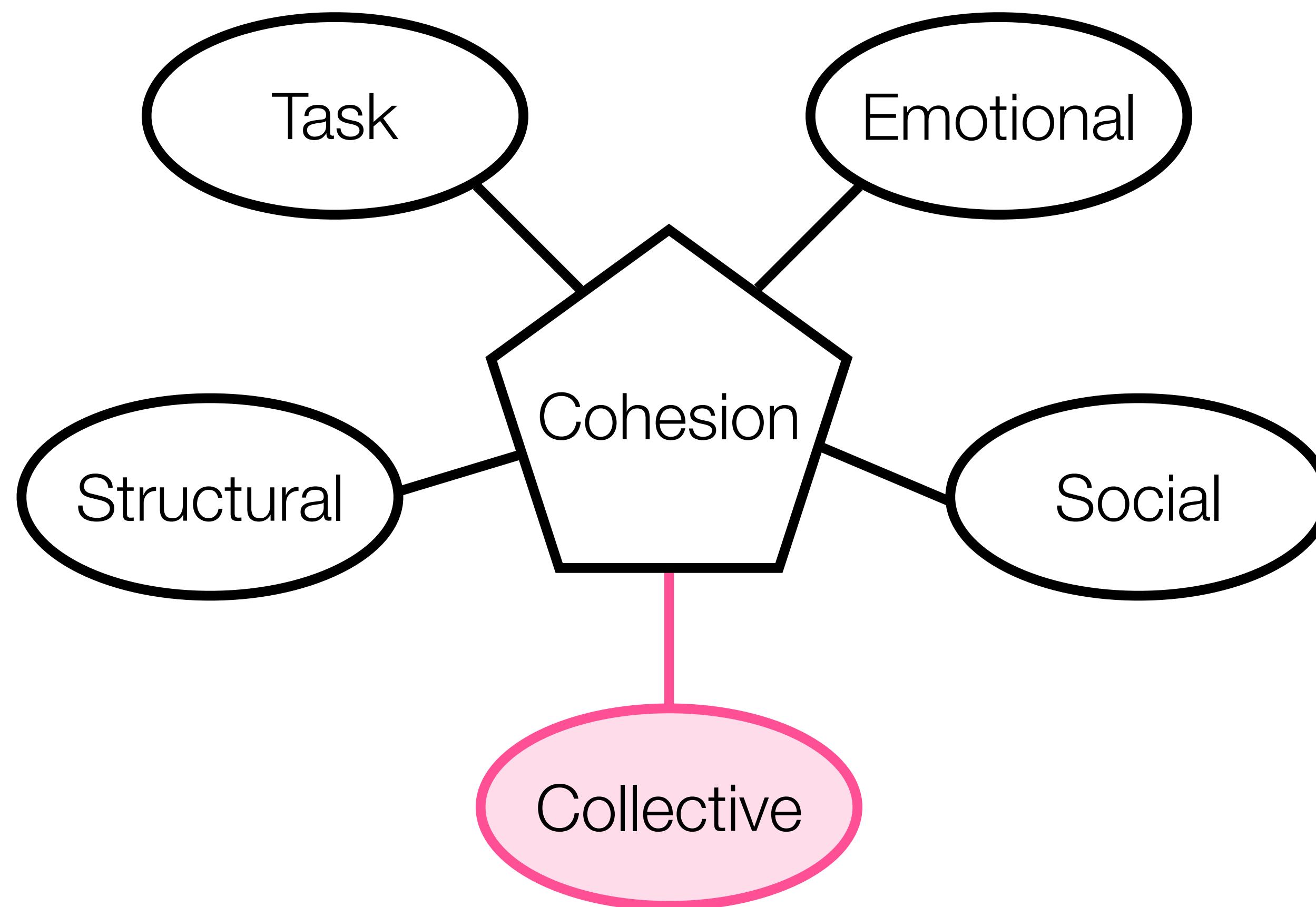
What is Emotional Cohesion?



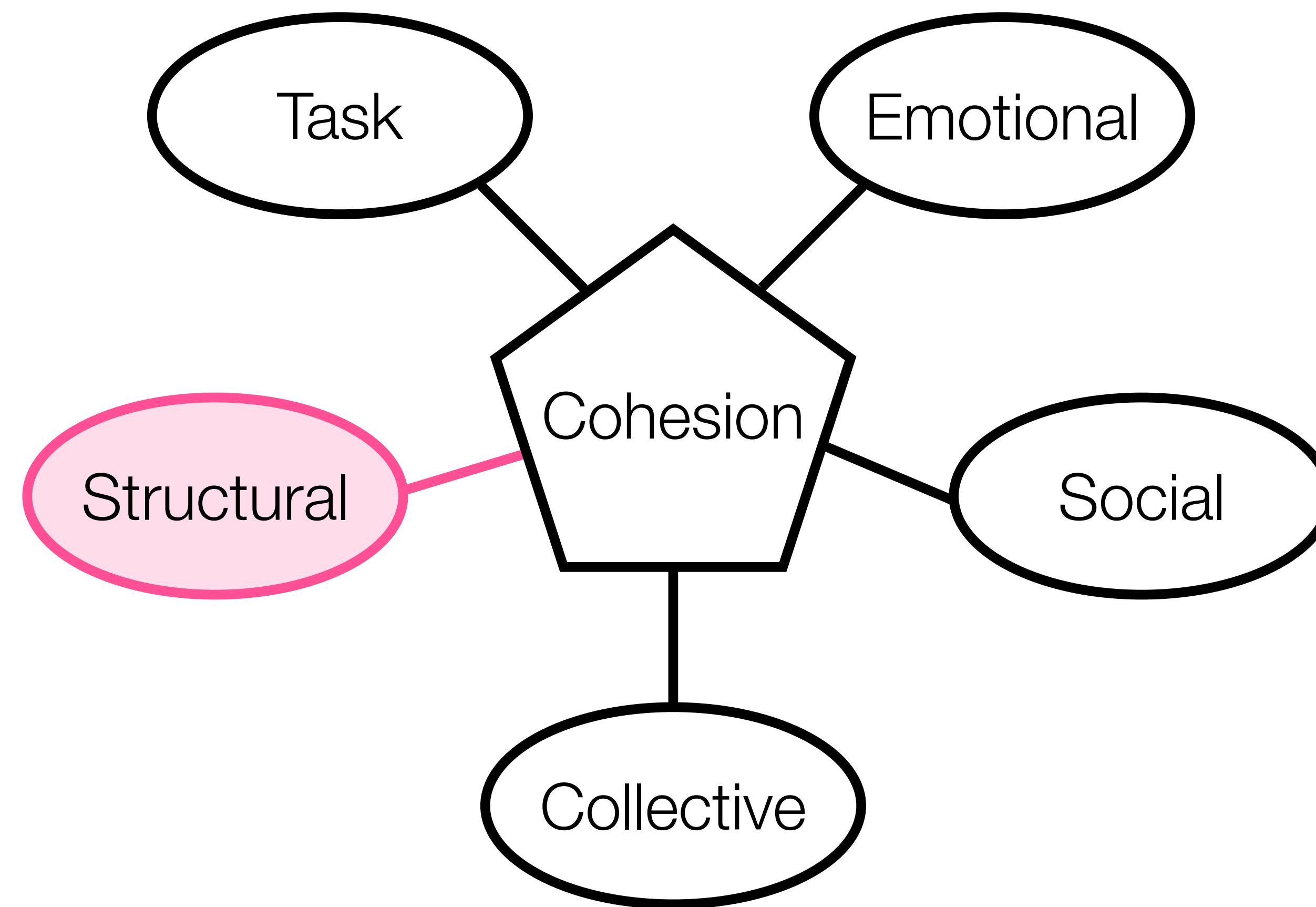
What is Social Cohesion?



What is Collective Cohesion?



What is Structural Cohesion?



Research Problem

*How can we endow a robotic teammate with
social capabilities to improve the **cohesive alliance**
in a multi-party setting with humans?*

Cohesive alliance between humans and robots

“**a coalition** in which the relation between group members, both humans and robots, **emerges from at least one of the dimensions of cohesion** and results in a shared sense of unity by all group members”

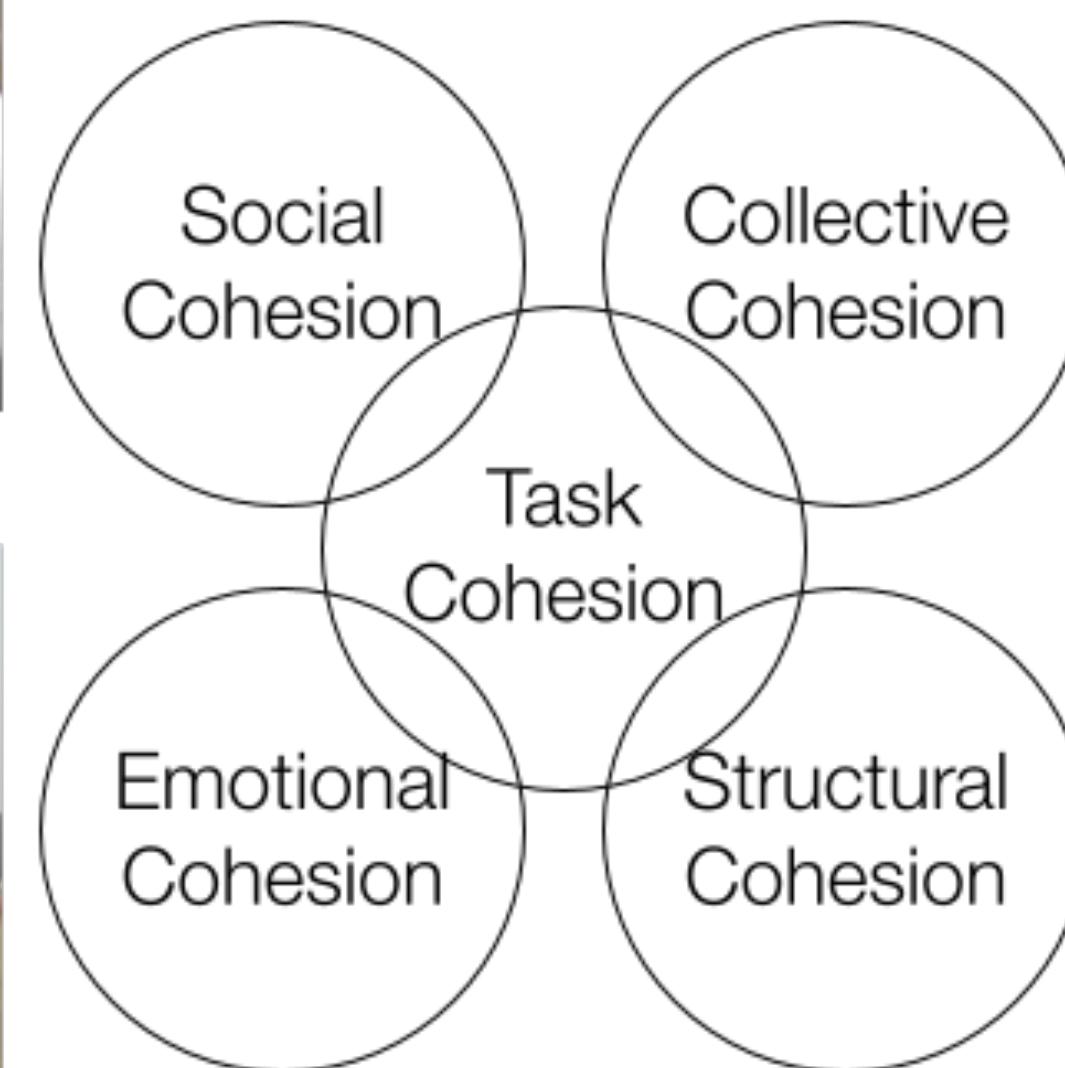
Contributions



Membership Preferences



Group-based Emotions



Prosociality



Multi-party Gaze

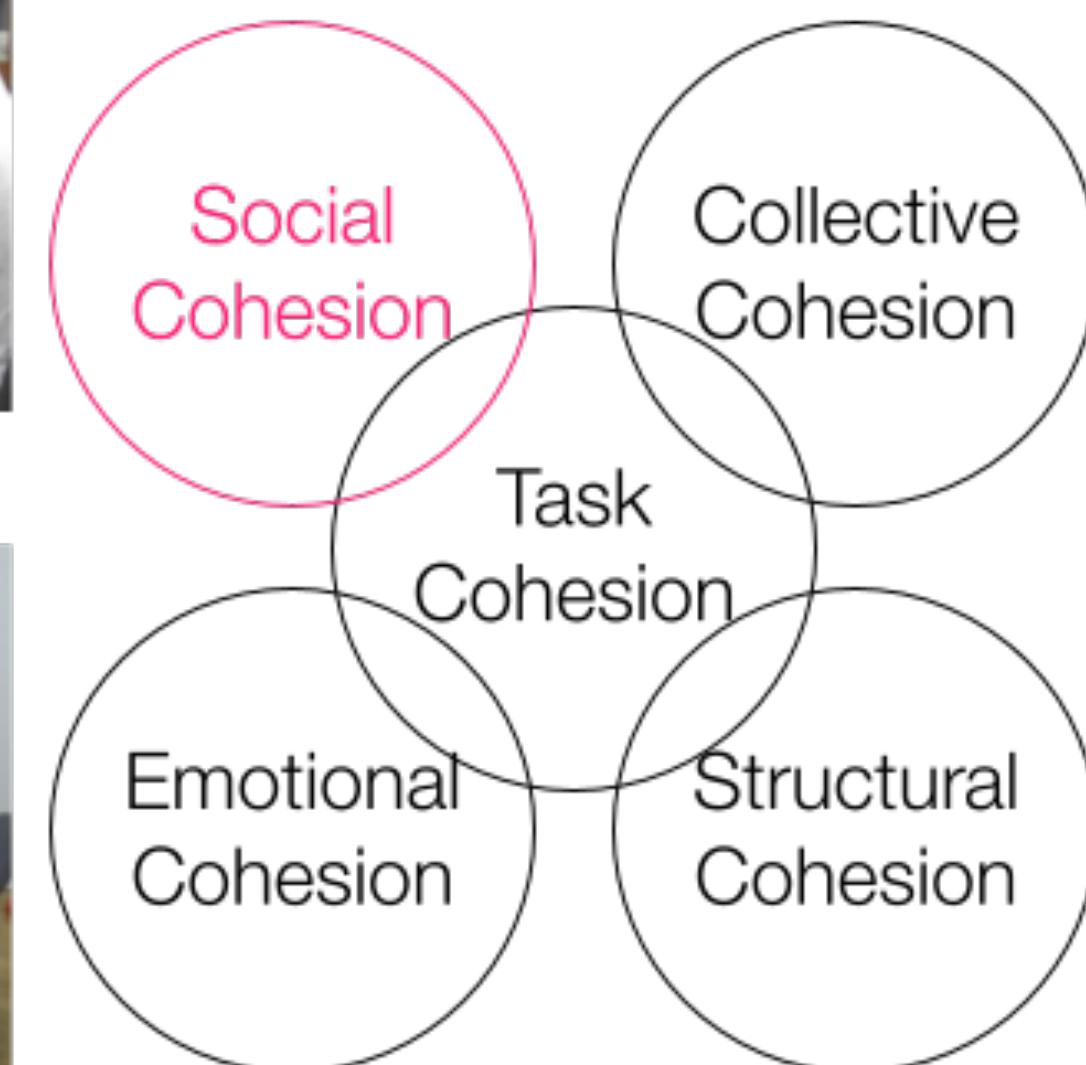
Contributions



Membership Preferences



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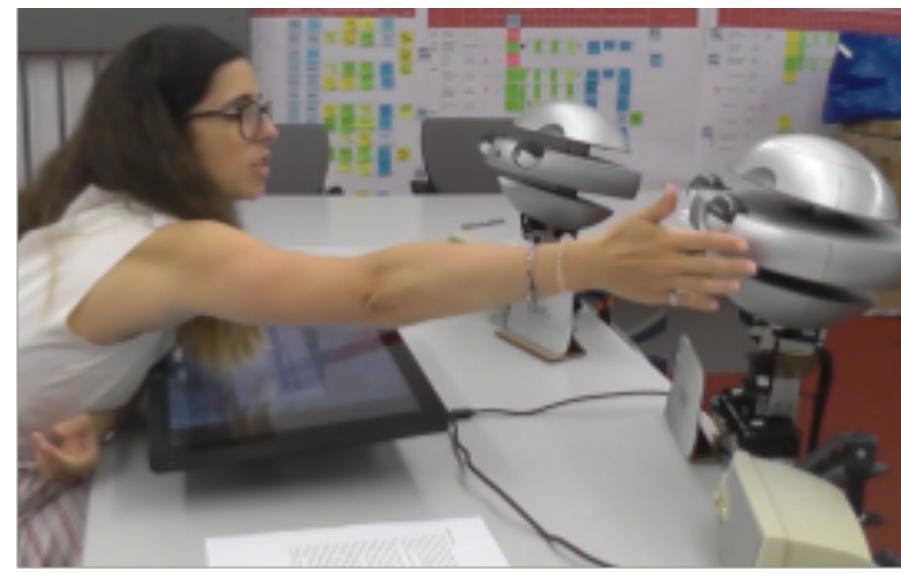
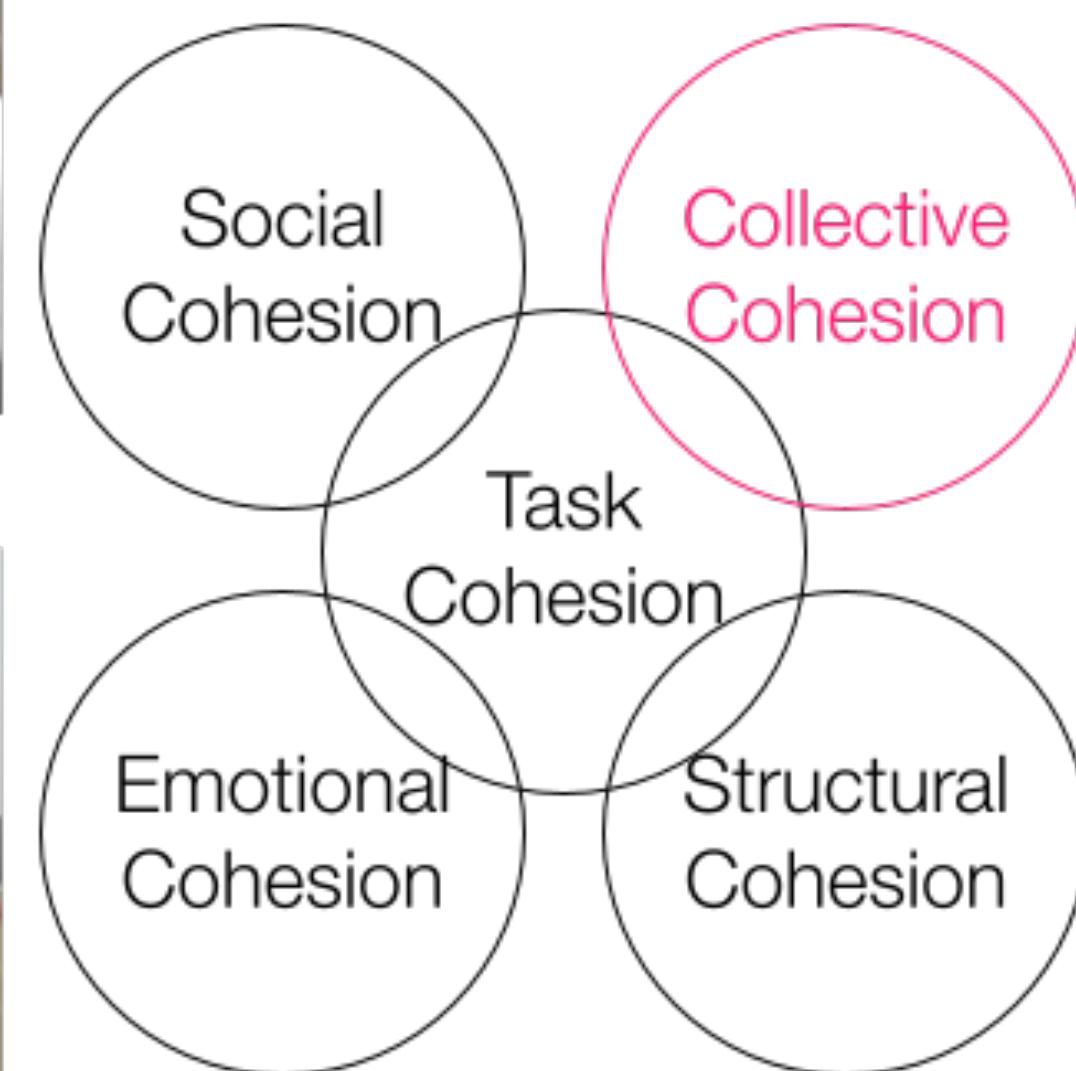
Contributions



