Agent-Based Testing and Repair of Heterogeneous Distributed Systems

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Abstract

In this paper, we propose a distributed use of software-based self-testing, where intelligent agents are responsible for the transfer of software routines to the distributed processors, which in turn will be able to execute the routines and test/repair the corresponding subsystem. This distributed strategy is flexible, re-usable and re-programmable.

Keywords

Intelligent agent, distributed BIST and BISR, processor testing.

1. Introduction

Plain BIST and BISR are not well suited for the testing, diagnosis and repair of heterogeneous, distributed and geographically scattered systems, such as nationwide telecommunications or energy distribution systems. A simplified view of such a distributed system is presented in figure 1.

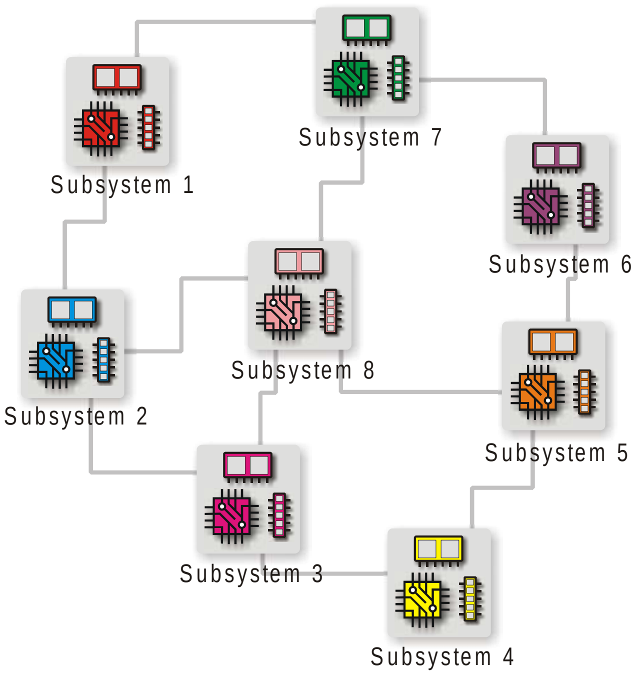

Figure 1. Distributed system with many subsystems.

Decentralization of test and repair greatly reduces the communicational overhead and increases the flexibility and reliability of the testing system itself. The multiagent approach is only natural to such a problem, as multiagent societies are naturally heterogeneous, decentralized and distributed.

An *agent* is, as implemented here, a piece of software capable of independent existence within an environment provided for it, which is able to communicate with entities similar to it, to unaidedly accomplish the work assigned to it and also to travel between geographically separated locations in its environment.

The agents' communication capabilities and mobility lead to the concept of *multiagent society*, which is here a distributed collection of interacting, mobile agents, residing in different parts of the multiagent environment. We shall call a multiagent society whose main actor is the tester agent a *testing society*. Most DBIST approaches [1]-[5] use a central control authority to start/stop the remote BIST tests, to generally organize the DBIST process and gather together the results. There are also distributed, decentralized testing techniques, some involving agents [6], [7].

We present an agent society whose agents test the components (processors, memories, etc) of subsystems in a distributed system. The agents are used for the transfer of embedded software portions to the subsystems for the effective execution of BIST sessions. Agents enable the BIST functions of these subsystems, therefore the distributed BIST nature of the solution. The agents may also repair the subsystem, for example if there is a backup processor installed.

2. Agent-based DBIST and DBISR of processors and their peripherals

2.1. Generalities

The IEEE 1232 family of standards, analyzed in [8], describe common exchange formats and software services for reasoning systems used in system test and diagnosis. The goal is to make the data exchange between two different diagnostic reasoners easy. The standard also defines software interfaces, for the use of external tools that can access the diagnostic data in a consistent manner. It allows exchanging diagnostic information and embedding diagnostic reasoners in any test environment.

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Intelligent agents are software modules able to make decisions on their own, communicate with each other, learn new things and even "travel" from system to system (see also [9]).

Most of the large systems we talk about are heterogeneous, comprising a large number of devices of different types. All these devices have different hardware and/or software, tasks, dependability requirements, but all are capable of running software (in order to be able to run the agent code).

A multi-agent approach and diagnosis ontology for diagnosis of spatially distributed technical systems is presented in [10]; however, in that approach, each subsystem has its own agent monitoring and diagnosing it, which can be costly in some cases. The memory holding the agent could be used for system purposes.

