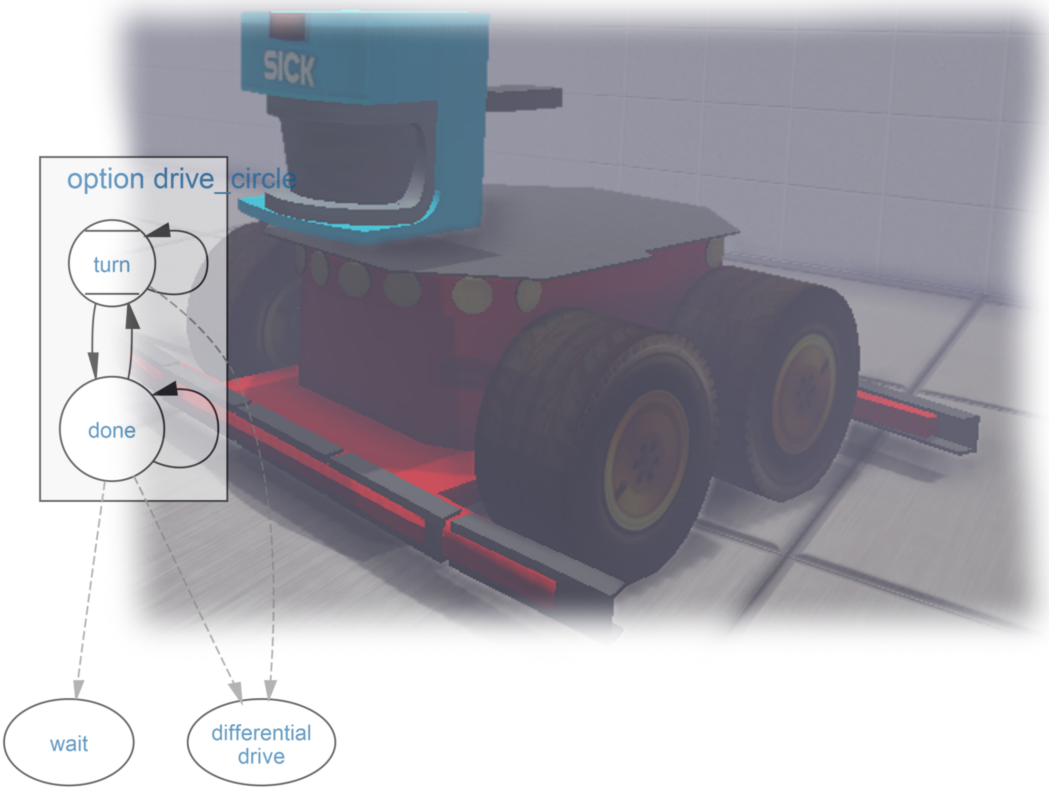
Combining Robocup Rescue and XABSL

Maarten P. de Waard



UNIVERSITEIT VAN AMSTERDAM

Bachelor project: Final Thesis

Combining Robocup Rescue and XABSL

Maarten P. de Waard
5894883

Bachelor thesis
Credits: 6 EC

Bsc. Artificial Intelligence

University of Amsterdam
Faculty of Science
Science Park 904
1098 XH Amsterdam

Supervisor
dr. A. Visser

Informatics Institute
Faculty of Science
University of Amsterdam
Science Park 904
1098 XH Amsterdam

June 26th, 2012

Abstract

In this research, a product will be introduced, that combines the Extensible Agent Behavior Specification Language (XABSL) with any program, capable of having a socket connection. A use of this product is shown, by combining it to the rescue project on the University of Amsterdam, using *UsarCommander*, a program designed to control one or more robots, in a virtual rescue operation.

1 Introduction

The research will be focussing on combining the *Extensible Agent Behavior Specification Language* (XABSL) with any program capable of making a socket connection. In particular, the focus will lay on virtual rescue operations, otherwise known as the *RoboCup Rescue League*. Using a behavior specification language will make it possible to separate specification of behaviors from implementation.

Currently, the focus of research in the rescue missions is mainly on creating smart implementations of sensors. Much of the actual controlling of robots is done by hand, using programs that forward the camera images of the robots to a human operator controlling them. Some of these operators use simple behaviors to help them, like for example making the robot automatically traverse a path to a specified point. This kind of simple task can be called a behavior.