Membership Preferences



Group-based Emotions



Prosociality



Multi-party Gaze

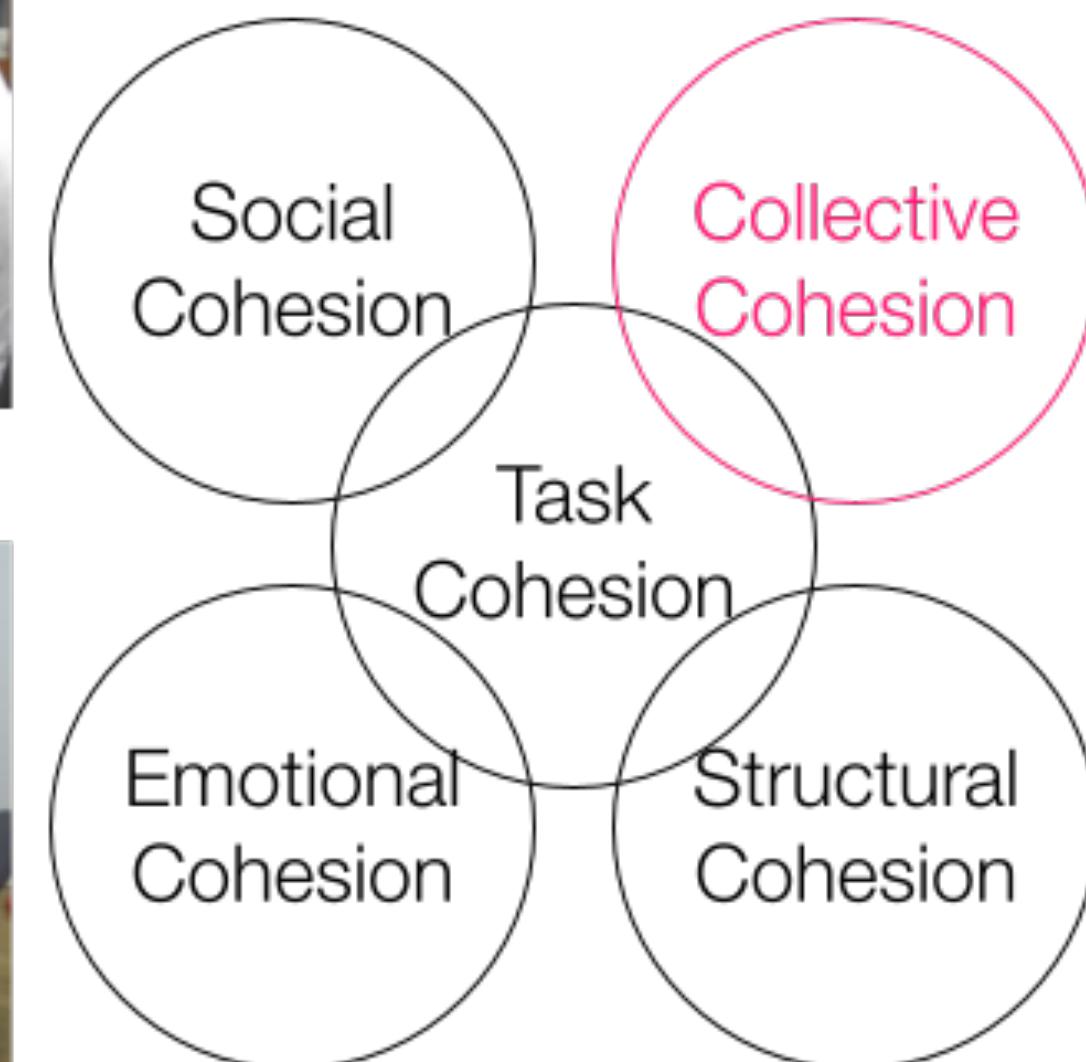
Contributions



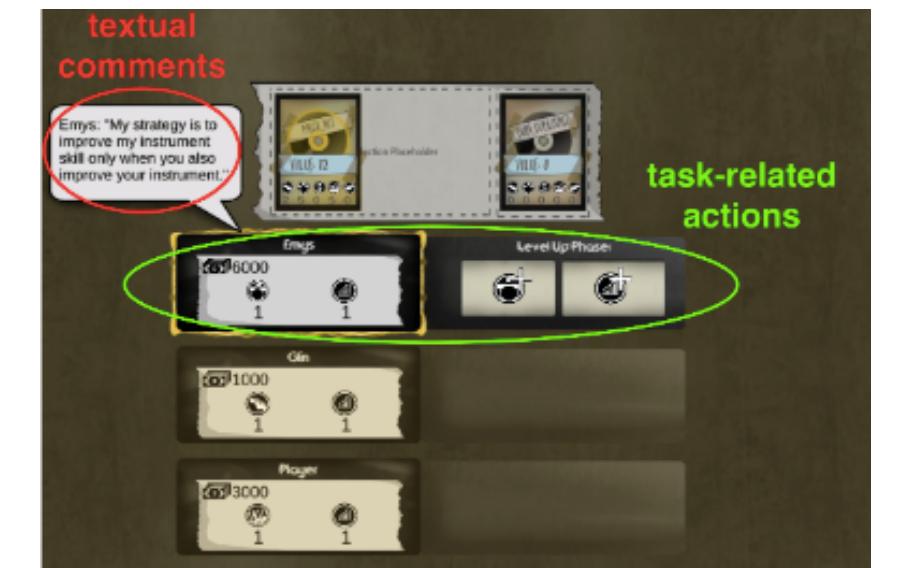
Membership Preferences



Group-based Emotions



Prosociality



Embodiment



Multi-party Gaze

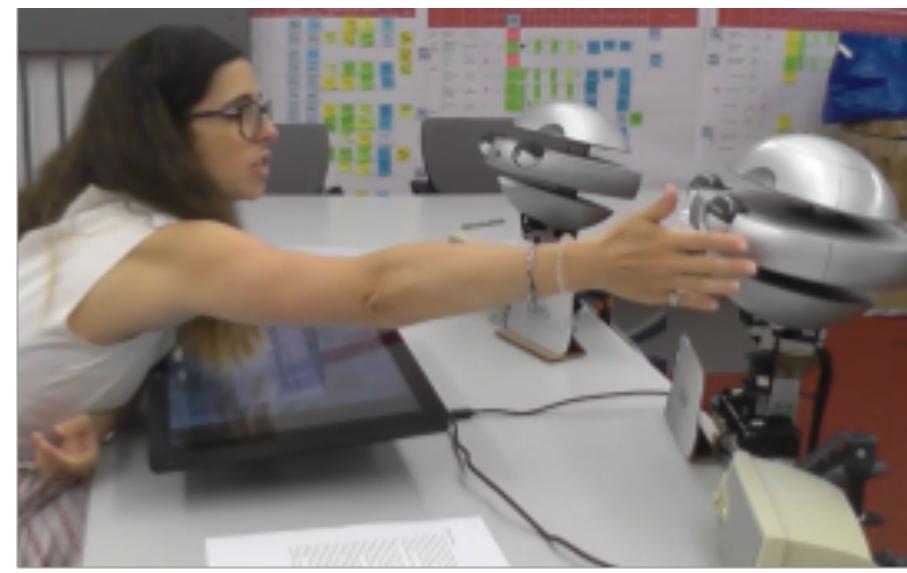
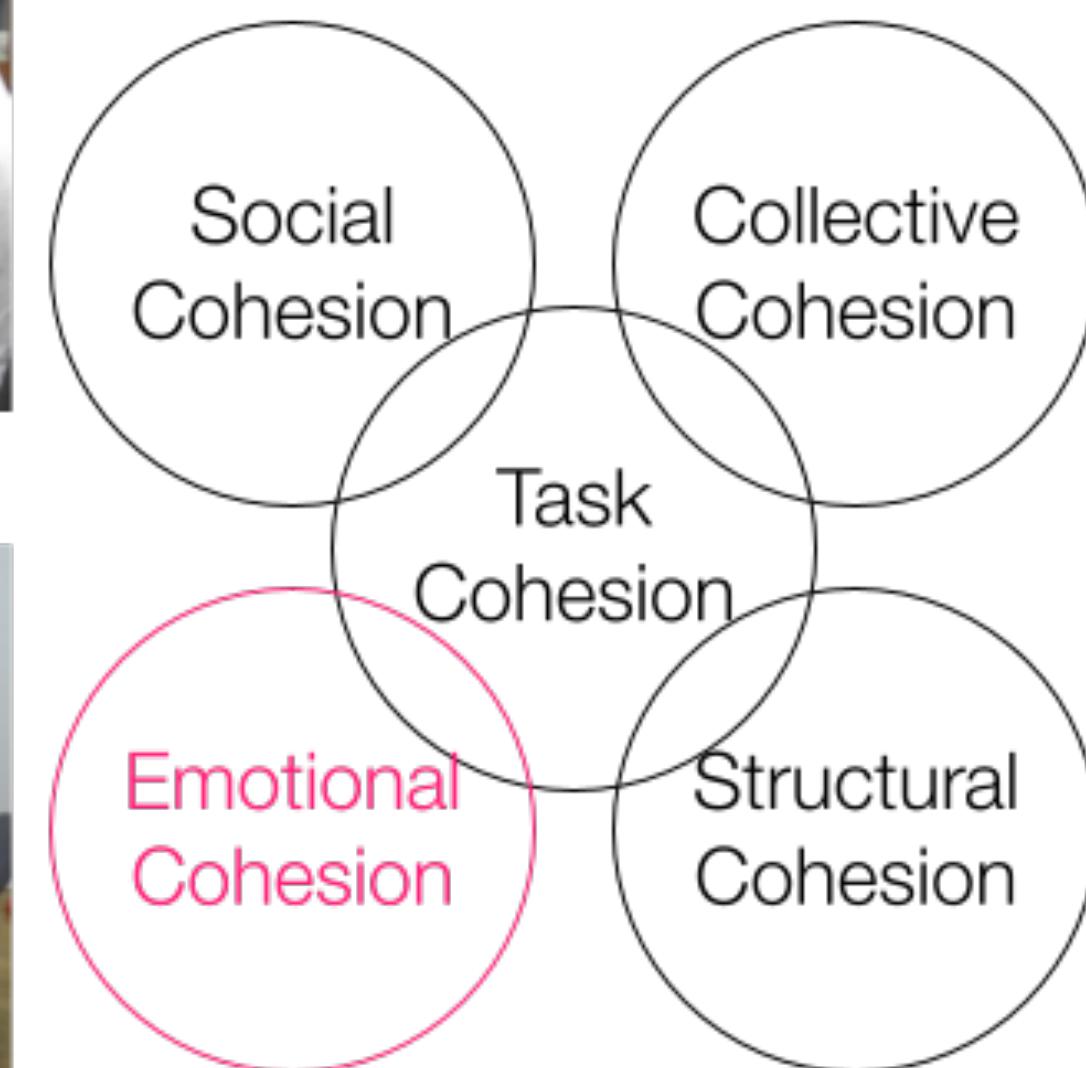
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Membership Preferences



Group-based Emotions



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Multi-party Gaze

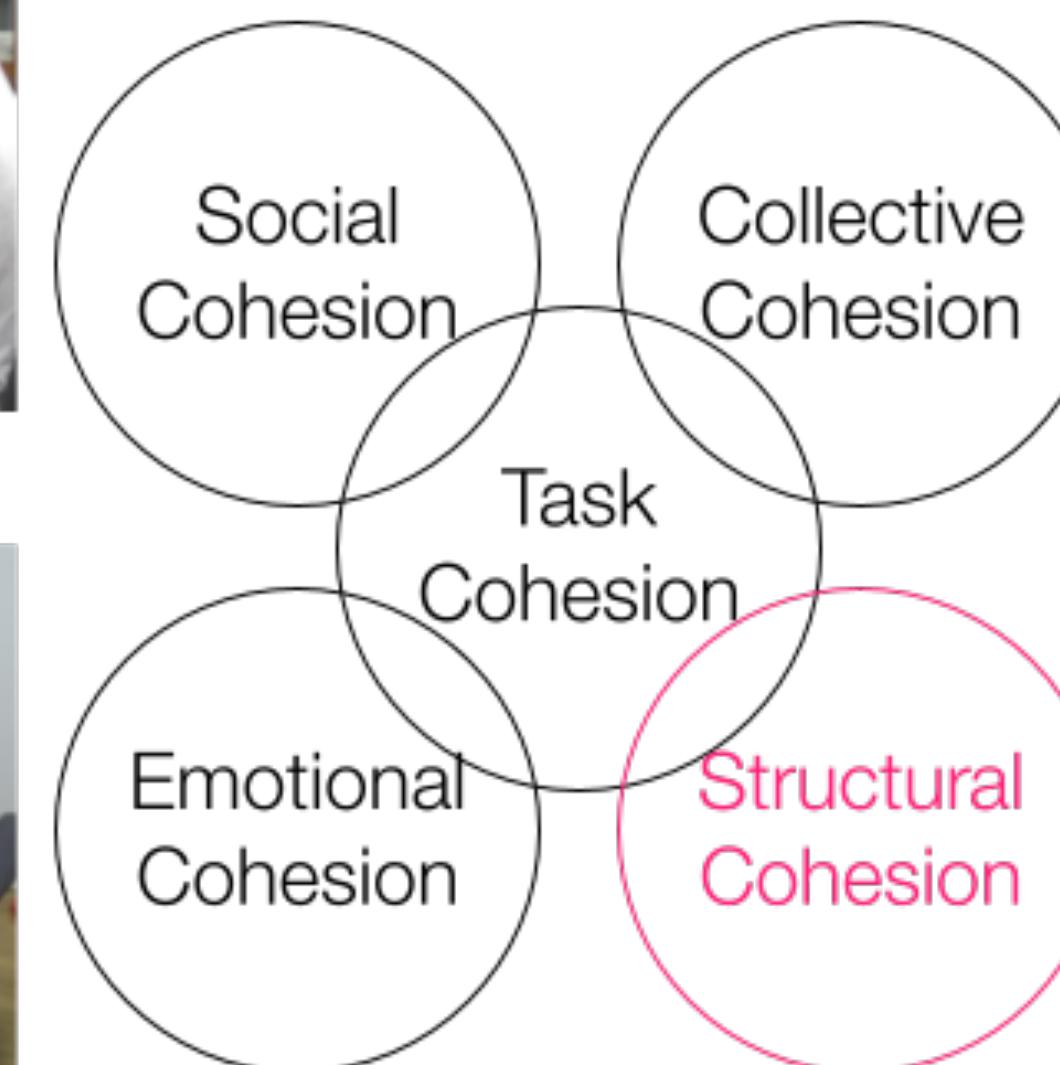
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Membership Preferences



Group-based Emotions



Prosociality



Multi-party Gaze

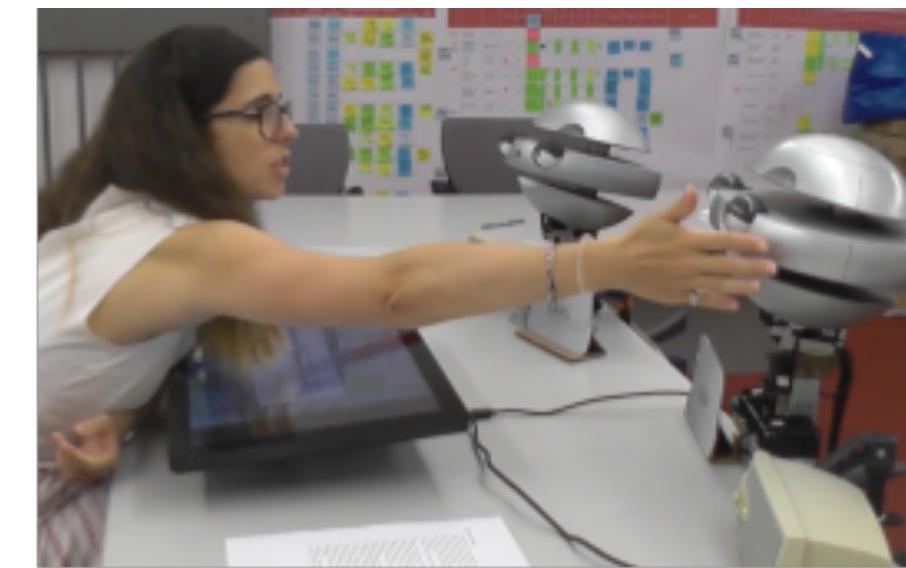
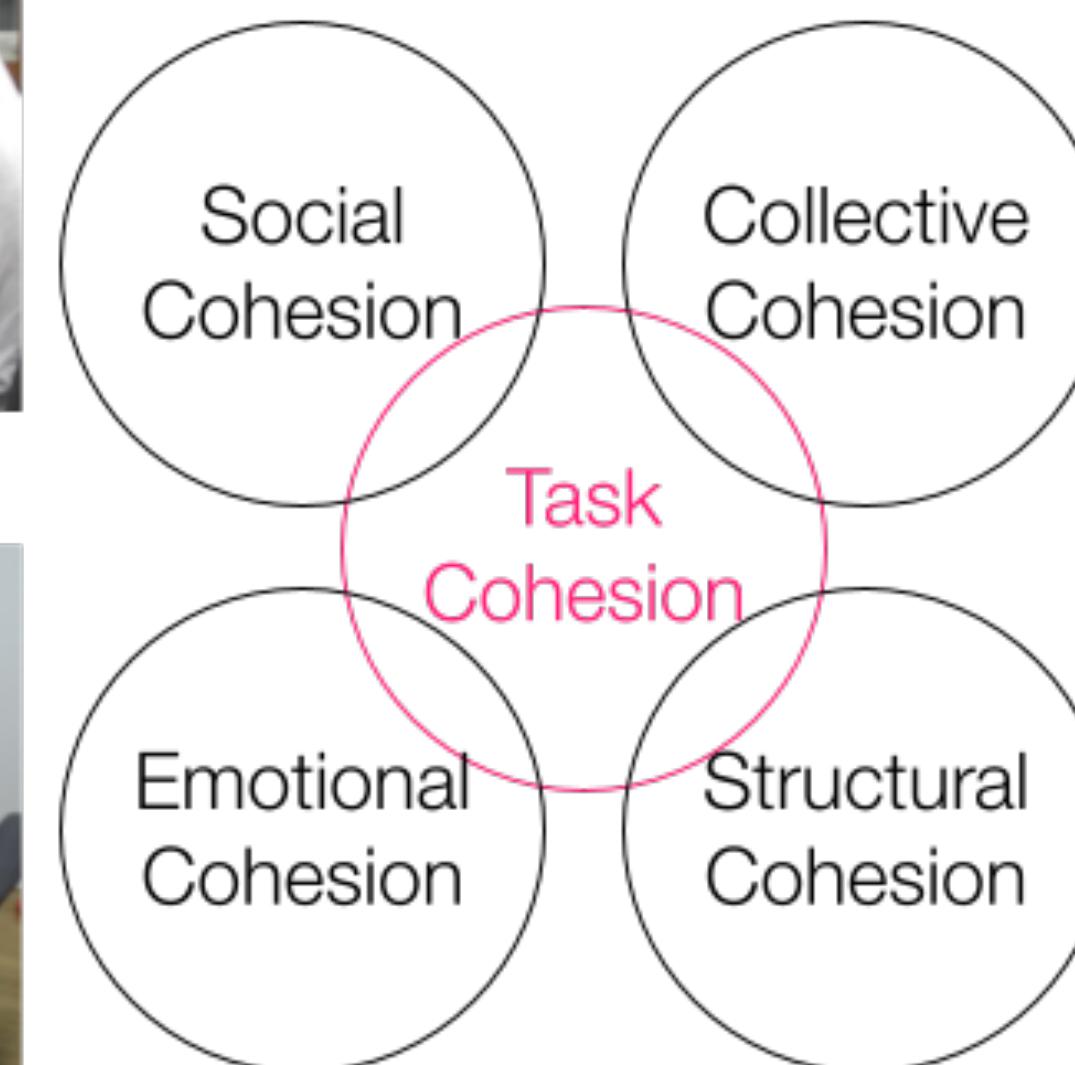
Contributions



Membership Preferences



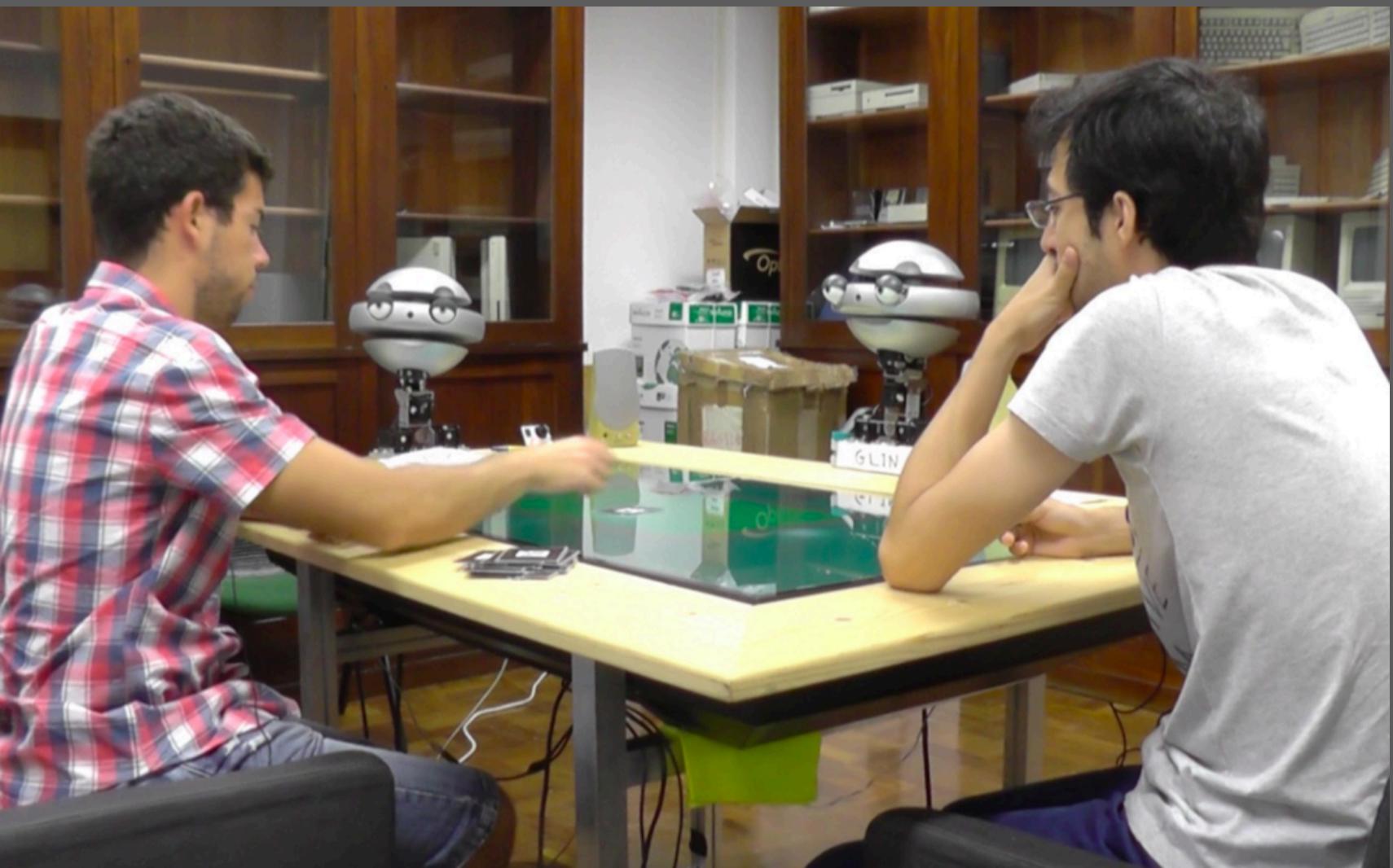
Group-based Emotions



Prosociality



Multi-party Gaze



Social
Cohesion

Membership Preferences & Team Formation

Project Goal & Research Questions

Social Cohesion

Project Goal & Research Questions

Social Cohesion

- How do relationships and attractions develop towards robotic teammates?

