# Evaluating Gaia using a Pervasive Computing Benchmark

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## 1. Introduction

Pervasive computing allows the coupling of the physical world to the information world, and provides a wealth of ubiquitous services and applications that allow users, machines, data, applications, and physical spaces to interact seamlessly with one another. In [1], we identified a set of metrics that comprised a pervasive computing benchmark. These proposed metrics facilitate the assessment and evaluation of different aspects of pervasive computing and its support for a wide variety of tasks. In this document, we present an evaluation of our prototype pervasive environment using the proposed benchmark.

## 2. Evaluating Gaia

As an example of the kinds of results produced by our proposed benchmark, we evaluated our pervasive environment and our middleware for pervasive computing, Gaia, using some of the metrics in our benchmark. Some of the applications we evaluated were

1. Presentation task : slideshow presentation based on Microsoft PowerPoint
2. Notification/Trigger-based task : a "calendar" application that allows actions to be triggered based on time and other contexts
3. Collaboration task : a "scribble" application that allows multiple users to draw simultaneously
4. Information finding task : a "space status" application that allows users to find the people present in a room, the applications and devices present and the activity taking place in the room.

### 2.1 Evaluating Gaia System Support

The Gaia middleware supports several aspects of pervasive computing including security, context-sensitivity, event delivery, discovery and pervasive data access. We evaluate the context-sensitivity and security provided by Gaia using our benchmark.

#### *2.1.1 Evaluating Gaia Context Sensitivity*

Table 6 evaluates Gaia in terms of different types of contexts and whether they are used to enhance various kinds of tasks. We have not yet completed our evaluation of how well Gaia enhances various kinds of tasks (based on Table 2).

**Table 1. Gaia Context-Sensitivity Evaluation**

| Type of Context | Quality Metric | Presentation Task | Notification/Trigger-based Task | Collaborative Task | Information Finding Task |
|---|---|---|---|---|---|
| Location (using RF badges) | Quality Metrics : Resolution – 3 sq meters Confidence – 80% Freshness – 10 seconds | Used | Used | Not used | Used |
| Time | | Not used | Used | Not used | Not used |
| Environmental Conditions (Temperature, light, sound) | Quality Metrics : Freshness – 10 seconds Accuracy – 95% | Not used | Not used | Not used | Not used |
| Informational Contexts (City weather, stock quotes) | Quality Metrics : Freshness – 1 minute Accuracy – 100% | Not used | Used | Not used | Not used |
| User Context (User Activity) | Quality Metrics : Confidence – 76% | Not used | Used | Not used | Used |
| Group Context (Group Activity) | Quality Metrics : Confidence – 84% | Not used | Used | Not used | Used |
| Application Context | Not sensed | Not used | Not used | Not used | Not used |
| System Context | Not sensed | Not used | Not used | Not used | Not used |
| Physical Object Context | Not sensed | Not used | Not used | Not used | Not used |

### *2.1.2 Evaluating Gaia Security*

Table 7 shows how Gaia evaluates with respect to our proposed security metrics.

**Table 2. Gaia Security Evaluation**

| Metric | Presentation Tasks |
|---|---|
| Expressiveness of the security policy | 3* |
| User control over private information | 2** |

. * Gaia security policies support all identified features [2] except for the 'conflict resolution.' ** The Mist communication protocol [3] provides some control over identity and location privacy, but not for content.

### *2.1.3 Evaluating Gaia Discovery*

Gaia uses a Discovery Protocol built on top of entity heartbeats, the CORBA Naming Service, the CORBA Trading Service and a hierarchical organization of spaces. It also makes use of ontologies that describe the semantics of different entities and properties. This section summarizes the evaluation of the Discovery system based on our benchmark.