An improvement that can be made in these behavior controlled robots, is in the specification of which behavior should be selected in a certain situation and how the behavior is executed. This can be done by creating behavior-controlled robots, that can autonomously select the best behavior to activate on a certain moment, and using their sensors as input, can choose the right way to navigate.

This research will make use of XABSL, a behavior specification language, which makes it possible to separate the specification of a behavior, from the implementation.

Currently, not many behavior-controlled exploration algorithms exist. An exception is path finding on challenging terrain [7] . This research will result in a method to easily adjust and improve the behavior of any robot in any robot commanding program, especially focussing on UsarCommander, the program used by the UvA Rescue team[1].

There has however been research in Behavior Based Artificial Intelligence since 1986.

2 Behavior Based Artificial Intelligence

This was first researched by brooks [3], who laid the foundations of looking at intelligence in different layers. Brooks proposed that the following four elements were key requirements in a robot controlling system:

1. **Multiple goals:** A robot should be able to chase multiple goals at the same time, for example reaching a place in minimal time, while conserving power reserves. There should be an ability to prioritize goals, so that dangerous situations can be evaded while the main goals are still executed when the robot is able to. A simple example is being able to evade obstacles while reaching the place it wants to reach.

2. **Multiple sensors:** Most robots have more than one sensor, each having its own error measure. Some sensors have a bigger error in certain situations then others. For example while traversing inside a building, a robot should not be trusting its GPS sensor (Global Positioning Satelite), while being outside this would be a good option. A robot should be able to cope with these different errors, and use the right sensors at the right time with the right amount of trust.

3. **Robustness:** A robot's artificial intelligence should be robust. This means that when certain sensors fail, or unexpected deviations from it's normal environment occur (for example when a robot meant for inside-use comes outside a building, where there are less walls, but more small obstacles), the robot should still be able to act in a sensible way, in stead of just stop and stay still, or act randomly.

[1] Team description and more at: http://www.jointrescueforces.eu/wiki/tiki-index.php

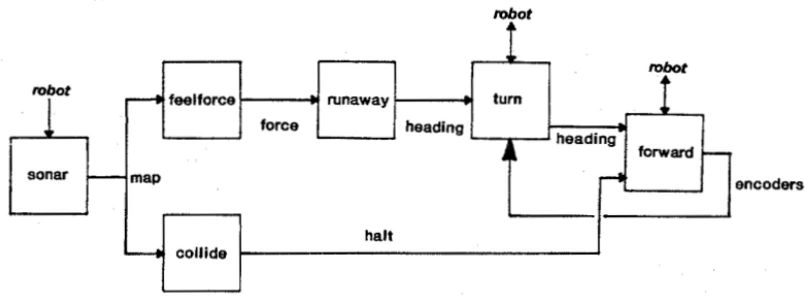


Figure 1: A level 0 control system, as proposed by Brooks

4. **Extensibility:** Brooks only speaks of being able to enlarge the processing power of the robot, when more sensors are loaded on the robot. I would like to add to this, that the intelligent system should have some kind of modularity in its software, making extending the system to work with a new kind of sensor, or even a totally different robot or environment (for example virtual vs the real world) easy, without having to rewrite big parts of code, or search through the program to find where a sensor should be added and where the activation of the sensor occurs, etc.

Brooks explains that typically, robot intelligences slice problems up in the following order: Sense, map sensor data in a world representation, plan, execute task and at last: control motors to do so. He then offers a new implementation of problem-decomposing, in the following order, and calls these 'Levels of competence'

0. "Avoid contact with objects (whether the objects move or are stationary)."
1. "Wander aimlessly around without hitting things."
2. "'Explore' the world by seeing places in the distance that look reachable and heading for them."
3. "Build a map of the environment and plan routes from one place to another."
4. "Notice changes in the 'static' environment."
5. "Reason about the world in terms of identifiable objects and perform tasks related to certain objects."
6. "Formulate and execute plans that involve changing the state of the world in some desirable way."
7. "Reason about the behavior of objects in the world and modify plans accordingly."