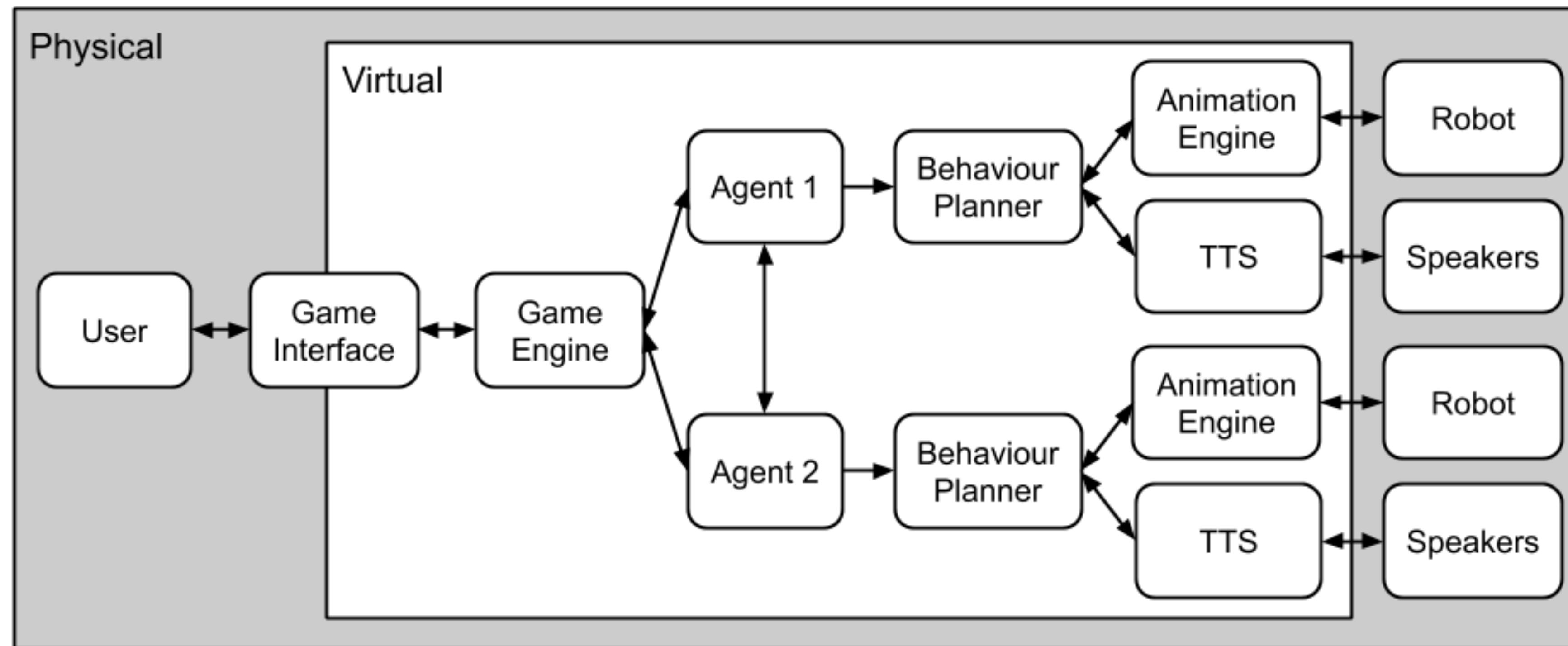
Project Goal & Research Questions

Social Cohesion

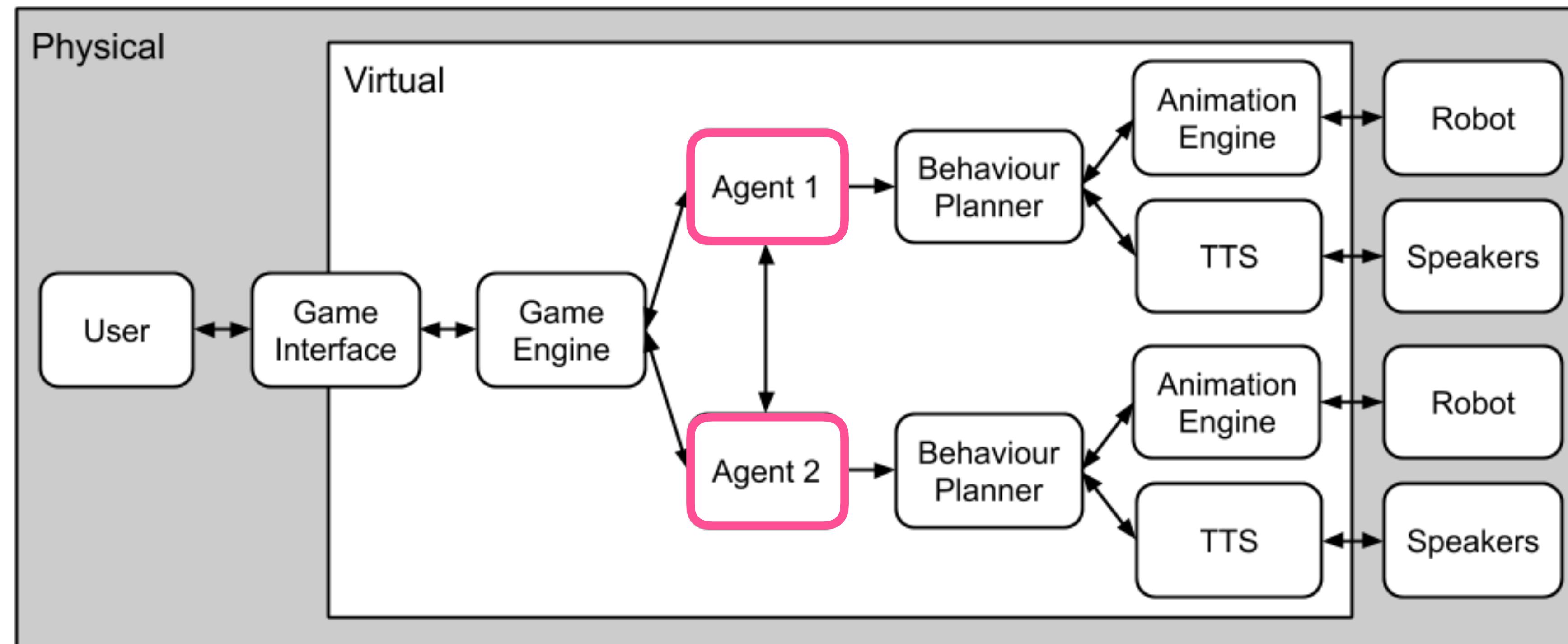
- How do relationships and attractions develop towards robotic teammates?
- Which traits do people prefer on robotic teammates?



Architecture for 2 autonomous robots

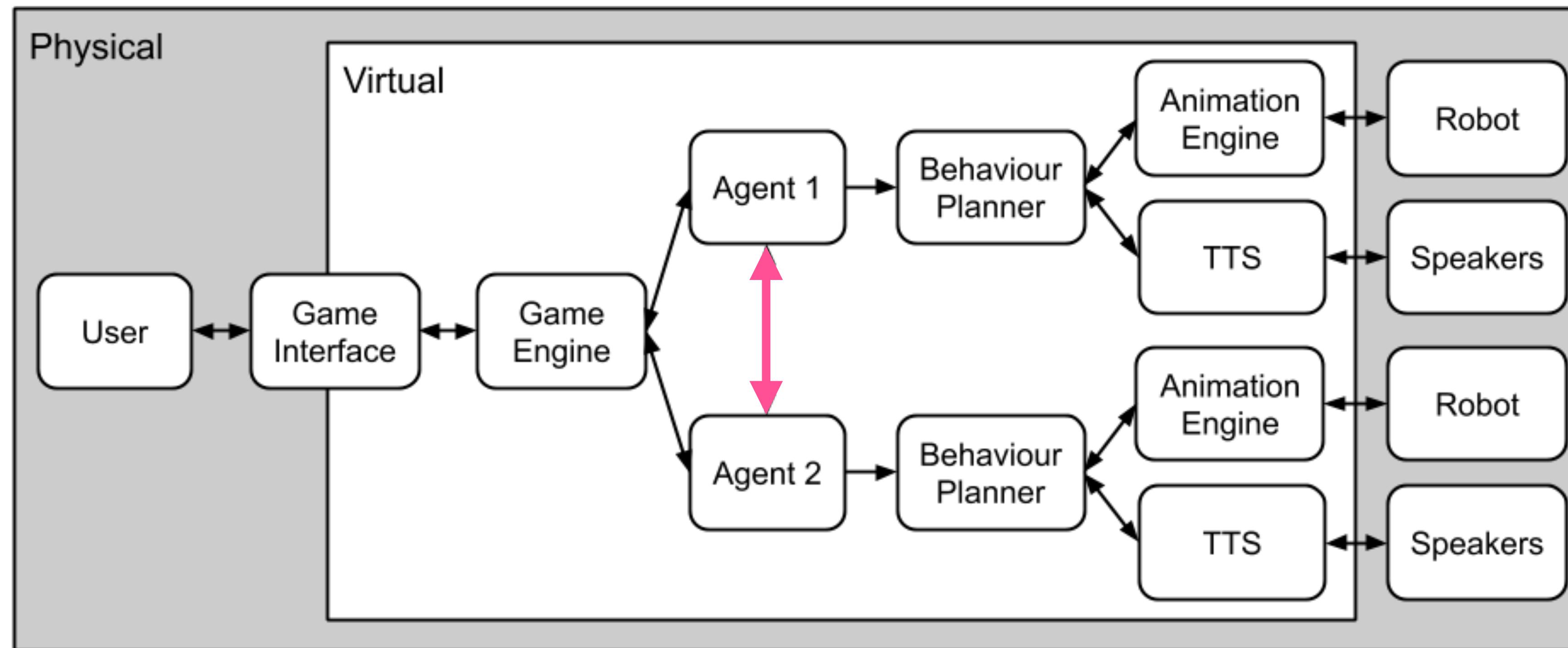


Architecture for 2 autonomous robots



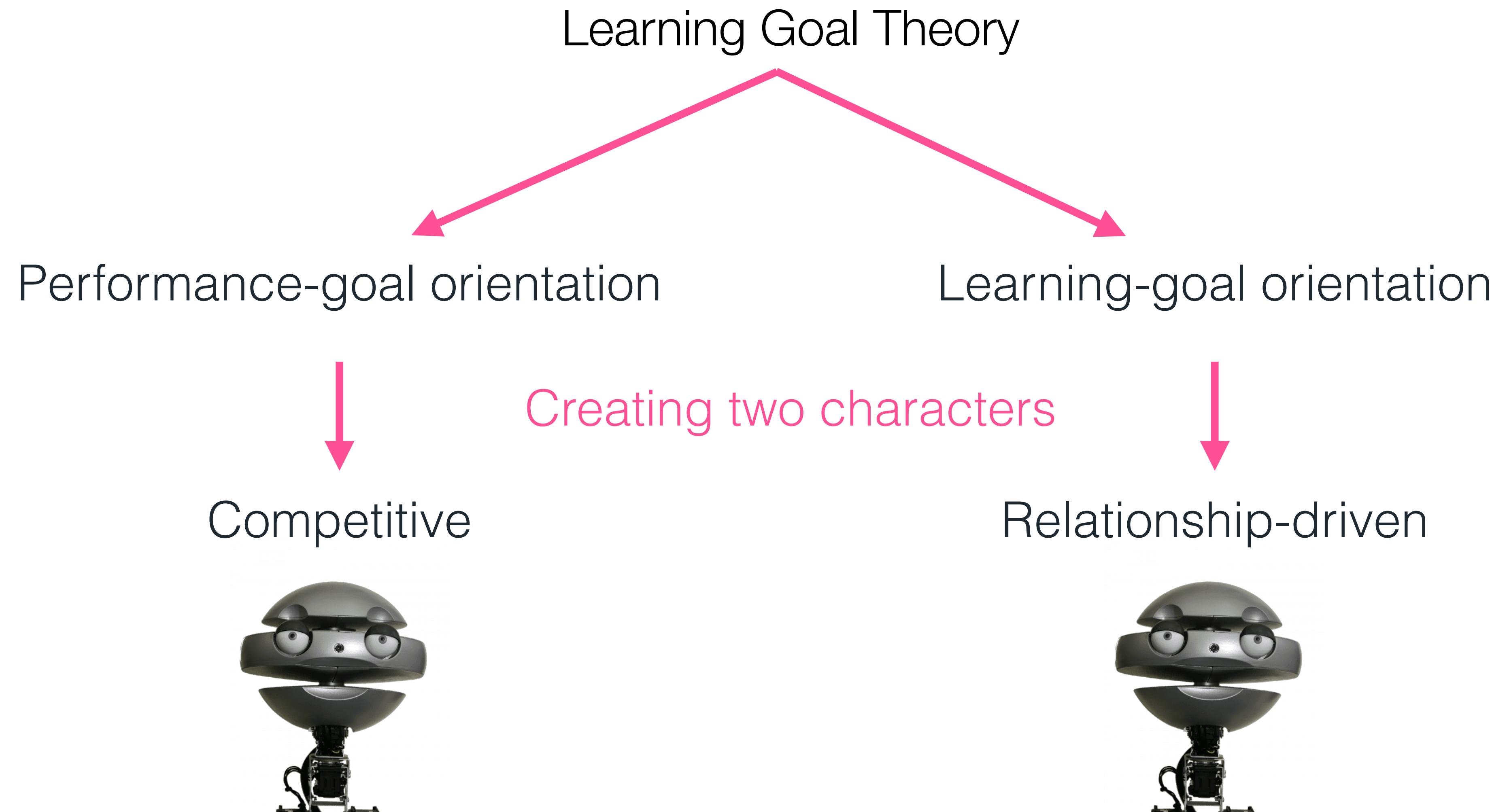
- Play the card game (Perfect Information Monte-Carlo Search)
- Social behaviours (FAtiMA toolkit)

Architecture for 2 autonomous robots



2-phase handshake protocol

Which traits do people prefer on robotic teammates?



Creating two characters

- Characters differed in verbal behaviours
- 420 speech utterances for each character

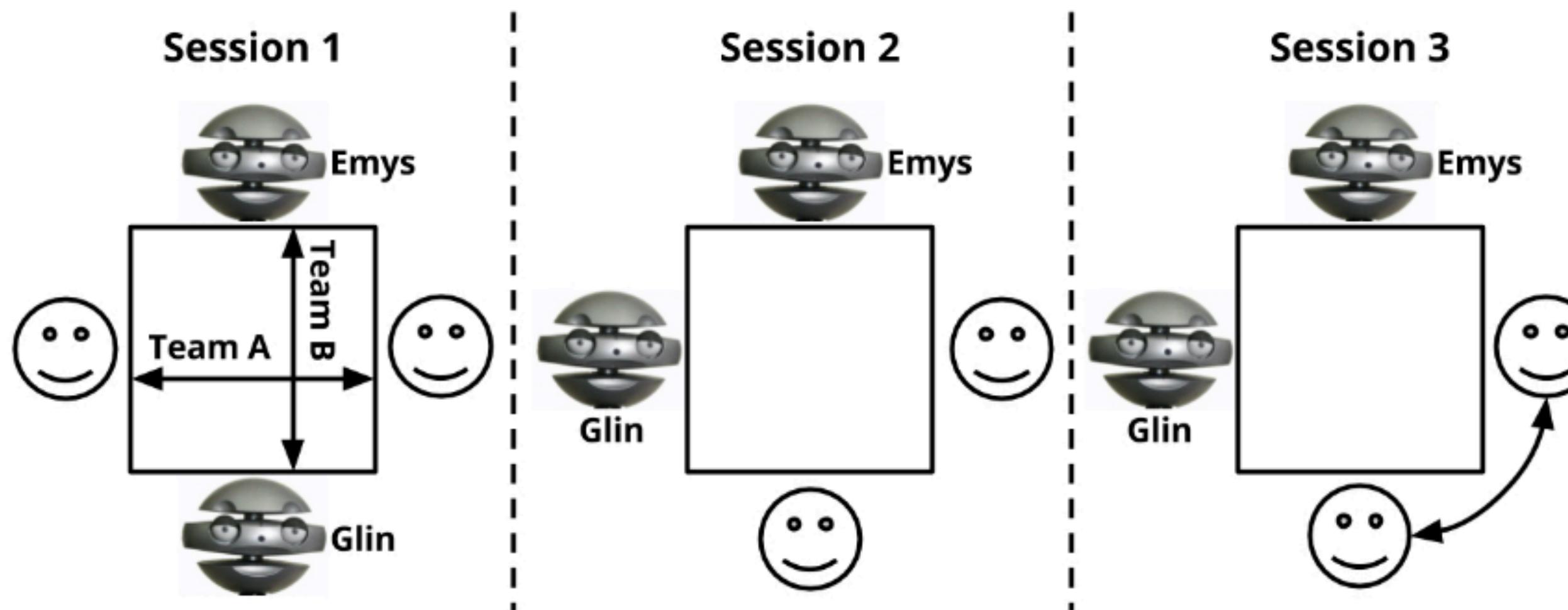
Game State	Competitive	Relationship-driven
<i>Self Playing</i>	"Watch and learn how this is played."	"I am so proud to be on your team!"
<i>Game Loss</i>	"This cannot continue like this! You have to play better!"	"No worries, next time we will do better!"

