

**2232 INTERNATIONAL FELLOWSHIP FOR OUTSTANDING RESEARCHERS**

**RESEARCH PROJECT PROPOSAL FORM**

2019

….. Term

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| **Proposal Title:** Developing a Machine Reasoning Engine for Artificial General Intelligence |
| **Project Coordinator:** Cengiz Erbas |
| **Host Institution:** Hacettepe University |

**PROPOSAL SUMMARY**

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| Machine learning (ML), in particular deep learning, forms the backbone of the current phase of AI revolution. ML systems can learn to answer questions narrowly posed around the training data sets. The next step in AI revolution towards human-level intelligence will require machine reasoning, or the ability to apply prior knowledge to new situations. We propose to develop a Machine Reasoning (MR) Engine that can learn arbitrary concepts and can discover higher-level cognitive relationships among them. MR Engine will complement the existing ML Systems in three dimensions:   1. It will not require problem-specific model development; 2. It can be trained with Small Data; and 3. It can identify cognitive relationships that are out of reach for ML tools and techniques.   MR Engine will be fully parallelizable, where availability of more computing resources will guarantee faster response.  This is an ambitious undertaking which can have huge scientific and industrial impact. Our conviction that such system can be built comes from two sources: (1) we have developed the core algorithms of MR Engine; and (2) we have experimented with them successfully in multiple domains. Our current prototype is able to learn simple arithmetic and geometric concepts and syntax of simple programming languages using small number of training samples and without requiring any problem-specific model development. We aim to further develop the prototype in a cloud computing platform (with more computing resources) to be able to solve real-world problems.  MR Engine aims to provide reasoning/induction capabilities that are out of reach for the existing machine learning techniques. It is based on a scaled down implementation of Solomonoff’s theory of universal inductive inference, which reduces AI to a search problem within the space of all programs. Even though this search space is nearly infinite, our experiments show that this framing is extremely effective when we look for discrete cognitive relationships among concepts. Solomonoff induction in its purist form is undecidable. To make the implementation tractable, we made 3 innovations that contributed to taming the expansion of the design space. These are:   1. Reducing the search space to context-free expressions, 2. Building the complexity from simple concepts through compositionality, and 3. Exploring the design space using evolutionary mechanisms.   We have built a prototype which runs on a PC with limited computing resources, and showed the domain independent reasoning capabilities of MR Engine on toy examples. With resources of a cloud computing platform, we will be able to leverage the inherent parallelism and make more realistic demonstrations. The prototyping effort enabled us to experiment with different algorithms, to benchmark alternative implementations, to better understand the roadblocks, and led to the three main innovations mentioned above that made the implementation possible.  The output of this project will be a fully operational AGI framework with which the researchers (globally) can experiment with. The framework will provide a reasoning engine that can learn arbitrary concepts by itself, but can also integrate with the existing machine learning models. The success of the project will be measured based on the following three criteria: (1) its ability to learn and reason in domain independent manner; (2) its ability to learn with small amount of training data; and (3) its ability to discover non-trivial cognitive relationships among arbitrary concepts.  The project will also contribute to training next-generation Turkish engineers in the field of Artificial Intelligence, which will be one of the most critical economic drivers of the global economy in the coming decades. This contribution to national human capital will not only be with academic education, but also with hands on knowledge transfer from the experience gained in one of the top AI companies in U.S. |
| **Keywords:** Artificial Intelligence (AI), Artificial General Intelligence (AGI), Machine Learning (ML), Machine Reasoning(MR) |