**Table 3. Gaia Discovery Evaluation**

| Metric | Evaluation |
|---|---|
| Directory Metrics | Distributed<br>Hierarchical<br>Soft-state<br>Directory address obtained by multicast or by specifying address |
| Announcement and Lookup Metrics | Pull based lookup<br>Unicast |
| Query Resolution Metrics | Precision : 100%<br>Recall : 100%<br>Not Context-Sensitive<br>Uses semantics |

## 2.2 Evaluating Programmability

The Gaia middleware provides various libraries that aid the creation of new applications and making them context-sensitive. In addition, it uses the model-view-controller framework to achieve multi-device application partitioning as well as to facilitate application mobility. Both end users and developers can configure applications using a scripting language called Lua. End-users can also use other GUIs for performing tasks involving moving application, context-sensitive adaptation and composing applications. Table 9 summarizes the programmability evaluation.

**Table 4. Gaia Programmability Evaluation**

| **Metric** | | **Presentation Task** | **Notification/Trigger-based Task** | **Collaborative Task** | **Information Finding Task** |
|---|---|---|---|---|---|
| Creation | New Application | 20 Man-hours | 10 Man-hours | 30 Man-hours | 10 Man-hours |
| | Supporting Additional Devices | 5 Man-hours | 2 Man-hours | 15 Man-hours | 2 Man-hours |
| Mobility | Programming support | 1 Man-hour<br>20 lines | 1 Man-hour<br>10 lines | 1 Man-hour<br>20 lines | N/A |
| | End-User ease of moving (using a GUI) | 5 | 5 | 5 | 5 |
| | End-User ease of duplicating (using a GUI) | 5 | 5 | 5 | 5 |
| Composition | Programming support | 2 Man-hours<br>50 lines | 2 Man-hours<br>50 lines | N/A | 1 Man-hour<br>30 lines |
| | End-User ease of use | 4 | 4 | 4 | 4 |
| | Expressivity | Only Sequential composition allowed and specified manually by the user | | | |
| Context Sensitivity | Programming support | 10 lines | 10 lines | 10 lines | 10 lines |
| | End-User ease of use | 4 | 4 | 4 | 4 |
| | Expressivity | Prolog Rules | | | |
| Automation | Percent of user actions automatically reduced | N/A | N/A | N/A | N/A |
| | Percent of correct automation decisions | N/A | N/A | N/A | N/A |
| | End-user ease of use | 2 | 2 | 2 | 2 |

### 2.3 Evaluating Usability

Finally, we evaluate the usability of our environment for different kinds of tasks. We have, so far, only evaluated the usability of a presentation task. The results are shown in Table 10.

**Table 5. Usability Evaluation for a Presentation Task**

| Metric | Presentation Task |
|---|---|
| Head Turns | 5 (1.22) |
| Physical Movement | 0 (0)* |
| A priori user knowledge | 4** |
| Keystrokes, clicks, taps and other atomic input actions | 12 |
| Error and Error Recovery | 0.8 (0.88) |
| User Satisfaction (1-5 scale) | 3.04 (1.57) |

Data was collected while observing 5 users perform a presentation task. Some of the entries in the results are shown as average (standard deviation).
*Gaia provides good support for facilitating presentation tasks in the space without requiring physical movement.
** User was required to understand some basic elements of the Gaia infrastructure to understand how to interact with the space.

## 3. References


1. Ranganathan, A., Al-Muhtadi, J., Biehl, J., Ziebart, B., Campbell, R.H., Bailey, B.P. "Towards a Pervasive Computing Benchmark", *submitted*

2. Al-Muhtadi, J., Ranganathan, A., Campbell, R.H. and Mickunas, M.D. "Cerberus: A Context-Aware Security Scheme for Smart Spaces," in the Proceedings of the First IEEE Annual Conference on Pervasive Computing and Communications (PerCom 2003), pp. 489-496, Fort Worth, Texas, March 26, 2003

3. Al-Muhtadi, J., Campbell, R.H., Kapadia, A., Mickunas, M.D., and Yi, S., "Routing Through the Mist: Privacy Preserving Communication in Ubiquitous Computing Environments," in the International Conference of Distributed Computing Systems (ICDCS 2002), pp. 65-74, Vienna, Austria, July 3, 2002