

The Rat's Life Benchmark: Competing Cognitive Robots

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ABSTRACT

This paper describes Rat's Life: a complete cognitive robotics benchmark that was carefully designed to be easily reproducible in a research lab with limited resources. It relies on two e-puck robots, some LEGO bricks and the Webots robot simulation software. This benchmark is a survival game where two robots compete against each other for resources in an unknown maze. Like the rats in cognitive animal experimentation, the e-puck robots look for feeders which allow them to live longer than their opponent. Once a feeder is reached by a robot, the robot draws energy from it and the feeder becomes unavailable for a while. Hence, the robot has to further explore the maze, searching for other feeders while remembering the way back to the first ones. This allows them to be able to refuel easily again and again and hopefully live longer than their opponent.

Keywords

benchmark, SLAM, navigation, autonomy, vision

1. WHY WE NEED COGNITIVE ROBOTICS BENCHMARKS

1.1 Introduction

Most scientific publications in the area of robotics research face tremendous challenges: comparing the achieved result with other similar research results and hence convincing the reader of the quality of the research work. These challenges are very difficult because roboticists lack common tools allowing them to evaluate the absolute performance of their systems or compare their results with others. As a result, such publications often fail at providing verifiable results, either because the studied system is unique and difficult to replicate or they don't provide enough experimental details so that the reader could replicate the system accurately.

Nevertheless, some of these publications become the de

facto state of the art and this makes it extremely difficult to further explore these research areas, and hence to demonstrate advances in robotics research.

This matter of fact is unfortunately impairing the credibility of robotics research. A number of robotics researchers proposed to develop series of benchmarks to provide a means of evaluation and comparison of robotics research results [1, 3, 4, 9, 19].

Although a few robotics benchmarks already exist, the only robotics benchmarks that are widely known and practiced are implemented as robot competitions.

1.2 Existing Robot Competitions and Benchmarks

Several popular robot competitions are organized on a regular basis, usually once a year. The Robocup soccer [6] and FIRA [16] is a robot soccer tournament with several categories (small size league, middle size league, standard platform league, simulation league, etc.). The Robocup Rescue is based on the Urban Search And Rescue (USAR) benchmark developed by the NIST [7] where robots have to search and rescue the victims of a disaster in a urban environment. MicroMouse [11], involves wheeled robots solving a maze. The FIRST [12], Eurobot [13] and Robolympics [14] are robot competitions more focused on education than research in various disciplines (often inspired from sports). The AAI Robot Competition [15] proposes different scenarios each year during the AAI conference, but often lacks a clear performance metrics. The DARPA Grand Challenge and Urban Challenge [17] and the European Land-Robot Trial [18] focus on unmanned ground and sometimes aerial vehicles racing against each other.

Although some of these competitions clearly focus on education and are more intended to students and children rather than researchers (FIRST, Eurobot), others competitions (Robocup, FIRA, AAI) are more intended to researchers. Such competitions are useful as they can provide elements of comparison between different research results. However one of the major problem is that the rules often change across the different editions of the same competition. Hence it is difficult to compare the progress achieved over time. Also these competitions are very specific to particular problems, like Robocup is focused mostly on robot soccer and has arguably a limited interest for cognitive robotics [5]. Moreover, in most cases, and especially in the Robocup case, installing a contest setup is expensive and takes a lot of resources (many robots, robot environment setup, room,

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maintenance, controlled lighting conditions, etc.).

1.3 Going Further with Cognitive Robotics Benchmarks

Among all the benchmarks we reviewed which are mostly robot competitions, none of them provides both stable rules with advanced cognitive robotics challenges and an easy setup. This paper proposes a new robotics benchmark called "Rat's Life" that addresses a number of cognitive robotics challenges while being cheap and very easy to setup for any research lab. The aim of this benchmark is to foster advanced robotics and AI research.

Comparing to soccer playing contests (RoboCup, FIRA), the Rat's Life benchmark is more bio-inspired as it focuses on foraging and survival. Also, it is more likely to contribute to scientific advances in Learning and Self Localization And Mapping (SLAM) as mazes are initially unknown to the robots. Moreover, it allows the researchers to focus on a single agent (competing against another) rather than a whole team of agents, making the problem somehow simpler to handle. Finally, it is cheaper.

