Proposal full title: ***H*uman-Inspired Reasoning in *E*mbodied, *S*ocial, Artificial *A*gents**

Proposal acronym: **HESA**

Call: H2020- FETOPEN-1-2014

Topic: FET - Open research projects – Novel ideas for radically new technologies

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List of participants

Participant No	Participant organization name	Part. short name	Country
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2	Universiteit Leiden	UL	Netherlands
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Abstract: Agent-based systems are increasingly being used as the underlying conceptual architecture for deploying complex, society-critical applications. This is no longer limited to networked software applications, but has begun to permeate physical devices including robotic systems. However, agents in current systems suffer from a sort of "autism" that stems from their inability to understand and take into account the expected behaviors of other agents and actors in the environment. This prevents them from interacting and coordinating successfully and predictabity with humans and among themselves in complex and unexpected situations. The solution that the HESA project proposes is for a paradigm shift from the current third-person, global designer view in analyzing and realizing these systems to one which is first-person based, whereby agents themselves exhibit "behavioral empathy". This is achieved by ascribing expected behaviors to other agents and use this information to deliberate in a proactive manner. The ascribed behaviors are initially formed on the basis of social stereotypes, but are monitored by the agents and refined at runtime. Technically, the HESA project will develop foundational and implementation principles for realizing social agents that reason about human and artificial agents. The methods to be devised will be grounded in psychological studies on human behavior in social contexts, and realized by using principles from knowledge representation, artificial intelligence, automated verification and synthesis methodologies. The resulting techniques will be implemented on a latest-generation series of robots and deployed in social robotic scenarios. The consortium brings together world-leading experts with different key expertise ranging from cognitive science, to knowledge representation, multi-agent systems, verification, cognitive robotics and industrial expertise in cognitive robot deployment. The interdisciplinary project will also benefit from a collaboration with leading psychology, knowledge presentation and cognitive robotics experts from the University of Melbourne, Australia, funded independently.

1. S&T Excellence

Multi-agent systems (MAS) are increasingly being used to design and implement complex networked applications. There is an a rising trend to adopt MAS-based architectures and underlying principles when developing interconnected physical devices, such as in cyber-physical systems, in the internet of things, and in cognitive robotics [Weis13]. These systems are intended to be deployed in complex and evolving environments and therefore require important aspects of autonomy and social awareness. At the same time, critical applications require a high-degree of reliability and predictability. Combining these two requirements remains one of the key problems in MAS: autonomous systems are notoriously difficult to predict and analyze, whereas rigid, non-adaptive implementations typical lack the ability to react appropriately in complex and unpredicted situations. As a result, there is reasonable skepticism in society to adopt and interact with these systems because artificial agents display a lack of social awareness. This difficulty is particularly evident in the context of multi-robot systems that are expected to become widespread in the near future. The result is an increasing risk that society will not be able to benefit fully from this key emerging technology.

To remedy this state of affairs, it has been argued that artificial agents should be built to consider other agents and people as peers (and not just as obstacles or as instructors), and that models studied in human psychology in which concepts such as joint action, coordination, expectation, and social norms can provide the building blocks upon which MAS can be analyzed and realized [Brat90, CoLe90, Wool09]. However, current agent-based systems, including multi-robot systems, surprisingly still display a high degree of "autism" [DiPH07, Kami07], because the individual agents, as developed, typically only consider their own goals and knowledge and do not take fully into consideration other agents as peers. In other words, in state-of-the art MAS, mental states are assigned to other agents when designing the MAS, but then they are compiled away from the single agents when in operation. We may call such an approach a *third-person view* (or designer view) of agents, to be contrasted to *first-person view*, where agents at runtime have a model of the world in which they are immersed in (which possibly includes other agents), and use such a model to deliberate about what to do next. In fact a first-person view of agents has long be advocated in reasoning about action in Knowledge Representation [McHa69, Reit01]. However, modeling explicitly other peers and ascribing to them sophisticated theories of mind has been considered notoriously difficult from the computational point of view [FHMV95]. To solve this difficulty, the working hypothesis of the project is rooted in Bateson's psychological insight [Bate72]:

Artificial agents, and in particular robots, do not need to necessarily have a deep understanding what other peers think, they only need to understand how other peers act.

We call such an ability "*behavioral empathy*", as opposed to cognitive or emotional empathy [RDHW07]. In contrast with a full theory of mind, equipping artificial agents with a model of the behaviors of other peers is much simpler, while possibly as effective in many cases [DWVV14]. The project will develop novel techniques that embed the principle of behavioral empathy at the heart of the development process.

1.1 Targeted breakthrough, Long term vision and Objectives

Targeted breakthrough. Based on the above principle, the HESA project aims at:

Developing the interdisciplinary science and the technology to enable artificial agents to embrace behavioral empathy

Technically the project targets the development of a unified, computationally grounded technology that enables the design, analysis, implementation and deployment of embedded agents that can display human-like capability of ascribing and reasoning about others behaviors, and act soundly and predictably in a social context. To achieve this we will develop logic-based techniques inspired by principles in cognitive and social psychology, and computationally grounded in knowledge-representation and formal verification that will permeate all phases of agent-based design and development. The work will take a first-person perspective of agency with particular emphasis on autonomy, the ability to reason about other agents' behavior, social constraints and expectations, and run-time synthesis of strategic behavior in changing environments. The agents will be assumed to be embodied in sophisticated devices, including robots, thereby enabling social interaction with humans and other agents.

Long term vision. Our long term vision is:

> *A society in which artificial agents, and in particular robots, will be widespread and interact socially with humans and among themselves by reasoning and predicting each other's behavior. For this to happen, their behavior needs to be predictable, safe and socially competent.*

Any successful attempt towards this goal will need a concerted interdisciplinary effort involving cognitive and social psychology, computer science and robot engineering. The consortium reflects this need.

Objectives. The scientific and technical objectives involve three different areas.

Psychological basis of HESA. The first objective includes the development and application of human-inspired psychological principles for predicting the behavior of other agents and people based on what we will call generalized expectations. Such expectations will be derived from generalized dynamic *event models* [StHo96] that represent the behavior that members of a particular social group (i.e., nurses in a hospital) can be expected to exhibit and from representations of situation-specific social norms. Event models will be created from a knowledge base that will initially be created from data collected in experiments and questionnaire studies in humans, so that the robotic agents share the same social information (stereotypes, social norms and rules) that human agents are using. Event models will serve to compute situation-specific expectations about the behavior of others. Following Zacks et al. [ZSSB07], these expectations will be used to inform and guide the robotic agent's own behavior but also to evaluate the validity of the knowledge base. More specifically, failures to predict the actual behavior of others will initiate the updating of the event model and the underlying knowledge base (according to principles taken from the cognitive neuroscience of cognitive control: [FrLO01]), so that both the *validity* of the social information the robotic agent has available and the *accuracy* with which it allows actual prediction increase steadily with experience.