In this paper, we propose an innovative solution based on multi-agent approach for testing and diagnosing distributed systems. It offers many advantages like flexibility, easy maintenance, diagnosis tool for parts of the overall system, and fault tolerance due to the Built-in Self-Repair. Some modern complex devices have also BIST-ed components, so we can decompose the diagnosis of the whole system to the diagnosis of components. Our approach differs from other multi-agent approaches, because the agents are portable, highly platform-independent, they can deal with many types of devices and the system administrator can use various, inexpensive and friendly tools to supervise the devices, tests, agents and the agent society in general.

Programmable processors are widely used in complex systems to perform critical system functions. In many cases, the system has a distributed nature where several processors are used in different locations of the system. It is well-known that apart from the functional usage of processors they can be a very powerful means of performing other non-functional operations in the system, such as testing, diagnosis, repair, etc.

Recently, a new self-testing strategy known as *software-based self-testing (SBST)* emerged [11]-[17]. According to SBST an (embedded) processor is used to execute software routines previously transferred to its memory and performs testing of itself and the surrounding components in a complex system or System-on-Chip (SoC). This new self-testing paradigm offers significant flexibility over hardware-based self-testing techniques that do not allow re-programmability and revisions. In software-based self-testing, new self-test routines can be uploaded at any time, new fault models can be targeted and new components can be tested.

2.2. Agent society

The agent society is able to share resources and repair the faults whenever possible. One or more agents diagnose each subsystem.

The agents travel from device to device, try to detect and repair errors, either by themselves or with the help of other agents or a central database. They can also gather "experience" through their work.

A view of the testing and repairing agent society is presented in figure 2. In this example, Agent 1 and Agent 5 just arrived to the subsystem they are supposed to test. Agent 4 and Agent 7 do not know how to test their devices, they will probably ask for help from another agent. Agent 2 just finished repairing a device and now hurries to another to test it. Agent 3 is at the beginning of testing its device, and is looking at it to see if there is anything wrong. Agent 6 was unable to test its device, so Agent 8 had to move in to test it. Note that the administrative agents (Nameserver, Facilitator, Visualizer) have not been drawn. More about these special agents later.

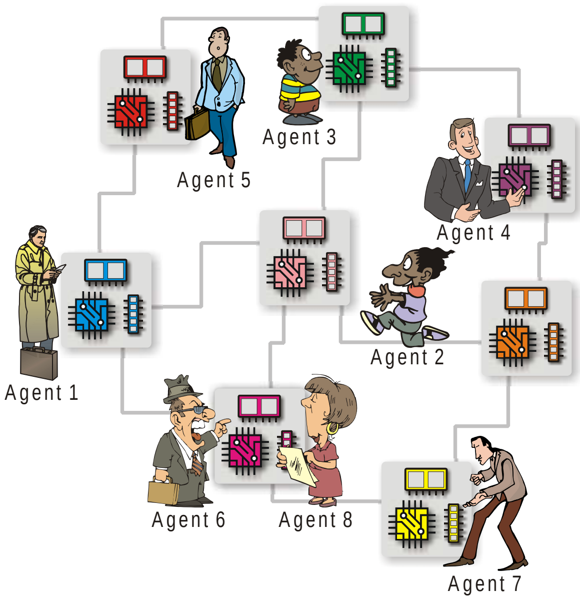

Figure 2 – Agents of the society, in action.

When an agent cannot detect a cause of an observed fault or cannot repair it, it appeals to other agents to start cooperation. Due to the diversity of devices in modern complex systems, heterogeneous agents can be implemented that take care of device(s) in their responsibility area.

Different agents have different repair capabilities and they have to ask their colleagues if they cannot repair the fault by themselves.

When it has to test a subsystem, an agent moves in, or "downloads" to the subsystem, into the memory. Then, the agent code is executed by the processor. The agent tests the processor, memory and other peripherals, using test patterns or test code downloaded and run by the processor. These steps are sketched in figures 3a, 3b and 3c.

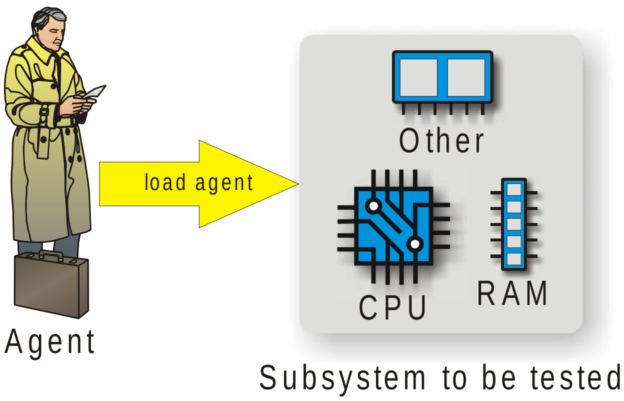

Figure 3a. The agent is loaded into the subsystem.