Validation of the two characters

Questionnaires dimensions	Competitive	Relationship-driven
Competitiveness index	+	-
McGill Friendship	-	+
Relationship Assessment	-	+
Likeability	-	+
Perceived Intelligence	=	=

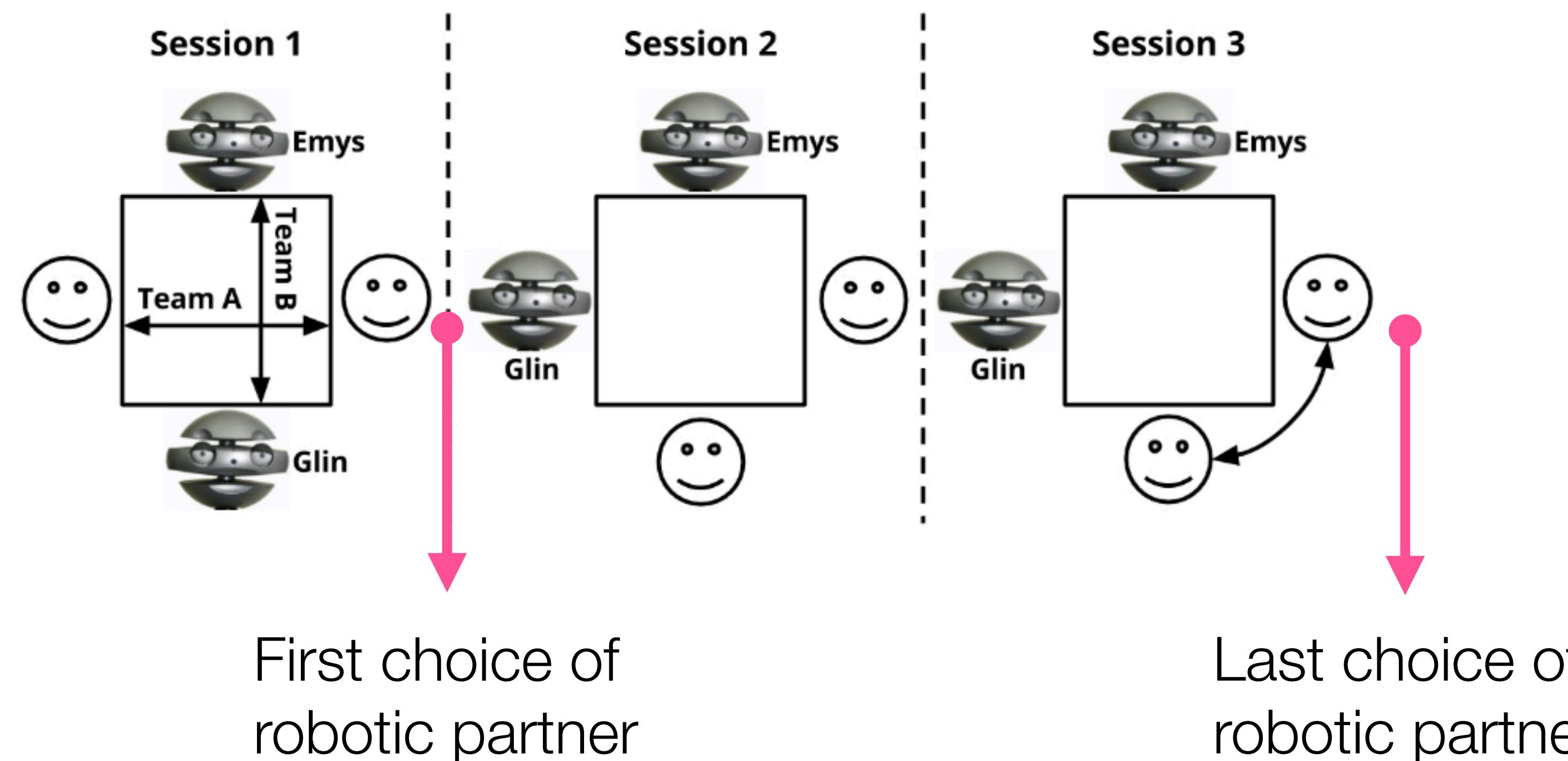
User Study

- 61 participants
- 3 sessions (1h30)



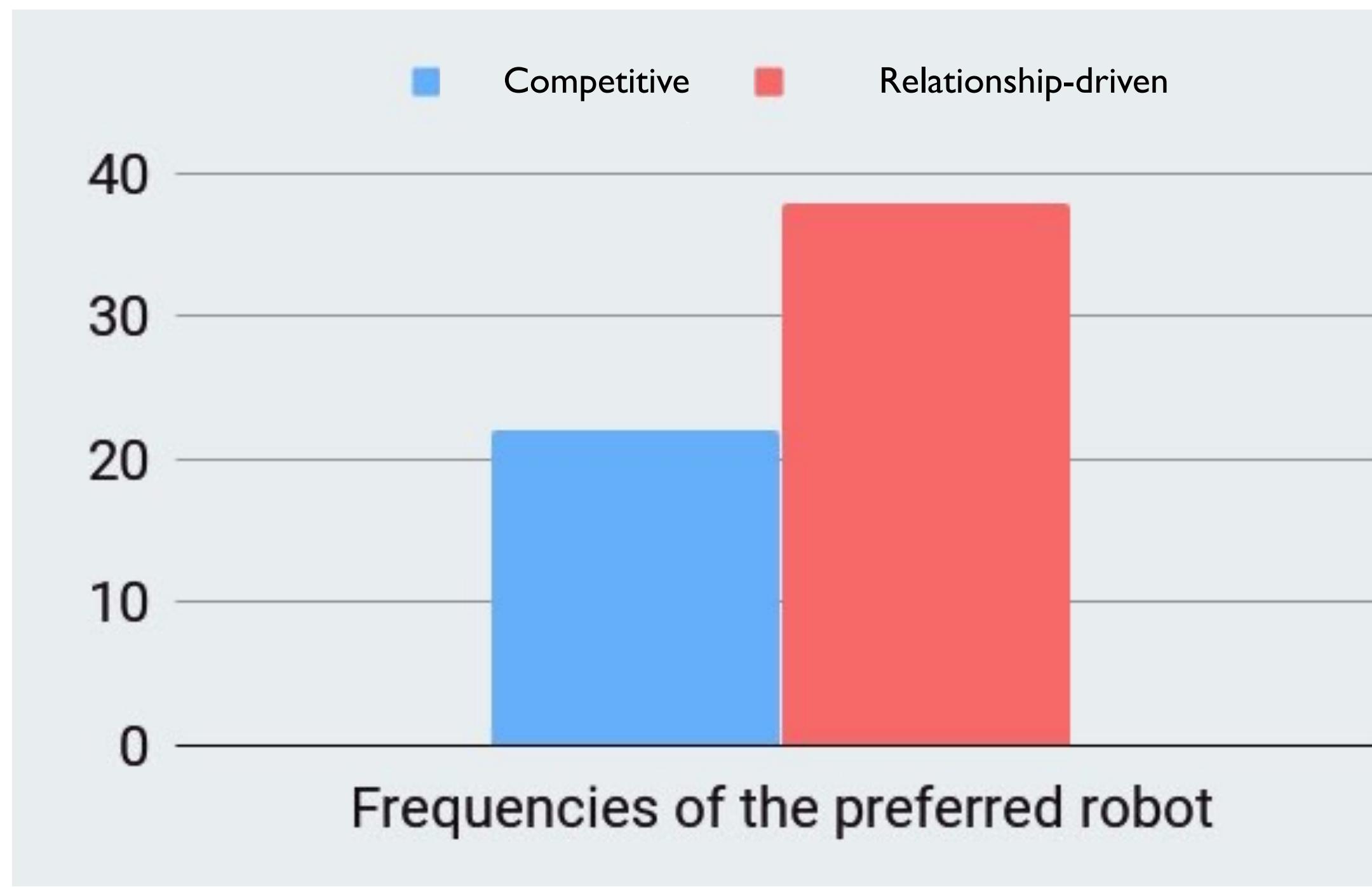
User Study

“Which robot will you prefer to partner with?”

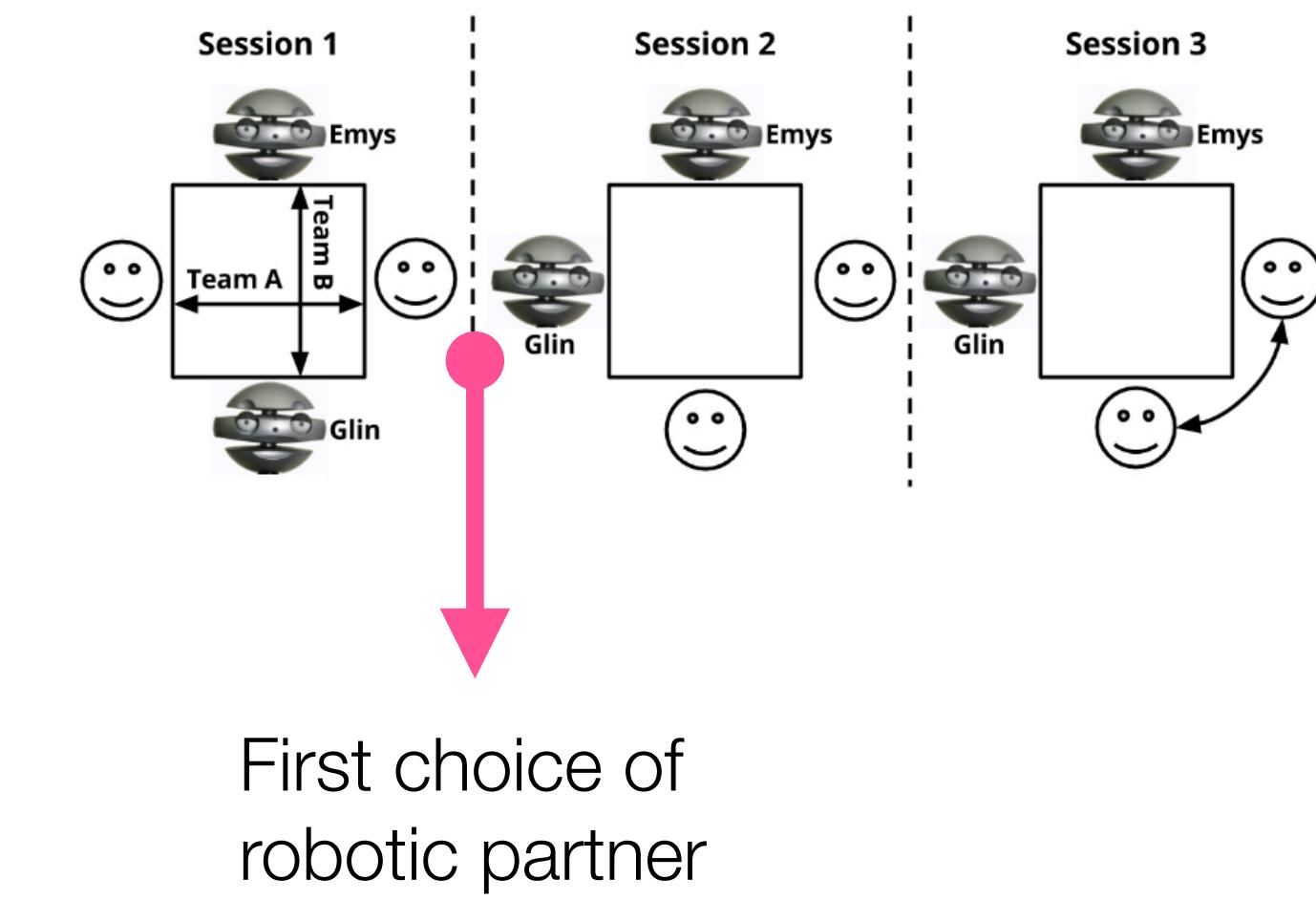


Which robot will people prefer to partner with?

In the **first** choice...

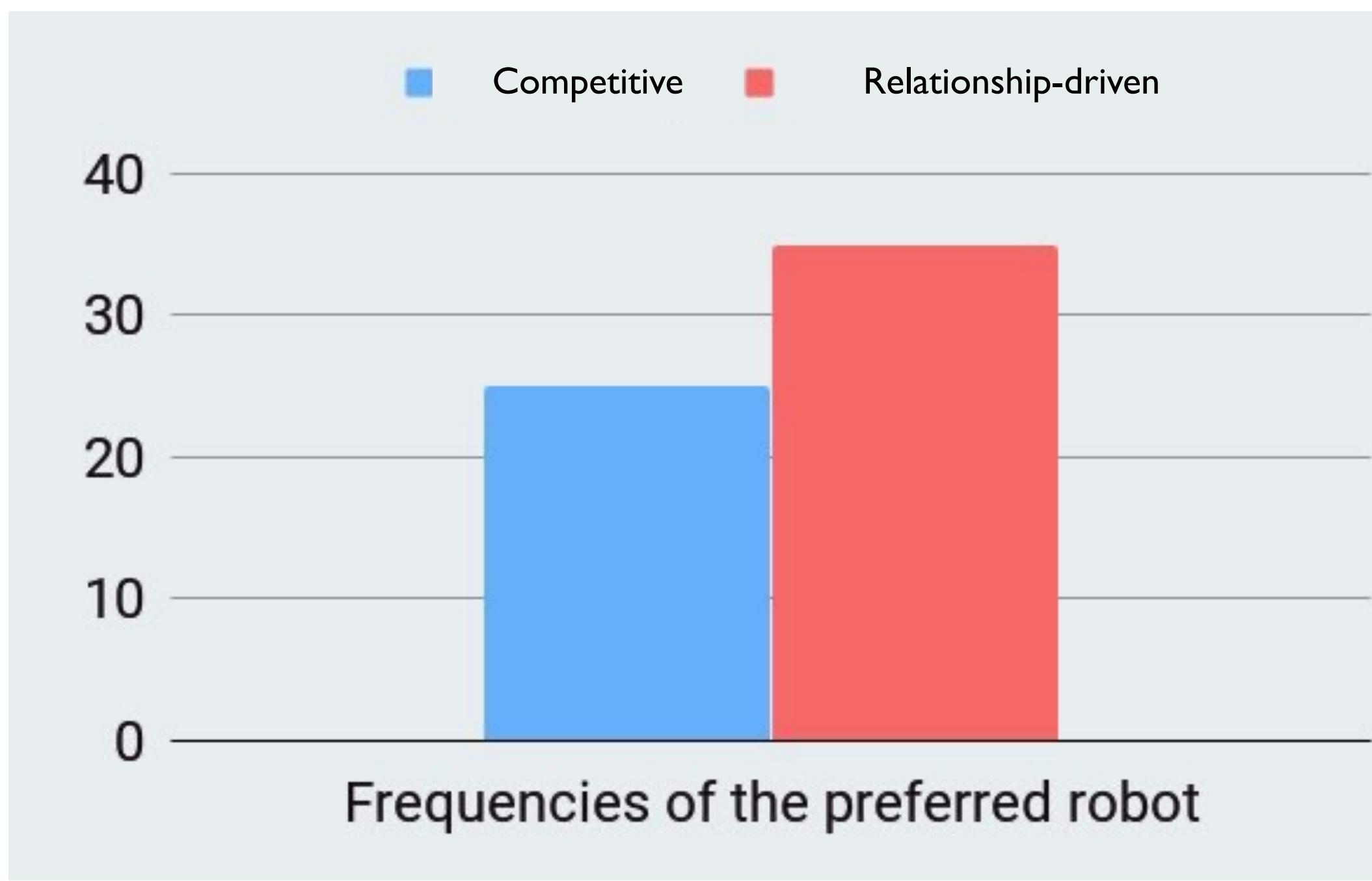


p=0.039

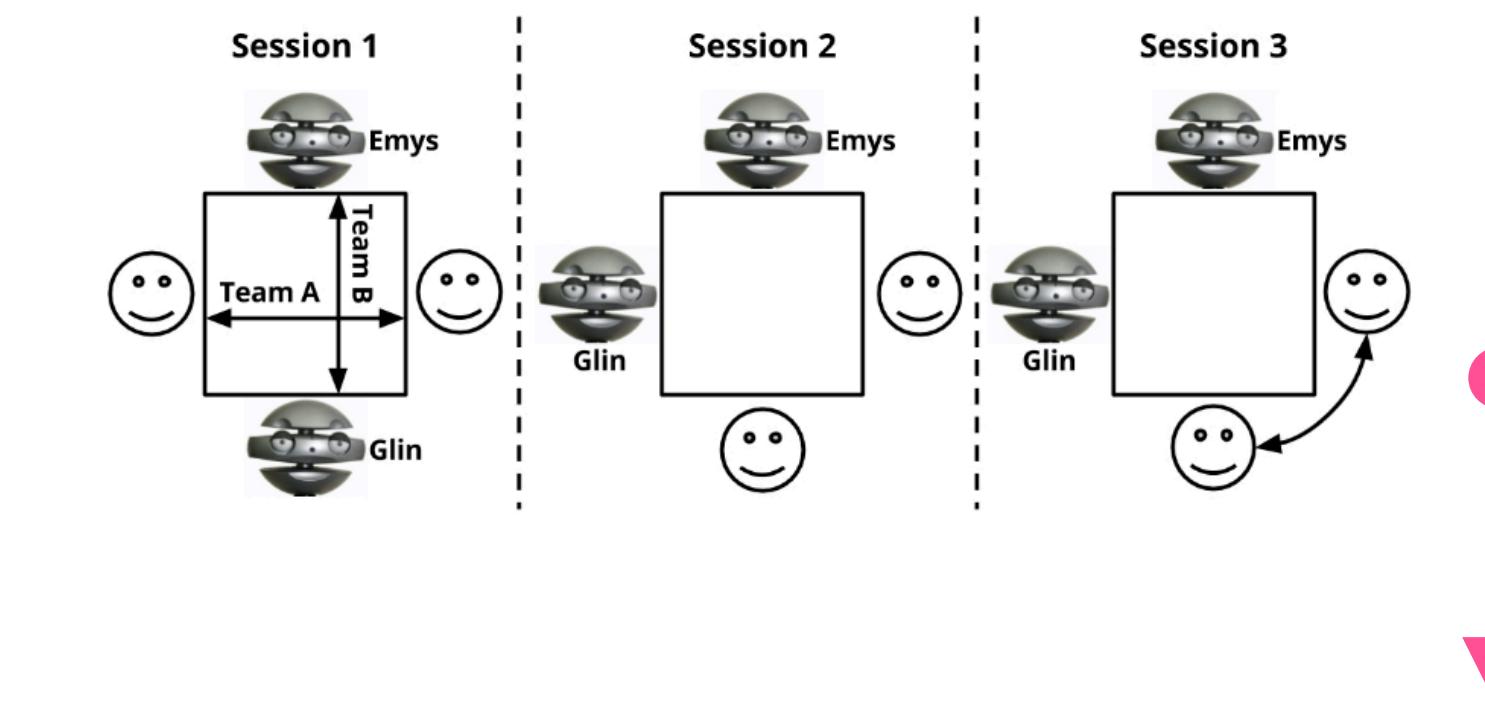


Which robot will people prefer to partner with?

In the **last** choice...

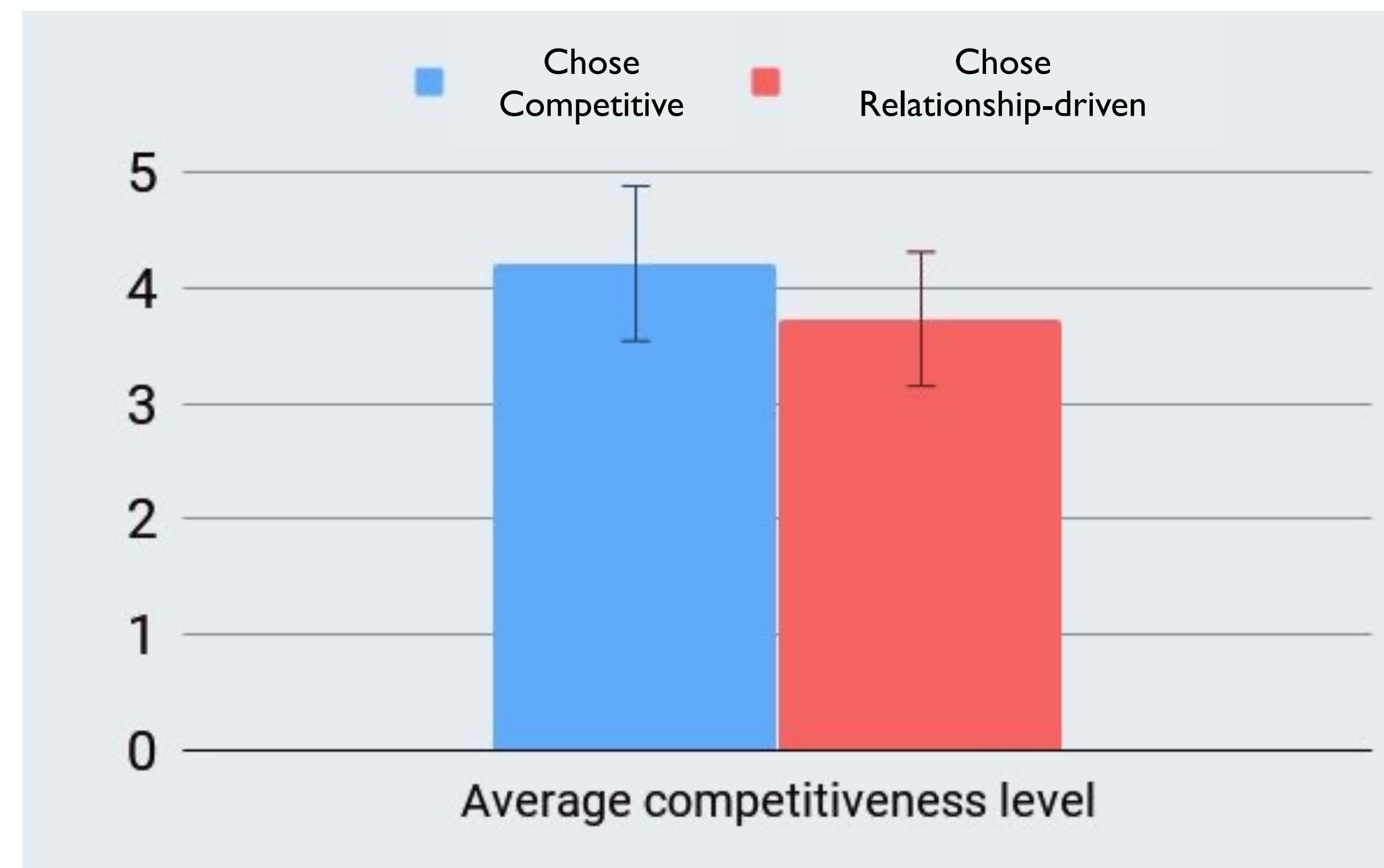


p=0.197



How do attractions develop towards robots?

- People's competitiveness was significantly different



p=0.005

How do attractions develop towards robots?

Significant association between the performance of the robots and people's preference ($p=0.008$)

Take-away Message

Social cohesion towards robotic teammates can be influenced by both personal characteristics and by the team performance.

The Learning-Goal Theory can be used to design social behaviours of robotic teammates in order to foster social cohesion.