2. BENCHMARK REQUIREMENTS

In order to be useful a benchmark has to be practiced by a large number of the best researchers trying to push further the current state of the art. This can be achieved by proposing a scientifically and practically appealing series of benchmarks that will convince researchers to invest their time with these tools. Hence the Rat's Life benchmark is trying to achieve a number of objectives:

2.1 Scientifically appealing

To be scientifically interesting, a benchmark has to address a number of difficult challenges in robotics. The Rat's Life benchmark focuses on cognitive robotics and addresses advanced research topics such as image processing, learning, navigation in an unknown environment, landmark recognition, SLAM, autonomy management, game strategies, etc.

2.2 Cheap and easy to setup

The benchmark should be easily practicable by any researcher. Hence it has to be cheap and easy to setup. All the components should be easily available. The Rat's Life benchmark costs no more than EUR 2000, for two e-puck robots and many LEGO components (including a LEGO NXT unit and four LEGO distance sensors). It requires only a table to setup a LEGO maze of 114x114 cm.

2.3 Accurate

Accuracy is a very important aspect of a benchmark. The environment, robots and evaluation rules should be defined very carefully in an exhaustive manner. This way, the benchmark is accurately replicable and hence different results obtained with different instances of the setup in different research lab can be compared to each others.

2.4 Comparable

Finally, a benchmark is useful if users can compare their own results to others and thus try to improve the state of the art. Hence a benchmark should keep a data base of the solutions contributed by different researchers, including binary and source code of the robot controller programs. These different solutions should be ranked using a common

performance metrics, so that we can compare them to each other.

3. STANDARD COMPONENTS

The Rat's Life benchmark is based on three standard affordable components: the e-puck mobile robot, LEGO bricks and the Webots robot simulation software (free version).

3.1 The e-puck mobile robot

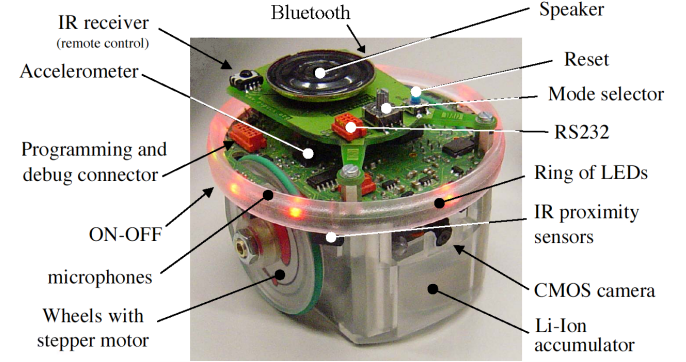


Figure 1: The e-puck robot

The e-puck mini mobile robot was originally developed at the EPFL for teaching purposes by the designers of the successful Khepera robot. The e-puck hardware and software is fully open source, providing low level access to every electronic device and offering unlimited extension possibilities. The robot is already equipped with a large number of sensors and actuators (figure 1). It is well supported by the Webots simulation software with simulation models, remote control and cross-compilation facilities. The official e-puck web site [23] gathers a large quantity of information about the robot, extension modules, software libraries, users mailing lists, etc. The robot is commercially available from Cyberbotics [21] for about EUR 570.

3.2 LEGO bricks

The LEGO bricks are used to create an environment for the e-puck robot. This environment is actually a maze which contains "feeder" devices (see next sections) as well as visual landmarks made up of patterns of colored LEGO brick in the walls of the maze (see figure 2). These landmarks are useful hints helping the robot to navigate in the maze. Since LEGO models are easily demountable, the maze is easily reconfigurable so that the users can create different instances of the maze according to the specifications of the benchmark.

All the maze, landmarks and the feeder devices are properly defined in a LEGO CAD file in LXF format using the LEGO digital designer software freely available from the LEGO factory web site [20]. The corresponding LXF files are freely available on the Rat's Life web site [10].

Thanks to the LEGO factory system, users can very easily order a box containing all the LEGO bricks necessary to build the environment of the robots.