Computing in HESA. The second objective involves the development of all aspects related to the computational side of HESA agents (HESAs). Firstly, this includes the development of novel knowledge-representation formalisms such as the extensions of the situation calculus [Reit01] and verification-oriented dynamic models such as interpreted systems [FHMV95]. This will provide the foundational principles for developing techniques and algorithms for reasoning about other agents from a first-person view. Reasoning will include the selection of ascribed behavioral templates to the other agents and automated synthesis of best-response behavior on this basis. The framework will comprise a monitor component that monitors other agents' behavior and detects discrepancies from their expected behavior. This will enable the agent to adapt, refine the expected behaviors of others, and dynamically replan its actions accordingly. Representation and reasoning will be firmly grounded in logic-based formalisms. This will ensure precise analysis, and provably correct implementations from design within the same unified account. Consideration will be given to the actual realizability of the system by tailoring the richness of the representation and reasoning formalisms with respect to their computational efficiency.

Engineering HESA. The third objective concerns the embedding of selected representation and reasoning methods above into state-of-the-art multi-robot systems. The knowledge representation and reasoning techniques developed in this project will be integrated into the robot programming language Golog [LRLL97, FeLa08]. Since Golog itself is firmly based on the situation calculus, a seamless integration can be expected. Moreover, Golog has been connected to state-of-the-art planning techniques [CELN07], among other things. Existing perception, interaction and execution monitoring capabilities developed for Golog will be adapted and extended to support the HESA approach. To facilitate platform-independence, all software components will be interfaced with the widely used Robot Operating System (ROS).

While a fully robotic society will not be realized in the life of the project, the resulting robots will be deployed in various scenarios and their performance will be evaluated against existing systems by checking coordination, competition and non-interference abilities in complex unannounced situations. Apart from deploying in in-house labs, the consortium will exploit the current involvement of IDM in the EU FP7 Social Robot Project, to deploy and evaluate HESA's results over the operating domain of Social Robot. This domain is related to day-to-day support to the elderly to stay active and independent in their preferred environment. For example, a behavioral empathic robot might remind an elder to take his medication, but not while he is watching his favorite TV show or receiving visitors; at the same time when bringing medication it would avoid interfering with another robot that is cleaning the room. In addition our Australian partners will exploit their unique position to evaluate the HESA approach into an existing in-operation multi-robot system for automated surface mining.

1.2 Relation to the work programme

The HESA proposal strictly adheres to the FET idea of leveraging on "Europe's excellent science base into a competitive advantage by uncovering radically better technological possibility". Specifically it matches all FET-Open characteristics:

***Long-term vision**:* The creation of a society in which artificial agents, and in particular robots, will be widespread, and will interact with social competence with other agents (humans or robots), by predicting their needs and ascribing expected behaviors to them when acting; see 1.1.

***Breakthrough S&T target**:* To provide the human-inspired logic-based scientific foundations for a paradigm shift in agent-based research, by moving from a precompiled interaction between agents to the development of behavioral emphatic agents that act autonomously, correctly and predictably; see 1.1.

***Foundational**:* The research aims at developing the scientific and technological foundations for behavioral empathic multi-agent and multi-robot systems. This in the long run will provide the basis for creating socially competent robots with advanced forms of coordination among agents and of human-robot interaction that are much closer to how humans act; see 1.1.

***Novelty**:* The research is based on a paradigm shift in MAS from third-person approach to a first-person one in which behaviors are ascribed to other peers, reasoned upon, monitored and revised, on the basis of precise psychological principles; see 1.3.

***High-risk**:* The research ambitiously combines psychological and social underpinnings and logic-based computing, while requiring computational efficiency to actually be engineered in practice. The quality of the consortium, which is formed by top scientist in all areas involved, will mitigate the high risk; see 1.1.

***Interdisciplinary**:* The research is interdisciplinary in nature, involving cognitive and social psychology, computer science and robot engineering, as detailed in 1.5.

1.3 Novelty, level of ambition and foundational character

Our research is grounded in four distinct research areas and will require cross-fertilization among these.

Cognitive/Social Science. Research in Cognitive, Social, and to some degree Developmental Psychology has looked into how humans represent and carry out intentional actions themselves and how they perceive and process intentional actions of others [HMAP01, Iaco01] -i.e., to show "behavioral empathy" (a term that we use to refer to the ability to know about and to take into consideration the behavior of others without necessarily reasoning about their underlying mental states, an implication that the standard empathy concept often also entails). Social psychological studies have investigated how people act in the presence of others, and how people adapt their behavior to social norms and rules and to the expectations of others [CiTr98, DiBa01]. Moreover, work in developmental psychology and the affective (neuro-) sciences has uncovered the development of the ability to take other people's mental states into account (empathy, theory of mind) [MaMP14]. Finally, studies in the cognitive (neuro-) sciences have investigated how events are cognitively represented and how these representations are used to predict upcoming events and updated if these predictions fail [ZSSB07]. However, the available theories and approaches are too abstract and/or too vague to provide artificial agents with a cognitive architecture that generates (behavioral) empathy in concrete social interaction. Moreover, formalized models are very rare in these domains (an exception being the event model of Zacks et al., that we will use and develop further in this project) and far from implementation. Our approach would be the first to bring together empirically founded principles from various psychological subdisciplines in order to model behavioral empathy and prediction in social situations. In particular, it aims at *setting the basis for a computationally grounded theory of (certain aspects of) mind, and social behavior.*

Knowledge Representation and Reasoning. Knowledge Representation and Reasoning (KR) stems from a deep tradition in logic. In particular, it aims at building systems that *know* about their world and are able to act in an informed way in it, as humans do. A crucial part of the system it that knowledge is represented symbolically, and that reasoning procedures are able to extract consequences of such knowledge as new symbolic representations. Such an ability is used to deliberate in an informed fashion the course of actions to take. This very idea is radically new in human history [Leve14]. It comes about after a long gestation, stemming from Aristotle, who developed the initial notion of logic though unrelated to notion of computation; continued by Leibniz, who brought forward a notion of "thinking as computation", though not yet symbolic; and later by Frege, who developed the notion of symbolic logic, though unrelated to computation; and finally by the breakthrough in human thinking of the early part of last century with Church, Godel, and Turing, who set the bases for symbolic logic bound together with computation and ultimately for Computer Science, though even they did not think about logic as a way of representing knowledge. The KR idea can only be traced back to McCarthy work in 1959 [McCa59], which gave rise to the area of Artificial Intelligence. In KR, a first-person view of an agent reasoning on its knowledge of the world to deliberate its action has been studied in depth through comprehensive frameworks, such as that of Situation Calculus [McHa69, Reit01, LRLL97, DeLL00, DeLP06]. Restricted forms of representations (essentially propositional) have been put forward to study efficient action deliberation or planning which in these years is producing a vast array of particularly fruitful results [GeBo13, DePS10, DFPS10, CaDH11, FeDL12, DePS13, DeVa13, GeTh14, DeDM14, DDGM14]. Recently this work has been complemented by a set of novel results that shows the effective computability of expressive variants of the original full-fledged (predicate based) Situation Calculus [DeLP12, DLPV14, DeLV14]. Such results are being complemented by the possibility of combining action theories with ontological representations in description logics [CDLL13, CDMP13, HCMD14]. Moreover, the techniques for applying belief revision to transition systems based on dynamic logic of assignments proposed recently [HMDW14], open up the possibility of grounding computationally the notion of "behavior revision". However virtually in all the works adopting a first-person view of agent in KR, the agent does not ascribe explicitly behaviors of other agents acting in the same world. To be more precise, such behaviors are blurred together with contingencies and exogenous events occurring in the environment the agent is immersed in. This gives what we have described as a form of autism to the agent, preventing the possibility of considering forms of social awareness and behavioral empathy. *In this project, we will put forward the notion of ascribed behaviors to other agents and develop novel knowledge representation formalisms for giving representational and reasoning means for the agent to act in a socially sound and behavioral empathic way.*