Each level of competence adds complexity to the entire system, thereby creating a layered implementation of behavior in an (in that time) untraditional way. Brooks proposes that each of these layers can be implemented in a finite state automaton, resulting in figure 2 as a representation for the zeroth level, and, by augmenting this with an FSA for level one and two, in figure 2.

In the level 0 representation, the robot will 'run away' when it is standing still and a moving object closes in. Alternatively, it will halt when a probable collision is detected. This is enough for simple obstacle avoidance.

This representation is augmented by inserting the avoidance and wander states above it parallel to the runaway state, in figure 2, This results in level 1 behavior: a robot capable of wandering around aimlessly, without hitting any objects. The direction outputted by the level 0 FSA is, when possible, overridden by the direction of the level 1 output.

As can be seen, this method a very large FSA, when we add the second level of control. This has the advantage of being capable of more complex behavior, in this case exploring an area, thus no more simply wandering around, but reaching places it has not yet explored. A disadvantage of this method, however, is that these big FSA's are quite complex to understand Adding more and more complexity to the system results in bigger and bigger images, resulting in more representation complexity and, in the worst case, in a system that only the creator can understand fully, but cannot anymore be

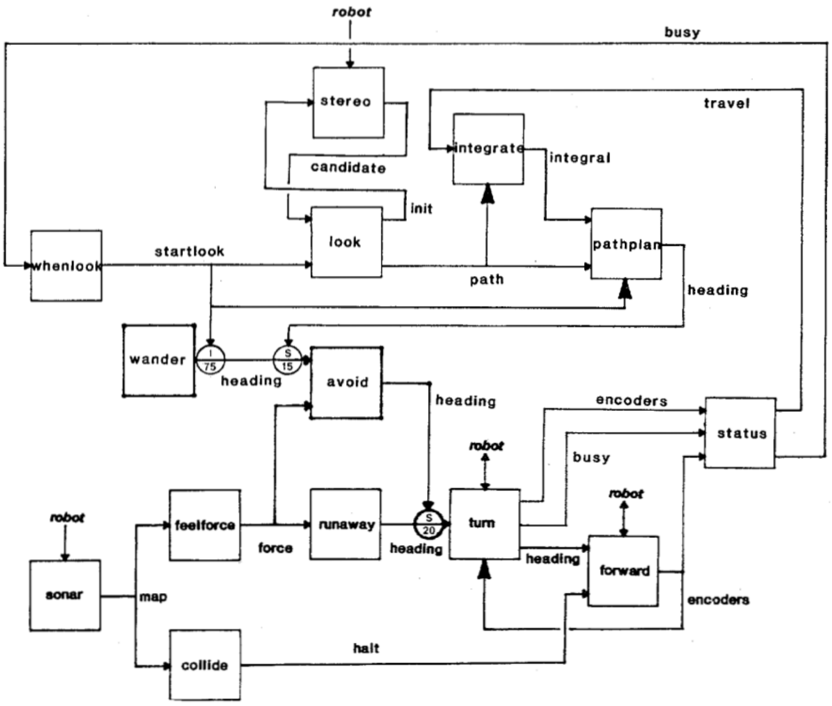


Figure 2: A level 2 control system, as proposed by Brooks

represented in a clear way. Of course it needs to be considered that this system was created in 1986, when computers were many times slower and capabilities were limited. Brooks managed to get the level 2 version working on a real robot in the time, by distributing the system over many cores.

This is the main advantage Brooks proposes, of this kind of implementation: The processes needed for the in- and output of the states, can be done with the least possible interaction between processes, making Brooks able to distribute the implementation over different processors and thereby able to run this, for that time, complex program.

Nowadays, this implementation is a bit outdated, mainly because of the complex structure of the representation. The behavior based approach, however, has been used in several solutions to controlling robots. These solutions will be discussed in the following section.

3 BBAI Implementations and Alternatives

This section will cover most of the BBAI implementations that can be chosen from when deciding to create an application that should be capable of specifying a Behavior Based artificial intelligence.

3.1 XABSL

One of the implementations of behavior based software is *XABSL*: a programming language, created to easily describe behaviors for autonomous agents based on hierarchical finite state machines [**?**]. It is the software that has been used by the German robotic soccer team to specify their robots' behaviors. The team won in 2008, and the years after that.