3.3 The Webots robot simulation software

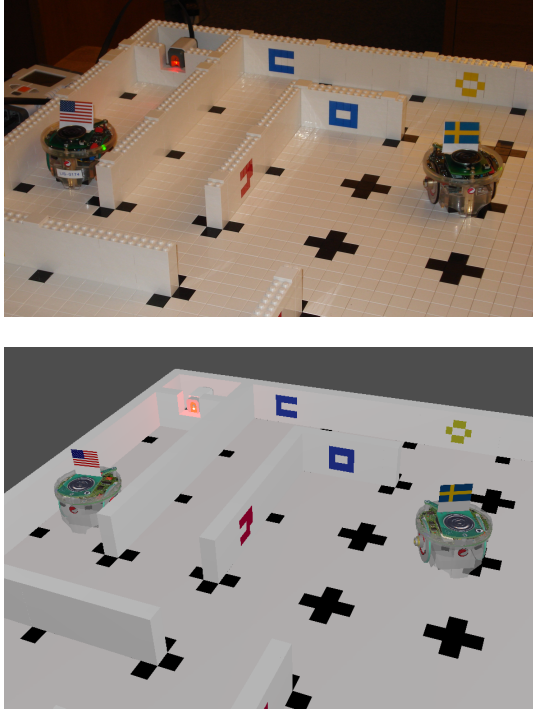


Figure 2: The Rat’s Life maze: LEGO bricks, e-puck robots and a feeder device (left) and its simulated counterpart (right)

Webots [8] is a commercial software for fast prototyping and simulation of mobile robots. It was originally developed at the Swiss Federal Institute of Technology in Lausanne (EPFL) from 1996 and has been continuously developed, documented and supported since 1998 by Cyberbotics Ltd. Over 500 universities and industrial research centers worldwide are using this software for research and educational purposes. Webots has already been used to organize robot programming contests (ALife contest and Roboka contest). Although Webots is a commercial software, a demo version is freely available from Cyberbotics’s web site [21]. This demo version includes the complete Rat’s Life simulation. So, anyone can download, install and practice the simulation of the Rat’s Life benchmark at no cost.

4. RAT’S LIFE BENCHMARK DESCRIPTION

This paper doesn’t claim to be a technical reference for the Rat’s Life benchmark. Such a technical reference is available on the Rat’s Life web site [10].

4.1 Software-only Benchmark

The Rat’s Life benchmark defines precisely all the hardware necessary to run the benchmark (including the robots and their environment). Hence the users of the benchmarks don’t have to develop any hardware. Instead, they can focus on robot control software development only. This is similar to the Robocup standard league where the robot platforms (Aibo robots) and the environment is fully defined and the competitors are limited to develop control software only. This has the disadvantage of preventing hardware research and is constraining the contest to the defined hardware only.

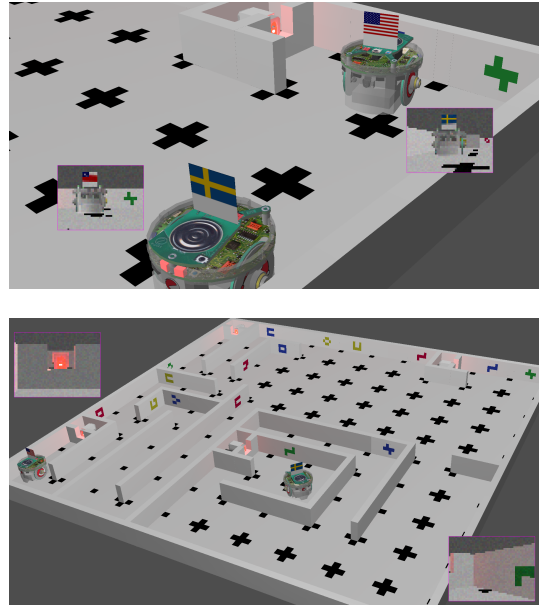


Figure 3: Closeup of the Rat’s Life simulated robots in Webots (left) and general overview (right)

However, it has the great advantage of letting the users focus on the most challenging part of cognitive robotics, i.e., the control software.

4.2 Configuration of the Maze

For each evaluation, the maze is randomly chosen among a series of 10 different configurations of the maze. In each configuration, the walls, landmarks and feeder are placed at different locations to form a different maze. Each configuration also has 10 different possible initial positions and orientations for the two robots. One of them is chosen randomly as well. This makes 100 possible initial configurations. This random configuration of the maze prevents the robots from having a prior knowledge of the maze, and forces them to discover their environment by exploring it. This yields to much more interesting robot behaviors. A possible configuration is depicted on figure 3 (right).