Multi-Agents Systems, verification, synthesis and monitoring. Multi-agent systems (MAS) are a leading paradigm in the design and deployment of distributed, autonomous systems, including robots. While implementation methodologies vary, at the core of an agent-based architecture is the autonomy of the entities, their goal-directedness and their ability to interact with their peers and humans by communicating, negotiating, etc. In MAS agents are often described by means of a high-level mental attitudes such as their knowledge, beliefs, goals, and desires [FHMV95, Wool09, Brat90, CoLe90, RaGe98, HVBM11] as well as their strategic objectives [AlHK02, MoMV10, DeLP06]. MAS behavior in the presence of norms and regulations have also been widely studied [BuDK13, WWW1]. Mental attitudes and norms have been formalized by means of a wide variety of modal languages. These are used, together with temporal logic, to specify the behaviors of MAS. *Verification methodologies* supporting expressive agent-based specification languages have been developed. These include OBDD-based model checking for MAS specified by knowledge-based specifications and strategic behavior [LoRa06], SAT-based bounded model checking [PeLo03], partial-order reductions [LoPQ10], abstraction [LPSS11], and parallel approaches [KwLQ10]. The state-of-the-art includes the availability of efficient, open-source model checkers for MAS such as MCMAS [LoQR09]. While this enabled the formal verification of MAS before deployment, research in MAS has also included the development of *synthesis techniques* for the automatic generation of joint plans and joint behaviors in MAS [CLMM14]. These techniques are closely linked to the model checking approaches described above. Synthesis techniques have found application in a wide range of areas spanning from robotic exploration to service-oriented computing. In services, automata-based synthesis has led to the development of methods to solve the orchestration and choreography problems, thereby providing the foundation for the realization of services that can compose at run-time [BCDL03, DePS13]. The logic-based verification and synthesis research above has also lead to the development of *symbolic monitoring techniques* for MAS. While it is of course important to be able to show properties of a system before deployment, monitoring its execution for faults is also essential. In recent research [LPSS11] methodologies that can monitor stream of events and match them against expected behavior of a system have been put forward and implemented. By means of these techniques a potential fault of the system, or simply an unexpected behavior, can be efficiently flagged at runtime and remedial action can be taken. While the work above constitutes some of the state-of-the-art in the area, it cannot readily be employed for on board reasoning and monitoring in HESAs. In fact, the methodologies above, in line with all work in verification and testing in software systems, are constructed from the designer's point of view. This enables an observer to state, ascribe and verify mental properties to the agents in the system (e.g., the evolution of their knowledge), but they connot be used by the agents themselves when conducting first-person reasoning. In this project, we will develop logic-based reasoning and monitoring techniques that will enable onboard reasoning for HESA. To do this we will adopt a first-person view and develop synthesis and monitoring methodologies. Some key advantages of this paradigm shift are that: *i) the methodologies will be provably correct, ii) reasoners and monitors developed will be readily implementable on the HESA robots. This will lead to a high degree of predictability and assurance for the HESA robots in their tasks and interaction with humans.*

Cognitive Robotics. A key requirement to develop autonomous robotic systems displaying intelligent behavior is the ability of the individual robots to perform first-person reasoning. For example, team members in the Robocup competition need to be able to consider and reason about the actions of other robots. In domestic robotic scenarios (e.g., Robocup@Home), the interaction with humans also needs to be considered. The current solutions to this problem are largely unsatisfactory as they are designed in an ad-hoc fashion without clear design principles and guarantees on the resulting behaviors. Some approaches in cognitive robotics, including [LeLa07], are deeply rooted in logic-based methods for knowledge representation and reasoning, with an emphasis on representing and reasoning about dynamically changing environments that are only partially known. A number of implemented robotic systems based on these ideas have been successfully deployed [TeBe13, LeIn04, BCFH98, FeLa08]; some of these are based on the Situation Calculus. While these initial approaches succeeded in equipping autonomous robots with powerful reasoning capabilities, these approaches largely do not take into account behaviors, possibly as resulting from goals, and intentions, of other agents (humans or other robots). When they do, e.g., [FeLa08], this is done at design time and creates systems that are rigid and cannot evolve at runtime. *This project aims at equipping robots with reasoning capabilities about behaviors of other robots and humans, taking these into account when deciding on a course of actions, and modifying the ascribed behaviors when necessary*.

1.4 Research methods

The *research approach* followed by the project envisions a multi-disciplinary effort involving cognitive and social psychology, computer science and robot engineering, to develop strong scientific foundations for behavioral empathic agents. In our investigation, we will constantly be careful to the actual realizability of the effort, by focusing on computational characterizations of the techniques developed and by implementing selected results and techniques in actual cognitive robots system, which will be validated in cases studies within in-house labs and real-life scenarios. The approach followed will be iterative, in the sense that as theory is developed, computational characteristics are studied and implementations are produced and evaluated, bringing feedback to the theory that can then be refined and extended, starting over the same process. All software developed will be open-source and available. Also open access to all project results will be granted. *Sex and gender* issues do not apply.

1.5 Interdisciplinary nature

The research proposed to be successful requires breaking down discipline barriers. In particular it requires a joint effort among three distinct disciplines, while generating added value to each of them:

Cognitive/Social Science. This project will combine knowledge and empirically based principles from cognitive, social, and developmental psychology, and from the cognitive and affective neurosciences. Focusing on only one or few of these disciplines would either remain too abstract to establish a cognitive architecture that operates in situ (e.g., social psychology describes and measures stereotypes and social rules without saying how they are implemented) or too much focused on the actual mechanism to the expense of the processed information (e.g., theories from cognitive neurosciences are concrete mechanistically but too little constrained to tell how social rules, say, are represented). Accordingly, this project will lead to a *gain in concreteness and insight for the computational grounding of theories related to behavioral empathy and social prediction.*

Computing. This area will bring about notions, techniques and results developed within knowledge representation, reasoning about actions, and MAS in AI, as well as notions like model checking, verification, automated synthesis, and monitoring in from CS. *It will gain a formal grounding for the development of actual behavioral empathic agents.*

Engineering. This area will bring about actual knowledge on multi-robot system development, and cognitive robotics. *It will gain principles for developing non-autistic, socially competent robots, which are going to be more suitable for coexisting in a human environment, being more behavioral empathic, and more predictable.*

2. Impact

2.1. Expected impacts

The expected impact of the project is the development of novel scientific methodologies and technologies for the deployment of behaviorally empathic multi-robot systems, that act in socially sound and predictable manners. The scientific developments will be evaluated both against commonly accepted criteria in Computer Science such as efficiency and scalability, but also through the development of a proof of concept robotic implementation that will enable us to assess the feasibility of the approach. While our primary objectives are scientifically ambitious and a full implementation cannot be realized within the life of the project, we believe the results to be obtained will have a tremendous impact to the deployment of robotic systems in Europe and elsewhere thereby benefiting our citizens, the industry, and society as a whole.

