Cognitive Resources-Aware Web Service Selection in Mobile Computing Environments

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ABSTRACT
The proactive and spontaneous delivery of services for mobile users on the move can lead to the depletion of users' mental resources, affecting the normal processes of their physical activities. This is due to the competition for limited mental resources between the human-computer interactions required by services and the users' physical activities. To deal with this problem we propose a service selection method based on two theories from cognitive psychology. This mechanism assesses the degree of demand for mental resources by both the physical activities and the services. Additionally, a service binding and scheduling algorithm ensures less cognitively-taxing mobile service compositions.

Categories and Subject Descriptors
D.2.11 [**Software Engineering**]: Software Architectures – *Domain-specific architectures*

Keywords
Mobile Web services composition; cognitive resources; cognitive engineering; human factors in service provisioning.

1. INTRODUCTION
Most of the research on mobile service composition has advocated to dynamically select, combine, and reconfigure Web service functionalities across heterogeneous environments, based on context-aware semantic spaces and requirements supposed by both mobile user's activities and quality-of-service (QoS) levels, among other features. Clearly, the literature has yet to address the assessment in advance of the cognitive burden – such as interruption irritability or information overload – that the quick rollout of service compositions during runtime in mobile computing environments may pace on users.

In order to interact with human computer interaction (HCI) services – e.g., services needed to visualize maps, listen music or sense vibrations – users need to perform various operations that we call HCI tasks. For instance, the functionality delivered by a document editor in a smartphone requires the users to search for options on the screen, push buttons, wait for options to load, read and mentally process information, etc.

The intermeshing of a physical activity – such us walking, driving, cycling, etc. – with a set of HCI tasks implies that the user needs to divide her attention and allocate her mental resources – the core assets used by cognition to think, remember, make decisions, etc. [3] – to each of them, like perception, attention, working memory, long-term memory, motor control, etc. Each of these mental resources is available in a limited amount in human beings [1]. This produces a competition for the same amount of limited mental resources, generating a problem known as cognitive resource depletion in the area of cognitive psychology [3], which leads to distractions, increases errors, stress, and frustration, as well as reduces the ability to perform mental planning, problem solving, and decision making.

In this paper we present a novel cognitive engineering mechanism to select service functionality that instantiate abstract service compositions during runtime, in accordance with situational demands of mental resources by users' activities and HCI tasks.

2. BACKGROUND
The proposed approach is based on two theories from cognitive psychology: the human-processing system theory (HPS) of Navon et. al. [1], and the multiple-resource theory (MRT) of Wickens [3]. The former rests on the idea of a limited amount of underlying resources in the human-processing system available at any moment. These mental resources are demanded in different degrees by time-sharing activities of a situation.

On the other hand, the MRT highlights the competition and interferences among mental resources allocated in different physical/cognitive dimensions – perceptual, cognitive or central processing, and responsive structures. It is based on a practical description of the different mental resources required by activities. According to this model, the performance of time-shared activities is sensible to their join difficulty and overlapping of common mental resources.

3. DYNAMIC BINDING AND SCHEDULING
We assume that service compositions are represented in BPEL (Business Process Execution Language), and consist of sequential and parallel constructs of abstract services coordinated by control-flow patterns (AND-Split/Join, XOR-Split/Join, OR-Split/Join,

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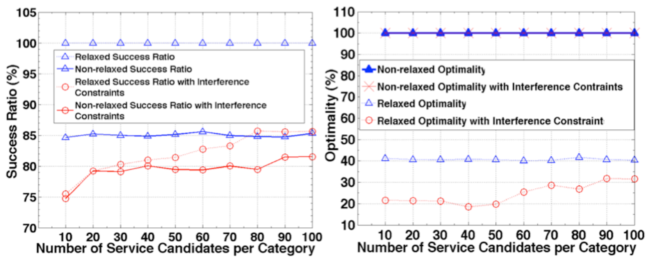

Figure 1: Metrics for Concurrency Bindings.

etc). We also assume that each service instance belongs to a list of functionally equivalent services representing a specific abstract service type. Each HCI task is associated with a profile of the cognitive dimensions of services (CoS), which provides a description of its cognitive attributes.

We define a service concurrency as a collection of time-shared abstract services in a parallel construct. The mechanism stochastically estimates the most probable time window of concurrent execution for these abstract services, based on the probability density functions of the users' interaction time with specific concurrent HCI services while engaged on a specific physical activity. These interacting times are stored as historical experience, which can be mined to obtain the functions.

3.1 Service Composition Analysis

In the first phase, the BPEL file with the service composition is translated into a directed acyclic graph (DAG) representation. This DAG is used to extract executable paths, in accordance with the control flow patterns that express the abstract service coordination. Executable paths represent all possible alternatives of the composition execution. Thus, sequential and/or parallel constructs are extracted from each executable path, which are used to bind service instances to its abstract services.

3.2 Cognitive Demand and Interference Assessment

Having a parallel construct, service concurrencies are computed based on the probability functions. This is used as an input for a binary linear programming problem (BILP) to select an optimal set of HCI services such that: (1) the total demand on mental resources by the HCI services and the user's activity is minimized, and (2) there not exist interferences among the demanded mental resources. This is done by extracting the cognitive dimension values from the CoS profile.

By solving the BILP problem our service selection mechanism identifies the set of background and HCI services that generate feasible, relaxed, or non-feasible solutions based on the availability of service instances in the search space. These service instances, their starting time evaluated in base of their temporal latencies, and their estimated durations derived from the probability density functions, define the scheduled execution plan to be orchestrated.

4. EXPERIMENTAL RESULTS

We have conducted a simulation to apply the mechanism to a set of various abstract service composites by considering the following data: (1) a set of different HCI abstract service types and their probability density functions generated from the Intel Computer Use Research (http://www2.berkeley.intel-research.net/~tlratten/public_usage~tlratten/public_usage_data/pud.html) report; (2) a set of randomly generated abstract service composites; (3) a set of 100 HCI service instances and their respective cognitive attributes; (4) a set of real user's activities and their cognitive attributes extracted from [2]. We define 200 test cases as the combination of two levels of our approach as follows: (1) level one: minimization of the cognitive demand, constrained on the maximum cognitive demand; (2) level two: inclusion of level one, constrained on the cognitive interferences.

The success ratio is about the percentage of concurrency bindings that do not exceed the maximum human cognitive capacity (see Figure 1), as defined in [3]. Level one is able to find around 85% of optimal solutions for any number of candidates. However, this is at the cost of facing cognitive interferences. The 100% success ratio of the second best, relaxed solutions provided by the BILP problem when the maximum human cognitive capacity is relaxed, means that always there exists a solution to the BILP problem at this level. The level two behaves with a bigger risk of not finding any feasible solution, with a success ratio between 75% and slightly superior to 80%. On the other hand, the optimality of the relaxed service concurrency bindings decreases at level two, while for the level one it is steady at the value of 40%. The optimality for level two approach barely reaches 30%. Therefore, at this level the mechanism is not appropriate to provide acceptable service concurrency bindings, since many second best solutions are extremely cognitively taxing to the user. However, this drawbacks are offset by the total elimination of cognitive interferences.

5. CONCLUSION AND FUTURE WORK

A mechanism to dynamically bind and schedule service instances with abstract mobile service compositions considering mental resources has been introduced. We are currently assessing cognitive demands of HCI tasks and activities by collecting data from bio-sensors like electrocardiograms and pupil dilation, and integrating our mechanism to a context manager to automatically trigger the optimization.

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