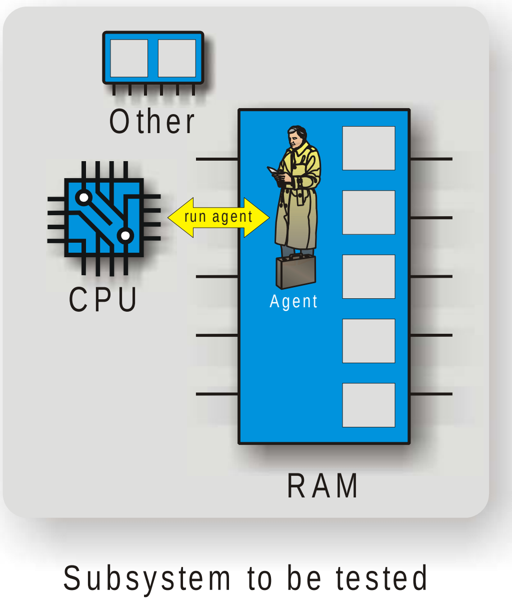

Figure 3b. The agent is contained in the subsystem's memory and is executed from there.

The analysis of a subsystem comprises three major steps:

- detection
- diagnosis
- repair

For each step, the agent has to:

- make a plan
- get the necessary information to execute the plan
- execute the plan
- analyze the results (not compulsory)
- decide (not compulsory)

The first step is to see if there is a fault or not. This may or may not be possible, depending on the agent's capability in finding a way to check that specific device.

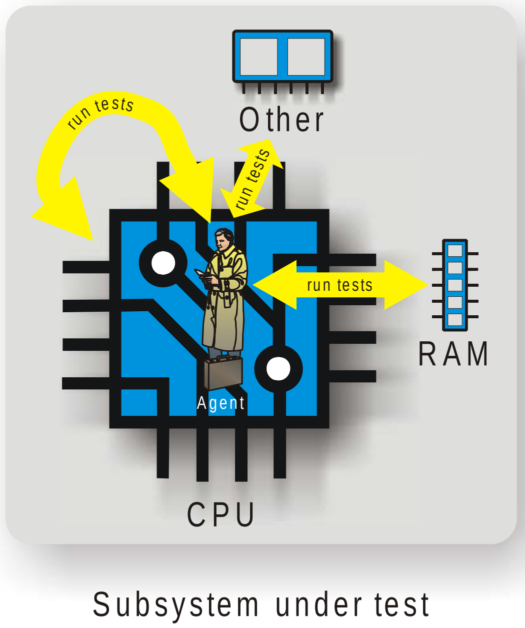

Figure 3c. The agent code is executed by the processor, and it runs the tests.

When the fault has been correctly diagnosed, the agent tries to repair it. Of course, being software by nature, the agent is limited mainly to software repairs.

There are four basic types of agents in the society:

- Tester agents
- Nameserver agents
- Facilitator agents
- Visualizer agents

Tester agents are the ones "working", i.e. effectively testing the devices.

Nameservers are like phone books, they make easier for the agents to find each other.

Facilitators are like the Yellow Pages, they know who has what and who knows how to detect or fix what problem.

Visualizers are the interfaces between the agent society and other systems, for example accepting commands from the system administrator and supplying information about tested devices and society status.

More about agent management can be found in [18].

2.3. Experimental agent platforms and resource needs

Table 1 presents some details about the most promising agent platforms we experimented with.

Table 1 – agent platforms experimented.

Agent platform	Characteristics
JADE	**Java Agent DEvelopment framework** This is an agent platform mainly for

	full-blown desktop computers (Java 2 Standard Edition). Theoretically, it is possible to port an open source J2SE Java Virtual Machine to the target microprocessor, so that it may run standard Java bytecode, but that would be an overkill. However, it turned out that JADE is good for testing, especially since its low-end version, JADE-LEAP, runs on embedded systems and the agents are able to connect to the desktop version.
JADE-LEAP	**Lightweight Extensible Agent Platform** This is the Java 2 Micro Edition version of JADE, the main advantage being the platform's small size (around 100KB). The micro-agents need from a few to tens of KBs, depending on their abilities, mainly testing "knowledge". The JVM adds to this around 200 KB, but this can be further reduced. Unless the test is needed to be real-time, a regular embedded microprocessor's processing power proved to be enough.
Embedded Linux	Another interesting platform is embedded Linux. The embedded Linux micro-core needs around 100KB, however with the networking stack, core utilities and the agent(s), it takes about 500-700KB. What we like about Linux with respect to Java is easier access to hardware (including existing Linux support for various hardware) and higher execution speed. One of the smallest Linux based computers is the "picotux", 35×19×19mm, or the ARM-based "gumstix" devices.
Single Board Computers	An SBC is, in fact, a hardware platform. It is a small computer, usually with network access, audio and video capabilities, adequate processing power, but all crammed on one small printed circuit board. The ones we worked with use x86 compatible or ARM processors. The majority uses Linux, for its flexibility. Good examples are the x86-based Mini-ITX and Pico-ITX mainboards.