Serious technical difficulties still remain in the development of robotic systems. While engineering aspects such as localization, navigation and robotic vision have made dramatic progress, robots still remain largely unable to perform high-level reasoning and are still incapable of meaningful forms of social behavior. To overcome these difficult problems we need to develop fundamental techniques enabling the social interaction among robots and with humans. This will be one of the key impacts of the HESA project. Equally, considerable concerns and reluctance remain at societal level towards the adoption of multi-robot systems. This largely originates in the pervasive nature of bugs in low-level modern technology such as the software running on mobile phones and desktop computers. A key technology that has been successfully used in hardware to ensure correctness of complex computer chip designs is logic-based automated reasoning and verification. To mitigate this risk and increase societal adoption, a further aim of the HESA project is to develop new logic-based methodologies from the designs to the implementations thereby aiming for correctness by construction for the reasoners in the robots. In summary, the long term impact of the project is to put forward the scientific underpinnings to enable the development of safe, secure, and predictable multi-robot systems that can interact with humans. The changes that robotic technology can bring are so ground-breaking and liberating for society (autonomous systems caring for the elderly, autonomous vehicles, etc.), that any advancement towards more effective, predictable and social competent robots will have a significant impact on developments.

While we believe the most important aspects of our impact will be long term scientific advances, the project will also have some short term technological impact through the HESA partner IDM. IDM have a long and successful history of advances in robotics in conjunction with EU projects. For example, the "4 Wheel Differential Outdoor Robot Platform" [WWW2] was born from the EU FP7 collaborative project FROG; the "Omnidirectional Platform" [WWW3] was the direct result of the EU FP7 collaborative project MOnarCH. IDM has deployed advanced commercial applications, such as the fleet of robots that have been running continuously 24/7 for over 4 years guiding visitors in the Ciudad Grupo Santander, near Madrid, a solution recently exported to the Bank Bradesco branch in the high-end JK Iguatemi Mall, Sao Paulo, Brazil.

As described in WP5, IDM will use the results of the projects to pioneer the development of radically novel robotic systems that can interact with humans and peers not in pre-assigned and monolithic ways as it is currently the case, but by reasoning about the expectations and the behaviors of their peers. This will enable IDM to solve longstanding issues in the deployment of robotic systems that can adapt and react to the specific circumstances and social context they are immersed in. Any success in this direction will be directly implemented into its agile line of products and services. Since the core of our results will be released as open source, any developments will be reusable by other companies and research labs potentially bringing benefits to a wide range of manufacturing scenarios and public spaces including hospitals, railway stations, airports, urban city centers, exhibitions, offices, etc.

We further note the interest in the project from partners outside Europe. More specifically, in context of our relationship with our Australian project partners, HESA will bring the ability to react to unexpected events and circumstances in the mining domain. The incorporation of HESA techniques into mining operations clearly has significant potential to increase the net present value of mining operations, which will have the effect of extending mine life and reducing energy consumption by minimizing re-handling. This will serve as a testbed of the project and any lessons learnt will be distributed in the European mining industry as well as related domains such as oil and gas exploration and extraction.

2.2 Measures to maximize impact

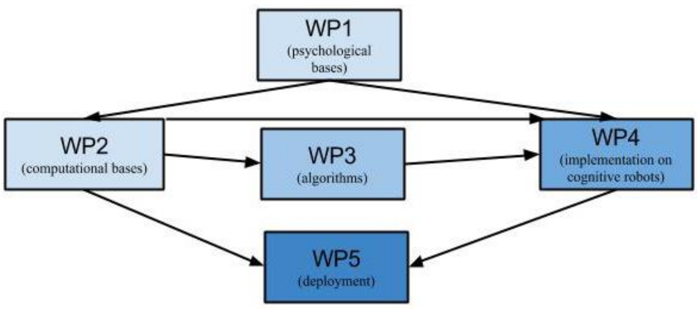
Dissemination. The HESA project plans to apply three major dissemination strategies. Firstly, the project will have a web site for posting project activity and achievements that will be accessible to the public. Secondly, the members of the project will publish technical and scientific results at scientific events.[1] These events are open to the public and attract the most relevant audience, thus increasing public awareness. Thirdly, we will seek engagement with other researchers in Europe and beyond. Specifically we will exchange results and collaborate with other EU funded initiatives, including the European Network for Social Intelligence (SintelNet) as well as newly funded H2020 projects as well as national projects. For example staff at Imperial College London will interact with personnel employed on related topics on other grants including "Trusted Autonomous Systems" (EPSRC; 2010-2015). All academic Pis in the HESA project are regularly invited (more than twice per year) to give advanced topics at international summer schools and conferences. In these occasions they will disseminate the project result and contribute to forming a new generation of scientists and engineers.

Exploitation. Academic units will exploit HESA results mainly in terms of foundational and applied research, through articles in top-level scientific journals, communications and presentations at top-level scientific conferences, but also in professional and technical press and in business-oriented workshops (including the IST conferences organized by the EC), trade shows, and professional exhibitions. In addition, academic partners plans to carry out technology transfer activities towards third party organizations. Further, they will exploit HESA through the strengthening of degree programs and other high-value courses to students, developing graduate courses based on the project results. Exploitation activities tailored toward industry will be specifically carried out during the project lifetime, and they will include an initial market analysis and elaboration strategy for further exploitation (as part of Deliverable D6.3 in the WP6).

Communication activities. The consortium will inform the public about the project through media outreach, web sites, and publications. HESA will also take advantage of some of the web 2.0 tools to increase awareness, e.g., twittering of news feeds when tool updates are put online or publications are accepted at conferences; blogging intermediate results and announcements.