4.3 Virtual Ecosystem

The Rat’s Life benchmark is a competition where two e-puck robots compete against each other for resources in a LEGO maze. Resources are actually a simulation of energy sources implemented as four feeder devices. These feeder devices are depicted on figure 4. They are made up of LEGO NXT distance sensors which are controlled by a LEGO NXT control brick. They display a red light when they are full of virtual energy. The e-puck robots can see this colored light through their camera and have to move forward to enter the detection area of the distance sensor. Once the sensor detects the robot, it turns its light off to simulate the fact that the feeder is now empty. Then, the robot is credited an amount of virtual energy corresponding to the virtual energy that was stored in the feeder. This virtual energy will be consumed as the robot is functioning and could be interpreted as the metabolism of the rat robot. The feeder will remain empty (i.e., off) for a while. Hence the robot has to find another feeder with a red light on to get more

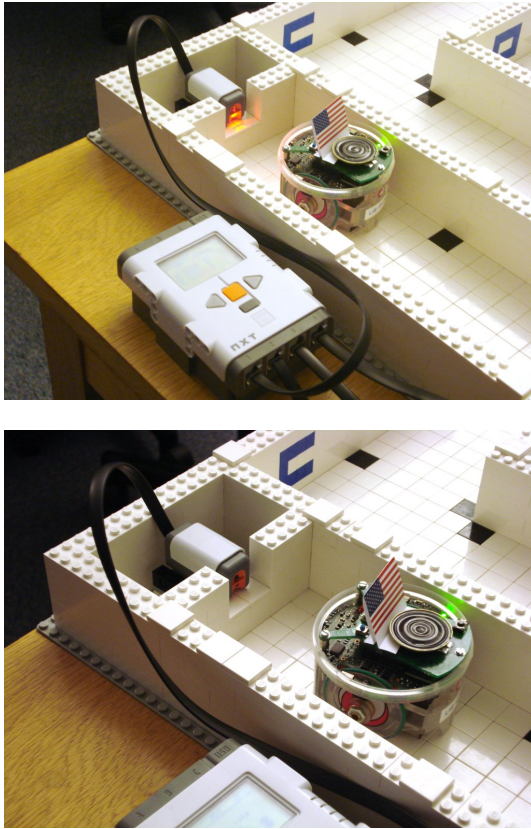


Figure 4: A full feeder facing an e-puck robot (left) and an empty one (right)

energy before its energy level reaches 0. When a robot runs out of virtual energy (i.e., its energy level reaches 0), the other robot wins.

4.3.1 Biological Comparison

This scenario is comparable to an ecosystem where the energy is produced by feeders and consumed by robots. The feeders could be seen as plants, slowly growing from the energy of the sun, water and ground and producing fruits whereas the robots could be seen as rats, foraging fruits. Since the fruits produced by a single plant are not sufficient to feed a rat, the rat has to move around to find more plants.

4.3.2 Electronics Comparison

Although the e-puck robots and feeder devices used in the Rat's contest are electronic devices, the energy is actually simulated for convenience reasons. However, it could be possible to deal with real electrical energy: the feeder would correspond to photovoltaic solar docking stations accumulating electrical energy over time and the robots could recharge their actual battery from these stations. However, such a system would be more complex to setup from a practical and technological point of view. This is why we decided to use virtual energy instead.

4.4 Robotics and AI Challenges

Solving this benchmark in an efficient way requires the following cognitive capabilities:

- Recognize a feeder (especially a full one) from a camera

image.

- Navigate to the feeder and dock to it to grab energy.
- Navigate randomly in the maze while avoiding to get stuck.
- Remember the path to a previously found feeder and get back to it.
- Optimize energy management.
- Try to prevent the other robot from getting energy.

This translates into a number of control software techniques, namely image processing, motor control, odometry, landmark based navigation, SLAM, autonomy management, game theory. Most of these techniques are still open research areas where new progress will benefit directly to robotics and AI applications. Both bio-inspired (neural networks, generic algorithms, learning) and traditional approaches (control theory, environment mapping) are concerned as no assumption is made on the technologies used to implement the controllers. Moreover, because of its similarities with experiments with rodents, the Rat's Life contest may be a very interesting benchmark for testing different bio-inspired models, such as place cells, grid cells, spatial learning, conditioning, etc.