1. **EXCELLENCE**

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| * 1. **Importance of the Subject, Scientific Excellence of the Project and Research Question/Hypothesis**   1.1.1. Scientific quality and innovation potential of the project,  Machine learning techniques have proven successful in leveraging big data to answer questions carefully posed around the training data sets. Deep neural networks work best with data that is produced from a process of continuous function, and are extremely successful in approximating arbitrary nonlinear functions. However, even though there are some successes in transfer learning, deep neural networks have proven difficult to generalize beyond their initial set of training questions. Pushing the boundaries of AI towards human-level intelligence requires new approaches that addresses such weaknesses of the current machine learning techniques.  Using the existing ML tools and libraries, we can build systems that can recognize objects, identify faces, forecast weather and projectile motion. However, the capability to learn continuous functions is only a small part of human-level intelligence. What differentiates human is the ability to command on languages of various forms, such as understanding natural languages, learning mathematics, developing programs, designing artifacts, discovering scientific theories, expressing through arts and literature. Such human-level faculties cannot be associated with a continuous function. Language, in essence, is produced by a process with as many discontinuities as the number of linguistic rules, logical inferences and asymptotic decision boundaries.  In this proposal, we aim to develop a machine reasoning system that will complement machine learning to achieve human-level intelligence. The proposed MR Engine will be able to learn the structure of underlying generating functions, grammars, or relationships, not simply classify the structures found in observed data. As opposed to machine learning techniques, MR Engine will not require problem-specific model development; it will not require massive training data; and it will be able to identify cognitive relationships that are out of reach for the current ML tools and techniques.  As an example, the developers can train ML models to identify eyes, ears and noses from human pictures. However, if you train MR Engine to identify a human face, it will be able to automatically discover that each human face contains two eyes, two ears, and one nose. If you further teach MR Engine the concept of human body, it continues building up these relationships recursively by discovering that a human body contains a face and by consequence it also contains two eyes and two ears. What is more important, MR Engine will be able to do this without requiring any new model development, and by using small number of training data.  The following figure illustrates our vision of how AGI will be build based on combination of ML and MR models, and arbitrary programs, where MR Engine can also integrate with and leverage the existing machine learning models, and handcrafted knowledge in the form of general-purpose programs.  Artificial General Intelligence Framework  MR Models  P  MRM  ML  ML Models  P  Programs  If we look at the figure from right to left, it encapsulates three different ways of building artificial intelligence capabilities, as follows:   * In its simplest form, intelligent functions can be developed by coding them in the form of Programs (P). Early work in AI (including Expert Systems) falls into this category. * Alternatively, we can build ML models (such as DNNs) that demonstrate intelligent capabilities. This part of the figure corresponds to the current stage of AI revolution. ML models use “features” that are extracted using programs (P) as input to do classification. However, it is important to note that the output of the model is not within the space of the features. We cannot feed the output of a model to itself recursively to build hierarchy of learned concepts. * Machine Reasoning (MR) Models will not have this limitation. MR Models will operate at the “concept” level. Both inputs and outputs of MR models will be within the space of concepts. The output of an MR model can therefore be fed into the same model recursively to build hierarchy of learned concepts. MR Models will also be able to use the existing ML models as well as other programs (P) as input, leveraging the existing AI systems.   This is an ambitious undertaking which can have huge scientific and industrial impact. Our conviction that such system can be built comes from the success of our prior prototyping efforts. We implemented key algorithms on a PC. Even though it is running with very limited computing resources, the prototype is able to learn simple arithmetic and geometric concepts within minutes from small number of training samples and without requiring any problem-specific model development. Moreover, the prototype is able to discover the cognitive relationships among such concepts all by itself. In another very promising example, it is able to learn the syntax of a simple programming language in a supervised manner from small number of program source code samples. We can provide a demo of the prototype, if requested.  MR Engine is based on a scaled down implementation of Solomonoff’s theory of universal inductive inference. For simplicity, the fundamental principle of Solomonoff induction can be expressed as: “*Do not search for patterns, rather search for programs that generate those patterns*.” This view reduces AI to a search problem within the space of all programs. Even though this search is nearly infinite, our experiments show that this framing is extremely effective when we look for discrete cognitive relationships among concepts.  The timeliness and innovation potential of the project is evident from the recent focus on building the next generation AI systems. DARPA (2019) AI Initiative, for example, outlined a vision which view ML based systems as second wave of AI. DARPA views ML-based second wave AI systems as statistically impressive but individually unreliable. The vision for the third wave gives priority to abstraction and reasoning capabilities, as well as contextual adaptation and explainability, which aligns very well with the proposed project.  