We also plan to implement the agent-based testing on aJile's hardware Java processors and other platforms.

2.4. Agent communication

At software level, the agents communicate with each other through the FIPA (Foundation for Intelligent Physical Agents) ACL (Agent Communication Language) [18]. For now, our agents have a reduced language set, mainly allowing sharing test sets, device test/repair data and system coverage plans.

The FIPA MTP (Agent Message Transport Protocol) specifications [18] present different ways of communication for the agents to exchange data. IIOP (Internet Inter-ORB Protocol), WAP (Wireless Application Protocol) and HTTP (HyperText Transfer Protocol), TCP/IP over wireline are described, as well as generic wireless solutions. They also deal with bit-oriented, string-oriented and XML-oriented message representations.

For a system with mobile subsystems to be tested, short range, standardized radio-based Bluetooth/WUSB (Wireless USB) chips can be used. For large scattered systems, radio-based Wi-Fi/WiMax solutions or GPRS/EDGE/3G boards are available. Wi-Fi works even with public Access Points, while GPRS boards are adequate for low-cost, always-on sporadic communication over large distances. Currently, our experiments use Bluetooh, Wi-Fi and 3G, while planning on WUSB. A simplified structure is shown in figure 4.

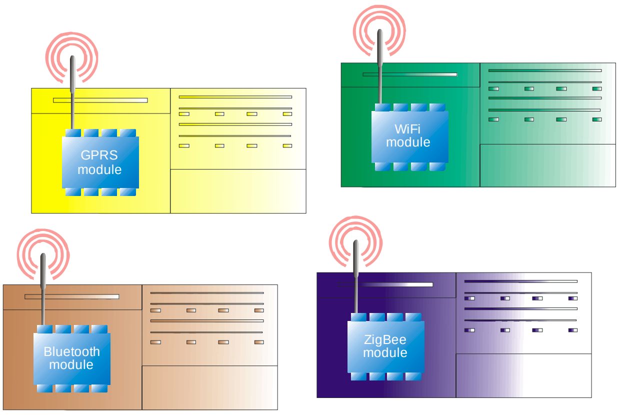

Figure 4. Wireless communication between the subsystems.

3. Conclusions and future work

We presented here a few ideas regarding DBIST and DBISR with intelligent agents. The agents are able to work together in order to find and possibly solve device problems.

The agents travel from device to device, try to detect and repair errors, and learn new solutions. They can "live" on their own, or work together with other agents and/or a database.

When an agent cannot detect a cause of an observed fault or cannot repair it, it appeals to other agents to start cooperation. We use a decentralized diagnosis model, which reduces the complexity and communication overhead of centralized solutions. Due to the diversity of devices in modern complex systems, heterogeneous agents can be implemented that take care of device(s) in their responsibility area.

Different agents have different repair capabilities and they have to ask their colleagues if they cannot repair the fault by themselves.

Tester agents do the testing and repair what is repairable. Visualizers supply the interface between the agent society and the outer world. Nameservers and Facilitators provide lookup services for the agents, so they find each other and also offer their services and knowledge.

The agent management and communication follow FIPA specifications, which describe the management services and communication protocols and formats.

The utilization of intelligent agents for the detection, diagnosis and repair of faults in distributed systems is the focus of the proposed architecture. Significant part of a subsystem can be self-tested using the processing power of the processors used in the various sites of a distributed system. The self-testing is executed using embedded software routines which are able to detect faults in the processors themselves as well as in other subsystem's parts such as the memory system and input/output system.

The proposed architecture is flexible and re-programmable. It can be used to perform distributed self-testing in systems with different processor architectures and with different components in each subsystem. The architecture is also *scalable* and *extensible* since every time a new component (new memory, new I/O device) is added to a subsystem, a new embedded software module can be transferred by an agent to perform self-testing to the new component.

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