Correia, F., Petisca, S., Alves-Oliveira, P., Ribeiro, T., Melo, F. S., & Paiva, A. (2017, July). Groups of humans and robots: Understanding membership preferences and team formation. In Robotics: Science and Systems. **[RSS'17]**

Correia, F., Petisca, S., Alves-Oliveira, P., Ribeiro, T., Melo, F. S., & Paiva, A. (2019). "I Choose... YOU!" Membership preferences in human–robot teams. Autonomous Robots, 43(2), 359-373. **[AuRo Journal]**

Other follow-up work

- Behavioural analysis on collected data (Bales IPA)

Oliveira, R., Arriaga, P., **Correia, F.**, & Paiva, A. (2020). Looking Beyond Collaboration: Socioemotional Positive, Negative and Task-Oriented Behaviors in Human–Robot Group Interactions. *International Journal of Social Robotics*, 12(2), 505-518. [\[IJSR Journal\]](#)

Collective
Cohesion



Prosociality in human-robot teams

Project Goal & Research Questions

Collective Cohesion

Project Goal & Research Questions

Collective Cohesion

- How do people perceive prosocial and selfish actions of robotic teammates?

Project Goal & Research Questions

Collective Cohesion

- How do people perceive prosocial and selfish actions of robotic teammates?
- Can the perception of those robots be affected by the outcome of team?

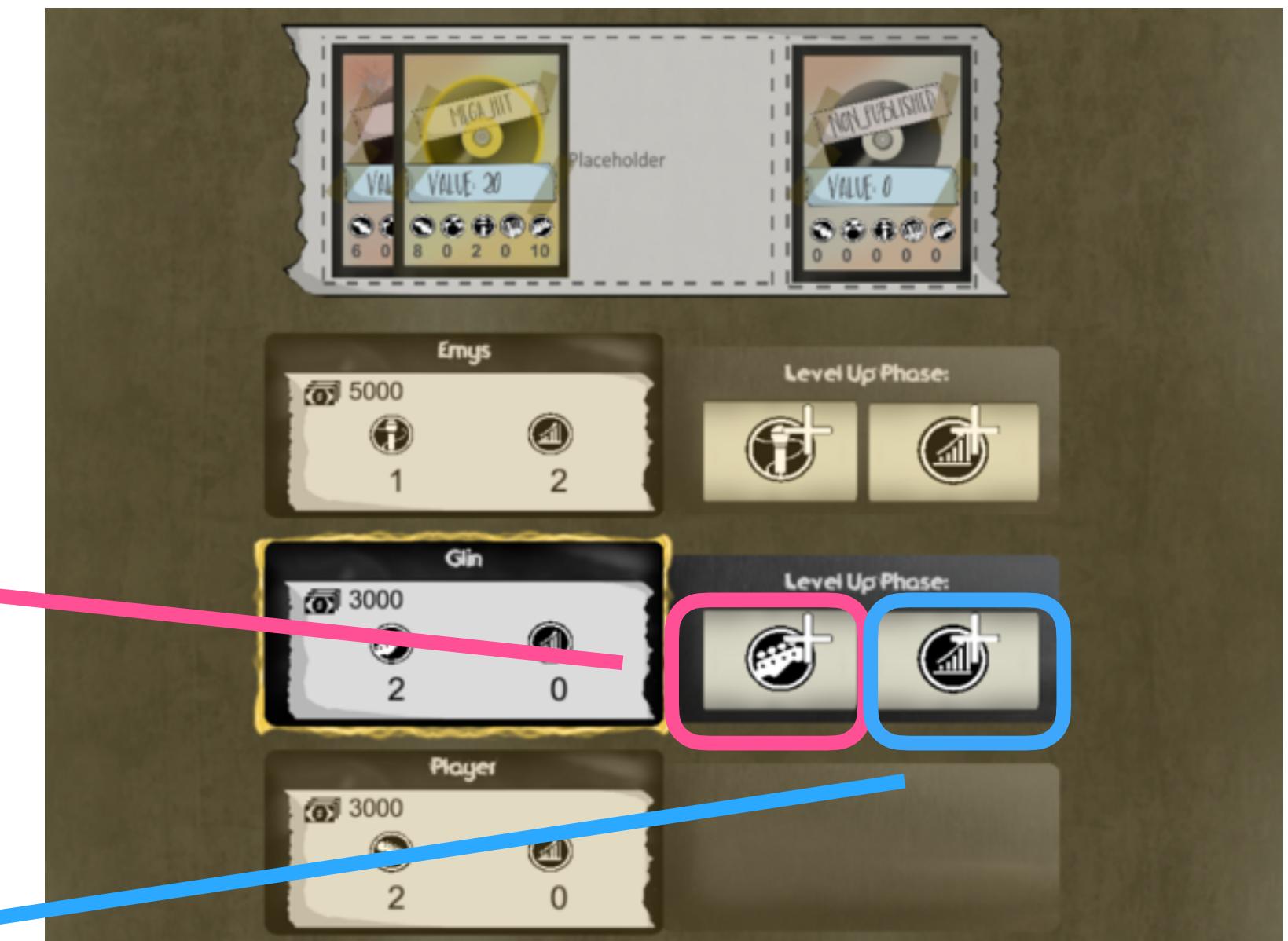
Project Goal & Research Questions

Collective Cohesion

- How do people perceive prosocial and selfish actions of robotic teammates?
- Can the perception of those robots be affected by the outcome of team?
- Does the outcome of the team affect people's cohesion?

User Study

- *For The Record* - Threshold game with uncertain returns
 - Common Goal - “play for instrument”
- **to cooperate**
 - Individual Goal - “play for marketing”
- **to defect**



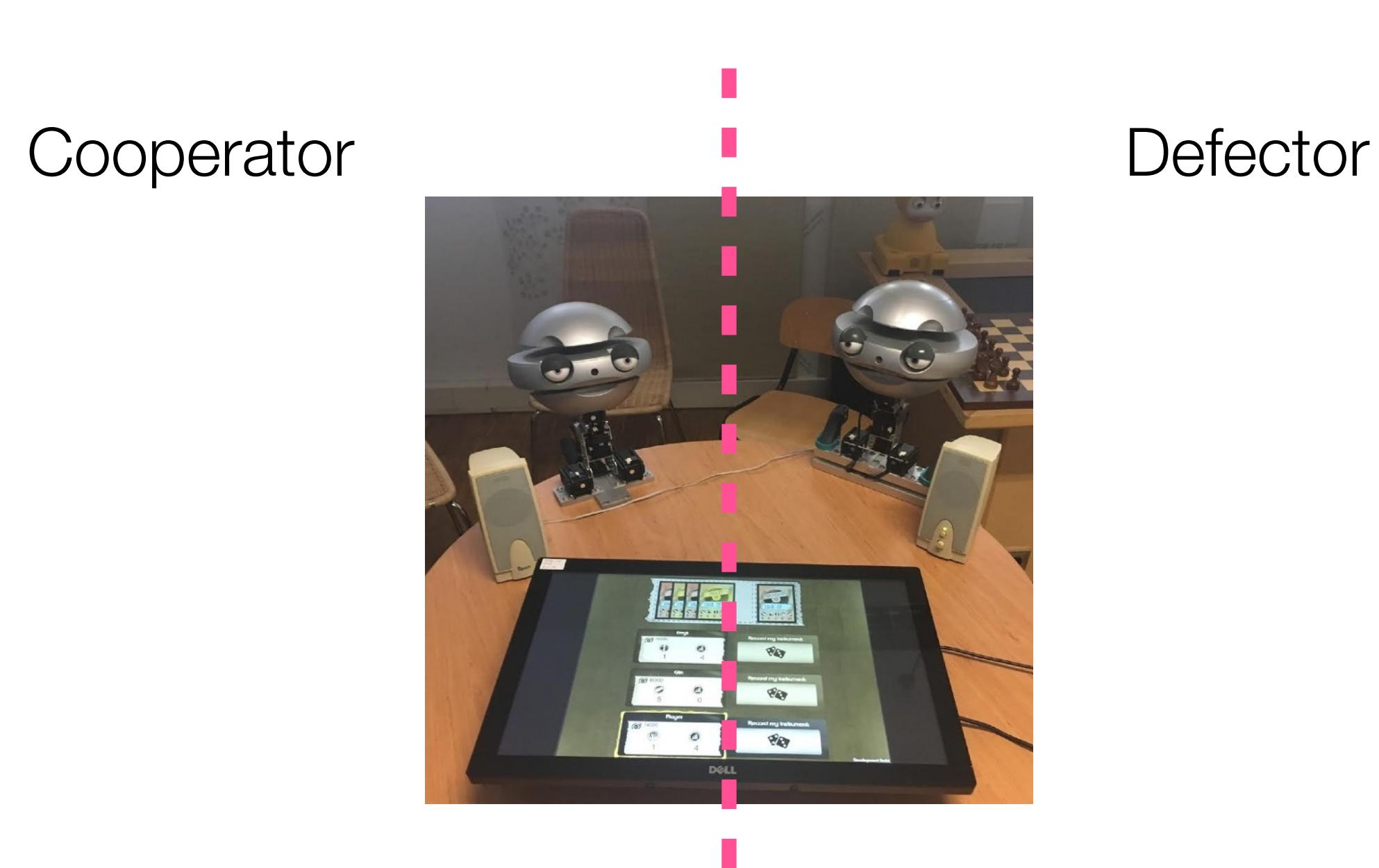
User Study

- Team of 3
 - 2 autonomous robots
 - 1 person
- 70 participants (large corporation)



Experimental Design

- Mixed experimental design
- Within-subjects variable - **strategy of the robots**



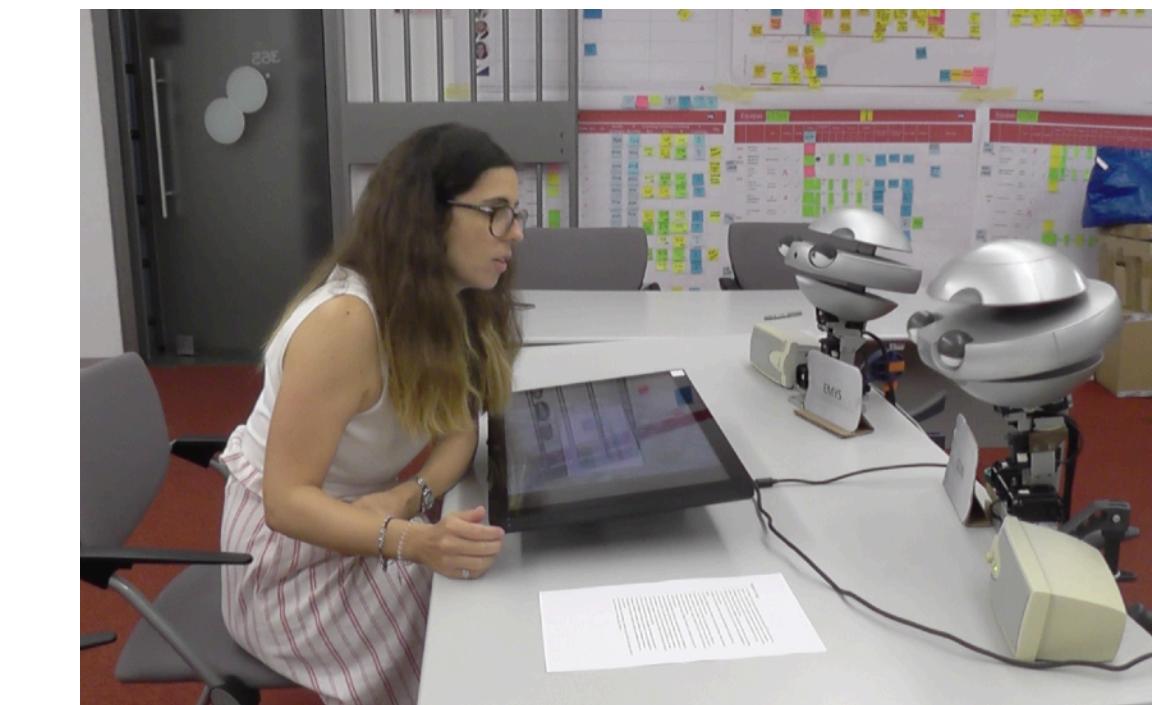
Experimental Design

- Mixed experimental design
 - Within-subjects variable - **strategy of the robots**
 - Between-subjects variable - **game result**

Winning



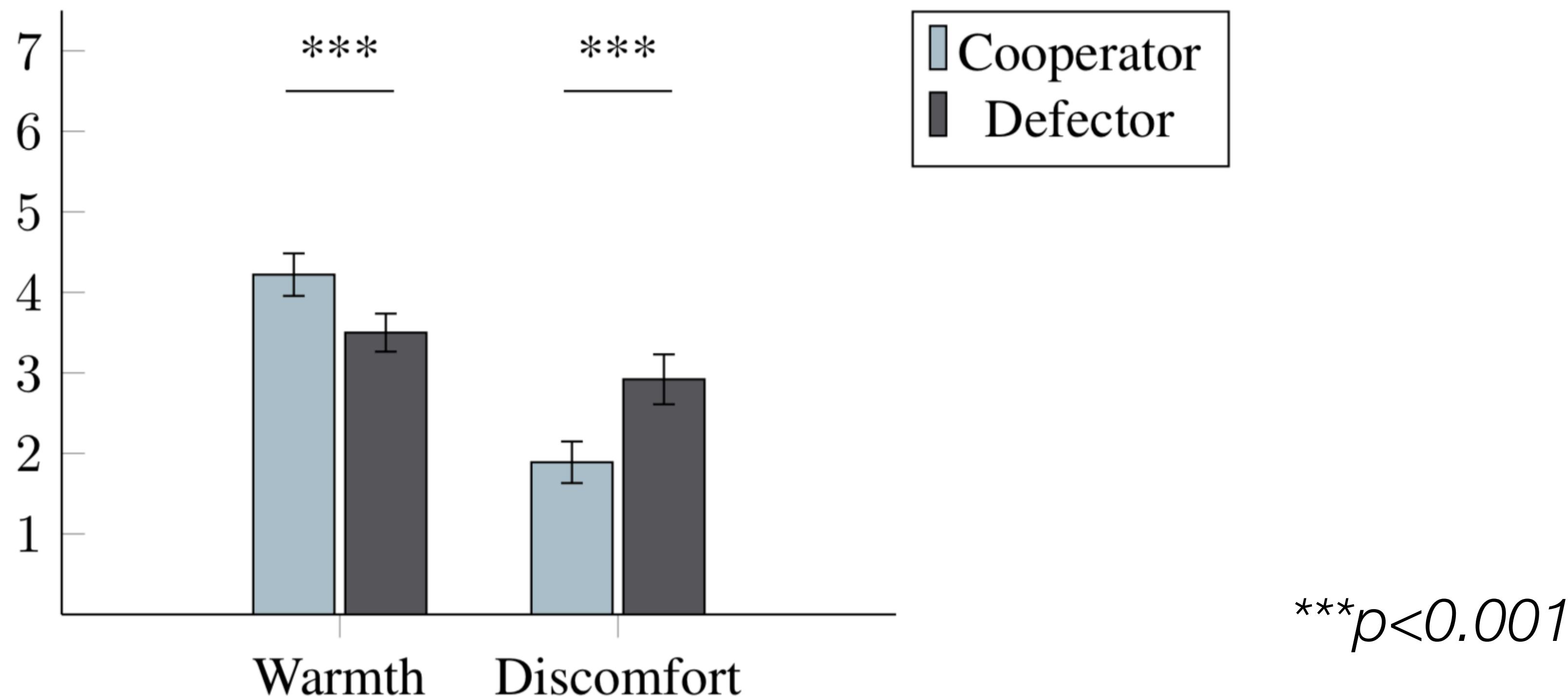
Losing





How do people perceive prosocial and selfish actions?

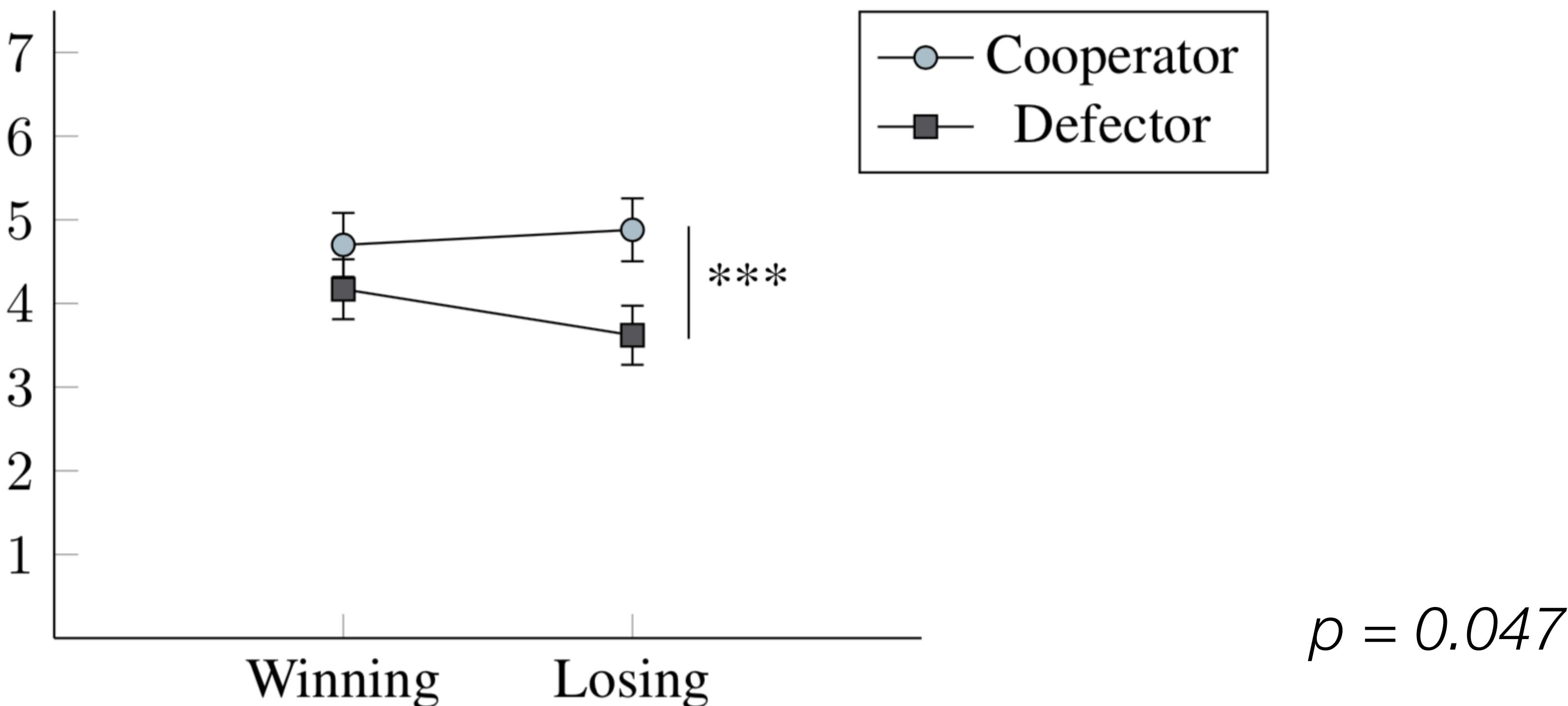
Perceived Warmth and Discomfort (RoSAS)



Carpinella, C. M., Wyman, A. B., Perez, M. A., & Stroessner, S. J. (2017, March). The robotic social attributes scale (rosas) development and validation. In Proceedings of the 2017 ACM/IEEE International Conference on human-robot interaction (pp. 254-262).

Can those perceptions be affected by the outcome?

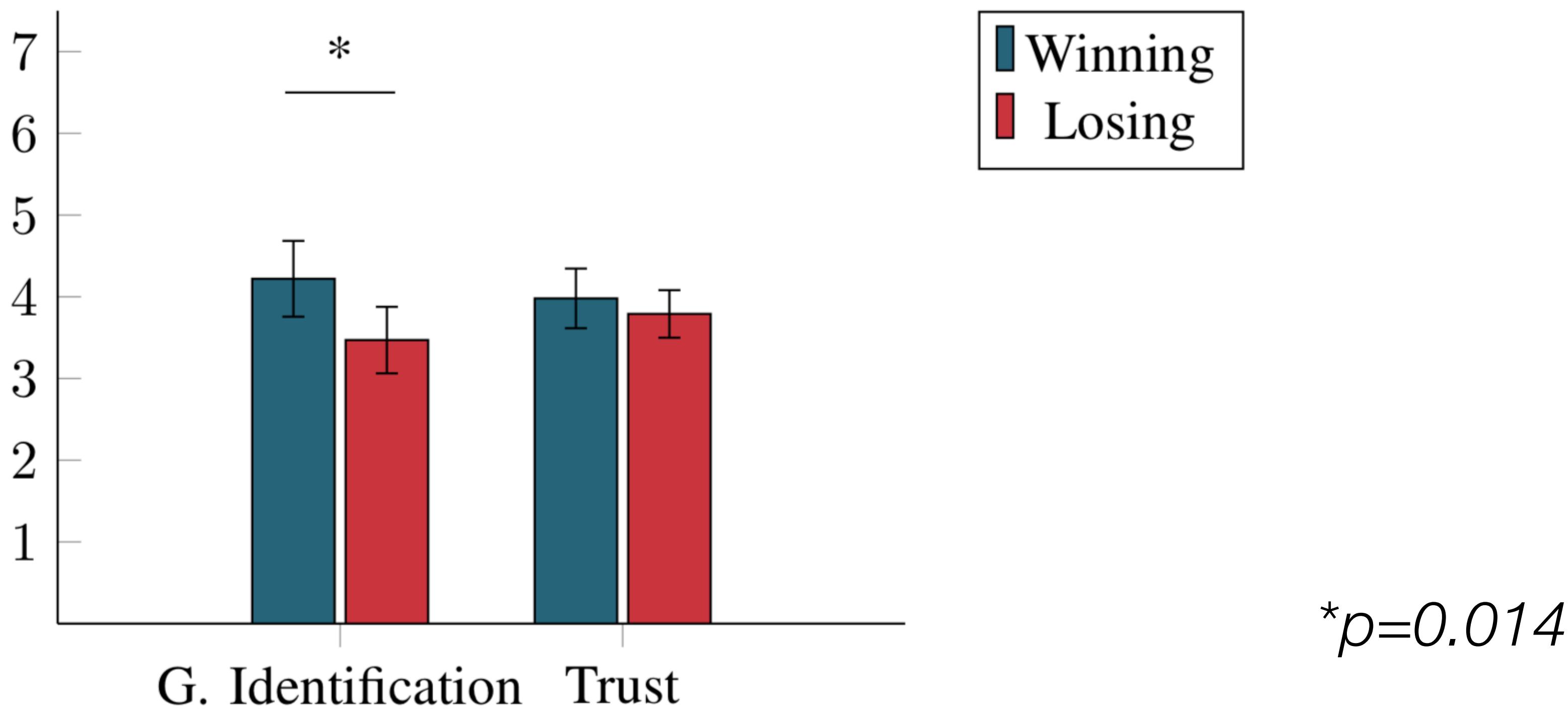
Perceived Competence (RoSAS)



Carpinella, C. M., Wyman, A. B., Perez, M. A., & Stroessner, S. J. (2017, March). The robotic social attributes scale (rosas) development and validation. In Proceedings of the 2017 ACM/IEEE International Conference on human-robot interaction (pp. 254-262).