1.1.2. Current scientific state of the art and ongoing developments in fields relevant to your proposal also regarding your previous works  Creating a machine reasoning engine falls into Artificial General Intelligence (AGI) research, which aims to create human-level artificial intelligence (Goertzel and Pennachin, 2010). Solomonoff’s theory of inductive inference is referenced frequently in AGI literature. Solomonoff induction in its purest form is undecidable, but there are several attempts in the literature to implement different variants of Solomonoff induction. Notable examples are AIXI by Marcus Hutter (2005), and Godel Machine by Jurgen Schmidhuber (2009). These are academic efforts, but it is quite likely that there are industrial/commercial applications of Solomonoff induction that are not publicized. It is worth mentioning that Shane Legg (Marcus Hutter’s Ph.D. student) worked on the problem extensively prior to founding DeepMind which was later acquired by Google.  There are at least two categories of studies in the literature that aim to address the limitations of the current machine learning systems. The first category includes the work to enhance the capabilities of neural networks so that they can learn “programs”, and the second category contains the work to enhance known symbolic systems, like inductive logic programming to be trainable like neural networks through gradient decent.  An example research for the first category, Graves et.al (2014 and 2016) from Google DeepMind enriched the capabilities of standard recurrent networks via a large addressable memory to be able to learn performing algorithmic tasks. They developed, what they call, Neural Turing Machines, which extended the capabilities of neural networks by linking them to external memory resources. This system does not construct an explicit symbolic representation of a program, but learn an implicit procedure that produces the intended results. This implicit procedure in a way operates at a lower level model of computation, similar to Turing machines or pushdown automata, but it is differentiable end-to-end, making it possible to be trained with gradient descent. This is achieved by defining fuzzy read and write operations that interact with all the memory elements rather than addressing a single element as in a normal Turing machine. The experiments demonstrated that Neural Turing Machine is capable of learning from example data simple algorithms, such as copy operations, n-grams and priority sort.  An example for the second category, in another relevant work from Google DeepMind, Evans and Grefenstette (2017) proposed a differentiable Inductive Logic Programming (ILP) framework. ILP is a set of techniques for constructing logic programs from examples. ILP has attractive features, such as: the learned program is an explicit symbolic structure that can be inspected and easier to understand than a large tensor of floating-point numbers; it is able to generalize well from a small number of examples; and it enables continual and transfer learning, as the learned programs are free from side-effects and can be copied and pasted into the knowledge base. The main limitation of ILP is its inability to handle noisy, erroneous, or ambiguous data. If training examples contain any mislabeled data, ILP systems fails to learn the intended rule (De Raedt and Kersting, 2008).  Differentiable ILP (dILP) aims to address the weaknesses of ILP by using neural networks. Evans and Grefenstette (2017) showed that dILP is able to solve moderately complex tasks requiring recursion and predicate discovery. The main component of this work is a differentiable implementation of deduction through forward chaining on definite clauses. The main limitation of the dILP system is that it requires significant memory resources, which limits the range of benchmark problems that the system can be tested with.  1.1.3. Methodological/conceptual/theoretical contribution to the related scientific and technological area,  The proposed project aims to achieve similar goals, but based on a different approach. MR Engine will complement the existing ML Systems in three dimensions:   * it will not require problem-specific model development; * it can be trained with Small Data; and * it can identify cognitive (logical, mathematical and linguistic) relationships that are out of reach for the existing ML tools and techniques.   MR Engine will be fully parallelizable. Availability of more computing resources (such as that can be obtained from a cloud computing platform) will guarantee faster response.  MR Engine aims to provide reasoning/induction capabilities that are out of reach for the existing machine learning techniques. It is based on a scaled down implementation of Solomonoff’s theory of universal inductive inference, which reduces AI to a search problem within the space of all programs. Even though this search space is nearly infinite, our experiments show that this framing is extremely effective when we look for discrete cognitive relationships among concepts.    Solomonoff induction in its purist form is undecidable. To make the implementation tractable, we made 3 innovations that contributed to taming the expansion of the design space. These are:   1. Reducing the search space to context-free expressions, 2. Building the complexity from simple concepts through compositionality, and 3. Exploring the design space using evolutionary mechanisms.   MR Engine avoids undecidability by reducing the design space to context-free expressions, which is sufficient to express many interesting problems, in particular the ones mentioned earlier that are related to human faculties that require language understanding.  Second, compositionality allows building complexity from simple concepts hierarchically, consistent with how humans understand the nature. We do not try to understand, for example, human anatomy at the atomic level, rather we build our knowledge base hierarchically: physics works at the atomic level; chemistry operates at molecular level; biology starts at cellular level, and so on. MR Engine applies this exact principle, which in effect, reduces the search immensely, and enables us to handle complexity.  Finally, MR Engine imitates nature which creates complexity (and intelligence) through evolution by natural selection. MR Engine applies this principle to eliminate the need to explore unproductive branches within the design space, speeding up the search vastly.  MR Engine is a compute-bound application, however it will be fully parallelizable, and be able to scale to consume all the available processing resources to provide a faster response. The current prototype, which runs on a PC with limited computing resources, showed the domain independent reasoning capabilities of MR Engine on toy examples. With resources of a cloud computing platform, we will be able to leverage the inherent parallelism and make more realistic demonstrations. |