3. Implementation

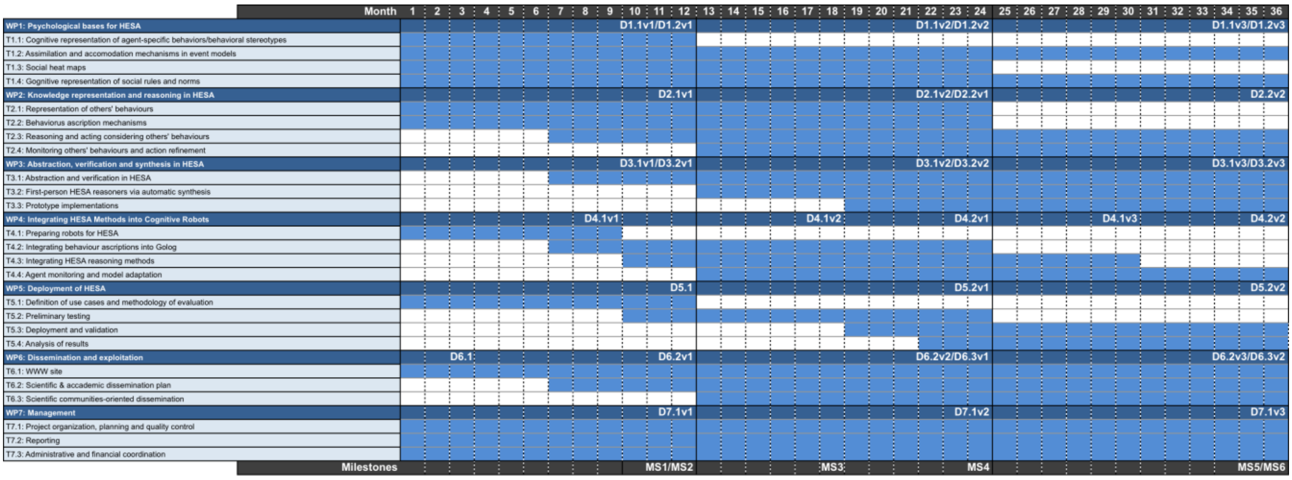
3.1 Project work plan



The project is organized in 7 work packages (WPs). WP1-WP4 deal with the scientific aspects of the project, namely the psychological bases, computational bases, algorithms, and implementation in a system of cognitive robots, respectively. WP5 will be devoted to deployment in actual scenarios of the technology

[1] In particular, venues such as IJCAI, AAAI, KR, AAMAS, CAV, VMCAI, TACAS, AIJ, JAIR, TOCL, TOSEM, JCSS, IS, JAAMS in AI and CS, CogRob, ICRA, IROS, RSSESCOP, Robotics and Autonomous Systems, International Journal of Robotics Research in Robotics, Annual Conference of the European Society for Cognitive Psychology (ESCOP), Annual meeting of the Psychonomic Society, Frontiers in Neurorobotics, Frontiers in Psychology, Cognition, Psychological Science in Psychology.

developed, including the system of cognitive robotics. WP6 deals with dissemination and exploitation, and WP7 deals with management. The main dependencies between the first 5 WPs is depicted in the figure. In fact, feedback between these 5 WPs will be continuously taken into account. The timing of the WPs and their activities are reported in Gantt chart below:



Work package 1 - Psychological basis of HESA

Work package number			WP1	Start Date or Starting Event		M1
Work package title			Psychological basis of HESA			
Participant number	1	2	3	4	5	6
Short name of participant	UOR	**UL**	ICL	RWTH	IDM	UNIMELB
PM per participant:	6	**35**	3	4	0	6

Objectives. Develop an empirically grounded model of agent/action representation and social awareness in social situations.

Description of work

Task 1.1: Cognitive representation of agent-specific behaviors/behavioral stereotypes (UL) [M1-12]. This task aims at creating a database of typical behaviors attributed to key agents of the relevant scenarios. Empirical data will be collected in representative human adults. The behaviors in the database will be weighted for probability and situational significance.

Task 1.2: Assimilation and accommodation mechanisms in event models (UL) [M1-36]. This task will study and carry out experiments on how human adults use previous knowledge about behavioral stereotypes to predict the behavior of others and update their knowledge base if their predictions fail. The empirical findings will used to create a dynamic model of event representation, based on principles from cognitive sciences [ZSSB07] and cognitive neuroscience [FrLO01, McMO95].

Task 1.3: Social heat maps (UL) [M1-24]. This task will include empirical studies to assess how human adults represent groups of agents and how they keep and update such representations. The main idea is that people create situational, dynamic heat maps, in which available social agents are weighted according to their potential actions (i.e., according to the situational social relevance of these actions and the probability that they are carried out).

Task 1.4: Cognitive representation of social rules and norms (UL) [M1-36]. This task will include empirical studies on how humans represent social rules and norms, how they adjust these representations to the current situation (e.g., how they represent the probability that rules and norms are applied by others in the current situation), and how they use these representations to predict the behavior of others.

Deliverables

D1.1 Techniques for the representation of behaviors and stereotypes and dynamic model of action/agent representation [M12, M24, M36]

D1.2 Mechanisms of creating and social heat maps and representing social rules and norms [M24, M36]

Work package 2 - Knowledge representation and reasoning in HESA

Work package number			WP2	Start Date or Starting Event		M1
Work package title			Knowledge representation and reasoning in HESA			
Participant number	1	2	3	4	5	6
Short name of participant	**UOR**	UL	ICL	RWTH	IDM	UNIMELB
PM per participant:	**28**	9	9	9	0	9

Objectives. To develop a logic-based, computational grounding for knowledge representation and reasoning in HESAs and specifically the development of 1) a suitable languages and semantics for representing behaviors ascribed to peers; ascription mechanisms of behaviors to peers; 3) reasoning and acting in social contexts; 4) monitoring and revising behaviors. All methods will be assessed against their computational feasibility in the context of the project, including their computational complexity.

Description of work

Task 2.1: Representation of others' behaviors (UOR) [M1-24]. This task aims to study and developing a first-person based formal representation of the expected behaviors of other peers, and their individual and joint capabilities, their expected deliberation in given situations, their attitude to cooperation, or otherwise, as well as the tasks they are executing. The work will be grounded on knowledge representation and multi-agent systems and will follow closely the research developed in WP1 on human-based theories of interaction (in particular T1.1, and 1.4). Technically, this will involve the development of logic-based, decidable theories representing complex behaviors of HESAs. A key outcome of this work will be novel formalisms based on situation calculus and interpreted systems to represent behaviors in HESAs as described above.

Task 2.2: Behaviors ascription mechanisms (UOR) [M1-24]. This task will study the mechanisms that will enable HESAs to ascribe behaviors to peers at runtime from a set of predefined stereotypes that represent common acting patterns in social situations. The behavior ascribed to peers will change dynamically as the agents change their understanding of the situation they are in in view of their monitoring activities (T2.4). The ascription mechanisms and its runtime adaption will follow the work conducted in cognitive psychology and social awareness studies for humans from WP1, (in particular T1.2 and T1.3). Technically, we will formalize, in collaboration with WP1, repositories of behavioral patterns described as transition systems to be composed and customized during reasoning (T2.3). The outcome of this task will be a collection of ascription mechanisms for the expected behavior of HESA peers.

Task 2.3: Reasoning and acting considering others behaviors (UOR) [M7-36]. This task will study the reasoning and the deliberation mechanisms that HESAs will adopt in order to act socially, by considering others as companions, adversaries, peers and act accordingly. The approach will be based on logic techniques in AI and formal methods in CS. The WP will develop novel approaches to reasoning about actions in a social context and the related problems of situation awareness, incomplete information, information classification and actions ontologies, reasoning about others' expected behaviors and violations, strategic action deliberation, and synthesis and refinement of execution plans. A key concern will be the assessment of any technique identified against its computational feasibility, including its decidability and computational complexity, thereby providing valuable input to WP3. The outcome of the task will be a collection of techniques for reasoning and acting in social contexts from a first-person point of view as well as their computational analysis.