The best robots are expected to be able to somehow fully memorize the maze they explore with the help of the landmarks, to rapidly find their way to the feeders, to maintain an estimation of the status of every feeder and to develop a strategy to prevent the opponent from recharging.

4.5 Online Contest

4.5.1 Real World and Simulation

The Rat's Life contest is defined both as a real environment and a simulation. However, the same control programs, written in C or Java programming language, can run on both the simulation and the real robots. To run the control program on the real robots, there are actually two options. The user can either execute the controller program on a computer remote controlling the robot or cross-compile it and execute it on the real robot. In the first case, the program running on the computer remote controls the real robot by reading the sensor values from and sending the motor commands to the Bluetooth connection with the robot. In the second case, the control program is executed directly on the real robot. All the necessary software tools for remote control and cross-compilation are integrated within the Webots software, making the transfer from the simulation to the real robot a very easy process. This way, the same controller program can control both the real and the simulated robot.

4.5.2 Participation to the Contest

In order to participate in the online contest, the competitors can download the free version of Webots from Cyberbotics' web site [21]. They can program the simulated e-puck robots to perform in the simulated maze. Then, they have to register a contestant account on the contest's web site [10]. Once open, this account allows the competitors to upload the controller programs they developed with the free version of Webots. Participation to the contest is totally free of charge.

4.5.3 Ranking System

Every business day (i.e., Monday to Friday) at 12 PM (GMT) a competition round is started in simulation and can be watched online from the Rat's Life web site [10]. A hall of fame displays a table of all the competitors registered in the data base and who submitted a robot controller program. If there are N competitors in the hall of fame, then $N - 1$ matches are played. The first match of a round opposes the last entry, i.e., number N at the bottom of the hall of fame, to the last but one entry, i.e., number $N - 1$. If the robot number N wins, then the position of these two robots in the hall of fame are switched. Otherwise no change occurs in the hall of fame. This procedure is repeated with the new robot number $N - 1$ (which may have recently changed due to the result of the match) and robot number $N - 2$. If robot number $N - 1$ wins, then it switches its position with robot number $N - 2$, otherwise nothing occurs. This is repeated with robots number $N - 3$, $N - 4$, etc. until robots number 2 and 1, thus totaling a number of $N - 1$ matches.

This ranking algorithm is similar to the bubble sort. It makes it possible for a newcomer appearing initially at the bottom of the ranking, to progress until the top of the ranking in one round. However, any existing entry cannot loose more than one position in the ranking during one round. This prevents a rapid elimination of a good competitor (which could have been caused by a buggy update of the controller program for example).

4.5.4 And The Winner Is...

The contest is open for a fixed period of time. During this period of time, new contestants can register and enter the contest. The contestants can submit new versions of their controller program any time until the closing date. Once the closing date is reached, new entry and submissions of new versions are disabled. Then, seven final rounds are run. The final ranking for each competitor is computed as the average ranking over these seven final rounds. The competitor ranked at the top position is declared to be the "winner of the simulated Rat's Life benchmark" and its authors receive a prize for this: a Webots PRO pack. Moreover the top 3 competitors are selected for a real world series of 3 rounds (i.e., 6 matches). The winner of these real world rounds is declared to be the "winner of the real world Rat's Life benchmark" and receives a prize: an e-puck robot.

The real world rounds should however occur during an international conferences or robotics competition to ensure that a large number of people, including a scientific committee, attends the event and can check that nobody is cheating the benchmark.

The contest will run continuously over years so that we can measure the progress and performances of the robot controllers over a fairly long period of robotics and AI research.

5. EVOLUTION OF THE COMPETITION OVER TIME

5.1 Movie Database

Observing the evolution of the competition over days was very interesting and we decided to store all the simulation movies in a data base to be able to analyse this evolution afterwards. The movie database contains more than 2500 movies (totalling more than 50 GB of data) and is freely

available online at <http://www.cyberbotics.com/ratslife/movies/>.

5.2 Participation to the Contest

The competition started on January 7th, 2008 with one, then two competitors. Table 1 summarizes the evolution of the participation to the contest over time.