1. **IMPACT**

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| **2.1. Ambition**  Machine reasoning can be a game changer in AI, and may lead the next wave of AI revolution. The proposed project aims to contribute to the current developments in this emerging field. As explained in Section 1.1.3 of this proposal, MR Engine will make three notable contributions to the advances in machine reasoning. Since, it will not require problem-specific model development, and can be trained with Small Data, MR Engine will make the development of AI applications much easier than today. Moreover, these AI applications will be much smarter, as they will be able to identify cognitive relationships among arbitrary concepts. More importantly, the development of MR Engine will give an opportunity to Turkish researchers to get exposed to the developments in this field in its early phases.  The work will also contribute to make the decisions of AI systems to be more understandable by humans. One of the weaknesses of deep neural networks is its inability to explain its decisions and actions to human users. Deep learning may generate a large tensor of floating-point numbers. It is extremely difficult to understand the decision process of such systems. MR Engine will help producing more explainable models, and provide human users with more visibility into why the system is acting in certain ways. This is an important area to increase the acceptance of AI systems by the society.  These advancements are aligned with DARPA’s vision for the next generation AI. With the new AI initiative, DARPA is giving a lot of focus and priority to abstraction and reasoning capabilities, as well as contextual adaptation and explainability of AI systems.  MR Engine can contribute significantly to developing better commercial applications. In the long-run, the industrial impact of machine reasoning and MR Engine can be threefold:   1. First, it can make the current AI platforms (including ML training frameworks) much more attractive for customers, as it enables developers to integrate higher-level cognitive capabilities to their applications with minimum effort. 2. Second, it can make the current AI applications smarter. Voice assistants, for example, can benefit hugely from MR Engine in many areas, such as, improving its Natural Language Processing (NLU) capabilities. 3. More importantly, it can revolutionize the industry with a new genre of MR Engine-enabled devices and applications that are adaptable to wide range of situations.   **2.2. Expected impacts**  2.2.1. Improving innovation capacity and the integration of new knowledge (strengthening the competitiveness and growth of companies by developing innovations meeting the needs of Turkey; and, where relevant, by delivering such innovations to the markets)  According to McKinsey Global Institute, AI will create $13 trillion of economic value by 2030 (Bughin, et.al 2018). This is higher than the economic impact of any other technological revolution, may be except the invention of computers. A great majority of this wealth is expected to come from product and service innovations in many sectors, including, retail, travel, transportation and logistics, automotive and assembly, basic materials, advanced electronics, healthcare, telecom, oil and gas, and agriculture. Turkish economy has no luxury to stay out of this transformation. The proposed project will contribute to advancing the technological base in Turkey, and give an opportunity to Turkish researchers and engineers to get exposed to the developments in this field in its early phases.  Considering concentration of the hi-tech firms in Turkey, we expect that the proposed project has potential to make the biggest impact in two markets: (1) consumer electronics (2) homeland security.    Turkish companies (such as, Arcelik and Vestel) has significant presence in the consumer electronic market. Success in this market heavily relies on technologic competitiveness, and AI is expected to be an important source of innovation. We expect that voice assistants (such Amazon’s Alexa as well as Arcelik’s Asista) can be an early user of machine reasoning capabilities. NLU engines currently uses handcrafted grammars and models to match user utterances to user intents. This will no longer be the case. Machine reasoning engines will be able to learn the structure of user intents from the user utterances by building context-free expressions to represent the grammar of the natural language. We intent to demonstrate this capability in a small scale as part of this project.  We also expect that Homeland Security applications, such as surveillance and abnormal activity detection, and unmanned systems, such as UAVs, will benefit greatly from machine reasoning. MR Engine in this sense have potential to contribute to companies like ASELSAN, TAI, Havelsan and Milsoft to develop innovative products. TUBITAK’s research institutes are also active in this area, and may show interest in MR Engine as a research prototype to experiment with applications of machine reasoning in homeland security. Development of innovative products in homeland security is important not only for commercial success, but also to reduce Turkey’s dependence to other countries.  2.2.2. Plan for delivering project activities and outputs to different target groups.  