Does the outcome affect people's cohesion?

Group measures

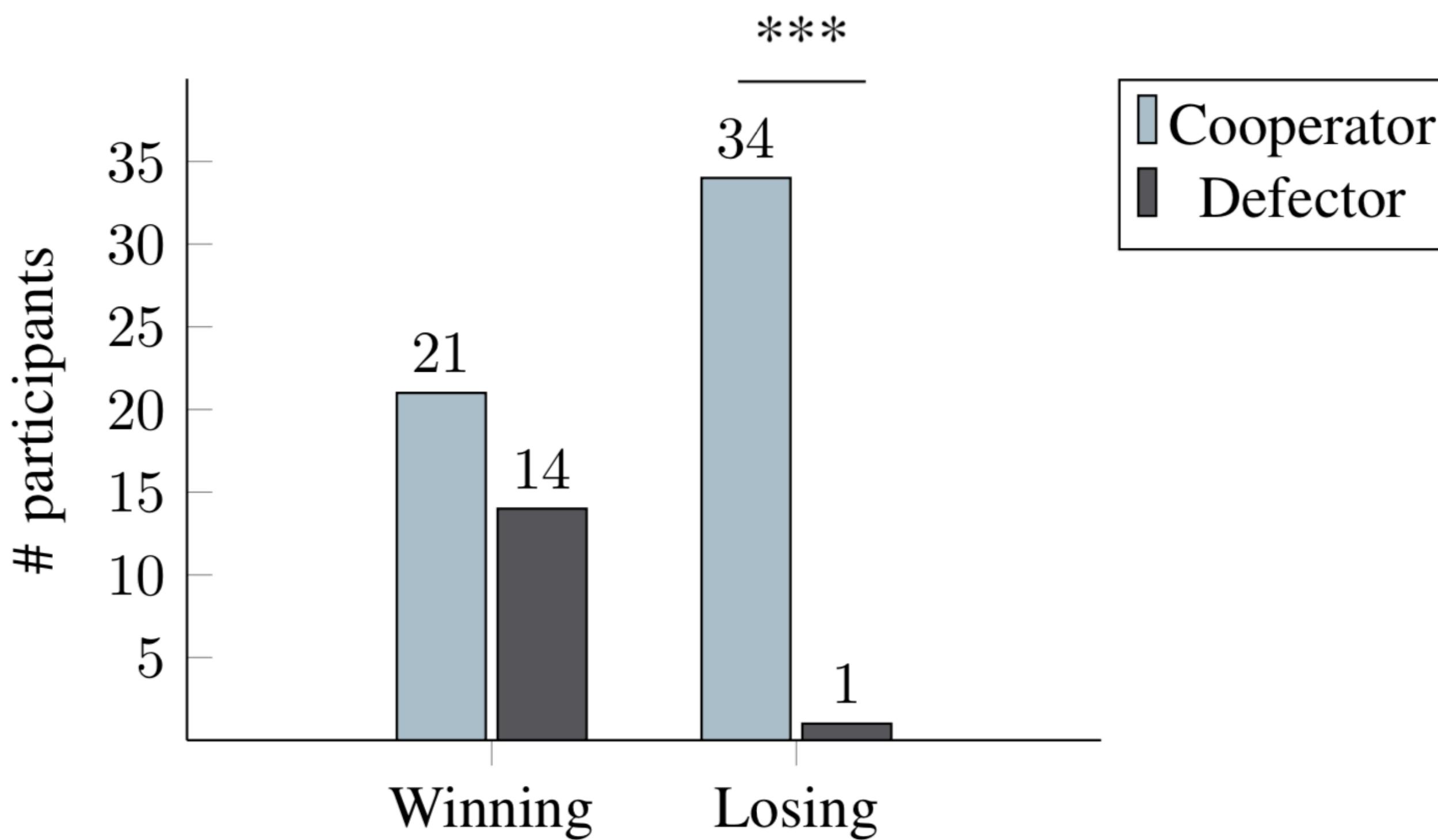


C. W. Leach, M. Van Zomeren, S. Zebel, M. L. Vliek, S. F. Pennekamp, B. Doosje, J. W. Ouwerkerk, and R. Spears, "Group-level self-definition and self-investment: a hierarchical (multicomponent) model of in-group identification." *Journal of personality and social psychology*, vol. 95, no. 1, p. 144, 2008

K. Allen and R. Bergin, "Exploring trust, group satisfaction, and performance in geographically dispersed and co-located university technology commercialization teams," in *In Proceedings of the NCIIA 8th Annual Meeting: Education that Works*, 2004, pp. 18–20.

Does the outcome affect people's cohesion?

Preference for a hypothetical future game



*** $p<0.001$

Take-away Message

The collective cohesion portrayed by the robots affects people's perceptions.

The outcome of the game can influence people's reported collective cohesion.

Positive outcomes can “forgive” selfish behaviours...

Correia, F., Mascarenhas, S. F., Gomes, S., Arriaga, P., Leite, I., Prada, R., Melo, F. S. & Paiva, A. (2019, March). Exploring prosociality in human-robot teams. In 2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI) (pp. 143-151). IEEE. [HRI'19]

Other follow-up work

- The display of verbal criticism by robotic teammates
- Evolutionary advantages of selecting cooperative partners only when a previous game was lost

Correia, F., Chandra, S., Mascarenhas, S., Charles-Nicolas, J., Gally, J., Lopes, D., ... & Paiva, A. (2019, October). Walk the Talk! Exploring (Mis) Alignment of Words and Deeds by Robotic Teammates in a Public Goods Game. In 2019 28th IEEE International Conference on Robot and Human Interactive Communication **[RO-MAN]**

Santos, F. P., Mascarenhas, S., Santos, F. C., **Correia, F.**, Gomes, S., & Paiva, A. (2020). Picky losers and carefree winners prevail in collective risk dilemmas with partner selection. Autonomous Agents and Multi-Agent Systems, 34(2), 1-29. **[JAAMAS Journal]**

Other follow-up work

- The role of agents' transparency
- The impact of embodied features (Chapter of the thesis)

Tulli, S., Correia, F., Mascarenhas, S., Gomes, S., Melo, F. S., & Paiva, A. (2019, May). Effects of agents' transparency on teamwork. In International Workshop on Explainable, Transparent Autonomous Agents and Multi-Agent Systems (pp. 22-37). Springer, Cham. **[ExTRAAMAS Special Issue]**

Correia, F., Gomes, S., Mascarenhas, S., Melo, F. S., & Paiva, A. (2020). The Dark Side of Embodiment-Teaming Up With Robots VS Disembodied Agents. Proceedings of Robotics: Science and Systems. **[RSS'20]**



Emotional
Cohesion

A model of Group-
based Emotions

Project Goal & Research Questions

Emotional Cohesion

Project Goal & Research Questions

Emotional Cohesion

- How can a robot express group feelings?

Project Goal & Research Questions

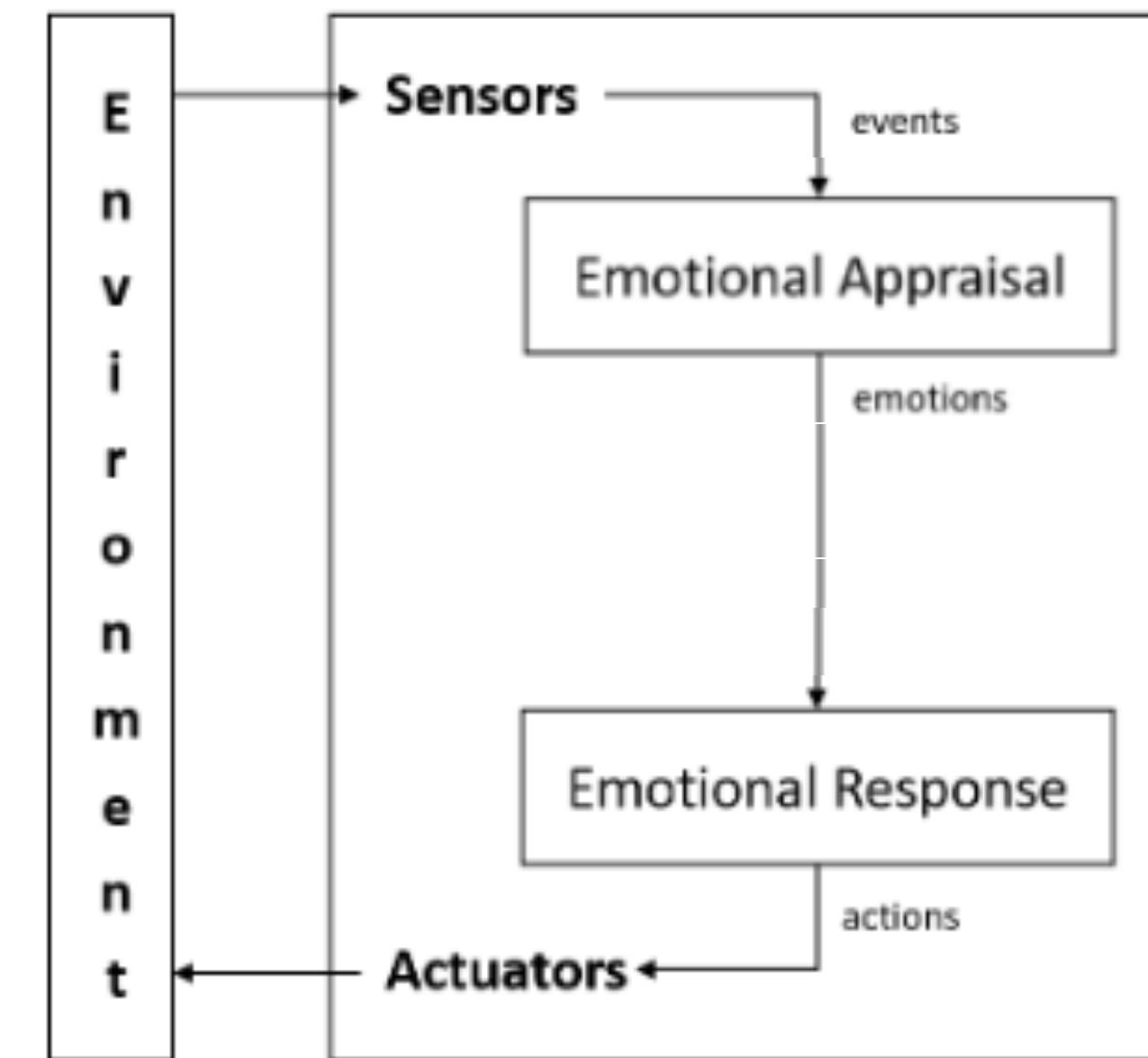
Emotional Cohesion

- How can a robot express group feelings?
- Does the expression of group feelings by the robot increase people's cohesion?

What are Group-based Emotions?

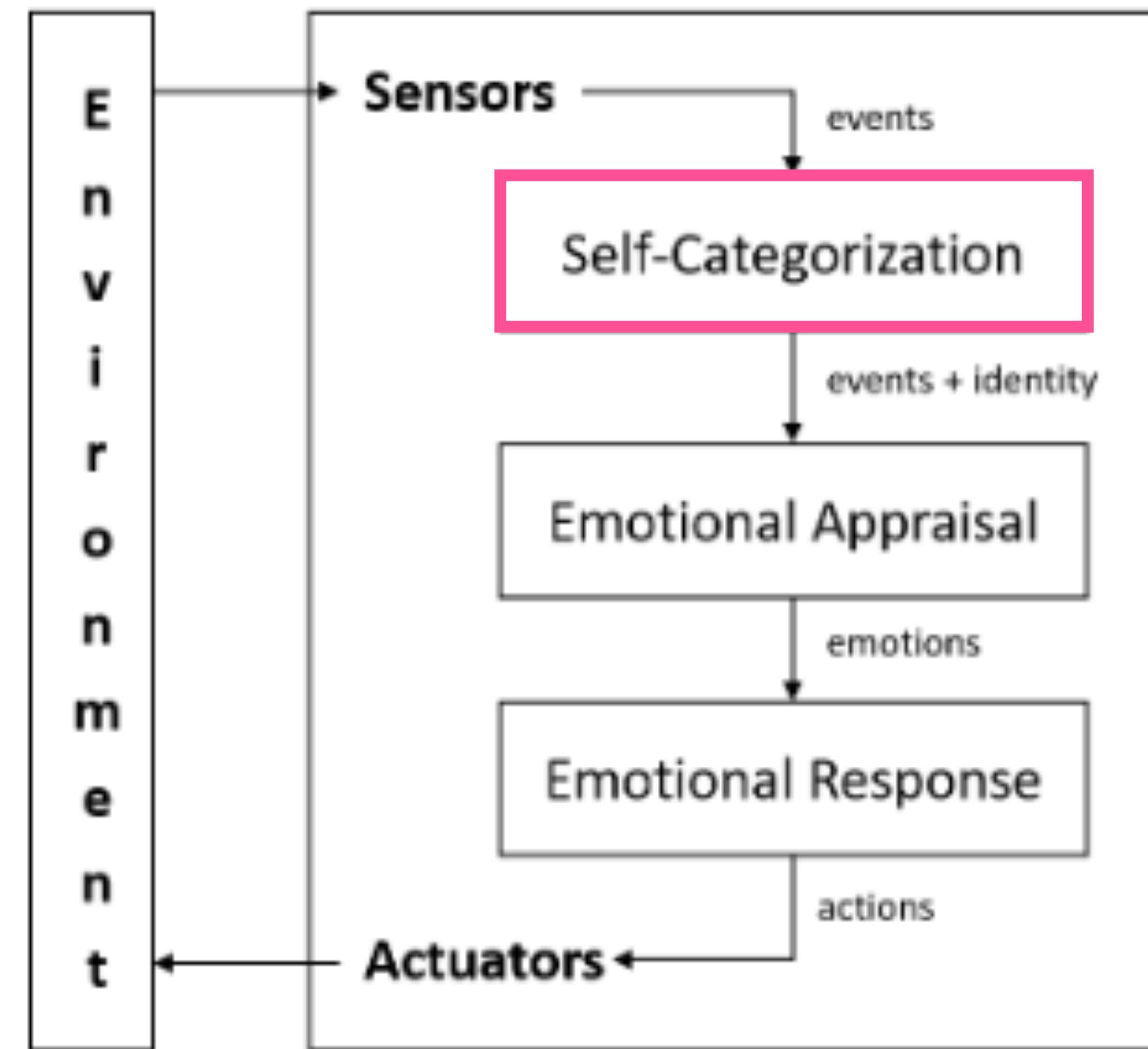


How can a robot express group feelings?



**Current models for generation of emotions
do not allow for Group-based Emotions!**

A model of Group-based Emotions

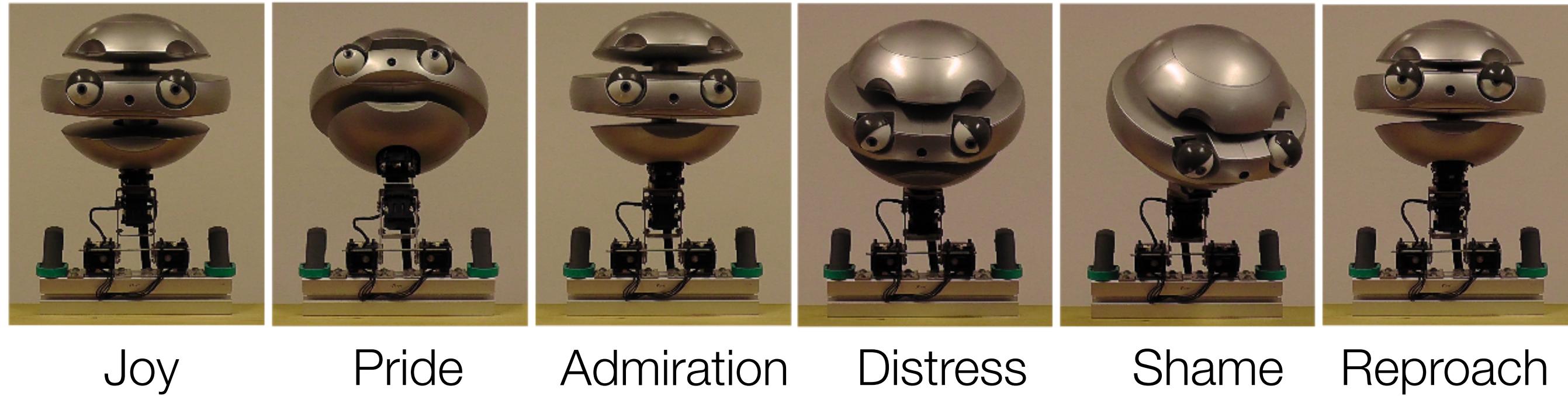


User Study

- Card game
- 2 autonomous robots
 - 1 with group-based emotions
 - 1 with individual-based emotions



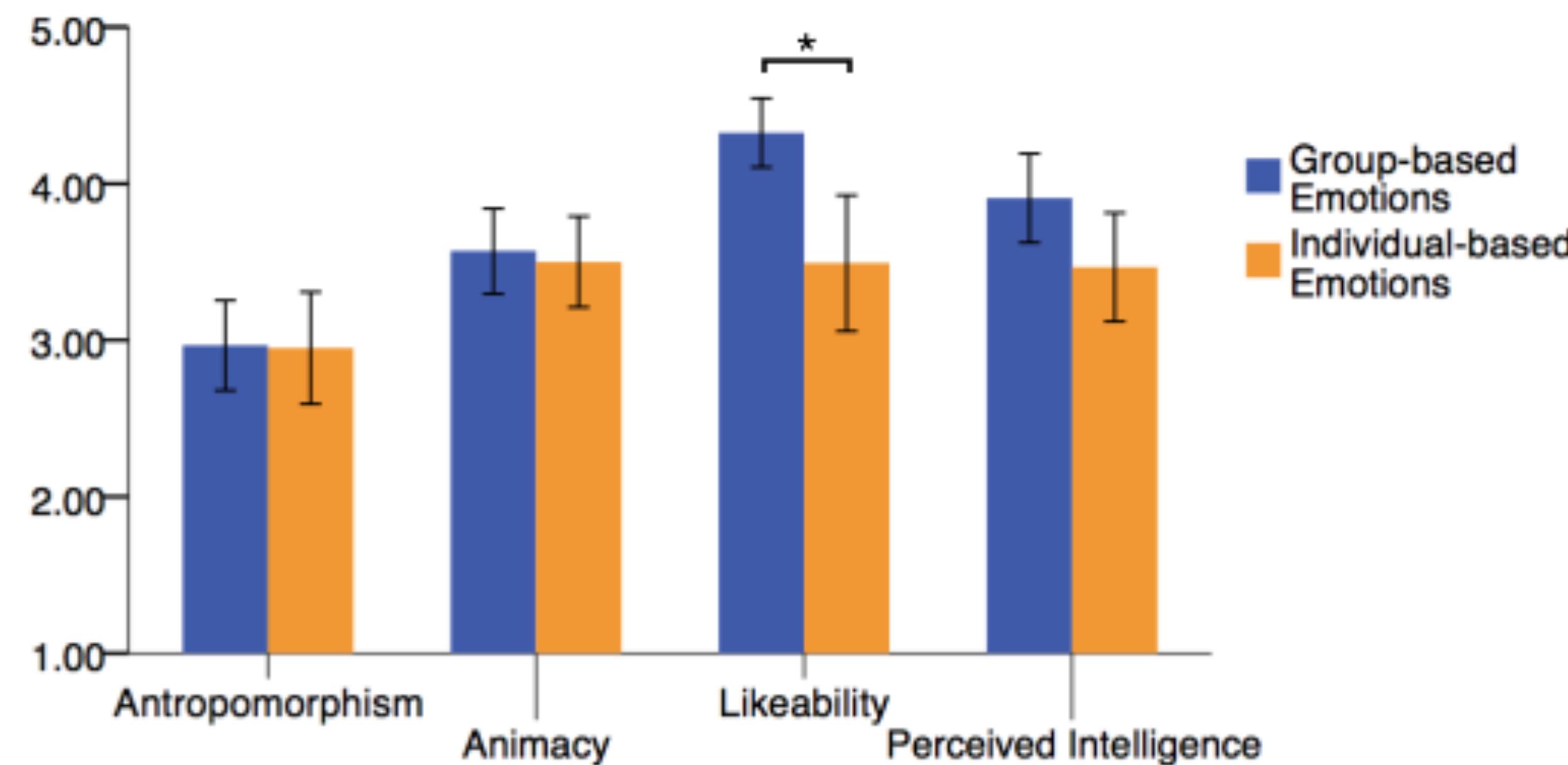
User Study - Manipulation



	Robot that expresses individual-based emotions				Robot that expresses group-based emotions			
	Admiration	Reproach	Pride	Shame	Admiration	Reproach	Pride	Shame
Partner increased score	I am impressed with your move!	—	—	—	—	—	We are the best!	—
Partner decreased score	—	With that move, I cannot win.	—	—	—	—	—	We were not so good this time...