Table 1: Evolution of the participation to the Rat's Life contest

Date	Number of Competitors
January 31 st	6
February 29 th	15
March 31 st	23
April 30 th	26
May 31 st	36
June 30 th	to be completed

5.3 Evolution of Behaviors

The behavior of the robot controllers evolves in a similar fashion as a genetic algorithm. Competitors are uploading new versions of their robot controller fairly frequently. Sometimes, a new version brings a significant performance breakthrough and drives the competitors' robot on the top of the hall of fame. This performance breakthrough is then immediately analysed by the other competitors seeing the simulation movies. They take inspiration from it to improve their own robot controller and submit their new improved version to the contest. Rapidly, a large number of competitors can replicate this winning behavior on their robot and most of the robots in the contest adopt this new efficient behavior. This co-evolution dynamics is similar to what happens in genetic algorithm where the behavior of efficient individuals spreads rapidly across the population. If we could plot a fitness function over time, such breakthroughs would correspond to sudden increase of the fitness value making steps in the evolutionary process.

5.4 Major breakthroughs

During the contest, several major performance breakthroughs could be observed simply by analysing the behavior of the robots in the simulation movies. One could identify five major breakthroughs which happened chronologically one after the other, bringing each time an improved performance:

5.4.1 Random Walkers

The random walkers came actually from the very first version of the sample source code included with the contest software development kit, made available to all the competitors. This simple control algorithm similar to Braitenberg vehicles [2] let the robots move randomly while avoiding the obstacles. By chance some of them met a feeder from time time, but this behavior is very inefficient and rely mostly on luck. Also, this very first version was not very efficient at navigating and often caused the robot to get stuck in some unexpected situations, like facing a corner.

5.4.2 Vision-Enabled Random Walkers




Last round completed Jun-05-2008 - 37 active competitors out of 139								
Rank	Country	Flag	Rat's name	Author	Ready	Last update	Progress	Movies
1			Ratatouille	Manuel	✓	Jun-05-2008 23:50	-	
2			golum	Laurent	✓	Jun-03-2008 13:25	+2	
3			Krysicka	Martin Pilat	✓	May-06-2008 12:26	-1	
4			AMT	Ares Macrotechnology	✓	May-24-2008 20:08	-1	
5			Bins.GPR	Ricardo Luis Binsfeld	✓	Apr-17-2008 17:05	-	
6			Ratchou	Xavier	✓	Jun-03-2008 21:01	+3	
7			muchachada wii	muchachada wii	✓	May-31-2008 13:35	-1	
8			Tony	Anthony Morse	✓	Jun-05-2008 16:02	-1	
9			Wayne	Wayne	✓	Jun-03-2008 01:51	-1	
10			Comstar	Comstar	✓	May-03-2008 19:38	+1	
11			hinchotamus	His Robotamus	✓	Mar-30-2008	-1	

Figure 5: Rat's Life Hall Of Fame, on June 6th, 2008

The so called vision-enabled random walkers are an improved version of the original random walker making an extensive use of vision to recognize the feeders and adjust the trajectory of the robot to reach the feeder instead of simply moving randomly. This results in slightly more efficient robots who won't pass in front of a feeder without getting energy from it. A vision-enabled random walker is included in the sample code currently distributed to the competitors. This sample version has however been largely improved by different competitors over time.

5.4.3 Right Hand Explorers

One of the problems with the random walkers is that a Braitenberg vehicle behavior is not very efficient at exploring extensively a maze and hence at finding the feeders. Maze exploration algorithms exist and are much more efficient. The right hand algorithm is one of the simplest and best known maze exploration algorithms. It consists in simply following the first wall found on the right hand side of the robot (this also works with the left hand side of course). Using this algorithm combined with some vision to reach efficiently the feeders, a significant performance breakthrough was reached. The first right hand explorer appeared on February 22nd, with a robot named Tony (which reached rank #1 of the hall of fame on February 22th very rapidly) and was rapidly copied by many other competitors as this behavior is both easy to understand and to re-program.

5.4.4 Energy-aware robots

Getting the energy from the feeder as soon as you find the feeder is nice, but there is an even better strategy: Once a robot finds a feeder, it can simply stop and sit in front of the feeder, thus preventing the other robot from reaching this feeder. In the meanwhile the robot sitting in front of the feeder should watch its energy level and decide to move to the feeder once its energy level reached a very low value, just enough to make that move to the feeder and refuel. During this waiting time, the other robot may be struggling to find a feeder and possibly loose the game if it runs out of energy. This kind of energy-aware robots appeared on February 28th, with a robot named Ratchou (which reached rank #1 thanks to this breakthrough). Similarly to the right hand explorer, it was rapidly copied by other competitors as it was easy to understand and to re-program as well.