We will implement MR Engine in a cloud platform (AWS), and make it available through the web to the Turkish universities, research institutes and industry. The parties interested in experimenting with machine reasoning will be able to connect to MR Engine through a web address, and train and test reasoning models. We will provide well written documentation which explains step by step how to upload data, perform supervised or unsupervised training, and test the trained models. We will also enable the integration of existing ML models with the MR Engine. We will engage with each party interested in the system, as each user represents a potential for a new use case.  We will reach out to the following target groups through seminars and quarterly newsletters as explained in the dissemination and exploitation plan (in Section 2.3):   1. Universities 2. Research institutes (TUBITAK) 3. Hi-tech SMEs (Teknokent’s) 4. Industry (Arcelik, ASELSAN, Havelsan and MilSoft)   We propose to budget a limited sum to be able to pay for cloud computing costs for reasonable use of the system. For parties interested in using the system more extensively, we will let them pay for cloud computing fees based on usage.  We will also reach out to potential international customers of this project, first through participation in European R&D programs, and through participation in conferences where we can showcase MR Engine. Our eventual goal is to get sufficient international attraction to justify offering MR Engine as an AWS application accessible through AWS console.  2.2.3. The potential of the project results to solve social problems,  One of the weaknesses of current AI tools is that ML systems is not able to explain its decisions and actions to human users. Deep neural networks operate like a black box. They generate a large tensor of floating-point numbers, and it is extremely difficult for humans to make sense of the decision process of such systems. This is an important roadblock for current AI to become widely applicable in society, in particular for applications where the decisions have to be explainable and defensible. The proposed project will also contribute to make the decisions of AI systems to be more understandable by humans. The output of MR Engine will not be a set of floating-point numbers. The users will be able to read the model in the form of a program. It will also be illustratable as a graph, providing human users with more visibility into why the system is acting in certain ways. This is an important area to increase the acceptance of AI systems by the society.  MR Engine will help democratizing AI to larger segments of society. Current AI systems rely on big data. Only large corporations in particular application domains have access to data large enough to train models that can achieve acceptable levels of accuracy. It will be much easier for MR Engine to be trained by larger segments of the society, as it will not require domain-specific model development and can be trained with small data.  AI is a critical technology that will have huge impact in the world economy, and Turkey cannot afford to stay outside of the AI revolution. The development of MR Engine will give an opportunity to Turkish researchers to get exposed to the developments in this field in its early phases. The project will contribute to training a new generation of computer scientists, not only as good technicians who can train ML models, but also as visionaries who can understand its limitations, appreciate the recent developments in the field and contribute to taking AI to the next level.  We believe that the project will also contribute to solving the socio-economic problems by:   * Improving the competitiveness of Turkish firms and creating high paying jobs * Developing more innovative products   **2.3. Measures to maximize impact**  **2.3.1. Dissemination and exploitation** **of results**  The following is our 3-year plan for the dissemination and exploitation of the project results:  Year 1 Dissemination and Exploitation Plan:   1. Create a project web site to communicate the project objectives to the AI community in Turkey, and provide links to the relevant publications. 2. Create a distribution list for project newsletter, which will contain the university faculty that may be interested in the project, as well as contacts from TUBITAK research institutes, Turkish industry and Teknokent’s. 3. Publish quarterly project newsletter to bring awareness to the project and results. 4. Organize an AGI seminar at Hacettepe Teknokent. 5. Make a presentation in at least one state universities in Anatolia to talk about the recent developments in AI. 6. Submit a triple patent application (covering US, EU, Japan) based on the project objectives.   Year 2 Dissemination and Exploitation Plan:   1. Make MR Engine available to the research community through AWS cloud computing platform with documentation about how to train models. 2. Make a presentation in at least one TUBITAK research institute to talk about the project and the intermediate results. 3. Participate in at least one project proposal for the European R&D programs. 4. Make a presentation in at least two state universities in Anatolia to talk about the recent developments in AI.   Year 3 Dissemination and Exploitation Plan:     1. Make a presentation at the annual AGI Conference. 2. Make a presentation in at least one national conference in Turkey. 3. Submit academic publications based on the project results. 4. Participate in at least one project proposal for the European R&D programs. 5. Submit a triple patent application covering (US, EU, Japan) based on the project results.   In addition, I will teach one course per semester at the host institute Hacettepe University Computer Engineering department. |