How do people perceive a robot that expresses group feelings?

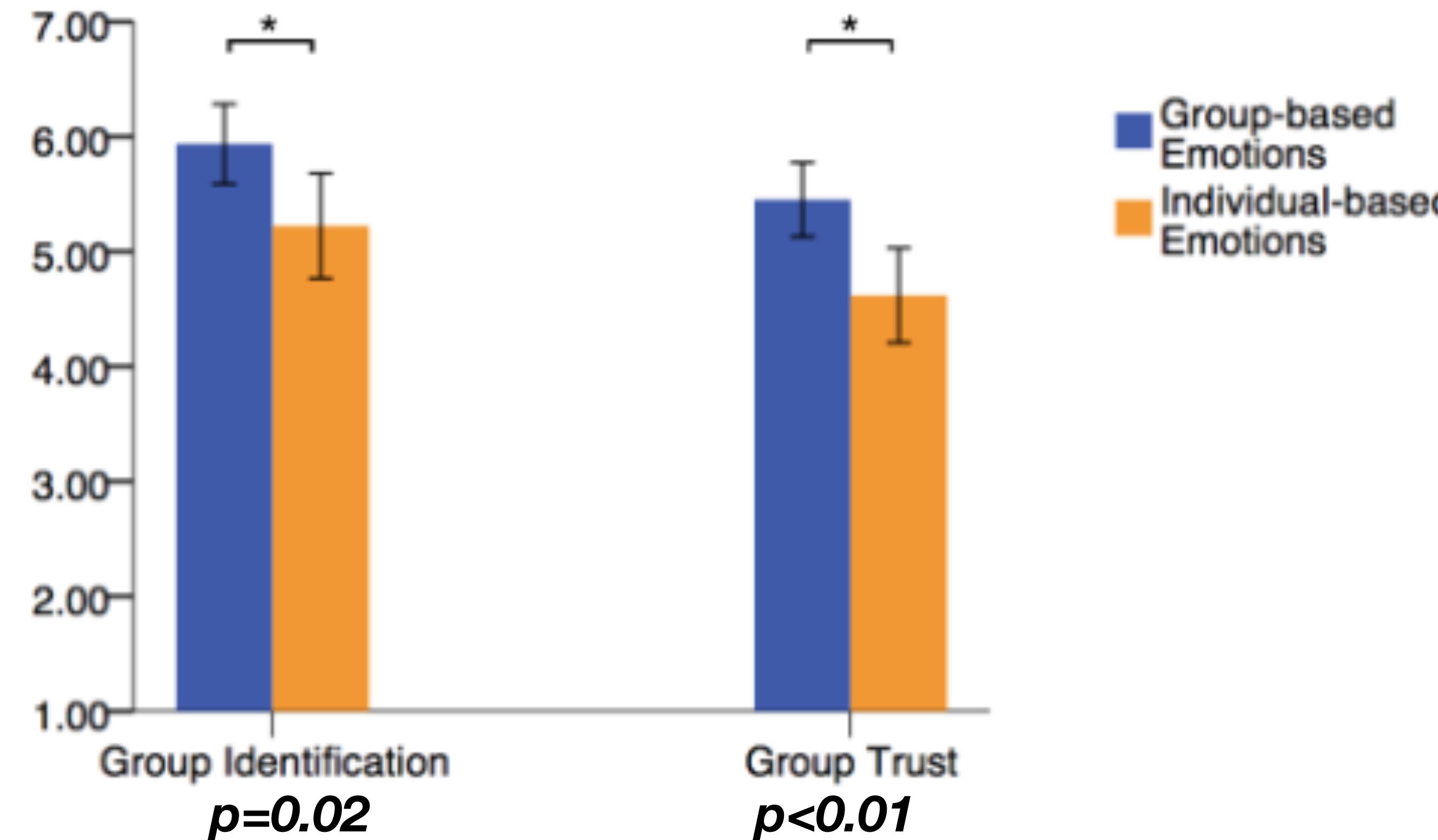
Social attributes (Godspeed)



$p=0.07$ $p=0.79$ **$p<0.01$** $p=0.80$

Does the expression of group feelings increase people's cohesion?

Group measures



C. W. Leach, M. Van Zomeren, S. Zebel, M. L. Vliek, S. F. Pennekamp, B. Doosje, J. W. Ouwerkerk, and R. Spears, "Group-level self-definition and self-investment: a hierarchical (multicomponent) model of in-group identification." *Journal of personality and social psychology*, vol. 95, no. 1, p. 144, 2008

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Take-away Message

Robotic teammates can express emotional cohesion through the group-based emotions and, it turn, foster collective cohesion.

Other follow-up work

- Stereotype Content Model (warmth and competence) in HRI

Oliveira, R., Arriaga, P., **Correia, F.**, & Paiva, A. (2019, March). The stereotype content model applied to human-robot interactions in groups. In 2019 14th ACM/IEEE International Conference on Human-Robot Interaction [**HRI19**]

Structural
Cohesion



Gaze behaviours in Multi-party Settings

Project Goal & Research Questions

Structural Cohesion

Project Goal & Research Questions

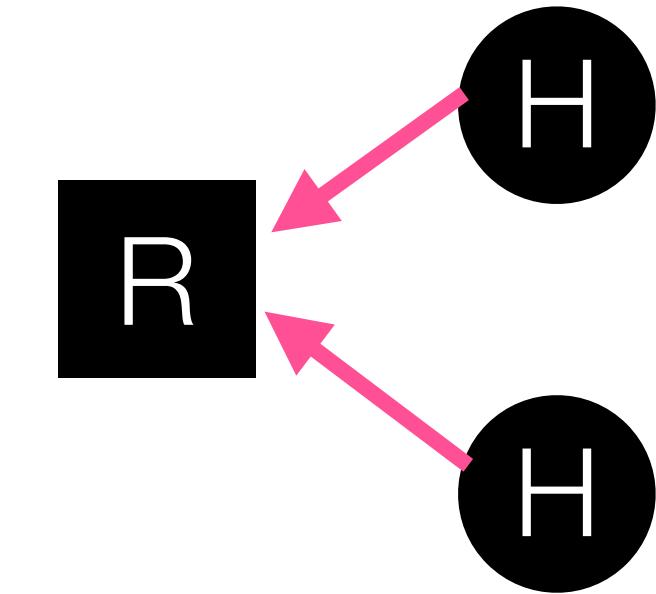
Structural Cohesion

- What is the degree of connectivity that a robotic teammate should consider in its perceptive skills?

Project Goal & Research Questions

Structural Cohesion

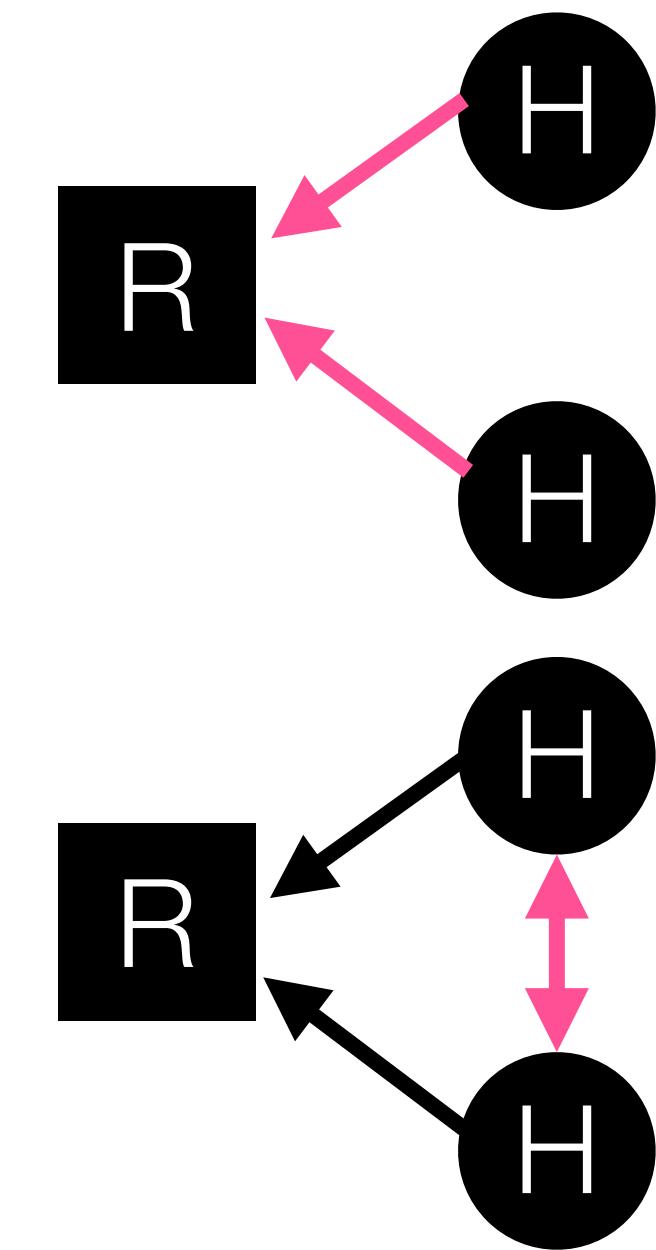
- What is the degree of connectivity that a robotic teammate should consider in its perceptive skills?
- Should a robotic teammate perceive communicative acts only towards itself?



Project Goal & Research Questions

Structural Cohesion

- What is the degree of connectivity that a robotic teammate should consider in its perceptive skills?
- Should a robotic teammate perceive communicative acts only towards itself?
- Or should it also perceive communicative acts between other pairs of team members?



Project Goal & Research Questions

Structural Cohesion

- In a silent coordination task...
- Are the **gaze behaviours** of a robotic teammate able to **enhance** the perceived **teamwork** of its human-robot team?

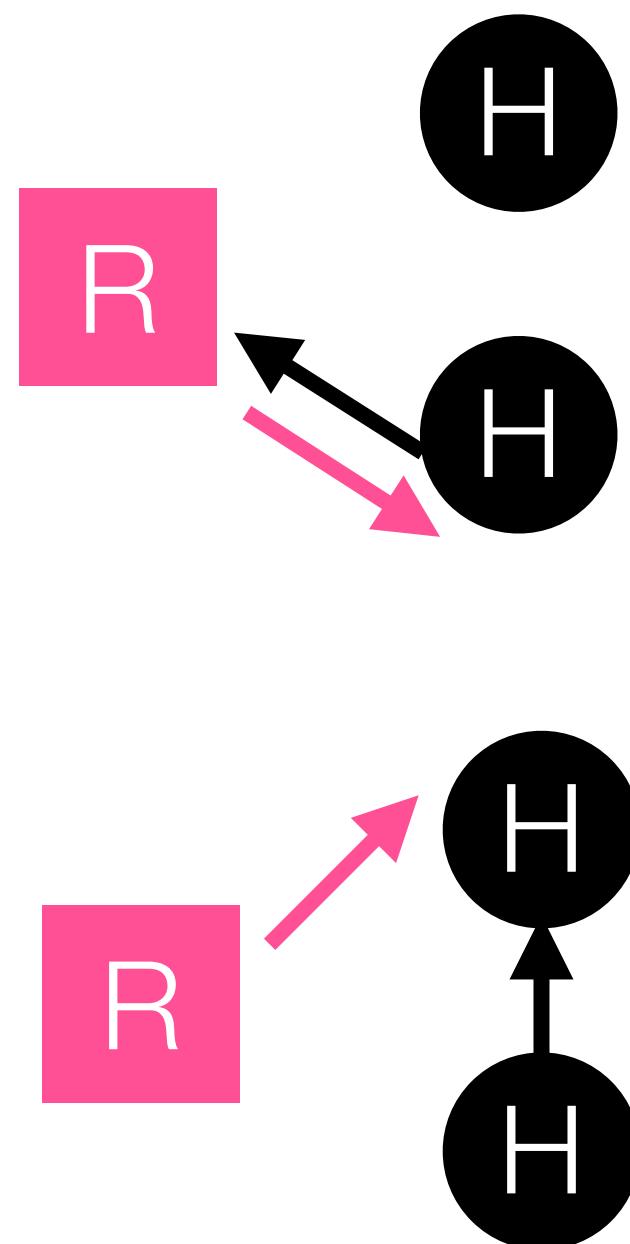
Gaze Behaviour in a Multi-party setting

Attentive Gaze

Responding Gaze

Gaze Behaviour in a Multi-party setting

Attentive Gaze



- If the teammate X looks at the *Robot*, the robot will return the gaze so that “eyes would meet” (*attempt to establish mutual gaze*).

Responding Gaze

- If the new gaze target of a teammate X is $Y \neq \text{Robot}$, it gazes at target Y (*attempt to establish joint attention*).

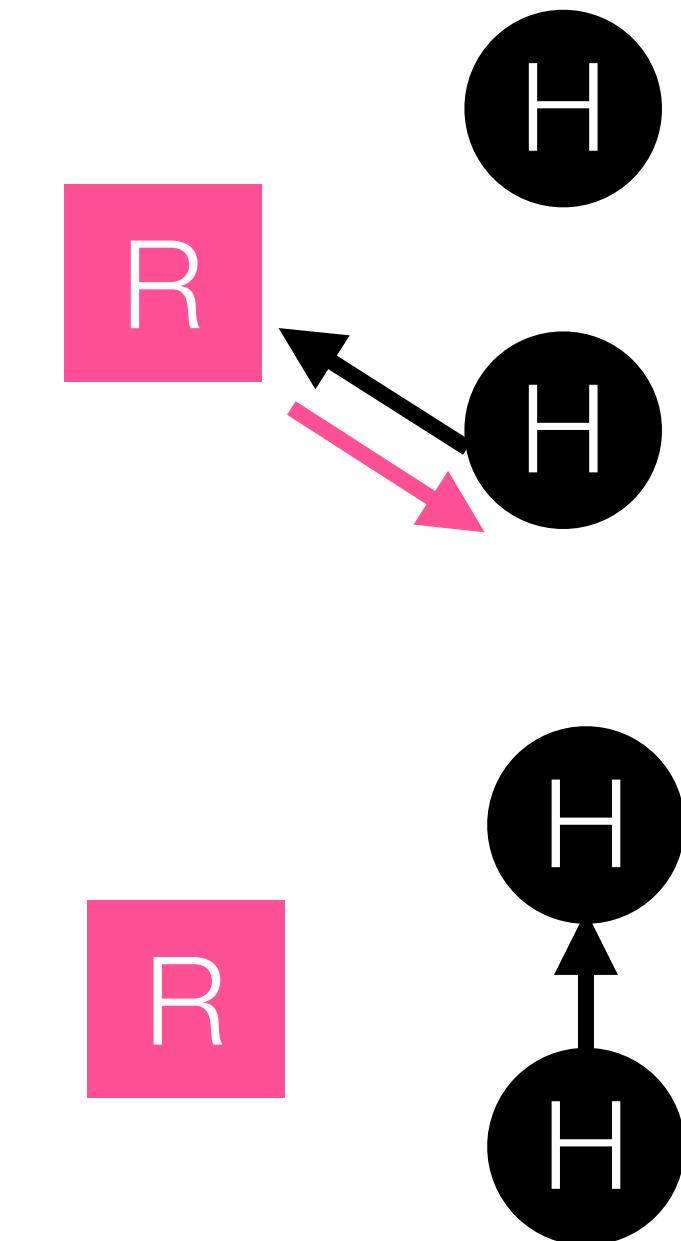
Gaze Behaviour in a Multi-party setting

Attentive Gaze

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Responding Gaze

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- If the new gaze target of a teammate X is $Y \neq Robot$, it gazes back at target *Screen*.



Gaze Behaviour in a Multi-party setting

Attentive Gaze



Responding Gaze



Gaze Behaviour in a Multi-party setting

Attentive Gaze

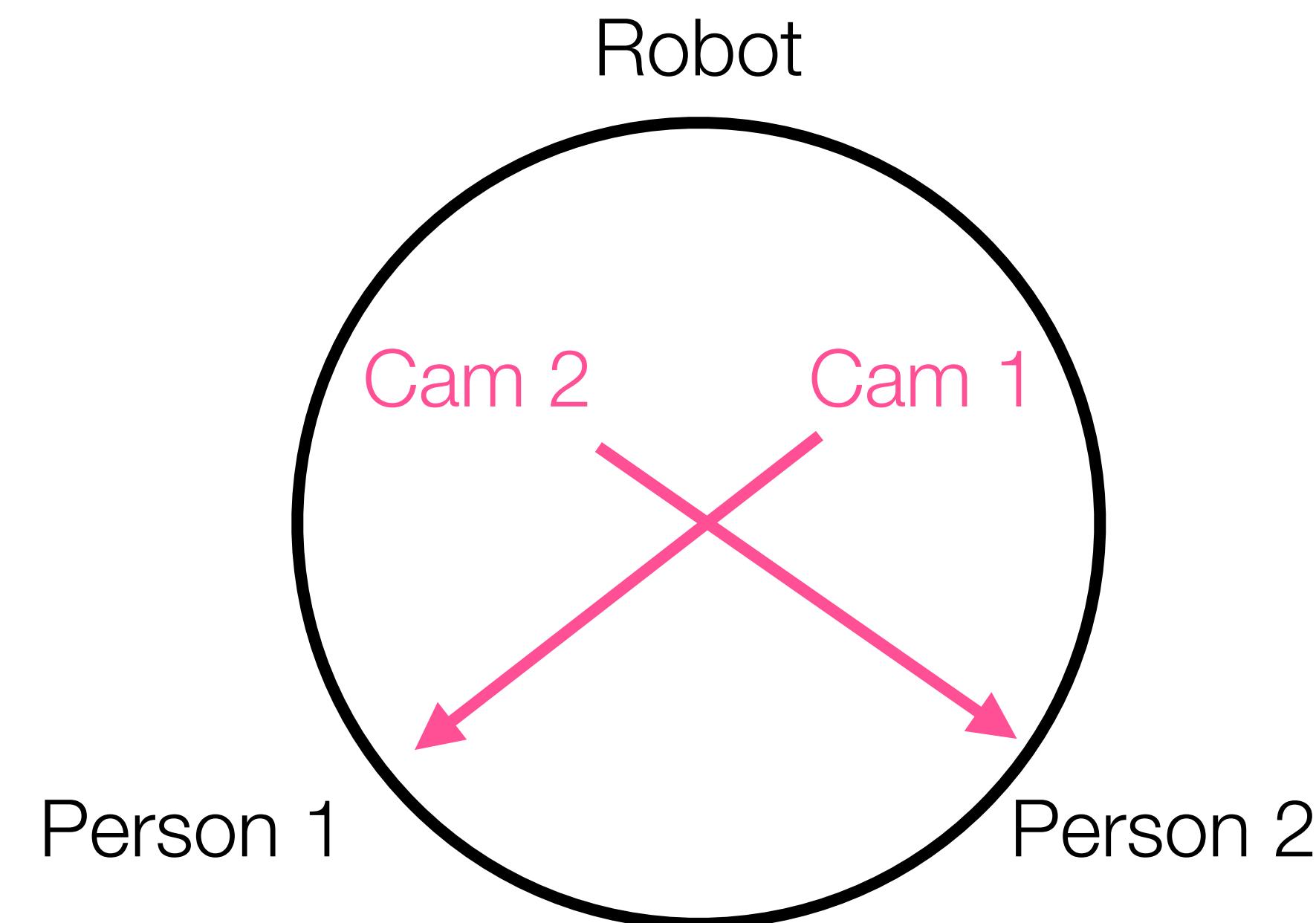


Responding Gaze



Development autonomous robot

- Reactive behaviour according to the heuristics
- Gaze detection (OpenFace)
 - Dedicated per person



Scripted interactions

- 10 scripted interactions for human behaviour

S1 (4''): 

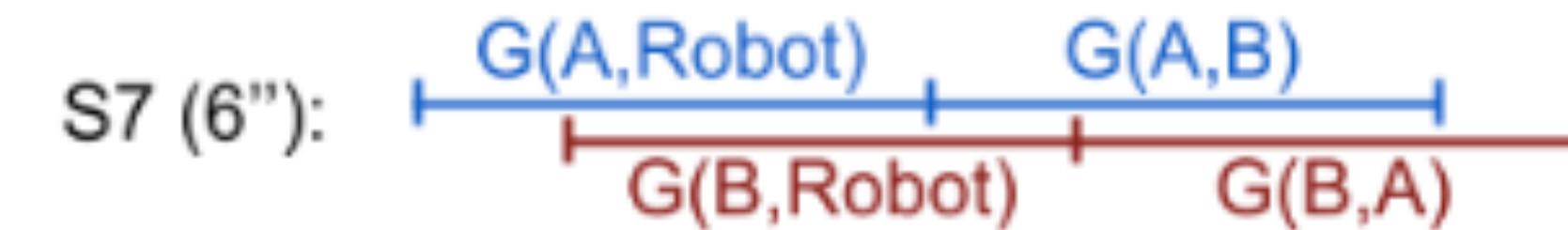
S2 (5''): 