Task 2.4: Monitoring others' behaviors and action refinement (ICL) [M13-36]. This task will develop monitoring and refinement techniques for HESAs. It will consist of a methodology to process the peers' behaviors, as observed by an agent by means of monitors, and revise the future behavior expected by the agent from the peers. The model revision and selection technique will be based on psychological studies in WP1 (in particular T1.2 and T1.3) and implemented through various notions of model distance that take inspiration from the literature of model updates, and revision in AI and CS. Technically we will develop algorithms on logic-based representations including transition systems that will select the most likely model stereotype in view of the observed behavior up to a certain point. The model update will also provide input to the local action refinement component for the agent himself to provide the best action response in the circumstances. The outcome of the task will be a number of novel approaches to select at runtime the most likely behavioral template in view of the observed behaviors.

Deliverables

D2.1 Representation of others' behaviors and behavior ascription mechanisms. [M12; M24]

D2.2 Reasoning on other's behavior and monitoring. [M24; M36]

Work package 3 - Abstraction, verification and synthesis in HESA

Work package number			WP3	Start Date or Starting Event		M7
Work package title			Abstraction, verification and synthesis in HESA			
Participant number	1	2	3	4	5	6
Short name of participant	UOR	UL	**ICL**	RWTH	IDM	UNIMELB
PM per participant:	16	0	**29**	6	0	6

Objectives. To develop logic-based, computationally efficient techniques for verification, first-person reasoning and monitoring in HESAs. Proof of concept implementations will also be released.

Description of work

Task 3.1. Abstraction and verification in HESAs (ICL) [M7-36]. This task will be concerned with developing logic-based verification methodologies for HESAs so that HESA systems can be analyzed and any bug can be detected and rectified. The work conducted here will naturally follow the semantics and algorithms developed in WP1 and WP2. Technically, we will develop symbolic model checking techniques for verifying the correctness of HESA systems. We expect HESA systems to be complex to analyze; given this, we will also develop abstraction methodologies to reduce the state spaces appropriately. The outcome of this task will be a number of verification methodologies to assess the correctness of HESAs at design time.
Task 3.2. First-person HESAs reasoners via automatic synthesis (ICL) [M13-36]. In this task, we will develop reasoners for the individual HESAs in a system. This will enable the agents to deliberate at run-time on what specific course of action to take in the social situation they inhabit in view of the expectations they have of their peers' behavior. Technically, we will develop automatic synthesis algorithms against specifications expressing strategic behavior (e.g., expressed in ATL, strategy logic, etc.). We will benefit from the work in Task 3.1 as synthesis and model checking share basic underlying methodologies. They will be used on the same semantics from WP1 and be guided by the worst-case complexity analysis of WP2. The outcome of the task will be a suite of synthesis algorithms to be used as prototype reasoners.
Task 3.3: Prototype Implementations (ICL) [M18-36]. In this task, we will realize open-source prototype implementations for the algorithms developed in T3.1 and T3.2. The outcome will be prototype reasoners that use logic-based technology for verification, first-person reasoning and monitoring in HESAs.

Deliverables

D3.1 Verification algorithms for HESAs and prototype [M12; M24; M36]

D3.2 First-person reasoning algorithms for HESAs and prototype [M24; M36]

Work package 4 - Integrating HESA Methods into Cognitive Robots

Work package number			WP4	Start Date or Starting Event		M1
Work package title			Integrating HESA Methods into Cognitive Robots			
Participant number	1	2	3	4	5	6
Short name of participant	UOR	UL	ICL	**RWTH**	IDM	UNIMELB
PM per participant:	6	6	6	**26**	9	6

Objectives. The objective of this WP is to implement and integrate methods developed in WP2+3 into the high-level control software of cognitive robots. The starting point will be the robotic software framework developed at Aachen. Suitable modifications and extensions of Golog need to be developed to implement the ascription of behaviors of other agents, their adaptation due to monitoring of other agents at runtime, and the action selection based on these ascriptions.

Description of work

Task 4.1: Preparing robots for HESA (RWTH) [M1-9]. The work is based on the robotic software framework developed at RWTH, which includes middleware [NFBL10] with an interface to ROS, and the high level control language Golog based on the situation calculus. (Work on porting the software to a robot identical to those used in this project is already under way.) To prepare the robots for HESA-specific requirements, existing 2D and 3D perception methods needed for agent monitoring (T4.4) will be adapted.

At the logic-based control level, symbolic representations of actions and fluents, together with their connections to actuators and perception routines suitable for in-house and deployment application scenarios in WP5 will be developed. In-house scenarios will be implemented and evaluated within the RWTH robotic lab (see RWTH description in part 4), as well as in public spaces of the university.

Task 4.2: Integrating behavior ascriptions into Golog (RWTH) [M7-24]. Based on WP 2.1, Golog representations need to be extended to allow for behavior ascriptions of other agents, taking a first-person point of view. A starting point for this work can be a multi-agent version of the knowledge-based programming paradigm developed in [ClLa06]. Stereotypical behaviors from in-house and deployment application scenarios will be implemented and used for testing.

Task 4.3: Integrating HESA Reasoning methods (RWTH) [M10-30]. Reasoning methods and behavior synthesis methods developed in WP2+3 need to be integrated into the Golog framework and combined with existing methods for classical planning [CELN07] and decision-theoretic planning [FeLa08].

Task 4.4: Agent monitoring and model adaptation (RWTH) [M13-36]. Monitoring of other agents' behavior will be based on existing perception methods from T4.1. The recognition of behavior will use the methods developed in WP2+3, combined with existing plan recognition techniques in Golog [SBSL12]. Rather than aiming for a general solution, the focus will be on solving monitoring issues as they arise in the application scenarios of WP5. Based on this, update mechanisms for ascribed behaviors will be integrated into the framework. Methods from WP2+3 for action refinement will be combined with existing re-planning techniques such as [FeLa08].

Deliverables

D4.1 A Golog interpreter with built-in facilities for behavior ascription and HESA reasoning techniques [M9,M18; M30]

D4.2 Behavior monitoring and action selection adaptation mechanisms integrated into Golog [M24; M36]

Work package 5 - Deployment of HESA

Work package number			WP5	Start Date or Starting Event		M12
Work package title			Deployment of HESA			
Participant number	1	2	3	4	5	6
Short name of participant	UOR	UL	ICL	RWTH	**IDM**	UNIMELB
PM per participant:	6	6	2	8	**21**	16

Objectives. Proof of concept of actual deployment of HESAs system.

Description of work

Task 5.1: Definition of Use Cases and methodology for evaluation (IDM) [M1-M12]. This task addresses the definition of the use case scenarios that will be used to demonstrate and evaluate the achievements of the project. Two use cases are being considered: robot assistants in daily care centre, and multi-robot system for automated surface mining.