1. **IMPLEMENTATION**

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| **3.1. Methodology**  High-level software architecture of MR Engine is shown below. The web/user interface layer manages the interactions with the user. The reasoning engine contains the algorithms that form theories based on the training data, and applies them to new situations. MR Engine implements the deductive and inductive reasoning logic using supervised and unsupervised training data. Unsupervised training module allows MR Engine to discover new concepts all by itself based on the utility of alternative hypotheses. Design space explorer searches the design space in parallel leveraging all the available cloud processing resources. The data management layer serves as an interface between these layers and the theory knowledge base.    Reasoning Engine  Supervised  Unsupervised  Data Management  Web / User Interface  Design Space Explorer  Pn  P2  P1  **. . . .**  We propose to implement this architecture in 4 phases in a gated manner, where each phase is implemented and its developer experience is evaluated before moving to the next as follows:   * Phase 1: Implement the skeleton of MR Engine, including the web/user interface, the data management module, and the design space explorer. * Phase 2: Develop the base algorithms to learn concepts through supervised training. * Phase 3: Discover new concepts using unsupervised training and build concept hierarchy. * Phase 4: Demonstrate general learning capabilities in multiple domains.   Phase 1 constitutes developing and validating the initial skeleton of MR Engine on AWS. This will include the development of the web/user interface, the data management module and the design space explorer. At the end of this phase, the users will be able to upload training data to MR Engine; inquire the knowledge base through data management functions; and be able to test the design space exploration functions on the cloud computing platform.  Phase 2 implements part of reasoning engine together with the base functionality to learn unconstrained concepts by supervised learning. It will also provide the functionality for application developers to integrate existing deep learning models with the MR Engine. Supervised learning will be able to use the concepts previously learned and build a hierarchal representation. Probabilistic search functions will also be implemented in this phase.  Phase 3 implements the capability to discover new concepts through unsupervised learning, and to be able to express these new concepts in terms of the concepts previously learned. It will extend the module that build hierarchy of concepts automatically by discovering cognitive relationships among them. We will experiment and try to achieve unlimited layers of hierarchy.  Phase 4 validates the use cases and demonstrates general learning capabilities in multiple domains, including, but not limited to arithmetic, geometry, strings and programs. The validation parameters will be the number of training samples for each concept, time to learn the concept, cost of learning, the size of the learned representation, and accuracy metrics.  The implementation of the above 4 phases will take place in six work packages. The methodology used in each work package is given below in Section 3.2.1.  **3.2. Management structure: Work packages, Success Criteria, Risk Management**  3.2.1. **Work packages:** A list of work packages and description of each work package; responsible team members (project leader, researchers and scholar) with their roles (Table 3.2a);  *WP1: Project Management*  The aim of this work package is to ensure the best use of project resources to achieve the proposed results and to maximize the impact. It will include technical coordination among project participants, financial management, risk management, as well as periodic reporting to TUBITAK.  *WP2: Uses Cases and Validation*  The aim of this work package is twofold: (1) to identify, at the start of the project, use cases from multiple application domains at varying degrees of complexity, and (2) to evaluate, at the end of the project, if the implementation of MR Engine can perform these use cases. The primary success criteria for the project is to demonstrate that the reasoning engine can work across domains without requiring domain-specific coding. At a minimum, the use cases will come from the following application domains:   1. Arithmetic (odd/even numbers, modulo arithmetic, integer multiplication) 2. Strings / Time Series (regular expressions, context-free expressions, DNA sequences) 3. Geometry / Image Processing (geometric shapes, composite shapes, OCR) 4. Programs (function calls, program syntax) 5. Others   *WP3: Research in AGI Algorithms*  The aim of this work package is to conduct research to advance the state-of-the-art in AGI and to develop an enhanced vision for future developments in MR Engine. These will be prioritized and part of it will be implemented as part of the project, whereas others will be left for future. We group the research activities into three categories. The first category includes the following:   1. Recursion and compositionality to discover relationships among concepts 2. Ability to learn context-free expressions 3. Tree traversal logic to explore the design space   The second category aims to reduce the size of the design space and to speed up the search using evolutionary mechanisms, as follows:   1. Elimination of isomorphic representations 2. Generating intact representations only 3. Distributed genetic algorithms   The third category will enhance the basic implementation to build hierarchy for 2D data and to develop innovative ways of unsupervised learning:   1. 1D versus 2D tokenization 2. Unsupervised concept discovery   *WP4: Development in Cloud Platform*  The aim of this work package is to implement the machine reasoning algorithms in AWS by achieving full parallelism, and to demonstrate its ability to learn using Small Data without domain-specific model development. We will evaluate the use of AWS lambda functions to ensure availability of maximum processing power while minimize costs. This will be achieved with the following four tasks:   1. Multiprocessing to leverage all the cores 2. Data management functions 3. Memory management functionality 4. Ability to leverage existing ML models 5. Intuitive user interfaces to communicate and inspect results   *WP5: Teaching and Advising Ph.D. Students*  The aim of this work package is to contribute to the training of undergraduate and graduate students at Hacettepe University in AI technologies. This will include teaching a course at each semester, and co-advising 5 Ph.D. students. Potential areas for Ph.D. dissertation topics are: Artificial General Intelligence, deep learning, genetic algorithms, cloud computing, parallel search algorithms, grammar induction and formal languages.  *WP6: Dissemination and Exploitation*  The aim of this work package is to disseminate the project results to academic and industrial audience in Turkey, publish in international academic forums, and to exploit the results for industrial applications, as detailed in Section 2.3.1.  3.2.2. **Success Criteria**: The objectives of each main WPs in the Work-Time Schedule, related **success criteria** and importance of the WP for success of the project, so that the project can be considered fully successful, should also be defined in the table by also regarding deliverables and milestones (Table 3.2.b);  3.2.3. **Risk Management**: Describe any critical risks, relating to project implementation, that the stated project's objectives may not be achieved. Detail any risk mitigation measures. Please provide a table with critical risks identified and mitigating actions (Table 3.2c).  **3.3. Research Infrastructures**  To be able to access and leverage the high processing power, the project will use the cloud computing platform of AWS. The project does not require any infrastructure and/or laboratory from the host institute, except availability of internet access and office space for project participants. |
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**3.2.a. A list of work packages\* and description of each work package; responsible team members (project leader, researchers and scholar) with their roles**