The language is used to specify a finite state automaton hierarchy. This means that the user defines several finite state automata, which can activate each other. Each state makes decisions on certain variables, and as an output activate another state or another FSA. The hierarchies are built up from the following components:

A XABSL-specification is built up from the following components:

- **Agents:** A rooted acyclic graph, containing all the behaviors for one agent. Several of these agents can be created, all having their own graph and thus their own behavior.

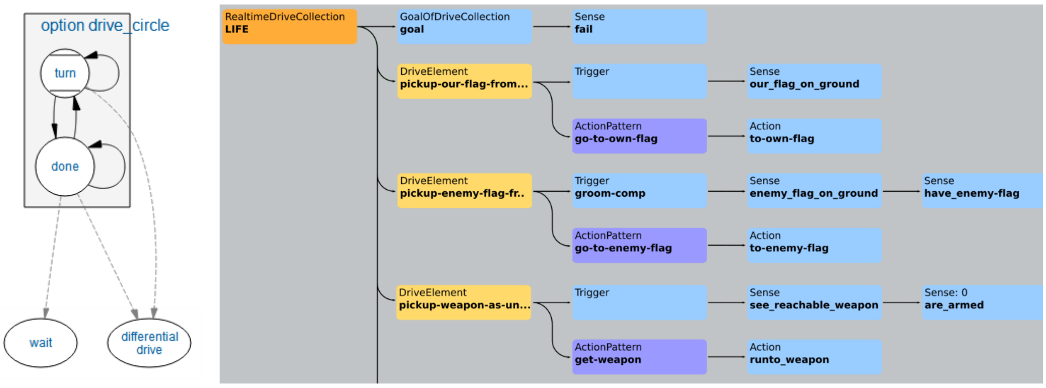


Figure 3: Left: An example of a figure generated by the XABSL compiler, from XABSL code. Right: a POSH hierarchy

- **Options:** Complex agent behavior. Each option is on itself a finite state machine, containing several states. When creating an agent, the start option can be specified, which makes the user able to create different agents from one Option hierarchy. Options can also have parameters, enabling an option to have different outputs for different agents. Figure 3.1 contains an example of a simple option, that makes the agent turn 360 degrees and then stop and wait for a certain amount of time.

- **States:** Options are bounded to each other by states, each state has a decision tree, and an action. The decision tree decides whether to stay at this state, or to go to another state. These decisions are based on variables that can either be internal, or inputs.

  When a decision tree decides to stay at its current state, an action is performed. Actions can be activation of a basic behavior, or of another option. Several actions per state are permitted.

- **Basic behavior:** At every leaf of an option (so, every state with no other states to reference to) a basic behavior is activated. This is a small piece of native code (C++ or Java), that influences the actions of the agent in its world.

This is an improvement over Brooks' BBAI, because the FSA's are now no longer directly connected to each other through state connections, but are connected via the actions of certain states, in that way improving the comprehensibility of the representation, thereby also improving the modularity of the system, because modules can be better recognized and then expanded.

By using basic behaviors, that can be written in C++ or Java, XABSL also enables distribution of the system: Each basic behavior can run its own module. This way basic behavior can be a module that simply makes a robot move, but also a module that finds a ball in a soccer field, using libraries like OpenCV. This makes a XABSL application capable of the same things as any native C++ or Java application, which is almost everything one or more computers can do.

Section **??** will explain more clearly the advantages of XABSL, and the possibilities of agents, options, states and basic behaviors.

3.2 POSH

POSH [2] is a very similar alternative implementation of a Behavior Specification Language. Posh is defined as a *Behavior Oriented Design*, which is a combination of *Object Oriented Design* (OOD, used by object oriented programming languages like Java and C++) and *Behavior Based Artificial Intelligence* (BBAI).

From OOD the language takes the object hierarchy that it is known for. In object oriented languages a person is capable of creating an object based on another object. These can be *Abstract classes*, or *Interface classes*. When using an abstract class to define an object, this means the class can be extended by another object: The new object automatically has all the properties its *Base class* (the original, abstract, class) has, but can override some of them, or add new ones. An interface class can define what its subclass should have, for example when an interface class specifies a method that searches for a doorway, using laser sensors, its subclass should implement this method. The interface class itself does not have any actual implementations. BOD objects are literally built in an object oriented language, thereby having all its advantages

The BBAI-part of it is the decomposition of intelligence as subtasks called *acts*. Examples of acts are knowing your position and planning a route. There is no implementation of prioritizing certain acts above others, other than that they come earlier in the POSH diagram.