Task 5.2: Preliminary testing (IDM) [M10-M24]. The aim of this task is the testing and validation of the intermediate achievements from the project. This will define further improvements to mitigate integration issues and fine-tuning processes.

Task 5.3: Deployment and validation (IDM) [M19-M36]. This task comprises the deployment and validation of the developed components over the two use case scenarios. Previous experience of partners IDM and UNIMELB with these scenarios will facilitate integration of the developed software components.

Task 5.4: Analysis of results (IDM) [M21-M36]. This task will apply the methodologies and tools defined in T5.1 to analyze the results collected from the two trials. From this analysis a set on conclusions and recommendations will be issued, which will serve as input for the dissemination and exploitation of the project achievements.

Deliverables

D5.1 Definition of use cases and system functionalities [M12]

D5.2 Evaluation Report on the deployed system [M24; M36]

Work package 6 - Dissemination and Exploitation

Work package number			WP6	Start Date or Starting Event		M1
Work package title			Dissemination and Exploitation			
Participant number	1	2	3	4	5	6
Short name of participant	UOR	UL	ICL	RWTH	**IDM**	UNIMELB
PM per participant:	4	1	1	1	**4**	1

Objectives. This work package is about the dissemination of the research and development work carried out in the framework of the HESA project, and about the potential use of the resulting technologies in real commercial and industrial settings.

Description of work

Task 6.1: Website (UOR) [M1-36]. Develop a HESA website to help to disseminate the project to the research communities and facilitate the internal communication of consortium members.

Task 6.2: Dissemination Plan and Publications (UOR) [M7-M36]. Develop and disseminate material on HESA through various channels, including top ranked conferences and journals in artificial intelligence, robotics, and cognitive science; YouTube videos; press releases; public science and industry expositions.

Task 6.3: Exploitation Plans for Results Developed within HESA (IDM) [M13-36]. Develop yearly exploitation plans to facilitate adoption of the results, methodologies and technologies, developed within HESA. In the last year this activity will focus on the adoption of HESA technologies by industrial/public third party organizations involved in constructing complex MAS and multi-robot systems.

Deliverables

D6.1 Public website [M3]

D6.2 Description of knowledge generated by the consortium and dissemination achieved [M12; M24; M36]

D6.3 Exploitation plan for adoption of the HESA technologies, and future developments [M24; M36]

Work package 7 - Management

Work package number			WP7	Start Date or Starting Event		M1
Work package title			Management			
Participant number	1	2	3	4	5	6
Short name of participant	**UOR**	UL	ICL	RWTH	IDM	UNIMELB
PM per participant:	**12**	0	0	0	0	0

Objectives. The aim of this WP is to oversee the overall management activities related to the project.

Description of work

Task 7.1: Project organization, planning and quality control (UOR) [M1-36]. Organization of project's meetings. Monitoring, progress and quality of research. Ensure communication among partners at all levels.

Task 7.2: Reporting (UOR) [M1-36]. Interim and Annual reports to be prepared for the EU Commission.

Task 7.3: Administrative and financial coordination (UOR) [M1-36]. Document and periodic reports production and archive. Costs to be controlled coordinated and consolidated. EC payments and distribution coordination and follow-up.

Deliverables

D7.1 Annual reports [M12; M24; M36]

D7.2 Final report [M36]

3.1.4 List of Work Packages

WP No	Workpackage title	Lead contractor	Person-months	Start month	End month	Del. No
WP1	Psychological basis of HESA	**UL**	54	**1**	**36**	D1.1, D1.2
WP2	Knowledge representation and reasoning in HESA	**UOR**	64	**1**	**36**	D2.1, D2.2
WP3	Abstraction, verification and synthesis in HESA	**ICL**	57	**7**	**36**	D3.1, D3.2
WP4	Integrating HESA Methods into Cognitive Robots	**RWTH**	59	**1**	**36**	D4.1, D4.2
WP5	Deployment of HESA	**IDM**	59	**1**	**36**	D5.1, D5.2
WP6	Dissemination and Exploitation	**IDM**	12	**1**	**36**	D6.1, D6.2, D6.3
WP7	Management	**UOR**	12	**1**	**36**	D7.1, D7.2
			317			

3.1.5 List of Deliverables

No	Deliverable title	Date	Nature	Diss. level
D1.1	Techniques for the representation of behaviors and stereotypes and dynamic model of action/agent representation	12,24,36	R	**PU**
D1.2	Mechanisms of creating social heat maps and representing social rules and norms	24,36	R	**PU**
D2.1	Representation of others' behaviors and behavior ascription mechanisms	12,24	R	**PU**
D2.2	Reasoning on other's behavior and monitoring	24,36	R	**PU**
D3.1	Verification algorithms for HESAs and prototype	12,24,36	R, OTHER	**PU**
D3.2	First-person reasoning algorithms for HESAs and prototype	24,36	R, OTHER	**PU**
D4.1	A Golog interpreter with built-in facilities for behavior ascription and HESA reasoning techniques	9,18,30	R, OTHER	**PU**
D4.2	Behavior monitoring and action selection adaptation mechanisms integrated into Golog	24,36	R, OTHER	**PU**
D5.1	Definition of use cases and system functionalities	12	R, DEM	**PU**
D5.2	Evaluation Report on the deployed system	24,36	R, DEM	**PU**
D6.1	Public website	3	DEC	**PU**
D6.2	Description of knowledge generated by the consortium and dissemination achieved	12,24,36	R	**PU**
D6.3	Exploitation plan for adoption of the HESA technologies, and future developments	24,36	R	**PU**
D7.1	Annual reports	12,24,36	R	**PU**
D7.2	Final report	36	R	**PU**

3.2 Management and risk assessment

The aim of the project management is to guarantee that the objectives of the project are achieved on time, on budget, and with high quality. The HESA project will be managed with sound and efficient decision-making, execution, and control, and will maximize partner accountability, commitment, involvement, and prospects of success. To implement the above goals, the proposed project management structure includes the following figures: Project coordinator, WP Leaders, and General Assembly (GA), the latter consisting of the principal investigators of all units, and chaired by the project coordinator. The relationship between all contractors will be fixed in a *Consortium Agreement*. The project units will meet at least quarterly. In addition, periodic meetings among WPs teams will be organized depending on the work to be carried out as well as specific integration meetings when *milestones* are reached. Milestones are reported in the table below.