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| **WP No** | **WP Name and Description** | **Responsible Team Member (with roles)** | **MONTHS** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** | **36** |
| 1 | Project Management | C. Erbas | X |  | X |  |  | x |  |  | x |  |  | x |  |  | X |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |
| 2 | Use Cases and Validation | E.A. Sezer,  M.O. Efe | X | x | x | x | x | x |  |  |  |  |  |  |  |  |  | x | x | x |  |  |  |  |  |  |  |  |  |  |  |  | x | x | x | x | x | x |
| 3 | Research in AGI Algorithms | C. Erbas  Researcher-1 | X | x | x | x | x | x | x | x | x | x | X | x | x | x | X | x | x | x | x | X | x | X | x | x | x | x | x | x | x | x | x | x | x |  |  |  |
| 4 | Development in Cloud Platform | C. Erbas  Researcher-2 | X | x | x | x | x | x | x | x | x | x | X | x | x | x | X | x | x | x | x | X | x | X | x | x | x | x | x | x | x | x | x | x | x |  |  |  |
| 5 | Teaching and Advising Ph.D. | C. Erbas,  Co-advisors (?) | X | x | x | x | x |  |  |  | x | x | X | x | x | x | X | x | x |  |  |  | x | X | x | x | x | x | x | x | x |  |  |  | x | x | x | x |
| 6 | Dissemination and Exploitation | C. Erbas |  |  | x |  |  | x |  |  | x |  |  | x |  |  | X |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |  |  | x |

**\*Work package** (WP) means a major sub-division of the proposed project.

The main WP to be included in the project, duration of each WP and by whom each WP to be carried out should be written in the work-time schedule. The principal investigator (PI), researcher and personnel to be assigned to each work package are described in detail. The literature review, preparation stages for progress and final report, dissemination activities, writing articles and purchasing of any material to be used during the project should not be shown as separate WP.

**Table 3.2.b. Success Criteria Table\***

|  |  |  |  |
| --- | --- | --- | --- |
| **WP No** | **Objective of the WP** | **Success Criteria** | **Importance of the WP for success of the Project (%)\*\*** |
|
| 1 | Performing project management activities, including progress and final reporting, purchasing, managing subcontractors | Timely publication and approval of progress and final reports. Successful management of subcontractors. | %5 |
| 2 | Literature review of relevant work and developing use cases for machine reasoning and validating the system | Identify use cases from multiple application domains, and evaluate if the AWS implementation of MR Engine can perform these use cases. | %10 |
| 3 | Research in developing algorithms for design space exploration, model representations and compositionality | Demonstrate the ability to build hierarchy of learned and derived concepts automatically. Demonstrate at least 10x per core performance improvements by developing distributed algorithms. | %30 |
| 4 | Implementation of the algorithms in AWS, benchmarking, and demonstration with real-world examples | Demonstrate machine reasoning algorithms in AWS achieving full parallelization. Demonstrate its ability to learn using Small Data without domain-specific model development in at least 4 application domains. | %35 |
| 5 | Teaching one class each semester and co-advising Ph.D. students for dissertation activities | Teach one course per semester, and act as the co-advisor of 5 Ph.D. students with at least 3 successfully defending Ph.D. proposals. | %10 |
| 6 | Dissemination and exploitation of project results, such as academic publications, seminars, and patent applications | Complete all the activities given in 2.3.2, including: at least two triple-patent applications, at least one article in AGI conference, AGI seminars in at least two central Anatolian universities. | %10 |

**(\*)**The rows and columns in the schedule can be enlarged and increased.

**(\*\*)**The sum of percentages in the columns should be 100.

The success criterion describes the criteria for each WP to be considered successful. The criterion of success is indicated by quantitative or qualitative criteria (expression, number, percentage, etc.) to be measurable and monitorable.