5.4.5 SLAMers

SLAM stands for Self Localization And Mapping. Comparing to other techniques mentioned above, it involves a much more complicated algorithm and requires an efficient image processing. SLAMer robots actually seems to use the right hand algorithm on a first stage to explore extensively the maze, but they build dynamically a map of this maze while exploring it and eventually don't use the right hand algorithm at all. Their internal representation of the environment contains the walls, the feeders and likely the landmarks. This map is then used by the robot to get back to previously found feeders. It turned out to be very efficient and clearly outperformed the simpler reactive controllers. The first SLAMer robot is Ratatouille who implemented a first version of visual SLAM-based navigation on April 6th and reach rank #1. This first version was however probably not well tuned (or somehow buggy) and it happened to loose in rare occasions against lucky and efficient right-hand explorers. However, the author of Ratatouille continued to improve the performance of his SLAMer robot and finally sat steadily on the very top of the hall of fame for more than two months. The other competitors, including Tony among others, tried hard to implement such an efficient SLAM-based navigation controller, they were not very successful until June 5th. At this point a competitor with a robot controller named gollum developed a pretty efficient SLAMer robot able to challenge Ratatouille. Golum reached rank #2 on June 5th and had a really disputed and very interesting match against Ratatouille, but was not successful.
(to be continued)

5.4.6 Super-SLAMers

The author of Ratatouille actually never stopped from April 6th to improve his SLAM-based robot controller. A major improvement was probably the estimation of the status of the feeders, combined with an estimation of the time needed to travel the maze to reach the feeder. From the most recent simulation movies, Ratatouille seems to be able to anticipate that a mapped feeder will become available again: when the feeder is still red, Ratatouille starts to navigate towards this feeder and about one second before it reaches the feeder, the feeder becomes green again. This makes Ratatouille the most efficient robot controller currently on the Rat's Life benchmark (see figure 5). At this point, it is difficult to imagine a better behavior than the one exhibited by Ratatouille.

6. TRANSFER TO THE REAL WORLD

At the time of writing, the competition occurred only in simulation. We plan to run a series of rounds in the real world, using the same robot controller as the ones used in simulation for the top three robots. We are currently working to fix wireless communication speed issues to allow a reliable and real time remote control of real robots allowing to test the best Rat's Life controllers in the real world. We believe that some calibrations of the sensors, motors and image processing algorithms might be necessary to be able to transfer the best control algorithms from the simulation to the real world. This issue will be discussed in an upcoming publication.

7. CONCLUSION

Thanks to the Rat's Life benchmark, it becomes possible to evaluate the performance of various approaches to robot control for navigation in an unknown environment, including various SLAM and bio-inspired models. The performance evaluation allows us to make a ranking between the different control programs submitted, but also to compare the progresses achieved over a short period of time of research on this problem. However, this period of time could be extended and we could, for example, compare the top 5 controller programs developed in 2008 to the top 5 controller programs developed in 2012 to evaluate how much the state of the art progressed.

The control program resulting from the best robot controllers could be adapted to real world robotics applications in the areas of surveillance, mobile manipulators, UAV, cleaning, toys, etc. Also, interesting scientific comparisons with biological intelligence could be drawn by opposing the best robot controllers to a real rat (or a rat-controlled robot) in a similar problem. Similarly, we could also oppose the best robot controllers to a human (possibly a child) remote controlling the robot with a joystick and with limited sensory information coming only from the robot sensors (mainly the camera).

We hope that this initiative is a step towards a more general usage of benchmarks in robotics research. By its modest requirements, simplicity, but nevertheless interesting challenges it proposes, the Rat's Life benchmark has the potential to become a successful reference benchmark in cognitive robotics and hence open the doors to more complex and advanced series of cognitive robotics benchmarks.

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- [14] ROBOlympics. <http://www.robotlympics.net>
- [15] AAAI Robot Competition and exhibition. <http://palantir.cs.colby.edu/aaai07>
- [16] The Federation of International Robot-soccer Association (FIRA). <http://www.fira.net>
- [17] DARPA Grand Challenge. <http://www.darpa.mil/grandchallenge>
- [18] European Land-Robot Trial ELROB. <http://www.elrob.org/>
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