Milestone	Name	Related WPs	Date	Means of verification
M1	Definition of behavior representation, reasoning tasks and stereotypes	WP1, WP2	M12	All partners fully understand and approve the first iteration of D1.1 and D2.1
M2	Definition of in-house and deployment use cases and system functionalities	WP4, WP5	M12	All partners fully understand and approve D4.1 and the first iteration of D5.1
M3	Scripted demo of in-house use cases, preliminary testing successful	WP5	M18	Demo successfully shows the novel capability of the pro- posed framework; all partner approve first iteration of D5.2
M4	Definition of monitoring and behavior adaptation techniques	WP1, WP2, WP3, WP4	M24	All partners fully understand and approve of the second iteration of D1.1, D2.1 and D3.1, and the first iteration of D1.2, D2.2, D3.2, D4.2
M5	Methods, techniques and technologies for HESA	WP1, WP2, WP3, WP4	M36	All partners fully understand and approve of the final iteration of D1.1, D2.1, D3.1, D1.2, D2.2, D3.2, and D4.2
M6	Final demo on cognitive robots that reason and act using behaviors ascribed to other agents	WP5	M36	Successful integration of HESA techniques into existing robotic software; demo successfully run and evaluated; all partners approve the final iteration of D5.2.

Risk assessment. As a scientifically and technologically challenging initiative, the HESA project carries a degree of risk, which the partners will control. During the quarterly meetings, the GA will hold a dedicated session to identify, evaluate, and track project risks. Members of the consortium have very significant experience in collaborative EU projects and have an excellent shared understanding of the technical issues ahead. Because of this we believe the coordination risks are minimal.

Description of risk	Inv.ed WPs	Proposed risk-mitigation measures
One partners fails	All	Carefully previous selected and fully engaged partners, most with cooperation and experience in EU projects.
UNIMELB cannot coordinate enough with EU partners	All	The project is carefully designed so as to guarantee success even in case UNIMELB drops out. In particular no critical tasks are assigned to UNIMELB. On the other hand, UNIMELB is very committed to the project and with great experience in international projects. Its contribution can potentially be of great benefit to the research.
Failure to coordinate and follow up on project progress and work plan, resulting in delays and failed tasks.	All	The prime contractor has significant experience in managing international projects, including the coordination of EU projects (e.g. WORKPAD, SM4All, SAPHARI). A strong management structure will be established including control measures to assure progress according to the work plan.
Some research tasks might be too complex	All	Research is organized through an iterative process to deal with complexity
Project results do not create exploitable impacts	WP5, WP6	The project includes a specific WP5 for deploying the developed technologies in a real use case as a proof of concept, creating a feedback loop for keeping the research industrially feasible and exploitable. The WP is led by a SME (IDM) with great experience in successfully conduct such activities. Moreover significant amount of resources are allocated in WP6 to dissemination and exploitation, and the WP is led again by IDM to emphasize dissemination and exploitation through industry channels.

3.3 Consortium as a whole

The consortium is formed by world leading research units with an outstanding scientific track record in the disciplines involved in the project: Cognitive Psychology (UL), Knowledge Representation and Reasoning (UOR), Multi-Agent Systems (ICL), Cognitive Robotics (RWTH), and by an industrial partner with extensive expertise in the development of robotic applications (IDM). The consortium members have a long experience in collaborative projects. They also share an excellent understanding of the technical matter. The industrial partner IDM has often been often involved in projects requiring the transfer of cutting-edge research results to actual deployment (see Section 2.1). All principal investigators of WP1-WP4 are very active in the most prestigious conferences (over the years they have covered hundreds of PC roles) and journals in their respective areas, hence collectively have the full picture of all research trends and synergies in the areas of the projects. For example, Prof. De Giacomo (UOR) was the Program Co-Chair of KR in 2014 and is the Review Editor in AIJ and Associate Editor of JAIR; and Prof. Lomuscio (ICL) was the Program Co-Chair in AAMAS 2014 and is in the Editorial Board of JAIR; Prof. Hommel (UL) is the Editor-in-Chief of *Frontiers in Cognition* and of *Psychological Research*; Prof. Lakemeyer is the Chair of the Steering Committee of the Cognitive Robotics Workshops series and the Completion Editor of AIJ. The consortium is complemented by UNIMELB, led by constraints programming pioneer Prof. Stuckey, bringing unique expertise in optimizing, deploying and scheduling, including mining operations involving robotics, which will be used for evaluating deployment of the HESA approach. The UNIMELB team has proven scientific track records in cognitive psychology (Prof. Kashima) and cognitive robotics and multi-agent systems (Prof. Sonenberg & Prof. Pearce). UNIMELB will be funded through a Horizon 2020 Research Consortia and Networks grant by University of Melbourne (see appendix).

3.4 Resources to be committed

The ambition reflected in the objectives of the project and its workplan is paired by the quality, variety and volume of resources to be set into motion. In estimating HESA budget, the Consortium has taken full advantage of previous experience in analogous projects, as well as the new regulations of Horizon 2020. In this respect, the budget has been drafted with contributions from all partners. Therefore, the adequacy of the financial planning to ensure the integration of resources and the proper development of the workplan has been secured. Completing HESA workplan will require the Project team to deploy an estimated human effort of 317 Person Months (PMs) over the project 36 months lifecycle. Due to the nature of the project, the major effort is concentrated in research activities and in deployment, which represent about 92% of the total PMs, while the effort planned for project management, as well as dissemination and exploitation activities represents 8% of total PMs. Based in our combined experience, we understand the budget is properly adapted to secure the attainment of HESA objectives and foreseen impacts. The cost for completing the HESA project is estimated in € 3.215.165 (€ 2.397.861 for EU member states and AUD $877.194 for Australia). HESA cost structure is it follows.

Personnel costs (69% of project costs). Personnel costs were calculated on the basis of person months agreed to be allocated to the Project by the partners' own personnel, and the corresponding PM cost rates provided by each of the partners. The effort per partner are depicted in the following table.

	Science				Deployment	Exploitation	Management	
WP#	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP10**	**Total PMs/Partner**
Short name	UL	UOR	ICL	RWTH	IDM	IDM	UOR	
UOR	6	**28**	16	6	6	4	**12**	**78**
UL	**35**	9	0	6	6	1	0	**57**
ICL	3	9	**29**	6	2	1	0	**50**
RWTH	4	9	6	**26**	8	1	0	**54**
IDM	0	0	0	9	**21**	**4**	0	**34**
UNIMELB	6	9	6	6	16	1	0	**44**
Total PMs/WP	**54**	**64**	**57**	**59**	**59**	**12**	**12**	**317**

Travel and subsistence costs (6,8% of project costs) cover all participants' travel and daily allowance that are likely to be needed to assure an adequate participation of partners in bilateral and Consortium-wide meetings, working sessions, as well as in events organized by third parties in direct relationship with project development. Costs estimations are based on 1.000 Euros/trip/participant average cost of travelling & subsistence. Notably, travel costs are also needed to set-up the deployment of the pilots, as well maintenance over the 18-months of pilots' running.

Equipment costs (1,8% of project costs) include three service robots, augmented with additional 2D and 3D sensors and interaction capabilities, needed by RWTH for testing and demonstration purposes (average cost: 3 x 15K€).

Dissemination and outreach costs (1,5% of total project efforts) include the logistics and related expenses related to the performance of activities in the area of outreach with targeted audiences beyond the Consortium borders, including dissemination events and open-access publication costs. In particular, 10K€ per partners have been budgeted for open-access publication costs.

Subcontracting. Subcontracting is considered only for audits.