Behaviors in BOD are thus specified as a *Behavior object*, written in an Object Oriented language. They are split up in actuators and senses. The actuators are used to act on the world, for example move in a certain direction, or pick something up, whereas the senses are used to inform the planner the current context. Context can be any piece of information about the world, or the agents internal state. The whereabouts of an object, or the data from a laser scanner can be context, but the agents current battery level is also context.. All the specified behaviors together form the *Behavior Library*, which can be used by the action planning system to select the right behavior on the right time.

Furthermore POSH uses three aggregates: simple sequences, competences and drive collections.

1. **Simple sequences:** The sequence is simply a sequence in which order a diagram should be traversed

2. **Competences:** A competence is a prioritised set of condition-action pairs. These condition-action pairs are based on the current context (described above). Because of the hierarchical structure of the system, only small pieces of context have to be processed at a time. When a certain part of competence is reached, competences have been passed higher up in the hierarchy, meaning that this information needs no more checking. In this part there is assumed that in the time it took to traverse the tree, the world has not changed significantly.

3. **Drive Collections:** The drive collection is a special competence, that is executed before each program cycle. The collection contains all vital condition-action pairs to be able to survive. For example when an enemy is close (given that the environment has enemies that can seriously harm the agent), the agent should hide from the enemy, or take other actions not to get harmed. The drive collection can also contain routines that have to be executed every once in a while, like checking the environment for safety

This is actually quite similar to XABSL, because selects actions based on decisions based on its findings. The actions are always executed by an external program. There are some important differences though:

- POSH is designed to be used by non-programmers. This means the interface is easy, colorful and simple, whereas XABSL prioritizes complex capabilities, ignoring the fact that non-programmers then couldn't use it. This improves the adaptability of XABSL far above the capabilities of POSH, resulting in ability to create more complex behaviors.

- Where XABSL has a close coupling with the perception stream of the robot, POSH has no variable management, enabling the system to be a lot easier to use, but also maximizing the complexity of the specified behaviors to a lower maximum than XABSL offers.

3.3 Petri Net Plans

Another possible method to represent robot behavior as plans, is by using *Petri Net Plans* (PNP), a language based on *Petri Nets* (Also known as Place/Transition Nets or P/T Nets).

A Petri net is a mathematical modelling language, making it an alternative to the use of Finite State Automata. The formal definition of a *net*, as given in [4], is the following:

"A *net* N is a triple (S, T, F), where S and T are two disjoint, finite sets, and F is a relation on $S \cup T$ such that $F \cap (S \times S) = F \cap (T \times T) = \emptyset$."

In this definition, the elements of S and T are respectively called *places* and *transitions*. The elements of F are called *arcs*. A transition t can be made, when a marking M marks all of its input places. If t is enabled at M, it will occur, and thus lead to the successor of marking M, which we call M'. This is denoted by $M \xrightarrow{t} M'$.

A *Petri Net* is a pair (N, M_0), with N representing a net, and M_0 representing the *initial* marking of N, which means that M_0 is the first marking of N. A sequence of transitions that enables the graph to go from marking M_0 to M_n, is called a *finite occurrence sequence*. Infinite occurrence sequences are possible too, when there is no clear end marking, but transitions keep on happening. If a state is reached where transitions can no longer occur, this is not called an infinite occurrence sequence.

The main advantage of Petri Nets, is that due to their definition, they are very analyzable. Three attributes exist, on which analysis can be done more easily than most comparable mathematical models.

1. **Reachability:** For most graphs it is hard to exactly calculate if every node in the graph can possibly be reached. For petri nets, it is possible to calculate this automatically, and with great certainty. An algorithm for this calculation is given in [6].

