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Architectural tactics for cyber-foraging: Results of a systematic literature review

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ABSTRACT

Mobile devices have become for many the preferred way of interacting with the Internet, social media and the enterprise. However, mobile devices still do not have the computing power and battery life that will allow them to perform effectively over long periods of time, or for executing applications that require extensive communication, computation, or low latency. Cyber-foraging is a technique to enable mobile devices to extend their computing power and storage by offloading computation or data to more powerful servers located in the cloud or in single-hop proximity. This article presents the results of a systematic literature review (SLR) on architectures that support cyber-foraging. Elements of the identified architectures were codified in the form of *Architectural Tactics for Cyber-Foraging*. These tactics will help architects extend their design reasoning toward cyber-foraging as a way to support the mobile applications of the present and the future.

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1. Introduction

Mobile Cloud Computing (MCC) refers to the combination of mobile devices and cloud computing in which cloud resources perform computing-intensive tasks and store massive amounts of data (Yang et al., 2013). Increased mobile device capabilities, combined with better network coverage and speeds, have enabled MCC such that mobile devices have become for many the preferred form for interacting with the Internet, social media, and the enterprise. However, mobile devices still offer less computational power than conventional desktop or server computers, and limited battery life remains a problem especially for computation- and communication-intensive applications.

Cyber-foraging (Satyanarayanan, 2001) is an area of work within MCC that leverages external resources (i.e., cloud or local servers; the latter often called surrogates) to augment the computation and storage capabilities of resource-limited mobile devices while extending their battery life. There are two main forms of cyber-foraging. One is computation offload, which is the offload of expensive computation in order to extend battery life and increase computational capability. The second is data staging to improve data transfers between mobile devices and the cloud by temporarily staging data in transit.

The goal of this article is to present the results of a Systematic Literature Review (SLR) to discover software architectures for cyber-foraging. Elements of the identified software architectures are codified into a set of architectural tactics for cyber foraging. Section 2 presents a summary of the research method. Section 3 presents the analysis of the identified primary studies using a categorization of architecture decisions that are relevant for cyber-foraging systems. The main observations and findings from the primary studies are presented in Section 4. Sections 5–7 present the architectural tactics for cyber-foraging that were extracted from the primary studies. Section 8 presents related work. Finally, Section 9 presents conclusions and the next steps in our research. A preliminary analysis of the primary studies has been published in Lewis et al. (2014), and a summary of the architectural tactics has been published in Lewis and Lago (2015).

2. Research method

To identify work related to architectures for cyber-foraging an SLR was conducted following the guidelines proposed in Dyba et al. (2007) and Kitchenham and Charters (2007). The research question was defined as:

What software architecture and design strategies for cyber-foraging from mobile devices can be identified in the literature?

The main data source was Google Scholar and snowballing was used to complement the set of primary studies. A set of 58 primary studies was identified and a total of 61 systems from these studies: 53 computation offload systems and 8 data staging systems. Table 1 shows the computation offload systems found in the primary studies and Table 2 shows the data staging systems.

The complete SLR protocol is available as online material at http://www.andrew.cmu.edu/~gritter/slr-online-material.pdf.

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Table 1
Computation offload systems in primary studies.

System	Where			When		What												
						Granularity					Payload							
	Prox. disconnected	Prox. connected	Remote	Runtime decision	Always offload	Process	Function	Component	Service	Application	Computation	Partitioning algo.	Parameters	Application state	Device context	Source location	Setup instructions	Continuous data
mHealthMon (Ahnn and Potkonjak, 2013)			X	X					X				X					
Mobile Agents (Angin and Bhargava, 2013)			X	X				X			X		X					
Clone-to-Clone (C2C) (Aucinas et al., 2012)	X			X			X						X					
Chroma (Balan et al., 2007)	X			X			X						X					
Collaborative Applications (Chang and Hung, 2011)	X			X			X						X	X				
Computation and Compilation Offload (Chen et al., 2004)	X			X			X						X					
Cloud Media Services (Cheng and Probst, 2013)			X		X			X							X			
Roam (Chu et al., 2004)		X	X	X				X					X	X		X		
CloneCloud (Chun and Maniatis, 2009)	X				X	X								X				
MAUI (Cuervo, 2012)	X		X	X			X						X					
Kahawai (Cuervo, 2012)	X				X					X								X
HPC-as-a-Service (Duga, 2011)	X		X		X				X				X					
OpenCL-Enabled Kernels (Endt and Weckemann, 2011)	X		X	X				X			X		X					
Real Options Analysis (Esteves et al., 2011)	X		X	X			X						X					
3DMA (Fjellheim et al., 2005)			X	X				X					X					
Spectra (Flinn et al., 2002)	X			X			X						X					
AlfredO (Giurgiu et al., 2009)			X	X				X				X	X					
Collective Surrogates (Goyal, 2011)		X	X		X					X			X				X	
Grid-Enhanced Mobile Devices (Guan, 2008)		X	X		X			X					X					
Cloudlets (Ha et al., 2011)	X				X					X	X		X					
Virtual Phone (Hung et al., 2011)			X		X			X						X				
Single-Server Offloading (Imai, 2012)	X			X			X						X					
Cloud Operating System (Imai, 2012)		X			X			X			X		X					
Android Extensions (Iyer et al., 2012)			X		X			X					X					
ThinAV (Jarabek et al., 2012)		X	X		X				X				X					
Cuckoo (Kemp et al., 2012)	X		X	X				X			X		X					
ThinkAir (Kosta et al., 2012)			X	X			X				X		X					
MACS (Kovachev and Klamma, 2012)	X		X	X				X			X		X					
Scavenger (Kristensen, 2010)	X			X				X			X		X					
AMCO (Kwon and Tilevich, 2013)	X		X	X				X					X	X				
MCo (Lee, 2012)			X		X			X			X		X					
PowerSense (Matthews et al., 2011)	X			X					X				X					
AIDE (Messer et al., 2002)	X		X	X				X					X					
Application Virtualization (Messinger and Lewis, 2013)	X				X					X	X		X					
PARM (Mohapatra and Venkatasubramanian, 2003)	X			X				X					X					
Resource Furnishing System (Ok et al., 2007)		X	X		X					X								X
Cloud Personal Assistant (O'Sullivan and Grigoras, 2013)		X	X		X				X				X					
SOME (Park et al., 2012)			X		X		X						X					
SmartVirtCloud (Pu et al., 2013)		X		X			X				X		X					
Odessa (Ra et al., 2011)	X		X	X				X					X					
Smartphone-Based Social Sensing (Rachuri, 2012)	X		X	X				X					X					
MAPCloud (Rahimi et al., 2012)		X	X	X					X				X				X	
VM-Based Cloudlets (Satyanarayanan et al., 2009)	X				X					X	X		X					
IC-Cloud (Shi et al., 2013)	X		X	X			X						X					
SPADE (Silva et al., 2008)			X		X			X					X					
Slingshot (Su and Flinn, 2005)		X			X					X			X					
AIOLOS (Verbelen et al., 2012)	X		X	X				X			X		X					
Offloading Toolkit and Service (Yang et al., 2008)	X		X	X				X			X		X					
Mobile Data Stream Application Framework (Yang et al., 2013)			X	X				X				X	X					
Heterogeneous Auto-Offloading Framework (Zhang et al., 2009)			X	X				X					X					
Weblets (Zhang et al., 2011)			X	X				X					X					
DPartner (Zhang et al., 2012b)	X		X	X				X					X					
Elastic HTML5 (Zhang et al., 2012a)	X		X	X				X					X			X		

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