S3 (5''): 

S4 (5''): 

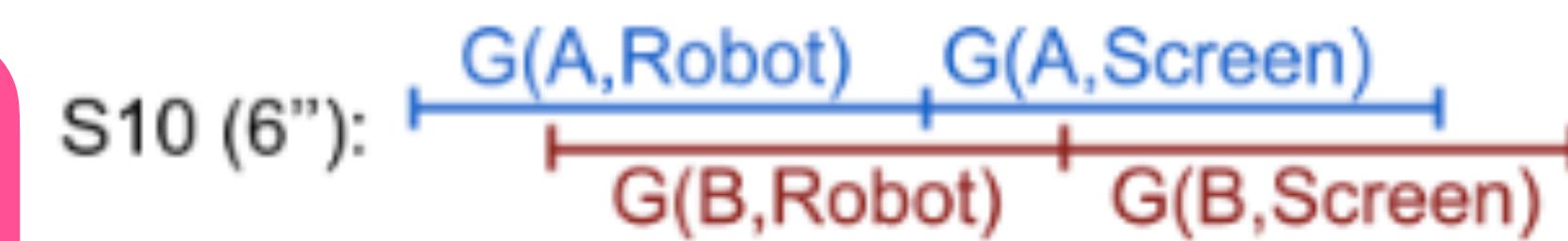
S5 (6''): 

S6 (6''): 

S7 (6''): 

S8 (6''): 

S9 (5''): 

S10 (6''): 

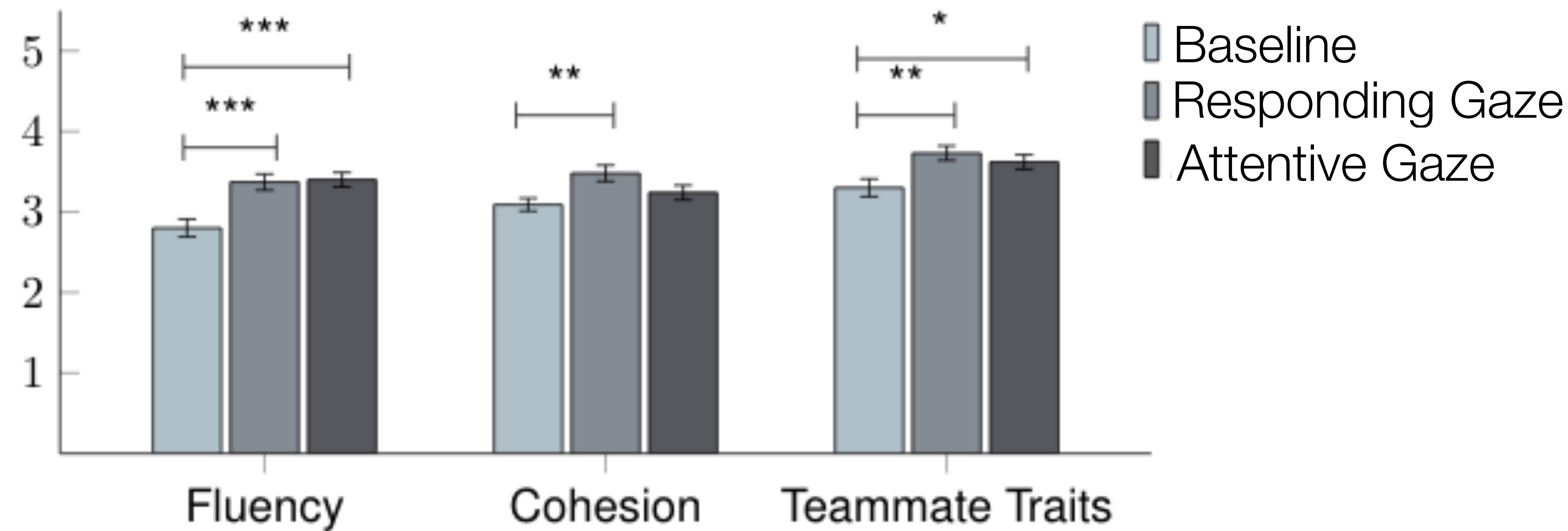
Video recordings with autonomous robot

- 3 conditions for the robot behaviour
 - Robot performing **Responding Gazes**
 - Robot performing **Attentive Gazes**
 - Robot does not react to perceptions (**Baseline**)

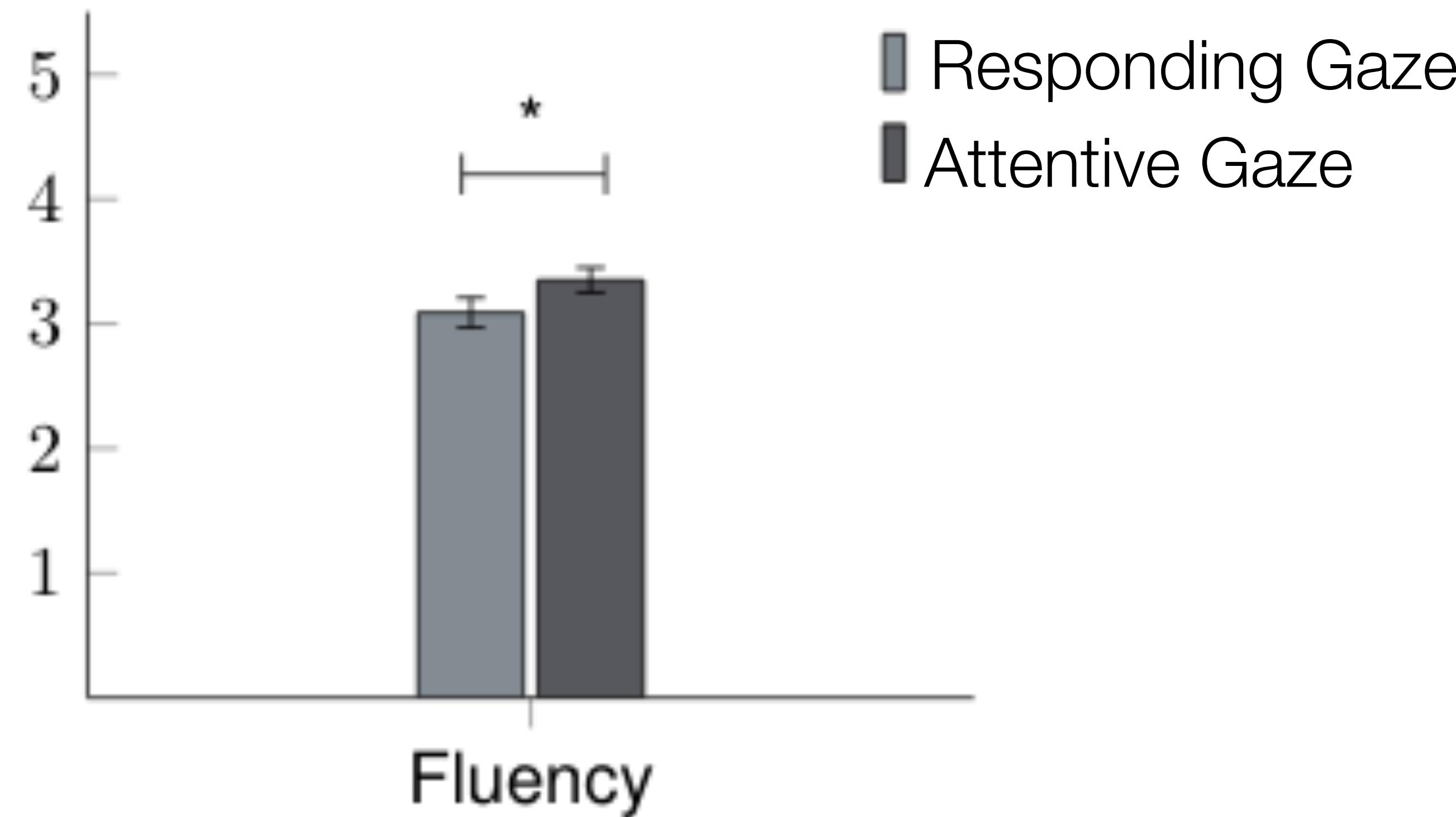
User Study

- (3 x 10) 30 small videos [4-6] seconds
- Prolific third-person evaluation
- 180 participants
- Gaze condition in a between-subjects
- Each video was rated by 30 people (avg.)

Do gaze behaviours influence perceived teamwork?



Responding Gaze VS Attentive Gaze



Take-away Message

The structural cohesion assumed by a robotic teammate in a multi-party silent task can affect the perception of teamwork.

Conclusions

Research Problem (Revisited)

*How can we endow a robotic teammate with
social capabilities to improve the cohesive alliance
in a multi-party setting with humans?*

Research Problem (Answered)

The cohesive alliance can be established and supported when the social capabilities of robotic teammates consider a “shared sense of unity with the group”.

Research Problem (Answered)

The cohesive alliance can be established and supported when the social capabilities of robotic teammates consider attractions (social), identification (collective), feelings (emotional), gaze communication (structural).

Contributions

C1. Computational mechanisms to develop autonomous social behaviour for robotic teammates in multi-party settings

How can we endow a robotic teammate with social capabilities to improve the cohesive alliance in a multi-party setting with humans?

Contributions

C2. Evaluation of people's behaviours and perceptions towards a mixed human-robot group

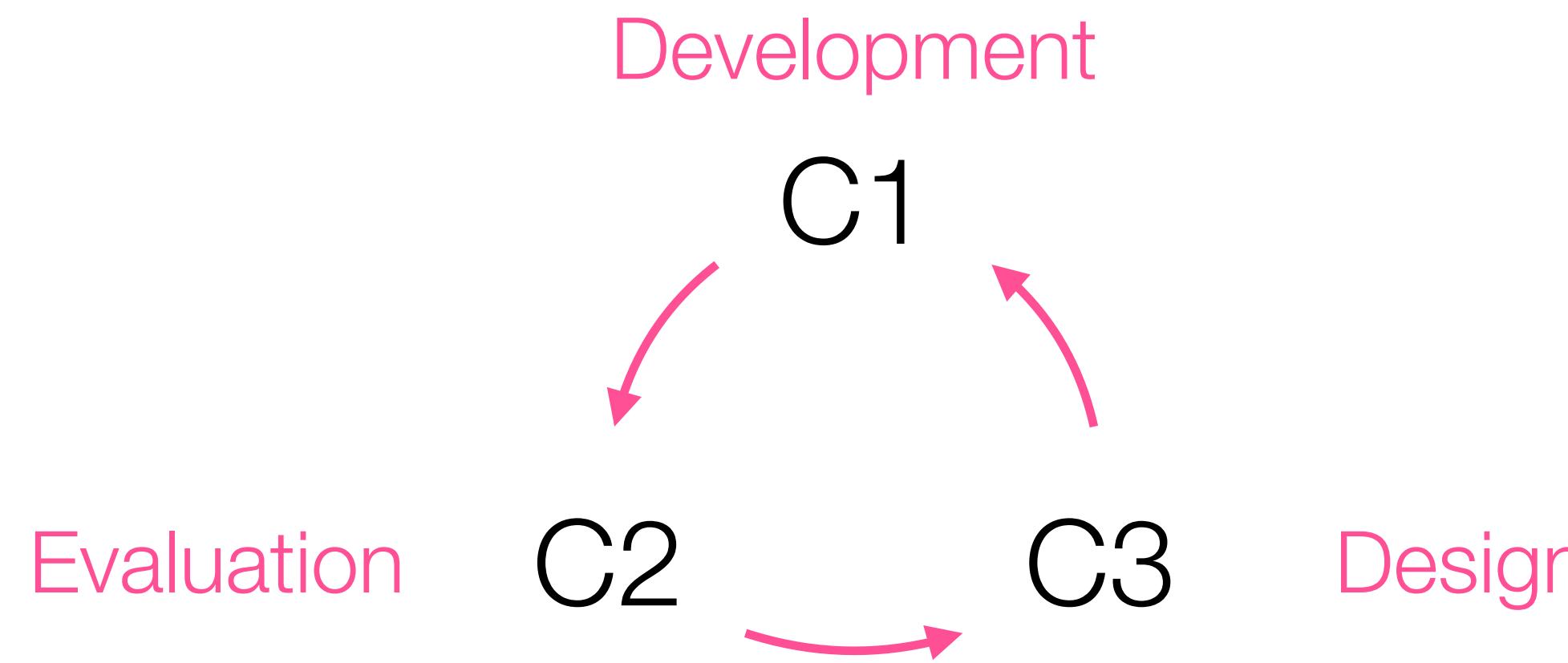
*How can we endow a robotic teammate with social capabilities **to improve the cohesive alliance in a multi-party setting with humans?***

Contributions

C3. Understanding relevant group processes
in mixed-groups of humans and robots

*How can we endow a robotic teammate with
[which] social capabilities to improve the cohesive alliance
in a multi-party setting with humans?*

Contributions



How can we endow a robotic teammate with social capabilities to improve the cohesive alliance in a multi-party setting with humans?

Future directions for H-R Teamwork in Multi-party

- *Different group sizes and human-robot configurations*
- *Different embodiments or anthropomorphic features*
- *Autonomous perception of group patterns*

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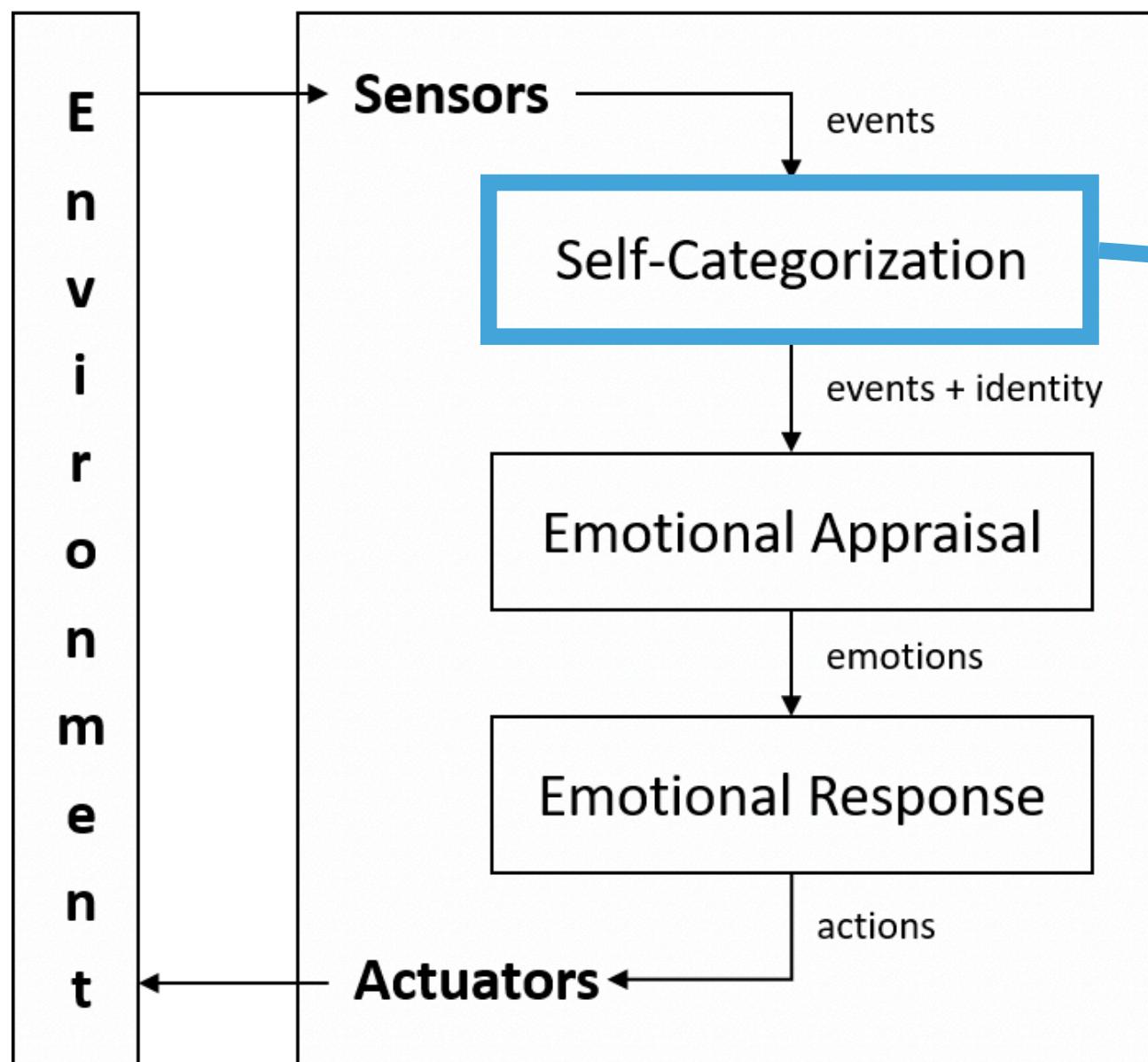
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Diana Lopes

Thank you all!

Extra Slides

A model for GbE in social robotic characters



```
while true do
    self ← Robot.Name
    e ← Sensors.PerceiveNewEvent()
    SG ← ContextManager.GetSalientSocialGroups()
    if SG ≠ Ø then
        g ← IdentityManager.SelfCategorisation(SG, self)
        if e.ResponsibleAgent ∈ g then
            e.ResponsibleAgent ← g.Name
            self ← g.Name
        end if
    end if
    AV ← Appraisal.DetermineVariables(e)
    E ← Appraisal.GenerateEmotions(AV, self)
    se ← StrongestEmotion(E)
    for all c ∈ Actuators.GetEmotionChannels() do
        Express(se, c)
    end for
end while
```

How?



Group-based Emotions

Assuming the robot is P1 and $\{P1, P3\} \in T1$

Event(P3,IncreasePoints(Trick,11))

```
{T1,T2} ← ContextManager.GetSalientSocialGroups()  
T1 ← IdentityManager.SelfCategorisation(SG, self)
```

If $P3 \in T1$

Then,

- Event(**T1**,IncreasePoints(Trick,11))
- Self ← **T1**

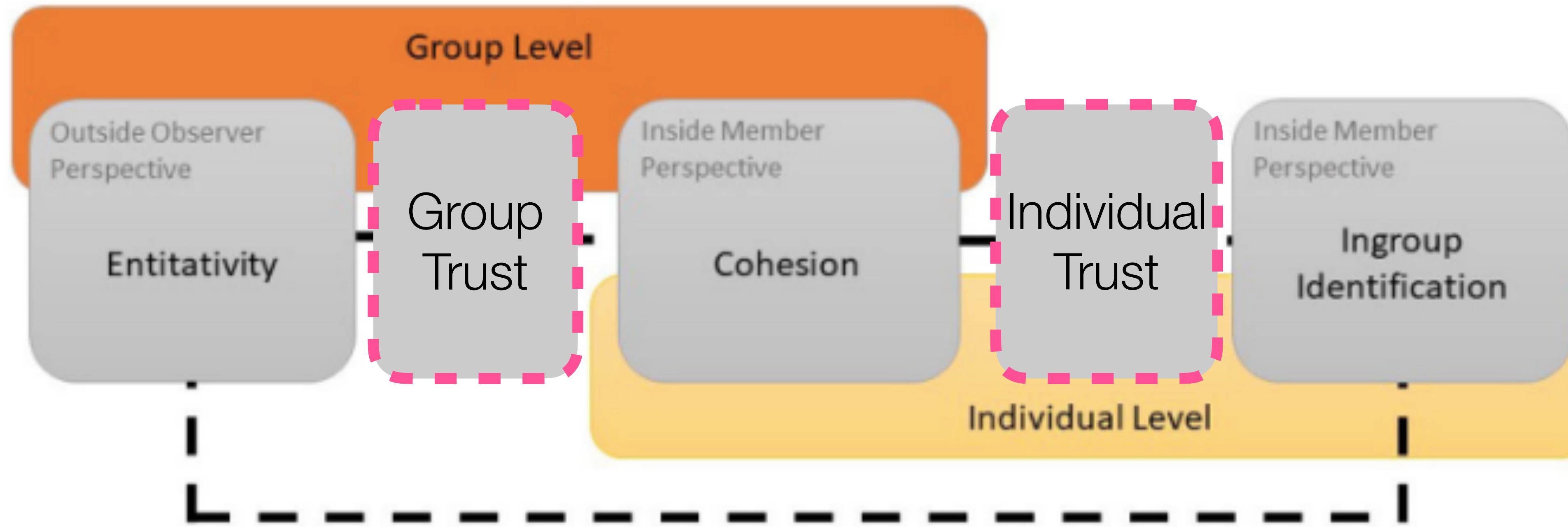


Individual-based Emotions

Assuming the robot is P1 and $\{P1, P3\} \in T1$

Event(P3,IncreasePoints(Trick,11))

Cohesion VS Identification VS Trust



Abrams, A. M., & Rosenthal-von der Pütten, A. M. (2020). **I-C-E Framework: Concepts for Group Dynamics Research in Human-Robot Interaction**. International Journal of Social Robotics, 1-17.