2. **Liveness:** Degrees of liveness can be assigned to Petri Nets. Loosely speaking, a petri net is live when every transition can always occur again. More precisely, the following *levels* of liveness are possible[2]:

    - $dead$: It can never fire, i.e. it is not in any firing sequence in $L(N, M_0)$
    - $L_1 - live$: (potentially fireable) if and only if it may fire, i.e. it is in some firing sequences in $L(N, M_0)$.
    - $L_2 - live$: if and only if it can fire arbitrarily often, i.e. if for every positive integer k, it occurs at least k times in some firing sequence in $L(N, M_0)$.
    - $L_3 - live$: if and only if it can fire infinitely often, i.e. if for every positive integer k, it occurs at least k times in V, for some prefix-closed set of firing sequences $V \subseteq L(N, M_0)$
    - $L_4 - live$ (live) if and only if it may always fire, i.e. it is L_1-live in every reachable marking in $R(N, M_0)$.

3. **Boundedness:** A petri net is *bounded* if its set of reachable markings is finite. For petri nets, it has been shown that this is also decidable, because an unbounded Petri net, is easily characterized in the following matter:

    An unbounded petri net is characterized by a reachable marking M, and a sequence of transitions σ, so that $M \xrightarrow{t} M + L$, where L is some non-zero marking and the sum of these markings is defined place-wise. The sequence σ can be called a *token generator* when it, starting at M leads to $M + L$. This generator makes the petri net unbounded.

For this section, it is extra important to know that Petri Nets have the ability of forking and joining their tokens. This means that from one state, two tokens can be output, going to two different states. On the other hand two tokens from different states can be asked as input for one state, making the state wait for output from both input transitions, before continuing by outputting one token of itself, in the next marking.

Petri net plans [9], is a language using these petri nets, to create special *plans*. Because of the petri nets fork and join abilities, Petri Net Plans is explicitly suitable for controlling several robots. The clear advantage of this approach, is that there is only one petri net plan needed, to control all the robots in the field, whereas most other methods have one plan per agent.

An example of a petri net plan can be seen in figure 3.3. It can be seen that the h_sync method is used to halt the robots until both have synced, and only then continue to the next state.

Other advantages of Petri Net Plans are closely related to the advantages of Petri Nets above Finite State Automata. A consideration has be done though: It is harder to specify a completely sufficient petri net plan, than to specify several simple Finite State Automata.

[2] From wikipedia

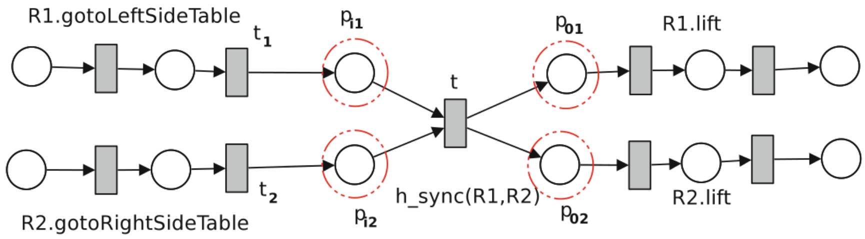


Figure 4: A petri net describing the actions of two robots, for a simple task execution. The robots use h_sync to synchronize. Due to the join capabilities of a petri net, none of the robots will continue to state p_{0n} before the sync is done.

```
act patrol2{int a}
    start:
        while(a != 0)
        {
            a = a-1;
            Turnto(180);
            Move(1000);
            Turnto(0);
            Move(1000);
        }
        succeed;
    onInterrupt:
        waitfor(sfDonePosition());
        suspend;
    onResume:
        a = a+1;
        goto start;
```

Figure 5: A simple specification of a patrolling behavior in COLBERT

3.4 COLBERT

COLBERT is a programming language using the Saphira Architecture. The abstract of [5] states that: “The design criteria for Colbert are:”

1. “To have a simple language with standard iterative, sequential and conditional constructs.”
2. “To have a clear and understandable semantics based on FSAs.”
3. “To have a debugging environment in which the user can check the state of the system and redefine Colbert activities.”
4. “To have an small, fast, and portable executive.”

The main advantage of COLBERT is that it is small and fast. And as we all know: quick reflexes are important in a dangerous world, so having small and fast behavior based AI has it advantages. COLBERT is based on a subset of ANSI C and it is even possible to compile it to native C code, to make the program even easier to run.

Figure 3.4 shows a small sample of specification in the COLBERT language.