**Table 3.2.c. Risk Management Table**

|  |  |  |
| --- | --- | --- |
| **WP No** | **Main Risks** | **Risk Management (Plan-B)** |
| 3 | Algorithms do not perform at a satisfactory level |  |
| 4 | Unable to find qualified engineers on time to implement the algorithms on AWS | To mitigate the risk, we will start looking for software engineers as soon as the project is approved by TUBITAK. |
| 5 | MR Engine fails to demonstrate the tasks identified as use cases | We will have two rounds of validation. The first one will be done at M16-18 to give a benchmark of what was accomplished. Final validation will be within the last 6 months of the project. |
| 6 | Unable to find Ph.D. students | To mitigate the risk, we will start looking for Ph.D. students as soon as the project is approved by TUBITAK. |
| 7 | Unable to get enough attention from Turkish industry | We will keep the industry aware of the project progress through newsletters. We will also seek to receive additional funding from European R&D programs to continue the project and to reach out the industry in Europe. |

The risks that can affect the success of the project negatively and the alternative plan(s) (Plan-B) that will be implemented in case of encountering with those by regarding the related work packages should be described. Implementation of Plan B should not lead to deviation from the main objectives of the project.

**DECLARATIONS**

|  |  |
| --- | --- |
| 1) The Coordinator declares to have the explicit consent of all applicants on their participation and on the content of this proposal. |  |
| 2) The Coordinator declares that the information contained in this proposal is correct and complete. |  |
| 3) The Coordinator declares that this proposal complies with ethical principles (including the highest standards of research integrity and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct). |  |

**4. ETHICAL ISSUES TABLE**

Please fill in the ethical issue table by ticking either the Yes-box or the No-box for each question. Please note that if you answer Yes to any of the questions below, you are requested to provide additional information.

|  |  |  |
| --- | --- | --- |
| Research on Humans | YES | NO |
| 1. Does your research involve human participants? |  |  |
| a. Are they volunteers for social or human science research? |  |  |
| b. Are they vulnerable individuals or groups? |  |  |
| c. Are they children/minors? |  |  |
| d. Are they patients? |  |  |
| e. Are they healthy volunteers (e.g. for medical studies)? |  |  |
| 2. Does your research involve physical interventions on the study participants? |  |  |
| a. Does it involve invasive techniques? |  |  |
| b. Does it involve collection of biological samples? |  |  |

|  |  |  |
| --- | --- | --- |
| Privacy Issues | YES | NO |
| 3. Does your research involve personal data collection and/or processing? |  |  |
| a. Does it involve the collection and/or processing of sensitive personal data (e.g. health, sexual lifestyle, ethnic, political opinion, religious or philosophical conviction)? |  |  |
| b. Does it involve processing or genetic information? |  |  |
| c. Does it involve tracking or observation of participants? |  |  |

|  |  |  |
| --- | --- | --- |
| Third Countries | YES | NO |
| 4. Does your research involve other countries? |  |  |
| 5. Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora simples, etc.)? |  |  |
| 6. Do you plan to import any material from other countries into Turkey? |  |  |
| 7. Do you plan to import any material from the Turkey to other countries? |  |  |
| 8. If your research involves low and/or lower middle-income countries, are benefits-sharing measures foreseen? |  |  |
| 9. Could the situation in the country put the individuals taking part in the research at risk? |  |  |

|  |  |  |
| --- | --- | --- |
| Environment, Health and Safety | YES | NO |
| 10. Does your research involve the use of elements that may cause harm to the environment, to animals or plants? |  |  |
| 11. Does your research deal with endangered fauna and/or flora and/or protected areas? |  |  |
| 12. Does your research involve the use of elements that may cause harm to humans, including research staff? |  |  |

|  |  |  |
| --- | --- | --- |
| Dual Use | YES | NO |
| 13. Does your research have the potential for military applications? |  |  |

|  |  |  |
| --- | --- | --- |
| Misuse | YES | NO |
| 14. Does your research have the potential for malevolent/criminal/terrorist abuse? |  |  |

|  |  |  |
| --- | --- | --- |
| Other Ethics Issues | YES | NO |
| 15. Are there any other ethics issues that should be taken into consideration? If yes, please specify: |  |  |

**Ethics Self-Assessment**

|  |
| --- |
| If your answer was *Yes* to one or more questions in the Ethical Issue Table (above), you **must** elaborate how you plan to cope with this/these issue(s). Please note down in the following field at first the **number of the question(s)** you ticked in the Ethical  Issue Table and then provide **information on how you address the mentioned ethical issue**. In addition, you can  (if applicable) refer to the corresponding page of your research proposal.  This project aims to develop a general-purpose technology, which is not in particular related to military applications. However, similar to any general-purpose technology, it can apply to wide-range of application areas, and potentially it can also be used in the defense industry. However, this should not be viewed as dual-use, because in comparison, it is not any different than building a general-purpose computer, or developing a general-purpose operating system. Since, we do not consider a general-purpose computer as dual-use technology, there is no reason to view MR Engine as a dual-use technology. |

**5. ANNEXES OF PROJECT PROPOSAL**

**ANNEX-1: REFERENCES**

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