These are the main alternatives. There are others, like using constraint logic, with aid of If-then-else statements directly in the main program. One can also use machine learning techniques, for example *Reincorcement Learning* methods are used by *Sarsa* and *Q-learning*. This is, however a complete different way of looking at the problem, with its own set of results, which are not comparable to the ones reachable with human-specified behaviors, because the current learning techniques are not yet sufficient.

4 Language of choice

In this research, of the above specified languages, XABSL has been chosen. There are a few advantages of XABSL above the others, but also a few disadvantages. The following part will discuss why XABSL is, in this case, a better choice than de aforementioned alternatives. Then, this section will explain more about how XABSL hierarchies are specified, and how they are combined with other programs, traditionally.

4.1 Advantages of Using XABSL

The first thing that needs to be considered when choosing a behavior specification type and language, is what characteristics are the most important. Here is a list of things that the ideal behavior specification language for multiple robot control should have.

- The points mentioned by Brooks:
  - *Multiple goals*
  - *Multiple sensors*
  - *Robustness*
  - *Extensibility*
- **Modularity:** It should be possible to build up a specification in small pieces, thereby keeping track of what is specified where, and not getting entangled in pages of code, of which no body remembers the function
- **Documentation:** Most programs, especially the ones used in the RoboCup, are not only used by one person. For a team to be able to work on a project together, it is good to easily understand the work somebody else has done. This is achieved by keeping documentation in your code, but it is achieved even more by documentations on websites or in other documents, that can be consulted without having to actually dig into the code.

All of the mentioned possibilities enable having **multiple goals**. POSH has the possibility of adding the set of extra important goals, which the others do not, but POSH has too many disadvantages in relation to XABSL to make this point count.

Of all the possibilities discussed, XABSL has the clearest solution for dealing with **Multiple sensors**. XABSL has input variables, which, together, are a world representation that is constantly updated by the Engine, that runs the decision-making program. Petri Net Plans has of course the added possibility of keeping track of several robots at the same time, in the same graph. This could be seen as an advantage above XABSL, but since XABSL offers us the possibility of adding extra variables from the running program, the relevant information about other robots could also be added to the reasoning engine via that method.

Robustness is the ability of functioning in another setting than usual. A lot of the robustness of a robots behavior is not in the language in which it is specified, but mainly in the specification itself. A way to force programs to be at least a bit robust, is by error-checking the specified behaviors before running the program. This can be done very easily in PNP, because Petri Nets have so many algorithms for complete checking of reachability, liveness and boundedness. XABSL however also offers a compiler that compiles your code and finds the necessary problems. A complete survey of if every node in the graph is reachable is not done, but to be able to do that, more knowledge of the input variables should be present.

Extensibility was a bigger problem in 1986 then now. Computer systems were slower, forcing programmers to create the fastest possible programs, when creating something heavy, like a behavior control system. Brooks' system had problems with their *level 2* specification, whereas nowadays the cheaper computers could run that. Inherently, almost all possible options of creating a behavior specification would allow for a system to be expanded with a new sensor, or a new kind of processor. In XABSL, adding a new sensor, would simply mean adding a new option, that accounts for dealing with that sensor. Another possibility would be to process the sensor to a world representation, in whatever program is used in combination with XABSL.

XABSL, together with POSH, are the most **modular** languages of the ones proposed. This is because of the modular way the behavior specifications are built up. My preference goes to XABSL in this case, because its finite state automata enable a bit more complex implementations than the acts used in POSH hierarchies.

In contrast to the other possibilities, the XABSL compiler offers a method of directly translating the code to svg images, and the comments to html context, and automatically combining those to a full web page, with the entire documentation. Figure 3 shows an example of an automatically generated image. These images, together with the extracted comments, make for a complete documentation, which provides overview to any one who's interested, in less time and effort than when some body would have to look through the code.

4.2 Disadvantages of Using XABSL

Especially PNP offers some great possibilities that XABSL does not. Using Petri nets in stead of the FSA-hierarchy XABSL provides, has the following advantages:

- Mathematical proof of reachability: It can be useful to be able to show that every node in a behavior specification can certainly be reached. Unreachable nodes mean bad specification, which mostly comes from, or results in bugs, which in their turn results in a program that could have worked better. Some of these differences, however, are resolved in [1]
- Multiple robots in one plan: PNP offers a possibility of using one plan with multiple robots, at the same time. Of course, when using XABSL two robots can use the same option tree, but when using PNP, the robots actually share the Petri Net Plan, enabling the system to work more efficiency. A part of this problem is solved by creating a shared world-representation in the program that is used in coherence with XABSL, but some functions, like for example the h_sync in figure 3.3, are difficult, if not impossible, to recreate using XABSL.

4.3 Creating a XABSL-specification

4.4 Traditionally Combining XABSL With Any Existing Program

5 RoboCup Rescue

5.1 Description

The project used in cooperation with the application, is UsarCommander. UsarCommander[3], originally developed by Bayu Slamet, and extended by Arnoud Visser and many others. This program takes care of connecting to USARSim (the simulator used in the Robocup) and makes the user able to easily get sensor data from the robots in it. It is also possible to control the robots with several types of behavior, like corridor-following, obstacle-avoidance, or tele-operation. The last of which enables the operator to manually control the robots by hand, using an interactive human interface.

Over time, the system has been expanded with many subprojects, for example one implementing a SLAM (Simultaneous Localisation And Mapping) algorithm, to make an accurate map from the sensor data of several robots [8]. All the information used and produced by these subprojects can be accessed by other subprojects, resulting in an ideal environment for creating new robot-controlling applications.

5.2 Motivation to use it

The main reason to use this program, instead of any other, to interface my software with USARSim is that it has so many features. The presence of many subprojects in the code, makes it possible to make a very efficient autonomous exploration algorithm interfacing with the subprojects at hand.

[3] Available at http://www.jointrescueforces.eu/wiki/tiki-index.php

Without using UsarCommander all the needed software should be taken from somewhere else, or implemented solely for this purpose.

Other software for this purpose is available too.

but since this is a bachelor thesis on the University of Amsterdam, and this is the software used by it in the RoboCup, this is the logical choice.

6 Approach

6.1 Interfacing both programs

Since the UsarCommander is written in Visual Basic, and the basic behaviors of XABSL are written in C++, a bridge should be made. This is done by creating a Dynamic Link Library (DLL). This DLL contains the needed functions of the C++ program, making them accessible for Visual Basic. The bridge works both ways, so Visual Basic can offer output symbols to the XABSL Engine, while the engine can offer input symbols to the agent.

6.2 Creating a succesful hierarchy

This section will tell about the FSM hierarchy I will make for autonomous exploration

7 Results

This section will contain results, hopefully in the form of explored maps, numbers of victims found, etc.

8 Conclusion

References

[1] R. Alur and M. Yannakakis. Model checking of hierarchical state machines. In *ACM SIGSOFT Software Engineering Notes*, volume 23, pages 175–188. ACM, 1998.

[2] C. Brom, J. Gemrot, M. Bıda, O. Burkert, S.J. Partington, and J.J. Bryson. Posh tools for game agent development by students and non-programmers. In *The Nineth International Computer Games Conference: AI, Mobile, Educational and Serious Games*, pages 126–133, 2006.

[3] R. Brooks. A robust layered control system for a mobile robot. *Robotics and Automation, IEEE Journal of*, 2(1):14–23, 1986.

[4] J. Esparza and M. Nielsen. Decidability issues for petri nets. *Petri nets newsletter*, 94:5–23, 1994.

[5] K. Konolige. Colbert: A language for reactive control in sapphira. In *KI-97: Advances in Artificial Intelligence*, pages 31–52. Springer, 1997.

[6] E.W. Mayr. An algorithm for the general petri net reachability problem. In *Proceedings of the thirteenth annual ACM symposium on Theory of computing*, pages 238–246. ACM, 1981.

[7] H. Seraji and A. Howard. Behavior-based robot navigation on challenging terrain: A fuzzy logic approach. *Robotics and Automation, IEEE Transactions on*, 18(3):308–321, 2002.

[8] B. Slamet and M. Pfingsthorn. Manifoldslam: a multi-agent simultaneous localization and mapping system for the robocup rescue virtual robots competition. *Master thesis in Artificial Intelligence at the Universiteit van Amsterdam*, 11, 2006.

[9] V.A. Ziparo, L. Iocchi, P.U. Lima, D. Nardi, and PF Palamara. Petri net plans. *Autonomous Agents and Multi-Agent Systems*, 23(3):344–383, 2011.